JEE Class Companion
Physics

For JEE Main and Advanced

Module-10

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Chapter_3 : Semi Conductor (PN-Junction)

Chapter_4 : Communication System

Syllabus

* **Modern Physics–1**

Bohr’s theory of hydrogen-like atoms; Characteristic and continuous X-rays, Moseley’s law; de Broglie wavelength of matter waves.

* **Modern Physics-2**

Atomic nucleus; Alpha, beta and gamma radiations; Law of radioactive decay; Decay constant; Half-life and mean life; Binding energy and its calculation; Fission and Fusion processes; Energy calculation in these processes.

* **Semi Conductor (PN Junction)**

As you have gone through the theory part that consists of given fundamental principles, definitions, concepts involved and solved problems. After going through theory part it becomes necessary to solve the unsolved problems based on the concepts given. To solve this purpose we are providing exercise part that comprises of various exercises based on the theory. By solving various kinds of problems you can check your grasp on the topic and can determine whether you have been able to find optimum depth in relevant topic or not.

Students are advised to solve the questions of exercises (Levels # 1, 2, 3, 4) in the same sequence or as directed by the faculty members, religiously and very carefully. Level # 3 is not for foundation course students, it will be discussed in fresher or target courses.

* **COMMUNICATION SYSTEM**

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CHAPTER 1

Modern Physics–1

Section A - Photoelectric Effect

1. NATURE OF LIGHT

It was a matter of great interest for scientists of know that what exactly from the light is made up of or how the light behaves. This is briefly described over here

1.1 Newton's Corpuscular Theory :

Newton was the first scientist who said that light is made 0 up tiny elastic particles called "Corpuscles" which travels with the velocity of light. So according to Newtons, light is a particle.

1.2 Huygen's Wave Theory :

Huygen was a scientist working parallel to Newton who come with a drastically different idea for nature of light & said that light is not a particle but a wave.

1.3 Maxwell's Electromagnetic Wave Theory :

During the time of Hygen, his views regarding nature of light were not accepted as newton was a popular scientist of his time. but, when maxwell asserted that light is a electromagnetic wave, scientists started believing that light is a wave.

1.4 Max Planck's Quantum Theory of Light :

Once again when scientists started believing that the light is a wave Max Planck came with different idea & asserted that light is not a wave but a photon (i.e. a particle) which he proved through balck body radiation spectrum. At this time there was a great confusion about the nature of light which was solved by de-broglie from where origin of theory of matter wave come into picture.

1.5 Debroglie Hypothesis

It supports dual nature of light (wave nature and particle nature). According to him the light consists of particles associated with definite amount of energy and momemtum. These particles were later named as photons.

The photon posses momentum and is given by

$$P = \frac{h}{\lambda} \qquad ...(1)$$

P = momentum of one photon

λ = wavelength of every point wave.

h = Planck's constant = 6.62×10^{-34} Js.

A photon is a packet of energy. It posses energy given by

$$E = \frac{hc}{\lambda} \qquad ...(2)$$

where c = speed of light

Debroglie relates particle property (momentum) with wave property (wavelength) i.e. he favours dual nature of light.

Electron volt : It is the energy gained by an electron when it is accelerated through a potential difference of one volt.

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

Now from eq. (2)

$$E = \frac{6.62\times10^{-34}\times3\times10^{8}}{\lambda} \text{ in Joule.}$$

$$E = \frac{6.62\times10^{-34}\times3\times10^{8}}{\lambda\times1.6\times10^{-19}} \text{eV}$$

$$E = \frac{12400}{\lambda} \text{ev}$$

where λ is in Å

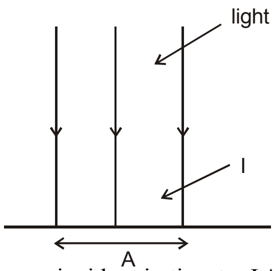
Properties of Photon :

1. Photon travels with speed of light.
2. The rest mass of a photon is zero.
3. There is no concept of photon conservation.
4. All the photons of a particular frequency or wavelength posses the same energy irrespective of the intensity of the radiation.
5. The increase in the intensity of the radiation imply an increase in the number of photon's crossing a given area per second.

☛ When light travels from one medium to another medium then
frequency = const (because it is the property of source)
but v, λ changes

EXAMPLE 1

A beam of light having wavelength λ and intensity 1 falls normally on an area A of a clean surface then
find out the number of photon incident on the surface.



Sol. Total energy incident in time $t = IAt$

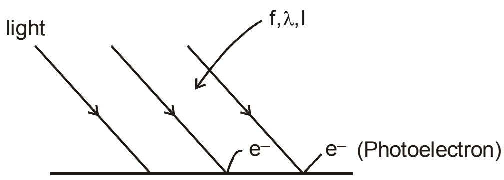
Energy of one photon $E = \frac{hc}{\lambda}$

Then number of photon incident in time t

$$= \frac{\text{Total energy incident}}{\text{energy of one photon}} = \frac{IAt\lambda}{hc}$$

A. PHOTOELECTRIC EFFECT

Electron Emission Process :



When light is incident on a metal surface it was observed that electrons are ejected from a metal surface some times even when incredicely dim light such as that from starts and distance galaxies incident on it and some time electrons not comes out from the metal surface even high energetic or high intensity light falling on the metal surface.
This shows that the electron emission from a metal surface is not depends on the intensity of incident light but it is basically depends on the energy of the incident.
Photons no matters in number of photons are very less in a dim light, photo electric effect can be seen.
During the phenomenon of photoelectric effect one incident photon on metal surface can eject at most only one electron.
A photon is an energy packet which is fully absorbed not partially. Thus one photon can not be absorbed by more than one electron.
The minimum amount of energy of photon required to eject an electron out of a metal surface is called work function It is denoted by ϕ.
The work function depends on the nature of the metal.

☛
1. The electron emission from a metal is only depends on the work function or energy of one photons.
2. But how many electrons comes out from the metal is depends on intensity of the falling light on energy of the light.
3. Energy of photon incident on metal will not necessarily cause emission of an electron even if its energy is more than work function. The electron after absorption may be involved in many other process like collision etc in which it can lose energy hence the ratio of no. of electrons emitted to the no. of photons incident on metal surface is less than unity.

1.6 Three Major Features of the Photoelectric effect which cannot be explained in terms of the classical of the wave theory of light are.

(a) **The intensity problem :** Wave theory requires that the oscillating electric field vector E of the light wave increases in amplitude as the intensity of the light beam is increased. Since the force applied to the electron is e**E**, this suggests that the kinetic energy of the photoelectrons should also increase the light beam is made more intense. However observation shows that maximum kinetic energy is independent of the light intensity.

(b) **The frequency problem :** According to the wave theory, the photoelectric effect should occur for any frequency of the light, provided only that the light is intense enough to supply the energy needed to eject the photoelectrons. However observations shows that there exists for each surface a characterstic cutoff frequency ν_{th}, for frequency less than ν_{th}, the photoelectric effect does not occur, no matter how intense is light beam.

(c) **The time delay problem :** If the energy acquired by a photoelectron is absorbed directly from the wave incident on the metal plate, the "effective target area" for an electron in the metal is limited and probably not much more than that of a circle of diameter roughly equal to that of an atom. In the classical theory, the light energy is uniformly distributed over the wavefront. Thus, if the light is feeble enough, there should be a measurable time lag, between the impinging of the light on the surface and the ejection of the photoelectron. During this interval the electron should be absorbing energy from the beam until it had accumulated enough to escape. However, no detectable time lag has ever been measured.

Now, quantum theory solves these problems in providing the correct interpretation of the photoelectric effect.

1.7 Threshold Frequency & Threshold Wavelength

We have discussed that to start photoelectric emission the energy of incident photon on metal surface must be more than the work function of the metal. If ϕ is the work function of the metal then there must be a minimum frequency of the incident light photon which is just able to eject the electron from the metal surface. This minimum frequency or threshold frequency ν_{th} can be given as

$$h\nu_{th} = \phi$$

Threshold frequency ν_{th} is a characteristic property of a metal as it is the minimum frequency of the light radiation required to eject a free electron from the metal surface.

As the threshold frequency is defined, we can also define threshold wavelength λ_{th} for a metal surface. Threshold wavelength is also called cut off wavelength. For a given metal surface threshold wavelength is the longest wavelength at which photo electric effect is possible. Thus we have

$$\frac{hc}{\lambda_{th}} = \phi$$

So for wavelength of incident light $\lambda > \lambda_{th}$, the energy of incident photons will become less then the work function of the metal and hence photoelectric effect will not start.

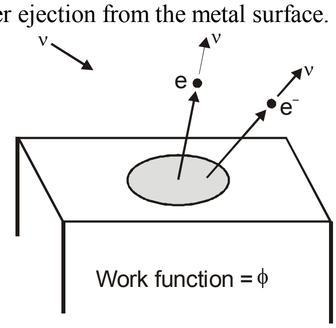
Thus for a given metal surface photoelectric emission will start at $\nu > \nu_{th}$ or $\lambda < \lambda_{th}$.

1.7 EINSTEIN RELATION:

Einstein suggested that the energy of photon $(h\nu > \phi)$ which is more than work function of a metal when incident on the metal surface is used by the electron after absorption in two parts.

(i) A part of energy of absorbed photon is used by the free electron in work done in coming out from the metal surface as work function.

(ii) The remaining part of the photon energy will be gained by the electron in the form of kinetic energy after ejection from the metal surface.



If a light beam of frequency ν (each photon energy $= h\nu$) is incident on a metal surface having work function ϕ then for $h\nu > \phi$, we have

$$h\nu = \phi + \frac{1}{2}mv_{max}^2 \qquad ...(1)$$

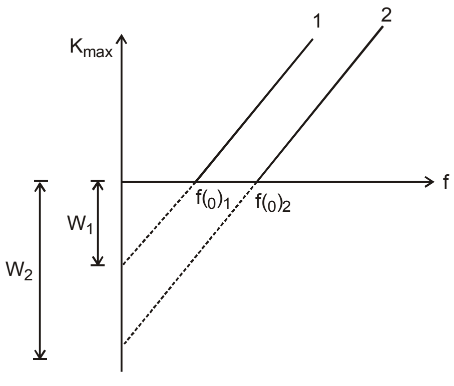
In equation (1) the second terms on right hand side of equation is $\frac{1}{2}mv_{max}^2$, which is the maximum kinetic energy of the ejected electron.

In practical cases whenever an electron absorbs a photon from incident light, it comes out from the metal surface if $h\nu > \phi$ but in process of ejection it may collide with the neighbouring electrons and before ejection it may loose some energy during collisions with the neighbouring electrons. In this case after ejection the kinetic energy of ejected electrons will be certainly less then $(h\nu - \phi)$. If we assume there are some electrons which do not loose any energy in the process of ejection, will come out from the metal surface with the maximum kinetic energy given as

$$\frac{1}{2}mv_{max}^2 = h\nu - \phi$$

Thus all the ejected electrons from the metal surface may have different kinetic energies, distributed from 0 to $\frac{1}{2}mv_{max}^2$.

Graph between K_{max} and f



Let us plot a graph between maximum kinetic energy K_{max} of photoelectrons and frequency f of incident light. The equation between K_{max} and f is,

$$K_{max} = hf - W$$

comparing it with y = mx + c, the graph between K_{max} and f is a straight line with positive slope and negative intercept.

From the graph we can note the following points.

(i) $K_{max} = 0$ at $f = f_0$

(ii) Slope of the straight line is h, a universal constant. i.e., if graph is plotted for two different metals 1 and 2, slope of both the lines is same.

(iii) The negative intercept of the line is W, the work function, which is characteristic of a metal, i.e., intercepts for two different metals will be different.

Further,

$W_2 > W_1$ $\quad\therefore\quad (f_0)_2 > (f_0)_1$

Here $\quad f_0$ = threshold frequency

as $W = hf_0$

EXAMPLE 2

The photoelectric threshold of the photo electric effect of a certain metal is 2750 Å. Find

(i) The work function of emission of an electron from this metal,

(ii) Maximum kinetic energy of these electrons,

(iii) The maximum velocity of the electrons ejected from the metal by light with a wavelength 1800 Å.

Sol. (i) Given that the threshold wavelength of a metal is $\lambda_{th} = 2750\,Å$. Thus work function of metal can be given as

$$\phi = \frac{hc}{\lambda_{th}} = \frac{12431}{2750}eV = 4.52\,eV$$

(ii) The energy of incident photon of wavelength 1800 Å on metal in eV is

$$E = \frac{12431}{1800}eV = 6.9\,eV$$

Thus maximum kinetic energy of ejected electrons is

$$KE_{max} = E - \phi = 6.9 - 4.52\text{ eV} = 2.38\text{ eV}$$

(iii) If the maximum speed of ejected electrons is v_{max} then we have

$$\frac{1}{2}mv_{max}^2 = 2.38\,eV$$

or

$$v_{max} = \sqrt{\frac{2\times2.38\times1.6\times10^{-19}}{9.1\times10^{-31}}} = 9.15\times10^5\text{ m/s}$$

EXAMPLE 3

Light quanta with a energy 4.9 eV eject photoelectrons from metal with work function 4.5 eV. Find the maximum impulse transmitted to the surface of the metal when each electrons flies out.

Sol. According to Einstein's photoelectric equation

$$E = \frac{1}{2}mv_{max}^2 = hv - \phi = 4.9 - 4.5 = 0.4 \text{ eV}$$

If E be the energy of each ejected photo electron

momentum of electrons is $P = \sqrt{2mE}$

We know that change of momentum is impulse. Here the whole momentum of electron is gained when it is ejected out thus impulse on surface is

$$\text{Impulse} = \sqrt{2mE}$$

Substituting the values, we get

$$\text{Maximum impulse} = \sqrt{2 \times 9.1 \times 10^{-31} \times 0.4 \times 1.6 \times 10^{-19}}$$

$$= 3.45 \times 10^{-25} \text{ kg m/sec}$$

EXAMPLE 4

In an experiment tungsten cathode which has a threshold 2300 Å is irradiated by ultraviolet light of wavelength 1800 Å. Calculate
(i) Maximum energy of emitted photoelectron and
(ii) Work function for tungsten
(Mention both the results in electron-volts)
Given Planck's constant $h = 6.6 \times 10^{-34}$ joule-sec, $1eV = 1.6 \times 10^{-19}$ joule and velocity of light $c = 3 \times 10^8$ m/sec

Sol. The work function of tungsten cathode is

$$\phi = \frac{hc}{\lambda_{th}} = \frac{12431}{2300} \text{eV} = 5.4 \text{ eV}$$

The energy in eV of incident photons is

$$E = \frac{hc}{\lambda} = \frac{12431}{1800} \text{eV}$$

The maximum kinetic energy of ejected electrons can be given as

$$KE_{max} = E - \phi = 6.9 - 5.4 \text{eV} = 1.5 \text{ eV}$$

EXAMPLE 5

Light of wavelength 1800 Å ejects photoelectrons from a plate of a metal whose work functions is 2 eV. If a uniform magnetic field of 5×10^{-5} tesla is applied parallel to plate, what would be the radius of the path followed by electrons ejected normally from the plate with maximum energy.

Sol. Energy of incident photons in eV is given as

$$E = \frac{12431}{1800} \text{eV}$$

As work function of metal is 2 eV, the maximum kinetic energy of ejected electrons is

$$KE_{max} = E - \phi$$

$$= 6.9 - \text{eV} = 4.9 \text{ eV}$$

If v_{max} be the speed of fasted electrons then we have

$$\frac{1}{2}mv_{max}^2 = 4.9 \times 1.6 \times 10^{-19} \text{ joule}$$

or

$$v_{max} = \sqrt{\frac{2 \times 4.9 \times 1.6 \times 10^{-19}}{9.1 \times 10^{-31}}} = 1.31 \times 10^6 \text{ m/s}$$

When an electron with this speed enters a uniform magnetic field normally it follows a circular path whose radius can be given by

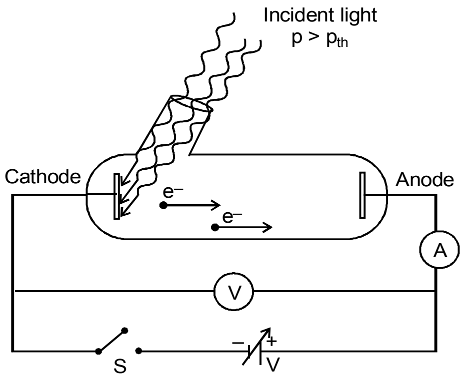
$$r = \frac{mv}{qB} \qquad [\text{As } qvB = \frac{mv^2}{r}]$$

or $$r = \frac{9.1 \times 10^{-31} \times 1.31 \times 10^6}{1.6 \times 10^{-19} \times 5 \times 10^{-5}}$$

or $r = 0.149$ m

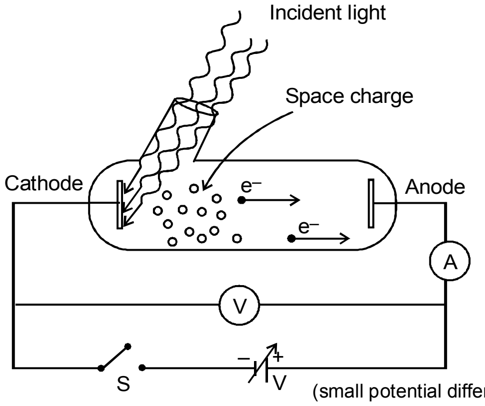
1.8 Experimental Study of Photo Electric Effect :

Experiments with the photoelectric effect are performed in a discharge tube apparatus as illustrated in figure shown. The cathode of discharge tube is made up of a metal which shows photoelectric effect on which experiment is being carried out.



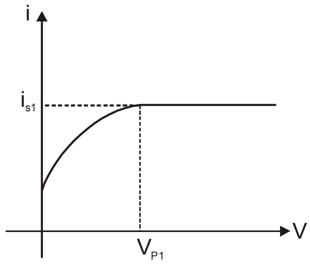
A high potential is applied to a discharge tube through a variable voltage source and a voltmeter and an ammeter are connected a measure the potential difference across the electrodes and to measure photoelectric current. Light with frequency more than threshold frequency of cathode metal is incident on it, due to which photoelectrons are emitted from the cathode. These electrons will reach the anode and constitute the photoelectric current which the ammeter will show.

Now we start the experiment by closing the switch S. Initially the variable battery source is set at zero potential. Even at zero potential variable source, ammeter will show some current because due to the initial kinetic energy some electrons will reach the anode and cause some small current will flow. But as we know majority of ejected electrons have low values of kinetic energies which are collected outside the cathode and create a could of negative charge, we call space charge, as shown in figure shown.



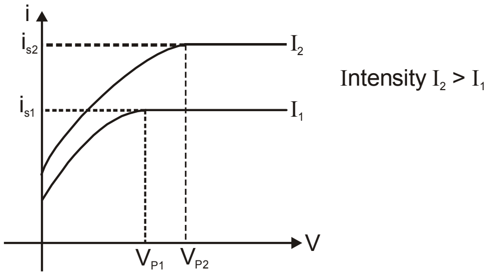
(small potential difference)

If the potential difference applied across the discharge tube is gradually increased from the variable source, positive potential of anode starts pulling electrons from the space charge. As potential difference increases, space charge decrease and simultaneously the photoelectric current in circuit also increases. This we can also see in the variation graph of current with potential difference as shown in figure shown.



A shown in graph, we can see as potential difference increases, current in circuit increases. But at a higher voltage V_{P1} space charge vanishes and at this voltage anode is able to pull the slowest electron (zero kinetic energy) ejected by the cathode. Now as all the ejected electrons from cathode start reading anode. If further potential difference is increased, it will not make any difference in the number of electrons reaching the anode hence, further increases in potential difference will not increases the current. This we can see in figure shown that beyond V_{P1} current in circuit becomes constant. This current i_{s1} is called saturation current. This potential difference V_{P1} at which current becomes saturated is called "pinch off voltage".

Now if the frequency of incident light is kept constant and its intensity is further increased, then the number of incident photons will increase which increases the number of ejected photo electrons so current in circuit increases and now in this case at higher intensity of incident light, current will not get saturated at potential difference V_{P1} as now due to more electron emission, space charge will be more and it will not vanish at V_{P1}. To pull all the electrons emitted from cathode more potential difference is required. This we can se from figure shown, that at higher intensity I_2 ($I_2 > I_1$) current becomes saturated at higher value of potential difference V_{P2}.



Beyond V_{P2}, we can see that all the electrons ejected from cathode are reaching the anode are current become saturated at i_{s2} because of more electrons. Another point we can see from figure shown that when $V = 0$ then also current is more at high intensity incident radiation as the number of electrons of high kinetic energy are also more in the beginning which will reach anode by penetrating the space charge.

1.9. Kinetic Energies of Electrons Reaching Anode

We know that when electrons are ejected from cathode then kinetic energies may vary from 0 to $\frac{1}{2}mv_{max}^2$. If V is the potential difference applied across the discharge tube then it will accelerates the electron while reaching the anode. the electron which is ejected from cathode with zero kinetic energy will be the slowest one reaching the anode if its speed is v_1 at anode then we have

$$0 + ev = \frac{1}{2}mv_1^2$$

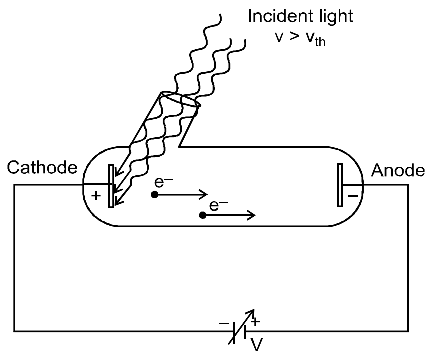
Similarly the electron ejected from cathode with maximum kinetic energy $\frac{1}{2}mv_{max}^2$ will be the fastest one when it will reach anode. If its speed is v_2 at anode then we have

$$\frac{1}{2}mv_{max}^2 + eV = \frac{1}{2}mv_2^2$$

Thus we can say that all the electrons reaching anode will have their speeds distributed from v_1 to v_2.

1.10 Reversed Potential Across Discharge Tube :

Now the experiment is repeated with charging the polarity of source across the discharge tube. Now positive terminal of source is connected to the cathode of discharge tube. When a light beam incident on the cathode with $(h\nu > \phi)$, , photoelectrons are ejected and move towards anode with negative polarity.



Now the electrons which are ejected with very low kinetic energy are attracted back to the cathode because of its positive polarity. Those electrons which have high kinetic energies will rush toward, anode and may constitute the current in circuit.

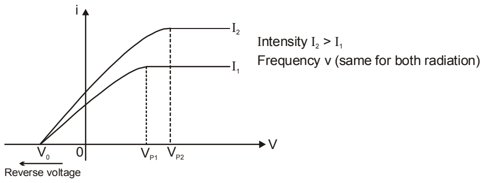
In this case the fastest electron ejected from cathode will be retarded during its journey to anode. As the maximum kinetic energy just after emission at cathode is $\frac{1}{2}mv_{max}^2$, if potential difference across the discharge tube is V then the seed v_f with which electrons will reach anode can be given as

$$\frac{1}{2}mv_{max}^2 - eV = \frac{1}{2}mv_f^2 \qquad ....(1)$$

Thus all the electrons which are reaching anode will have speed less then or equal to v_f. Remaining electrons which have relatively low kinetic energy will either be attracted to cathode just after ejection or will return during their journey from cathode to anode. Only those electrons will cause current of flow in circuit which have high kinetic energies more then eV which can overcome the electric work against electric forces on electron due to opposite polarity of source.

1.11 Cut off Potential or Stopping Potential :

We have seen with reverse polarity electrons are retarded in the discharge tube. If the potential difference is increased with reverse polarity, the number of electrons reaching anode will decrease hence photo electric current in circuit also decreases, this we can see from figure shown which shows variation of current with increase in voltage across discharge tube in opposite direction. Here we can see that at a particular reverse voltage V_0, current in circuit becomes zero. This is the voltage at which the faster electron from cathode will be retarded and stopped just before reaching the anode.



This voltage V_0, we can calculate from equation (1) by substituting $v_f = 0$ hence

$$\frac{1}{2}mv_{max}^2 - eV_0 = 0$$

or $$eV_0 = \frac{1}{2}mv_{max}^2$$

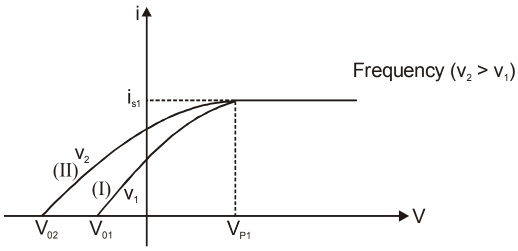
or $$V_0 = \frac{\frac{1}{2}mv_{max}^2}{e} \quad ...(2)$$

or $$V_0 = \frac{hv - \phi}{e} \quad ...(3)$$

We can see one more thing in figure shown that the graphs plotted for two different intensities I_1 and I_2, V_0 is same. Current in both the cases in cut off at same reverse potential V_0. The reason for this is equation-(2) and (3). It is clear that the value of V_0 depends only on the maximum kinetic energy of the ejected electrons which depends only on frequency of light and not on intensity of light. Thus in above two graphs as frequency of incident light is same, the value of V_0 is also same. This reverse potential difference V_0 at which the fastest photoelectron is stopped and current in the circuit becomes zero is called cut off potential or stopping potential.

1.12 Effect of Change in Frequency of Light on Stopping Potential :

If we repeat the experiment by increasing the frequency of incident light with number of incident photons constant, the variation graph of current with voltage will be plotted as shown in figure shown.



This graph is plotted for two incident light beams of different frequency v_1 and v_2 and having same photon flux. As the number of ejected photoelectrons are same in the two cases of incident light here we can see that the pinch off voltage V_{01} as well as saturation current i_{s1} are same. But as in the two cases the kinetic energy of fastest electron are different as frequencies are different, the stopping potential for the two cases will be different. In graph II as frequency of incident light is more, the maximum kinetic energy of photoelectrons will also be high and to stop it high value of stopping potential is needed. These here V_{01} and V_{02} can be given as

$$V_{01} = \frac{hv_1 - \phi}{e} \quad ...(4)$$

and $$V_{02} = \frac{hv_2 - \phi}{e} \quad ...(5)$$

In general for a given metal with work function ϕ, if V_0 is the stopping potential for an incident light of frequency v then we have

$$eV_0 = hv - \phi$$

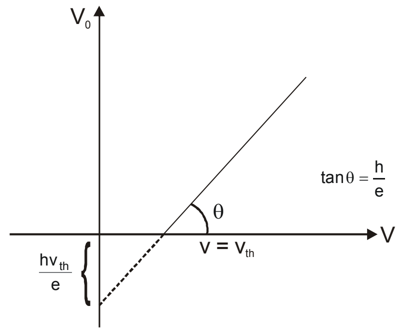
or $$eV_0 = hv - hv_{th} \quad ...(6)$$

or $$V_0 = \left(\frac{h}{e}\right)v - \frac{hv_{th}}{e} \quad ...(7)$$

Equation (7) shows that stopping potential V_0 is linearly proportional to the frequency v of incident light. The variation of stopping potential with frequency v can be shown in figure shown.

Here equation .(6) can be written as

$$\frac{1}{2}mv_{max}^2 = eV_0 = h(v - v_{th}) \quad ...(8)$$



This equation (8) is called Einstein's Photo Electric Effect equation which gives a direction relationship between the maximum kinetic energy stopping potential frequency of incident light and the threshold frequency.

EXAMPLE 6

Find the frequency of light which ejects electrons from a metal surface fully stopped by a retarding potential of 3 V. The photo electric effect begins in this metal at frequency of $6\times10^{14}\ sec^{-1}$. Find the work function for this metal.

Sol. The threshold frequency for the given metal surface is

$$v_{th} = 6\times10^{14}\,Hz$$

Thus the work function for metal surface is

$$\phi = hv_{th} = 6.63\times10^{-34}\times6\times10^{14} = 3.978\times10^{-19}\,J$$

As stopping potential for the ejected electrons is 3V, the maximum kinetic energy of ejected electrons will be

$$KE_{max} = 3eV$$

$$= 3\times1.6\times10^{-19}\,J = 4.8\times10^{-19}\,J$$

According to photo electric effect equation, we have

$$hv = hv_{th} + KE_{max}$$

or frequency of incident light is

$$v = \frac{\phi + KE_{max}}{h}$$

$$= \frac{3.978\times10^{-19} + 4.8\times10^{-19}}{6.63\times10^{-34}} = 1.32\times10^{15}\,Hz$$

EXAMPLE 7

Electrons with maximum kinetic energy 3eV are ejected from a metal surface by ultraviolet radiation of wavelength 1500 Å. Determine the work function of the metal, the threshold wavelength of metal and the stopping potential difference required to stop the emission of electrons.

Sol. Energy of incident photon in eV is

$$E = \frac{12431}{1500}eV$$

According to photo electric effect equation, we have

$$E = \phi + KE_{max} \Rightarrow \text{or} \quad \phi = E - KE_{max}$$

or = 8.29 – 3 eV or = 5.29 eV

Threshold wavelength for the metal surface corresponding to work function 5.29 eV is given as

$$\lambda_{th} = \frac{12431}{5.29}\,\text{Å} = 2349.9\,\text{Å}$$

Stopping potential for the ejected electrons can be given as

$$V_0 = \frac{KE_{max}}{e} = \frac{3eV}{e} = 3\,volt$$

EXAMPLE 8

Calculate the velocity of a photo-electron, if the work function of the target material is 1.24 eV and the wavelength of incident light is 4360 Å. What retarding potential is necessary to stop the emission of the electrons ?

Sol. Energy of incident photons in eV on metal surface is

$$E = \frac{12431}{4360}eV = 2.85\ eV$$

According to photo electric effect equation we have

$$E = \phi + \frac{1}{2}mv_{max}^2$$

or $$\frac{1}{2}mv_{max}^2 = E - \phi$$

= 2.85 – 1.24 eV = 1.61 eV

The stopping potential for these ejected electrons can be given as

$$V_0 = \frac{1/2\,mv_{max}^2}{e} = \frac{1.61eV}{e} = 1.61\ volts$$

EXAMPLE 9

Determine the Planck's constant h if photoelectrons emitted from a surface of a certain metal by light of frequency 2.2 × 10^15 Hz are fully retarded by a reverse potential of 6.6 V and those ejected by light of frequency 4.6 × 10^15 Hz by a reverse potential of 16.5 eV.

Sol. From photo electric effect equation, we have

Here $hv_1 = \phi + eV_{01}$ ...(1)

and $hv_2 = \phi + 2\,eV_{02}$ ...(2)

Subtracting equation (1) from equation (2), we get

$$h(v_2 - v_1) = e(v_{02} - v_{01})$$

or

$$h = \frac{(v_{02} - v_{01})(1.6\times10^{-19})}{(v_2 - v_1)}$$

or

$$h = \frac{(16.5-6.6)(1.6\times10^{-19})}{(4.6-2.2)\times10^{15}}$$

or $= 6.6 \times 10^{-34}$ J-s

EXAMPLE 10

When a surface is irradiated with light of wavelength 4950 Å, a photo current appears which vanishes if a retarding potential greater than 0.6 volt is applied across the photo tube. When a different source of light is used, it is found that the critical retarding potential is changed to 1.1 volt. Find the work function of the emitting surface and the wavelength of second source. If the photo electrons (after emission from the surface) are subjected to a magnetic field of 10 tesla, what changes will be observed in the above two retarding potentials.

Sol. In first case the energy of incident photon in eV is

$$E_1 = \frac{12431}{4950}\text{eV} = 2.51 \text{ eV}$$

The maximum kinetic energy of ejected electrons is

$$KE_{max1} = eV_{01} = 0.6 \text{ eV}$$

Thus work function of metal surface is given as

$$\phi = E_1 - KE_{max1} = 2.51 - 0.6 \text{ eV} = 1.91 \text{ eV}$$

In second case the maximum kinetic energy of ejected electrons will become

$$KE_{max2} = eV_{02} = 1.1 \text{ eV}$$

Thus the incident energy of photons can be given as

$$E_2 = \phi + KE_{max2}$$

$$E_2 = 1.91 + 1.1 \text{ eV} = 3.01 \text{ eV}$$

Thus the wavelength of incident photons in second case will be

$$\lambda = \frac{12431}{3.01}\text{Å} = 4129.9 \text{ Å}$$

When magnetic field is present there will be no effect on the stopping potential as magnetic force can not change the kinetic energy of ejected electrons.

EXAMPLE 11

(a) If the wavelength of the light incident on a photoelectric cell be reduced from λ_1 to λ_2 Å, then what will be the change in the cut-off potential ?

(b) Light is incident on the cathode of a photocell and the stopping voltages are measured from light of two difference wavelengths. From the data given below, determine the work function of the metal of the cathode in eV and the value of the universal constant hc/e.

Wavelength (Å)	Stopping voltage (volt)
4000	1.3
4500	0.9

Sol. (a) Let the work function of the surface be ϕ. If v be the frequency of the light falling on the surface, then according to Einstein's photoelectric equation, the maximum kinetic energy KE_{max} of emitted electron is given by

$$KE_{max} = hv - \phi = \frac{hc}{\lambda} - \phi$$

We know that, $KE_{max} = eV_0$

Where V_0= cut-off potential.

or $eV_0 = \frac{hc}{\lambda} - \phi$ or $V_0 = \frac{hc}{e\lambda} - \frac{\phi}{e}$

Now, $\Delta V_0 = V_{02} - V_{01}$

$$= \left(\frac{hc}{e\lambda_2} - \frac{\phi}{e}\right) - \left(\frac{hc}{e\lambda_1} - \frac{\phi}{e}\right)$$

$$= \frac{hc}{e}\left(\frac{1}{\lambda_2} - \frac{1}{\lambda_1}\right) = \frac{hc}{e}\left(\frac{\lambda_1 - \lambda_2}{\lambda_1\lambda_2}\right) \quad ...(1)$$

(b) From equation (1), we have

$$\frac{hc}{e} = \frac{\Delta V_0(\lambda_1\lambda_2)}{\lambda_1 - \lambda_2}$$

$$= \frac{(1.3 - 0.9)[(4000\times10^{-10})\times(4500\times10^{-10})]}{500\times10^{-10}}$$

$= 1.44 \times 10^{-6}$ V/m

Now, $V_0 = \frac{hc}{e\lambda} - \frac{\phi}{e}$

or

$$\frac{\phi}{e} = \frac{hc}{e\lambda} - V_0 = \frac{1.44\times10^{-6}}{4000\times10^{-10}} - 1.3 = 2.3\,V$$

or $\phi = 2.3$ eV

EXAMPLE 12

A low intensity ultraviolet light of wavelength 2271 Å irradiates a photocell made of molybdenum metal. If the stopping potential is 1.3 V, find the work function of the metal. Will the photocell work if it is irradiated by a high intensity red light of wavelength 6328 Å ?

Sol. The energy in eV of incident photons is

$$E = \frac{12431}{2271}\text{eV} = 5.47 \text{ eV}$$

As stopping potential for ejected electrons is 1.3 V, the maximum kinetic energy of ejected electrons will be

$KE_{max} = eV_0 = 1.3eV$

Now from photoelectric effect equation, we have

$$E = \phi + KE_{max}$$

or $\phi = E - KE_{max}$

or $\phi = 5.47 - 1.3eV = 4.17$ eV

Energy in eV for photons for red light of wavelength 6328 Å is

$$E' = \frac{12431}{6328}\text{eV} = 1.96 \text{ eV}$$

As $E' < \phi$, photocell will not work if irradiated by this red light no matter however intense the light will be.

Note

The student can now attempt section A from exercise.

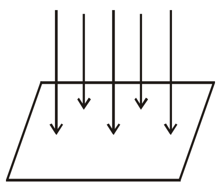
Section B - Radiation Pressure, Matter Waves + Davisson Germer Experiment

2. FORCE DUE TO RADIATION (PHOTON)

Each photon has a definite energy and a definite linear momentum. All photons of light of a particular wavelength λ have the same energy $E = \frac{hc}{\lambda}$ and the same momentum $p = \frac{h}{\lambda}$

When light of intensity I falls on a surface, it exerts force on that surface. Assume absorption and reflection coefficient of surface be 'a' and 'r' and assuming no transmission.

Assume light beam falls on surface of surface area 'A' perpendicularly as shown in figure.



For calculating the force exerted by beam on surface, we consider following cases.

Case (I) :

$a = 1, \quad r = 0$

initial momentum of the photon $= \dfrac{h}{\lambda}$

final momentum of photon = 0

change in momentum of photon $= \dfrac{h}{\lambda}$

(upward)

$$\Delta P = \frac{h}{\lambda}$$

energy incident per unit time = IA

no. of photons incident per unit time $= \dfrac{IA}{h\nu} = \dfrac{IA\lambda}{hc}$

$\therefore$ total change in momentum per unit time = n ΔP

$$= \frac{IA\lambda}{hc} \times \frac{h}{\lambda} = \frac{IA}{c} \text{(upward)}$$

force on photons = total change in momentum per unit time

$$= \frac{IA}{c} \text{(upward)}$$

$\therefore$ force on plate due to photon(F) $= = \dfrac{IA}{c}$

(downward)

$$\text{pressure} = \frac{F}{A} = \frac{IA}{cA} = \frac{I}{c}$$

Case : (II)

when r = 1, a = 0

initial momentum of the photon $= \dfrac{h}{\lambda}$ (downward)

final momentum of photon $= \dfrac{h}{\lambda}$ (upward)

change in momentum $= \dfrac{h}{\lambda} + \dfrac{h}{\lambda} = \dfrac{2h}{\lambda}$

$\therefore$ energy incident per unit time = I A

no. of photons incident per unit time $= \dfrac{IA\lambda}{hc}$

$\therefore$ total change in momentum per unit time

$$= n.\ \Delta P = \frac{IA\lambda}{hc}.\frac{2h}{\lambda} = \frac{2IA}{C}$$

force = total change in momentum per unit time

$F = \dfrac{2IA}{c}$ (upward on photons and downward on the plate)

$$\text{pressure} \quad P = \frac{F}{A} = \frac{2IA}{cA} = \frac{2I}{c}$$

Case : (III)

When $0 < r < 1$ $\qquad a + r = 1$

change in momentum of photon when it is reflected

$$= \frac{2h}{\lambda} \text{ (upward)}$$

change in momentum of photon when it is absorbed

$$= \frac{h}{\lambda} \text{ (upward)}$$

no. of photons incident per unit time $= \dfrac{IA\lambda}{hc}$

No. of photons reflected per unit time $= \dfrac{IA\lambda}{hc}.r$

No. of photon absorbed per unit time $= \dfrac{IA\lambda}{hc}(1-r)$

force due to absorbed photon (F_a)

$$= \frac{IA\lambda}{hc}(1-r).\frac{h}{\lambda} = \frac{IA}{c}(1-r) \text{ (downward)}$$

Force due to reflected photon (F_r)

$$= \frac{IA\lambda}{hc}.r\frac{2h}{\lambda} = \frac{2IA\lambda}{c} \text{ (downward)}$$

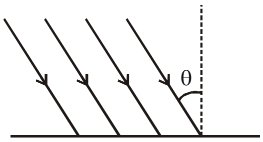
total force $= F_a + F_r$

$$= \frac{IA}{c}(1-r) + \frac{2IAr}{c} = \frac{IA}{c}(1+r)$$

Now pressure $P = \dfrac{IA}{c}(1+r) \times \dfrac{1}{A} = \dfrac{I}{c}(1+r)$

EXAMPLE 13

Calculate force exerted by light beam if light is incident on surface at an angle θ as shown in figure. Consider all cases.

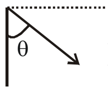


Sol. **Case - I** $a = 1, \quad r = 0$

initial momentum of photon (in downward direction at an angle θ with vertical) is h/λ

final momentum of photon = 0

change in momentum (in upward direction at an angle

θ with vertical) $= \dfrac{h}{\lambda}$ []

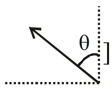
energy incident per unit time = I A cos θ

Intensity = power per unit normal area

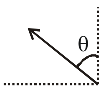
$$I = \frac{P}{A\cos\theta} \qquad P = I A \cos\theta$$

No. of photons incident per unit time $= \dfrac{IA\cos\theta}{hc}.\lambda$

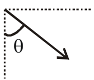
total change in momentum per unit time (in upward direction at an angle θ with vertical)

$$= \frac{IA\cos\theta\lambda}{hc}.\frac{h}{\lambda} = \frac{IA\cos\theta}{c}$$ []

Force (F) = total change in momentum per unit time

$F = \dfrac{IA\cos\theta}{c}$ (direction 

on photon and



on the plate)

Pressure = normal force per unit Area

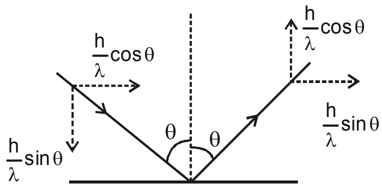
$$\text{Pressure} = \frac{F\cos\theta}{A} \qquad P = \frac{IA\cos^2\theta}{cA} = \frac{I}{c}\cos^2\theta$$

Case II When r = 1, a = 0

∴ change in momentum of one photon

$$= \frac{2h}{\lambda}\cos\theta \qquad \text{(upward)}$$

No. of photons incident per unit time



$$= \frac{\text{energy incident per unit time}}{h\nu}$$

$$= \frac{IA\cos\theta.\lambda}{hc}$$

∴ total change in momentum per unit time

$$= \frac{IA\cos\theta.\lambda}{hc} \times \frac{2h}{\lambda}\cos\theta = \frac{2IA\cos^2\theta}{c} \quad \text{(upward)}$$

∴ force on the plate $= \dfrac{2IA\cos^2\theta}{c}$ (downward)

$$\text{Pressure} = \frac{2IA\cos^2\theta}{cA} \qquad P = \frac{2I\cos^2\theta}{c}$$

Case III $0 < r < 1, \quad a + r = 1$

change in momentum of photon when it is reflected

$$= \frac{2h}{\lambda}\cos\theta \text{ (downward)}$$

change in momentum of photon when it is absorbed

$$= \frac{h}{\lambda} \text{ (in the opposite direction of incident beam)}$$

energy incident per unit time = I A cos θ)

no. of photons incident per unit time $= \dfrac{IA\cos\theta.\lambda}{hc}$

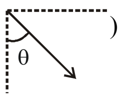
no. of reflected photon $(n_r) = \dfrac{IA\cos\theta.\lambda r}{hc}$

no. of absorbed photon $(n_Q) = \dfrac{IA\cos\theta.\lambda}{hc}(1-r)$

force on plate due to absorbed photons $F_a = n_a.\, \Delta P_a$

$$= \frac{IA\cos\theta.\lambda}{hc}(1-r)\frac{h}{\lambda}$$

$$= \frac{IA\cos\theta}{hc}(1-r)$$ (at an angle θ with vertical



)

force on plate due to reflected photons $F_r = n_r \, \Delta P_r$

$$= \frac{IA\cos\theta.\lambda}{hc} \times \frac{2h}{\lambda}\cos\theta \quad \text{(vertically downward)}$$

$$= \frac{IA\cos^2\theta}{c}2r$$

now resultant force is given by

$$F_R = \sqrt{F_r^2 + F_a^2 + 2F_aF_r\cos\theta}$$

$$= \frac{IA\cos\theta}{c}\sqrt{(1-r)^2 + (2r)^2\cos^2\theta + 4r(r-1)\cos^2\theta}$$

and, pressure $\quad P = \dfrac{F_a\cos\theta + F_r}{A}$

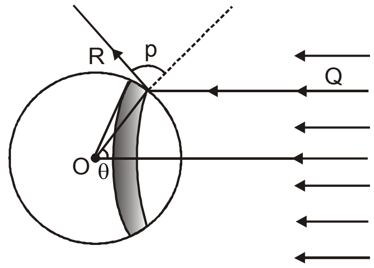
$$= \frac{IA\cos\theta(1-r)\cos\theta}{cA} + \frac{IA\cos^2\theta.2r}{cA}$$

$$= \frac{I\cos^2\theta}{c}(1-r) + \frac{I\cos^2\theta}{c}2r = \frac{I\cos^2\theta}{c}(1+r)$$

EXAMPLE 14

A perfectly reflecting solid sphere of radius r is kept in the path of a parallel beam of light of large aperture. If the beam carries an intensity I, find the force exerted by the beam on the sphere.

Sol. Let O be the centre of the sphere and OZ be the line opposite to the incident beam (figure). Consider a radius about OZ to get a making an angle θ with OZ. Rotate this radius about OZ to get a circle on the sphere. Change θ to θ +dθ and rotate the radius about OZ to get another circle on the sphere. The part of the sphere between these circles is a ring of area $2\pi r^2 \sin\theta \, d\theta$. Consider a small part ΔA of this ring at P. Energy of light falling on this part in time Δt is



$$\Delta U = I\Delta t(\Delta A \cos\theta)$$

The momentum of this light falling on ΔA is ΔU/c along QP. The light is reflected by the sphere along PR. The change in momentum is

$$\Delta p = 2\,\frac{\Delta U}{c}\cos\theta = \frac{2}{c}\,\Delta t\,(\Delta A\cos^2\theta)$$

(direction along $\vec{OP}$)

The force on ΔA due to the light falling on it, is

$$\frac{\Delta p}{\Delta t} = \frac{2}{c}\,\Delta A\cos^2\theta$$

(direction along $\vec{OP}$)

The resultant force on the ring as well as on the sphere is along ZO by symmetry. The component of the force on ΔA along ZO

$$\frac{\Delta p}{\Delta t}\cos\theta = \frac{2}{c}\,I\Delta A\cos^2\theta$$

(along $\vec{ZO}$)

The force acting on the ring is $\quad dF = \dfrac{2}{c}\,I(2\pi r^2 \sin\theta\,d\theta)\cos^3\theta$

The force on the entire sphere is $F = \displaystyle\int_0^{\pi/2} \frac{4\pi r^2 I}{c}\cos^3\theta\,d\theta$

$$F = \int_0^{\pi/2} \frac{4\pi r^2 I}{c}\cos^3\theta\,d(\cos\theta)$$

$$= -\int_{\theta-0}^{\pi/2} \frac{4\pi r^2 I}{c}\left[\frac{\cos^4\theta}{4}\right]_0^{\pi/2} = \frac{\pi r^2 I}{c}$$

Note that integration is done only for the hemisphere that faces the incident beam.

3. DE-BROGLIE WAVELENGTH OF MATTER WAVE

A photon of frequency v and wavelength λ has energy.

$$E = hv = \frac{hc}{\lambda}$$

By Einstein's energy mass relation, $E = mc^2$ the equivalent mass m of the photon is given by.

$$m = \frac{E}{c^2} = \frac{hv}{c^2} = \frac{h}{\lambda c} \quad ..(i)$$

or $\lambda = \frac{h}{mc}$ or $\lambda = \frac{h}{p}$ ...(ii)

Here p is the momentum of photon. By analogy de-Broglie suggested that a particle of mass m moving with speed v behaves in some ways like waves of wavelength λ (called de-Broglie wavelength and the wave is called matter wave) given by,

$$\lambda = \frac{h}{mv} = \frac{h}{p} \quad ...(iii)$$

where p is the momentum of the particle. Momentum is related to the kinetic energy by the equation,

$$p = \sqrt{2Km}$$

and a charge q when accelerated by a potential difference V gains a kinetic energy K = qV. Combining all these relations Eq. (iii), can be written as,

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

(de=Broglie wavelength)....(iv)

3.1 De-Broglie wavelength for an electron

If an electron (charge = e) is accelerated by a potential of V volts, it acquires a kinetic energy,

$$K = eV$$

Substituting the value of h, m and q in Eq. (iv), we get a simple formula for calculating de-Broglie wavelength of an electron.

$$\lambda \text{ (in Å)} = \sqrt{\frac{150}{V(\text{in volts})}}$$

3.2 de-Broglie wavelength of a gas molecule :

let us consider a gas molecule at absolute temperature T. Kinetic energy of gas molecule is given by

$$K.E. = \frac{3}{2} kT \text{ ; k = Boltzman constant}$$

$$\lambda_{\text{gas molecules}} = \frac{h}{\sqrt{2mkT}}$$

4. ATOMIC MODEL

A model is simply a set of hypothesis based on logical & scientific facts.

Theory : When any model satisfies majority of scientific queries by experimental verification then it is termed as theory otherwise, model is simply not accepted.

In Nutshell we can say that every theory is a model but every model is not a theory. So, after more & more clarity about the substances, various new models like Dalton, Thomseon, Rutherford, Bohr etc came into the pictures.

4.1 Dalton's atomic model :

(i) Every element is made up of tiny indivisible particles called atoms.

(ii) Atoms of same element are identical both in physical & chemical properties while atoms of different elements are different in their properties.

(iii) All elements are made up of hydrogen atom. The mass of heaviest atom is about 250 times the mass of hydrogen atom while radius of heaviest atom is about 10 times the radius of hydrogen atom.

(iv) Atom is stable & electrically neutral.

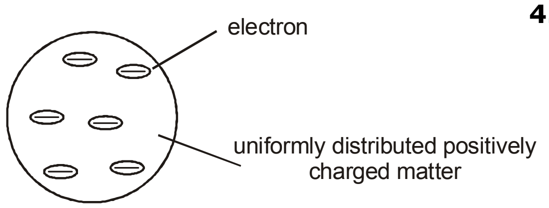
Reason of Failure of model :

After the discovery of electron by U. Thomson (1897), it was established that atom can also be divide. Hence the model was not accepted.

4.2 Thomson's Atomic Model (or Plum-pudding model)

(i) Atom is a positively charged solid sphere of radius of the order of 10^{-10} m in which electrons are embedded as seeds in a watermelon

(ii) Total charge in an atom is zero & so, atom is electrically neutral.



Achievements of model :

Explained successfully the phenomenon of thermionic emission, photoelectric emission & ionization

4.3 Type of line spectrum

(a) Emission line spectrum :

When an atomic gas or vapour at a pressure less than the atmospheric pressure is excited by passing electric discharge, the emitted radiation has spectrum which contains certain specific bright lines only. These emission lines constitute emission spectrum. These are obtained when electron jumps from excited states to lower states. The wavelength of emission lines of different elements are different. For one element the emission spectrum is unique. It is used for the determination of composition of an unknwon substance.

(b) Absorption line spectrum :

When white light is passed through a gas, the gas is found to absorb light of certain wavelength, the bright background on the photographic plate is then crossed by dark lines that corresponds to those wavelengths which are absorbed by the gas atoms.

The absorption spectrum consists of dark lines on bright background. These are obtained due to absorption of certain wavelengths, resulting into transition of atom from lower energy states to higher energy states. (The emission spectrum consists of bright lines on dark background.)

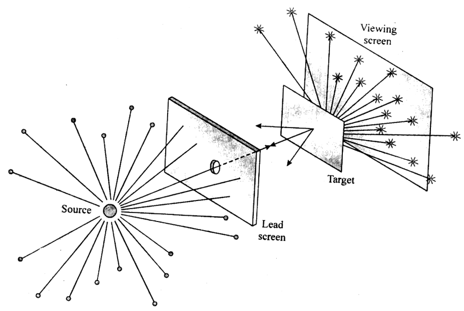
Failure of the model :

(i) It could not explain the line spectrum of H-atom

(ii) It could not explain the Rutherford's α - particle scattering experiment

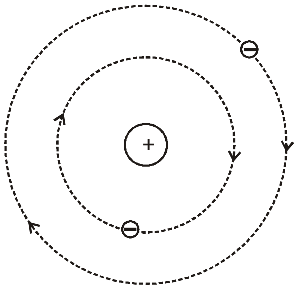
4.4 Ruthorford's Atomic Model

In 1911, Earnest Ruthorford performed a critical experiment that showed that Thomson's model could not be correct. In this experiment a beam of positively charged alpha particles (helium nuclei) was projected into a thin gold foil. It is observed that most of the alpha particles passed through the foil as if it were empty space. But some surprising results are also seen. Several alpha particles are deflected from their original direction by large angles. Few alpha particles are observed to be reflected back, reversing their direction of travel as shown in figure.



If Thomson model is assumed true than the positive charge is spread uniformly in the volume of an atom and the alpha particle can never experience such a large repulsion due to which it will be deflected by such large angles as observed in the experiment. On the basis of this experiment Ruthorford presented a new atomic model.

In this new atomic model it was assumed that the positive charge in the atom was concentrated in a region that was small relative to the size of atom. He called this concentration of positive charge, the nucleus of the atom. Electrons belonging to the atom were assumed to be moving in the large volume of atom outside the nucleus. To explain why these electrons were not pulled into the nucleus, Ruthorford said that electrons revolve around the "nucleus in orbits around the positively charged nucleus in the same manner as the planets orbit the sun. The corresponding atomic model can be approximately shown in figure.



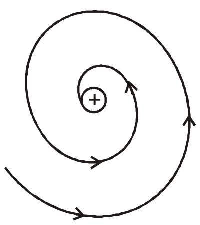
Reason of Failure of model :

1. It could not explain the line spectrum of H-atom.

Justification : According to Maxwell's electromagnetic theory every accelerated moving charged particle radiates energy in the form of electromagnetic waves & therefore during revolution of e^- in circular orbit its frequency will continuously vary (i.e. decrease) which will result in the conitnuous emission of lines & therefore spectrum of atom must be continuous but in reality, one obtains line spectrum for atoms.

2. It could not explain the stablity of atoms.

Justification : Since revolving electron will continuously radiate energy & therfore radii of circular path will continuously decrease & in a time of about 10^{-8} sec revolving electron must fall down in a nucleus by adopting a spiral path



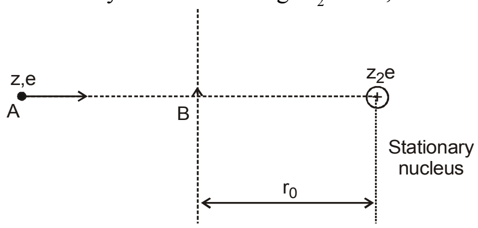
Path of electron spiral

DETERMINATION OF DISTANCE OF CLOSEST APPROACH :

When a positively charged particle approaches towards stationary nucleus then due to repulsion between the two, the kinetic energy of positively charged particle gradually decreases and a stage comes when its kinetic energy becomes zero & from where it again starts retracting its original path.

Definition : The distance of closest approach is the minimum distance of a stationary nucleus with a positively charged particle making head on collision from a point where its kinetic energy becomes zero.

Suppose a positively charged particle A of charge q_1 = ($=z_1e$) approaches from in finity towards a stationary nucleus of charge z_2e then, Suppose a positively charged particle A of charge q_1 ($= z_1$ e) approaches from in finity towards a stationry nucleus of charge z_2e then,



Let at point B, kinetic energy of particle A becomes zero then by the law of conservation of energy at point A & B,

$$TE_A = TE_B$$

$$KE_A + PE_A = KE_B + PE_B$$

$$E + 0 = 0 + \frac{k(z_1e)(z_2e)}{r_0} \text{ (in joule)}$$

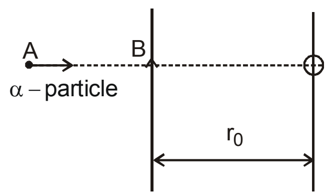
$$\therefore \quad r_0 = \frac{k(z_1e)(z_2e)}{E} \text{ m}$$

EXAMPLE 15

An α-particle with kinetic energy 10 MeV is heading towards a stationary point-nucleus of atomic number 50. Calculate the distance of closest approach.

Sol. $\therefore \; TE_A = TE_B$

$$\therefore \; 10 \times 10^6 \text{ e} = \frac{K \times (2e)(50e)}{r_0}$$



$r_0 = 1.44 \times 10^{-14}$ m

$r_0 = 1.44 \times 10^{-4}$ A

EXAMPLE 16

A beam of α - particles of velocity 2.1 × 10⁷ m/s is scattered by a gold (z = 79) foil. Find out the distance of closest approach of the α- particle to the gold nucleus. The value of charge/mass for α - particle is 4.8 × 10⁷ c/kg.

Sol. $\frac{1}{2}m_\alpha v_\alpha^2 = \frac{K(2e)(ze)}{r_0}$

$$r_0 = \frac{2K\left(\frac{2e}{m_\alpha}\right)(79\,e)}{v_\alpha^2}$$

$$= \frac{2\times(9\times10^8)(4.8\times10^7)(79\times1.6\times10^{-19})}{(2.1\times10^7)^2};$$

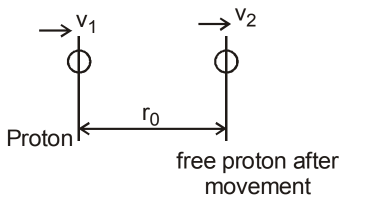
$$r_0 = 2.5\times10^{-14}\,m$$

EXAMPLE 17

A proton moves with a speed of 7.45 × 10⁵ m/s directing towards a free proton originally at rest. Find the distance of closest approach for the two protons.

Sol. → v = 7.45 × 10⁵ m/s   u = 0

Originally



At the time of distance of closest approach

By the law of cons. of energy

$$\frac{1}{2}mv^2 + 0 = \frac{ke^2}{r_0} + \frac{1}{2}mv_1^2 + \frac{1}{2}mv_1^2 \qquad ...(1)$$

By the cons. of momentum $mv + 0 = mv_1 + mv_1$

$$\therefore \qquad v_1 = \frac{v}{2}$$

From equation (1) $\frac{1}{2}mv^2 = \frac{ke^2}{r_0} + m\left(\frac{v}{2}\right)^2$

$$r_0 = \frac{4}{mv^2}\times ke^2 = \frac{4\times(9\times10^9)(1.6\times10^{-19})^2}{(1.66\times10^{-27})(7.45\times10^5)^2};$$

$$r_0 = 1.0\times10^{-12}\,m$$

Note

The student can now attempt section B from exercise.

Section C - Bohr Model, Bohr Model nuclear motion

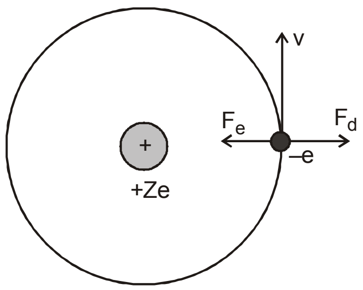
5 BOHR'S MODEL OF AN ATOM

Between 1913 and 1915 Niels Bohr developed a quantitative atomic model to the Hydrogen atom that could account for its spectrum. The model incorporated the nuclear model of the atom proposed by Rutherford on the basis of his experiments. We shall see that this model was successful in its ability to predict the gross features of the spectrum emitted by Hydrogen atom. This model was developed specifically for Hydrogenic atoms. Hydrogenic atoms are those which consist of a nucleus with positive charge + Ze (Z = atomic number, e = charge of electron) and a single electron. More complex electron-electron interactions in an atom are not accounted in the Bohr's Model that's why it was valid only for one electron system or hydrogenic atoms.

The Bohr model is appropriate for one electron systems like H, He^+, Li^{+2} etc. and it was successful upto some extent in explaining the features of the spectrum emitted by such hydrogenic atoms. However this model is not giving a true picture of even these simple atoms. The true picture is fully a quantum mechanical affair which is different from Bohr model in several fundamental ways. Since Bohr model incorporates aspects of some classical and some modern physics, it is now called semiclassical model Bohr has explained his atomic model in three steps called postulates of Bohr's atomic model. Lets discuss one by one.

5.1 First Postulate

In this postulate Bohr incorporate and analyses features of the Rutherford nuclear model of atom. In this postulate it was taken that as the mass of nucleus is so much greater then the mass of electron, nucleus was assumed to be at rest and electron revolves around the nucleus in an orbit. The orbit of electron is assumed to be circular for simplicity. Now the statement of first postulate is "During revolution of electron around the nucleus in circular orbit, the electric coulombian force on electron is balanced by the centrifugal force acting on it in the rotating frame of reference."



If electron revolves with speed v in the orbit of radius r. Then relative to rotating frame attached with electron, the centrifugal force acting on it is

$$F_{cf} = \frac{mv^2}{r} \qquad ...(1)$$

The coulombian force acting on electron due to charge of nucleus (+Ze) is

$$F_{electric} = \frac{K(e)(Ze)}{r^2} \qquad ...(2)$$

Now according to first postulate from equation (1) & (2) we have

$$\frac{mv^2}{r} = \frac{KZe^2}{r^2} \text{ or } \frac{mv^2}{r} = \frac{KZe^2}{r^2} \qquad ...(3)$$

Equation (3) is called equation of Bohr's first postulate.

5.2 Second Postulate

In the study of atom, Bohr found that while revolving around the nucleus the orbital angular momentum of the electron was restricted to only certain values, we say that the orbital angular momentum of the electron is quantized. He therefore took this as a second postulate of the model. The statement of second Postulate is, "During revolution around the nucleus, the orbital angular momentum of electron L could not have just any value, it can take up only those values which are integral multiples of Planck's Constant divided by 2π i.e. $h/2\pi$"

Thus the angular momentum of electron can be written as

$$L = \frac{nh}{2\pi} \qquad ...(1)$$

Where n is a positive integer, known as quantum number. In an orbit of radius r if an electron (mass m) revolves at speed v, then its angular momentum can be given as

$$L = mvr \qquad ...(2)$$

Now from equation (1) and (2), we have for a revolving electron

$$mvr = \frac{nh}{2\pi} \qquad ...(3)$$

Equation (3) is known as equation of second postulate of Bohr model. Here the quantity $\frac{h}{2\pi}$ occurs so frequently in modern physics that, for convenience, it is given its own designation h, pronounced as "h-bar."

$$\hbar = \frac{h}{2\pi} \simeq 1.055 \times 10^{-34} \text{ J-s} \qquad ...(4)$$

5.3 Third Postulate

While revolution of an electron in an orbit its total energy is taken as sum of its kinetic and electric potential energy due to the interaction with nucleus. Potential energy of electron revolving in an orbit of radius r can be simply given as

$$U = -\frac{K(e)(Ze)}{r} = -\frac{Kze^2}{r} \qquad ...(1)$$

For kinetic energy of electron, we assume that relativistic speeds are not involved so we can use the classical expression for kinetic energy. Thus kinetic energy of electron in an orbit revolving at speed v can be given as

$$K = \frac{1}{2}mv^2 \qquad ...(2)$$

Thus total energy of electron can be given as

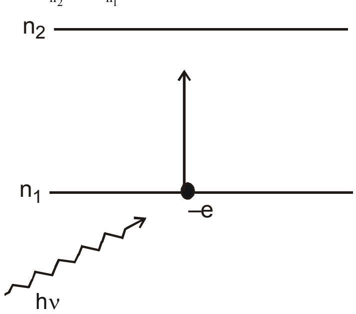
$$E = K + U = \frac{1}{2}mv^2 - \frac{KZe^2}{r}$$

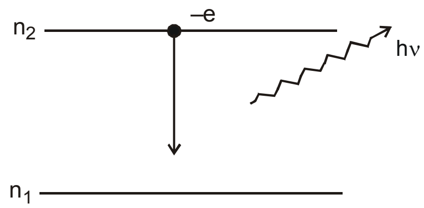
Here we can see that while revolving in a stable orbit, the energy of electron remains constant. From the purely classical viewpoint, during circular motion, as electron is accelerated, it should steadily loose energy by emitting electromagnetic radiations and it spiraled down into the nucleus and collapse the atom.

Bohr in his third postulate stated that "While revolving around the nucleus in an orbit, it is in stable state, it does not emit any energy radiation during revolution. It emits energy radiation only when it makes a transition from higher energy level (upper orbit) to a lower energy level (lower orbit) and the energy of emitted radiation is equal to the difference in energies of electron in the two corresponding orbits in transition. "

If an electron makes a transition form a higher orbit n_2 to a lower orbit n_1 as shown in figure. Then the electron radiates a single photon of energy

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





Here E_{n_2} and E_{n_1} are the total energies of electron in the two orbits n_2 and n_1. The emitted photon energy can be expressed as $h\nu$ where ν is the frequency of radiated energy photon. If A be the wavelength of photon emitted then the energy of emitted photon can also be given as

$$\Delta E = h\nu = \frac{hc}{\lambda} \qquad ...(1)$$

Similarly when energy is supplied to the atom by an external source then the electron will make a transition from lower energy level to a higher energy level. This process is called excitation of electron from lower to higher energy level. In this process the way in which energy is supplied to the electron is very important because the behaviour of the electron in the excitation depends only on the process by which energy as supplied from an external source. This we'll discuss in detail in later part of this chapter.

First we'll study the basic properties of an electron revolving around the nucleus of hydrogenic atoms.

5.4 Properties of Electron in Bohr's Atomic Model

Now we'll discuss the basic properties of an electron revolving in stable orbits, we call Bohr energy level. We have discussed that there are some particular orbits in which electron can revolve around the nucleus for which first and second postulates of Bohr model was satisfied. Thus only those orbits are stable for which the quantum number n = 1, 2, 3, ... Now for n^{th} orbit if we assume its radius is denoted by r_n and electron is revolving in this orbit with speed v_n. We can represent all the physical parameters associated with the electron in n^{th} orbit by using a subscript n with the symbol of the physical parameters like r_n, v_n etc.

(a) Radius of n^{th} Orbit in Bohr Model

Radius of electron in n^{th} Bohr's orbit can be calculated using the first two postulates of the Bohr's model, using previous equations, we get

$$v_n = \frac{nh}{2\pi m r_n}$$

Substituting this value of v_n in equation $mvr = \frac{nh}{2\pi}$, we get

$$r_n = \frac{n^2h^2}{4\pi^2 KZe^2 m}$$

or

$$r_n = \frac{h^2}{4\pi^2 Ke^2 m} \times \frac{n^2}{Z}$$

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

1.5.2 Velocity of Electron in n^{th} Bohr's Orbit

By substituting the value of r_n we can calculate the value of v_n as

$$v_n = \frac{2\pi KZe^2}{nh}$$

or $$v_n = \frac{2\pi Ke^2}{h} \times \frac{Z}{n}$$

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

(b) Time period of Electron in n^{th} Bohr's Orbit

Time period of electron of n^{th} orbit is given by

$$T_n = \frac{1}{f_n} \quad \text{or} \quad T_n = \frac{n^3h^3}{4\pi^2 K^2 Z^2 e^4 m}$$

(c) Current in n^{th} Bohr's Orbit

Electrons revolve around the nucleus in the n^{th} Bohr's Orbit then due to revolvution there is current in the orbit and according to the definition of current, the current in the n^{th} orbit will be total coulombs passing through a point in one seconds, and in an orbit an electron passes through a point f_n times in one second so the current in the n^{th} orbit will be

$$I_n = f_n \times e$$

or $$I_n = \frac{4\pi^2 K^2 Z^2 e^5 m}{n^3 h^3}$$

(d) Energy of Electron in n^{th} Orbit

We've discussed that in n^{th} orbit during revolution the total energy of electron can be given as sum of kinetic and potential energy of the electron as

$$E_n = K_n + U_n$$

Kinetic energy of electron in n^{th} orbit can be given as

$$K_n = \frac{1}{2} m v_n^2$$

From equation of first postulate of Bohr Model we have for n^{th} orbit

$$m v_n^2 = \frac{KZe^2}{r_n}$$

From equation

$$K_n = \frac{1}{2} m v_n^2 = \frac{1}{2}\frac{KZe^2}{r_n}$$

the potential energy of electron in n^{th} orbit is given as

$$U_n = -\frac{KZe^2}{r_n}$$

Thus total energy of e^- in n^{th} orbit can given as

$$E_n = K_n + U_R = \frac{1}{2}\frac{KZe^2}{r_n} - \frac{KZe^2}{r_n} = \frac{1}{2}\frac{KZe^2}{r_n}$$

☛ Here we can see that $|E_n| = |K_n| = \frac{1}{2}|U_n|$ which is a very useful relation, always followed by a particle revolving under the action of a force obeying inverse square law.

Now substituting the value of r_n we get

$$E_n = -\frac{1}{2} KZe^2 \times \frac{4\pi^2 KZe^2 m}{n^2h^2}$$

or $$= -\frac{2\pi^2 K^2 Z^2 e^4 m}{n^2 h^2}$$

or $$E_n = \frac{2\pi^2 K^2 Z^2 e^4 m}{h^2} \times \frac{Z^2}{h^2}$$

Substituting the value of constants in above equation we get

or $$E_n = -13.6 \times \frac{Z^2}{n^2} eV$$

The above equation can be used to find out energies of electron in different energy levels of different hydrogen atoms.

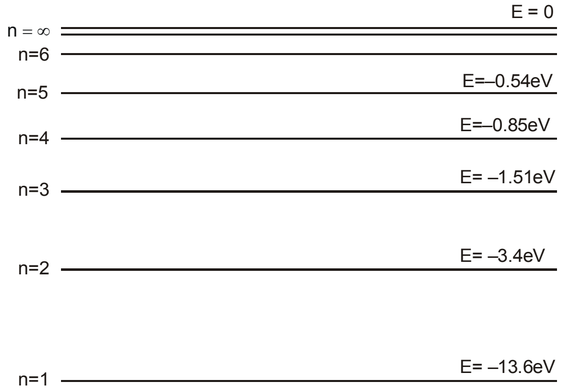
(e) Energies of Different Energy Levels in Hydrogenic Atoms

By the use of above equation we can find out the energies of different energy levels. Students should remember these energies for first six level as

$$E_1 = -13.6\ Z^2\ eV$$
$$E_2 = -3.40\ Z^2\ eV$$
$$E_3 = -1.51\ Z^2\ eV$$

$$E_4 = -0.85\ Z^2\ eV$$
$$E_5 = -0.54\ Z^2\ ev$$
$$E_6 = -0.36\ Z^2\ eV$$

The above equations clearly shows that as the value of n increases, the difference between two consecutive energy levels decreases. It can be shown with the the help of figure, which shows the energy level diagram for a hydrogen atom.



Now if we multiply the numerator and denominator of above equation by ch we get

$$E_n = -\frac{2\pi^2K^2e^4m}{ch^3}\times ch\times\frac{Z^2}{n^2}$$

or $\qquad E_n = -\,Rch \times \dfrac{Z^2}{n^2} eV$

Where $R = \dfrac{2\pi^2K^2e^4m}{ch^3}$ is defined as Rydberg Constant and the value of it is given as R = 10967800 m^{-1}, which can be taken approximately as $10^7\ m^{-1}$.

For n = 1 and Z = 1 the energy is given as

E = –Rch joules and is called as One Rydberg Energy

1 Rydberg = 13.6 eV = 2.17×10^{-18} joules

Lets discuss some examples on Bohr's atomic model to understand it better.

EXAMPLE 18

What is the angular mometum of an electron in Bohr's Hydrogen atom whose energy is – 3.4 eV ?

Sol. Energy of electron in n^{th} Bohr orbit of hydrogen atom is given by,

$$E = -\frac{13.6}{n^2}eV$$

Hence, $\qquad -3.4 = -\dfrac{13.6}{n^2}$

or $\qquad n^2 = 4$

or $\qquad n = 2$

The angular momentum of an electron in n^{th} orbit is given as $L = \dfrac{nh}{2\pi}$. Putting n = 2, we obtain

$$L = \frac{2h}{2\pi} = \frac{h}{\pi} \Rightarrow T = \frac{n^3h^3}{4\pi^2k^2Z^2e^4m}$$

Thus, $\quad T \propto n^3 \qquad$ or $\qquad \dfrac{T_1}{T_2} = \dfrac{n_1^3}{n_2^3}$

As $T_1 = 8T_2$, the above relation gives

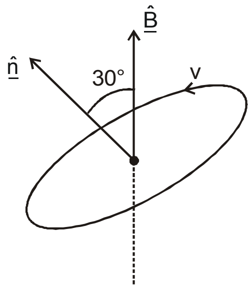
$$\left(\frac{n_1}{n_2}\right)^3 = 8 \qquad \text{or} \qquad n_1 = 2n_2$$

Thus the possible values of n_1 and n_2 are

$n_1 = 2, n_2 = 1$; $n_1 = 4, n_2 = 2$; $n_1 = 6, n_2 = 3$ and so on ....

EXAMPLE 19

An electron in the ground state of hydrogen atom is revolving in anti-clockwise direction in the circular orbit of radius R as shown in figure



(i) Obtain an expression for the orbital magnetic dipole moment of the electron.

(ii) The atom is placed in a uniform magnetic induction B such that the plane normal of the electron orbit makes an anlge 30° with the magnetic induction. Find the torque experienced by the orbiting electron.

Sol. (i) According to Bohr's second postulate

$$mvr = n\frac{h}{2\pi} = \frac{h}{2\pi} \qquad \text{(As for n = 1 first only)}$$

or $$v_1 = \frac{h}{2\pi m r_1}$$

We know that the rate of flow of charge is current.
Hence current in first orbit is
Now from each equation

$$i = ev_1 = e\left(\frac{v_1}{2\pi r_1}\right) = \frac{e}{2\pi r_1} \times v_1$$

$$i = \frac{e}{2\pi r_1} \times \frac{h}{2\pi n r_1} = \frac{eh}{4\pi^2 mr^2}$$

Magnetic dipole moment, $M_1 = i \times A_1$

or

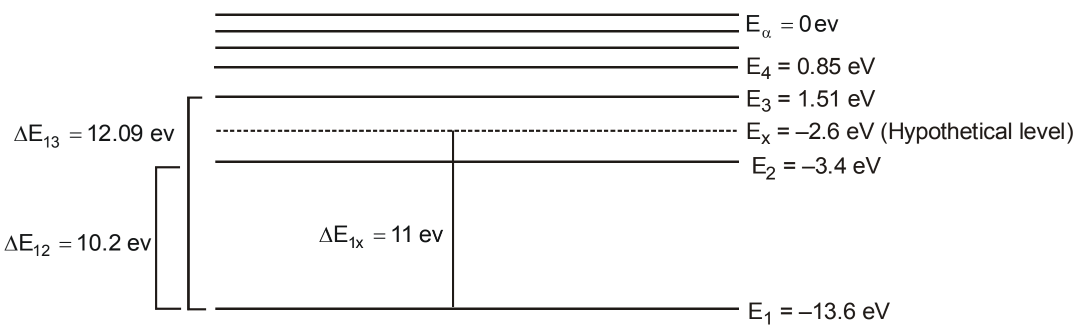
$$M_1 = \frac{eh}{4\pi^2 mr^2} \times \pi r_1^2 = \frac{eh}{4\pi m}$$

(ii) Torque on the orbiting electron in uniform magnetic field is

$$\vec{\tau} = \vec{M} \times \vec{B}$$

or $$\tau = MB \sin 30°$$

or $$\tau = \frac{eh}{4\pi m} \times \frac{B}{2} = \frac{ehB}{8\pi m}$$



6. EXCITATION AND IONIZATION OF AN ATOM

According to third postulate of Bohr model we've discussed when some energy is given to an electron of atom from an external source it may make a transition to the upper energy level. This phenomenon we call excitation of electron or atom and the upper energy level to which the electron is excited is called excited state. To excite an electron to a higher state energy can be supplied to it ijn two ways. Here we'll discuss only the energy supply by an electromagnetic photon. Other method of energy supply we'll discuss later in this chapter.

According to Planck's quantum theory photon is defined as a packet of electromagnetic energy, which when absorbed by a physical particle, its complete electromagnetic energy is converted into the mechanical energy of particle or the particle utilizes the energy of photon in the form of increment in its mechanical energy. When a photon is supplied to an atom and an electron absorbs this photon, then the electron gets excited to a higher energy level only if the photon energy is equal to the difference in energies of the two energy levels involved in the transition.

For example say in hydrogen atom an electron is in ground state (energy E_1 = –13.6 eV). Now it absorbs a photon and makes a transition to n = 3 state (Energy E_3 = –1.51 eV) then the energy of incident photon must be equal to

$$\Delta E_{13} = E_3 - E_1 = (-1.51) - (13.6) \text{ eV} = 12.09 \text{ eV}$$

Now we'll see what will happen when a photon of energy equal to 11 eV incident on this atom. From the above calculation of energy differences of different energy levels we can say that if the electron in ground state absorbs this photon it will jump to a state some where between energy level n = 2 and n = 3 as shown in figure. When electron in ground state absorbs a photon of 11 eV energy, its total energy becomes

$E = E_1 + 11 = -13.6 + 11 eV = -2.6$ eV

As discussed in previous sections, in an atom electron cannot take up all energies. It can exist only in some particular energy levels which have energy given as $-13.6/n^2$eV.

When a photon of energy 11 eV is absorbed by an electron in ground state. The energy of electron becomes –2.6 eV of it will excite to a hypothetical energy level X some where between n = 2 and n = 3 as shown in figure, which is not permissible for an electron. Thus when in ground state electron can absorb only those photons which have energies equal to the difference in energies of the stable energy level with ground state. If a photon beam incident on H-atoms having photon energy not equal to the difference of energy levels of H-atoms such as 11 eV, the beam will just be transmitted without any absorption by the H-atoms.

Thus to excite an electron from lower energy level to higher levels by photons, it is necessary that the photon must be of energy equal to the difference in energies of the two energy levels involved in the transition.

As we know that for higher energy levels, energy of electrons is less. When an electron is moved away from the nucleus to ∞th energy level or at $n = \infty$, the energy becomes (zero) or the electron becomes free from the attraction of nucleus or it is removed from the atom. In fact when an electron is in an atom, its total energy is negative $\left(E_n = -\frac{13.6}{n^2}Z^2\right)$. This negative sign shows that electron in under the influence of attractive forces of nucleus. When energy equal in magnitude to the total energy of an electron in a particular energy level is given externally, its total energy becomes zero or we can say that electron gets excited to ∞th energy level or the electron is removed from the atom and atom is said to be ionized.

We know that removal of electron from an atom is called ionization. In other words, ionization is the excitation of an electron to $n = \infty$ level. The energy required to ionize an atom is called ionization energy of atom for the particular energy level from which the electron is removed. In hydrogen atoms, the ionization energy for nth state can be given as

$$\Delta E_{n\to\infty} = E_\infty - E_n$$

or

$$\Delta E_{n\to\infty} = 0 - \left(-\frac{13.6Z^2}{n^2}\right)eV$$

or $$\Delta E_{n\to\infty} = \frac{13.6Z^2}{n^2}eV$$

When an electron absorbs a monochromatic radiation from an external energy source then it makes a transition from a lower energy level to a higher level. But this state of the electron is not a stable one. Electron can remain in this excited state for a very small internal at most of the order of 10^{-1} second. The time period for which this excited state of the electron exists is called the life time of the excited state. After the life time of the excited state the electron must radiate energy and it will jump to the ground state.

Let us assume that the electron is initially in n_2 state and it will jump to a lower state n_1 then it will emit a photon of energy equal to the energy difference of the two states n_1 and n_2 as

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

When ΔE is the energy of the emitted photon. Now substituting the values of E_{n_2} and E_{n_1} in above equation, we get

$$\Delta E = -\frac{2\pi^2K^2Z^2e^4m}{n_2^2h^2} + \frac{2\pi^2K^2Z^2e^4m}{n_1^2h^2}$$

or $$\Delta E = \frac{2\pi^2K^2Z^2e^4m}{h^2}\left(\frac{1}{n_1^2} - \frac{1}{n_2^2}\right)$$

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

Here 13.6 Z^2 can be used as ionization energy for n = 1 state for a hydrogenic atom thus the energy of emitted photon can also be written as

$$\Delta E = IP\left(\frac{1}{n_1^2} - \frac{1}{n_2^2}\right)$$

Equation can also be used to find the energy of emitted radiation when an electron jumos from a higher orbit n_2 to a lower orbit n_1. If λ be the wavelength of the emitted radiation then

$$\Delta E = \frac{hc}{\lambda}$$

This energy can be converted to eV by dividing this energy by the electronic charge e, as if wavelength is given in A, the energy in eV can be given as

$$\Delta E = \frac{hc}{\lambda e}(\text{in eV})$$

Substituting the values of h, c and e we get

$$\Delta E = \frac{(6.63\times10^{-34})\times(3\times10^8)}{\lambda\times(1.6\times10^{-19})\times10^{-10}}\ eV$$

$$\Delta E = \frac{12431}{\lambda}\ eV \qquad ...(a)$$

Here in above equation, lambda is in Å units
This equation is the most important in numerical calculations, as it will be very frequency used. From equation we have

or $$\frac{1}{\lambda} = \frac{-13.6Z^2}{hc}\left(\frac{1}{n_1^2} - \frac{1}{n_2^2}\right)eV$$

or $$\bar{v} = \frac{1}{\lambda} = -RZ^2\left(\frac{1}{n_1^2} - \frac{1}{n_2^2}\right)$$

(As Rydberg Constant R = 13.6/hc eV)

Here $\bar{v}$ is called wave number of the emitted radiation and is defined as number of waves per unit length and the above relation is used to find the wavelength of emitted radiation when an electron makes a transition from higher level n_2 to lower level n_1 is called Rydberg formula. But students are advised to use equation (a) in numerical calculations to find the wavelength of emitted radiation using the energy difference in electron volt. It can be rearranged as

$$\lambda = \frac{12431}{\Delta E\,(\text{in eV})}\text{Å}$$

☛ **No. of emission spectral lines :** If the electron is excited to state with principal quantum number n then from the n^{th} state, the electron may go to $(n-1)^{th}$ state, ..., 2^{nd} state or 1st state. So there are (n – 1) possible transitions starting from the nth state. The electron reaching (n – 1)th state may make (n – 2) different transitions. Similarly for other lower states. The total no. of possible transitions is $(n-1) + (n-2) + (n-3) + ...2 + 1 = \frac{n(n-1)}{2}$

☛ **No. of absorption spectral lines :** Since at ordinary temperatures, almost all the atoms remain in their lowest energy level (n = 1) & so absorption transition can start only from n = 1 level (not from n = 2, 3, 4, ... levels). Hence, only Lyman series is found in the absorption spectrum of hydrogen atom (which as in the emission spectrum, all the series are found No. of absorption spectral lines = (n – 1)

7. SPECTRAL SERIES OF HYDROGEN ATOM :

The wavelength of the lines of every spectral series can be calculated using the formula given by equation (a).

Five special series are observed in the Hydrogen Spectrum corresponding to the five energy levels of the Hydrogen atom and these five series are named as on the names of their inventors. These series are

(1) Lyman Series
(2) Balmer Series
(3) Paschen Series
(4) Brackett Series
(5) Pfund Series

These spectral series are shown in figure-1.11.

(1) Lyman Series : The series consists of wavelength of the radiations which are emitted when electron jumps from a higher energy level to n = 1 orbit. The wavelength constituting this series lie in the Ultra Violet region of the electromagnetic spectrum.

For Lyman Series $n_1 = 1$

and $n_2 = 2, 3, 4, ...$

First line of Lyman series is the line corresponding to the trnasition $n_2 = 2$ to $n_1 = 1$, similarly second line of the Lyman series is the line corresponding to the transition $n_2 = 3$ to $n_1 = 1$.

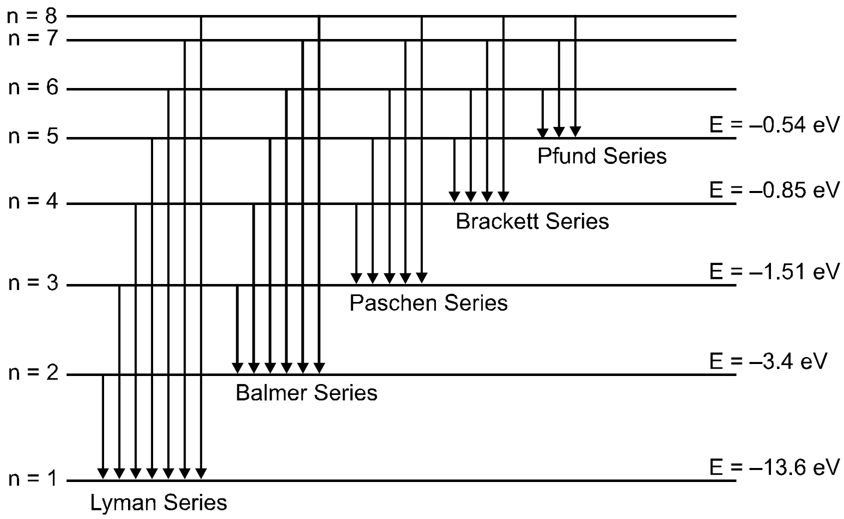
(2) Balmer Series : The series consists of wavelengths of the radiations which are emitted when electron jumps from a higher energy level to n = 2 orbit. The wavelengths consisting this series lie in the visible region of the electromagnetic spectrum.

(3) Paschen Series : The series consists of wavelengths of the radiations which are emitted when electron jumps from a higher energy level to n = 3 orbit. The wavelengths constituting this series lie in the Near Infra Red region of the electromagnetic spectrum.

(4) Brackett Series : The series consists of wavelengths of the radiations which are emitted when electron jumps from a higher energy level to n = 4 orbit. The wavelengths constituting this series lie in the Infra Red region of the electromagnetic spectrum.

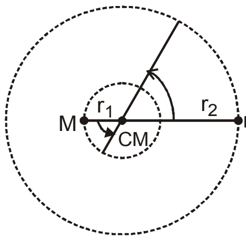
(5) Pfund Series : The series consists of wavelengths of the radiations which are emitted when electron jumps from a higher energy level to n = 5 orbit. The wavelengths constituting this series lie in the Deep Infra Red region of the electromagnetic spectrum.

We can find out the wavelengths corresponding to the first line and the last line for remaining four spectral series as mentioned in the case of Lyman Series.



8. APPLICATION OF NUCLEUS MOTION ON ENERGY OF ATOM

Let both the nucleus of mass M, charge Ze and electron of mass m, and charge e revolve about their centre of mass (CM) with same angular velocity (ω) but different linear speeds. Let r_1 and r_2 be the distance of CM from nucleus and electron. Their angular velocity should be same then only their separation will remain unchanged in an energy level.



Let r be the distance between the nucleus and the electron. Then

$$Mr_1 = mr_2$$
$$r_1 + r_2 = r$$

$$\therefore \quad r_1 = \frac{mr}{M+m} \quad \text{and} \quad r_2 = \frac{Mr}{M+m}$$

Centripetal force to the electron is provided by the electrostatic force. So,

$$mr_2\omega^2 = \frac{1}{4\pi\varepsilon_0}\frac{Ze^2}{r^2}$$

or $$m\left(\frac{Mr}{M+m}\right)\omega^2 = \frac{1}{4\pi\varepsilon_0}\cdot\frac{Ze^2}{r^2}$$

or $$\left(\frac{Mr}{M+m}\right)r^3\omega^2 = \frac{Ze^2}{4\pi\varepsilon_0}$$

or $$\mu r^3\omega^2 = \frac{e^2}{4\pi\varepsilon_0}$$

where $$\frac{Mm}{M+m} = \mu$$

Moment of inertia of atom about CM,

$$I + Mr_1^2 + mr_2^2 = \left(\frac{Mm}{M+m}\right)r^2 = \mu r^2$$

According to Bohr's theory, $\dfrac{nh}{2\pi} = I\omega$

or $$\mu r^2\omega = \frac{nh}{2\pi}$$

Solving above euqations for r, we get

$$r = \frac{\varepsilon_0 n^2h^2}{\pi\mu e^2 Z} \quad \text{and} \quad \mathbf{r = (0.529\ A)}\ \frac{n^2}{Z}\cdot\frac{m}{\mu}$$

Further electrical potential energy of the system.

$$U = \frac{-Ze^2}{4\pi\varepsilon r} \qquad U = \frac{-Z^2e^4\mu}{4\varepsilon_0^2 n^2h^2}$$ and kinetic energy.

$$K = \frac{1}{2}I\omega^2 = \frac{1}{2}\mu r^2\omega^2 \quad \text{and} \quad K = \frac{1}{2}\mu v^2$$

v-speed of electron with respect to nucleus. ($v = r\omega$)

here $$\omega^2 = \frac{Ze^2}{4\pi\varepsilon_0\mu r^3}$$

$$\therefore \quad K = \frac{Ze^2}{8\pi\varepsilon_0 r} = \frac{Z^2e^4\mu}{8\pi\varepsilon_0^2 n^2h^2}$$

$\therefore$ Total energy of the system $E_n = K + U$

$$E_n = -\frac{\mu e^4}{8\varepsilon_0^2 n^2h^2}$$

this expression can also be written as

$$E_n = -(13.6\text{eV})\frac{Z^2}{n^2}\cdot\left(\frac{\mu}{m}\right)$$

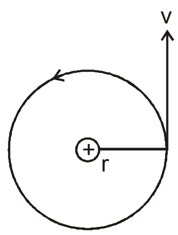
The expression for E_n without considering the motion of proton is $E_n = -\dfrac{me^4}{8\varepsilon_0^2 n^2h^2}$, i.e., m is replaced by μ while considering the motion of nucleus.

IMPORTANT FORMULAE

(1) Time period (T) : distance = time x speed

$$2\pi r = T \times v$$

$$T = \frac{2\pi r}{v}$$



$$T_n \propto \frac{n^3}{z^2}$$

$$T_n = \frac{n^2h^2}{4\pi k^2z^2me^4}$$

(2) Frequency of revolution

$$f_n = \frac{v_n}{2\pi r_0} = \frac{4\pi k^2 z^2 m e^4}{n^3 h^3} \; ; \; f_n \propto \frac{z^2}{n^3}$$

(3) Momentum of electron

$$P_n = \frac{2\pi m k z^2}{nh} \qquad P_n \propto \frac{1}{n}$$

(4) Angular velocity of electron

$$\omega_n = \frac{8\pi^3 k^2 z^2 m e^4}{n^3 h^3}, \quad \omega_n \propto \frac{z^2}{n^3}$$

(5) Current (I)

$$I = \frac{e}{T} = ev = \frac{ev}{2\pi r}; \; I \propto \frac{z^2}{n^3}$$

(6) Magnetic moment of electron (M)

$$M = iA$$

$$M = \frac{ev}{2\pi r} \times \pi r^2, \quad M = \frac{evr}{2}$$

$$M = \frac{e(mvr)}{2m} = \frac{eJ}{2m}; \quad \frac{M}{J} = \frac{e}{2m},$$

$$M = \frac{e}{2m}\left(\frac{nh}{2\pi}\right) = n\left(\frac{eh}{4\pi m}\right)$$

$M = n\mu_B$

μ_B = Bohr magneton = 9.3×10^{-24} Amp. m².

$M \propto n$

(7) Magnetic field of Magnetic induction at the centre

$$B = \frac{\mu_0 i}{2r} = \frac{\mu_0 ev}{4\pi r^2}$$

Note

The student can now attempt section C from exercise.

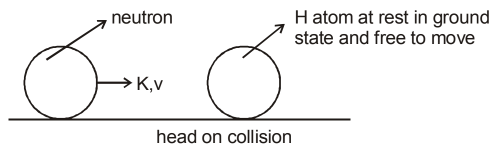
Section D - Atomic Collisions

9. ATOMIC COLLISION

In such collisions assume that the loss in the kinetic energy of system is possible only if it can excite or ionise.

EXAMPLE 1

Ex.20



What will be the type of collision, if K = 14 eV, 20.4 eV, 22 eV, 24.18 eV (elastic/inelastic/perectly inelastic)

Sol. Loss in energy (ΔE) during the collision will be used to excite the atom or electron from one level to another.

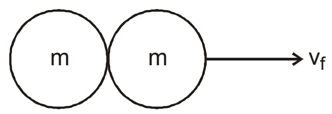
According to quantum Mechanics, for hydrogen atom.

ΔE = {0, 10.2 eV, 12.09 eV, ..., 13.6 eV}

According to Newtonion mechanics

minimum loss = 0, (elastic collision)

for maximum loss collision will be perfectly inelastic if neutron collides perfectly inelastically then, Applying momentum conservation



$$mv_0 = 2mv_f \quad \Rightarrow \quad v_f = \frac{v_0}{2}$$

$$\text{final} \quad K.E. = \frac{1}{2} \times 2M \times \frac{v_0^2}{4}$$

$$= \frac{\frac{1}{2}mv_0^2}{2} = \frac{k}{2} \quad \text{maximum loss} = \frac{K}{2}$$

According to classical mechanics (ΔE) = $[0, \frac{K}{2}]$

(a) If K = 14 eV,

According to quantum mechanics

(ΔE) = {0, 10, 2eV, 12.09 eV}

According to classical mechanics

ΔE = [0, 7 eV]

loss = 0,

hence it is elastic collision

(b) If K = 20.4 ev

According to classical mechanics

loss = [0, 10.2 eV]

According to quantum mechanics

loss = {0, 10.2 eV, 12.09 eV,...........}

loss = 0 elastic collision.

loss = 10.2 eV perfectly inelastic collision

(c) If K = 22 eV

Classical mechanics $\Delta E = [0, 1]$

Quantum mechanics ΔE = {0, 10.2 eV, 12.09 eV,.......}

loss = 0 elastic collision

loss = 10.2 eV inelastic collision

(d) If K = 24.18 eV

According to classical mechanics $\Delta E = [0, 12.09 \text{ eV}]$

According to quantum mechanics ΔE = {0, 10.2 eV, 12.09 eV, ...13.6 eV}

loss = 0 elastic collision

loss = 10.2 eV inelastic collision

loss = 12.09 eV perfectly inelastic collision

EXAMPLE 21

A He^+ ion is at rest and is in ground state. A neutron with initial kinetic energy K collides head on with the He^+ ion. Find minimum value of K so that there can be an inelastic collision between these two particle.

Sol. Here the loss during the collision can only be used to excite the atoms or electrons.

So according to quantum mechanics

loss = {0, 40.8eV, 48.3eV, ..., 54.4 eV} ...(1)

$$E_n = -13.6 \frac{Z^2}{n^2} \text{eV}$$

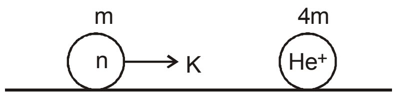
Now according to Newtonion mechanics

Minimum loss = 0

maximum loss will be for perfectly inelastic collision.

let v_0 be the initial speed of neutron and v_f be the final

common speed.



so by momentum conservation

$$mv_0 = mv_f + 4mv_f \qquad v_f = \frac{v_0}{5}$$

where m = mass of Neutron

$\therefore$ mass of He^+ ion = 4m

so final kinetic energy of system

$$\text{K.E.} = \frac{1}{2}mv_f^2 + \frac{1}{2}4mv_f^2 = \frac{1}{2}(5m)\frac{v_0^2}{25}$$

$$= \frac{1}{5}.(\frac{1}{2}mv_0^2) = \frac{K}{5}$$

$$\text{maximum loss} = K - \frac{K}{5} = \frac{4K}{5}$$

so loss will be $\left[0, \frac{4K}{5}\right]$

For inelastic collision there should be at least one common value other than zero is set (1) and (2)

$$\therefore \quad \frac{4K}{5} > 40.8 \text{ eV}$$

$$K > 51 \text{ eV}$$

minimum value of K = 51 eV

EXAMPLE 22

How many different wavelengths may be observed in the spectrum from a hydrogen sample if the atoms are excited to states with principal quantum number n ?

Sol. From the nth state, the atom may go to (n – 1)th state, ...2nd state or 1st state. So there are (n – 1) possible transitions starting from the nth state. The atoms reaching (n – 1)th state may make (n – 2) different transitions. Similarly for other lower states. The total number of possible transitions is

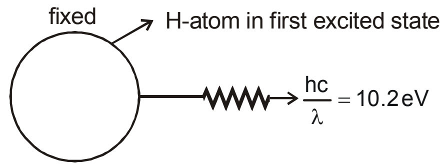
(n – 1) + (n – 2) + (n – 3) + ... 2 + 1

$$= \frac{n(n-1)}{2} \qquad \textbf{(Remember)}$$

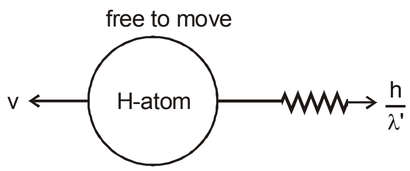
☛ **Calculation of recoil speed of atom on emission of a photon**

$$\text{momentum of photon} = mc = \frac{h}{\lambda}$$

(a)



(b)



m - mass of atom

According to momentum conservation

$$mv = \frac{h}{\lambda'} \qquad ...(i)$$

According to energy conservation

$$\frac{1}{2}mv^2 + \frac{hc}{\lambda'} = 10.2\,eV$$

Since mass of atom is very large than photon

hence $\frac{1}{2}mv^2$ can be neglected

$$\frac{hc}{\lambda'} = 10.2\,eV \qquad \frac{h}{\lambda} = \frac{10.2}{c}eV$$

$$mv = \frac{10.2}{c}eV \qquad v = \frac{10.2}{cm}$$

$$\text{recoil speed of atom} = \frac{10.2}{cm}$$

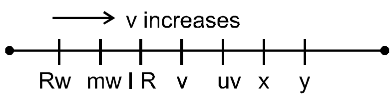
Note

The student can now attempt section D from exercise.

Section E - X-rays production, X-Rays Moseley's law, X-Ray Properties

10. X-RAYS

It was discovered by **ROENTGEN.** The wavelenth of x-rays is found between 0.1 Å to 10 Å. These rays are invisible to eye. They are electromagnetic waves and have speed c = 3 × 10^8 m/s in vacuum. Its photons have energy around 1000 times more than the visible light.

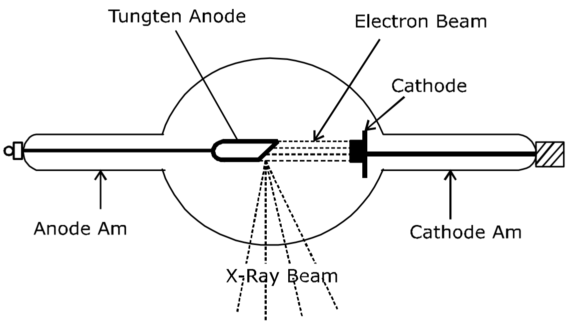


When fast moving electrons having energy of order of several keV strike the metallic target then x-rays are produced.

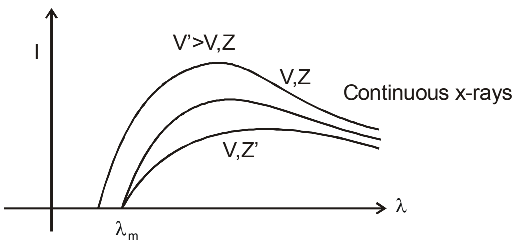
10.1 Production of x-rays by Coolidge Tube :

The melting point, specific heat capacity and atomic number of target should be high. When voltage is applied across the filament then filament on being heated emits electrons from it. Now for giving the beam shape of electrons, collimator is used. Now when electron strikes the target then x-rays are produced. When electrons strike with the target, some part of energy is lost and converted into heat. Since target should not melt or it can absorb heat so the melting point and specific heat of target should be high.

Here copper rod is attached so that heat produced can go behind and it can absorb heat and target does not get heated very high.



10.2 Variation of Intensity of X-rays with Intensity is plotted as shown in figure.



1. The minimum wavelength corresponds to the maximum energy of the x-rays which in turn is equal to the maximum kinetic energy eV of the striking electrons thus

$$eV = h\nu_{max} = \frac{hc}{\lambda_{min}}$$

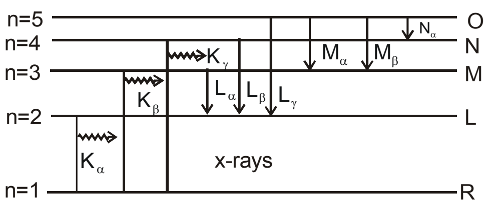
$$\Rightarrow \quad \lambda_{min} = \frac{hc}{eV} = \frac{12400}{V(\text{involts})} \text{Å}$$

We see that cutoff wavelength λ_{min} depends only on accelerating voltage applied between target and filament. It does not depend upon material of target, it is same for two different metals (Z and Z′).

2. **Charactristic X-rays**

The sharp peaks obtained in graph are known as characteristic x-rays because they are characteristic of target mateial.

λ_1, λ_2, λ_3, λ_4, ... are the charecteristic wavelength of material having atomic number Z are called **characteristic x-rays** and the spectrum obtained is called **characteristic spectrum.** If target of atomic number Z′ is used then peaks are shifted.



Characteristic x-rays emission occurs when an energetic electron collides with target and remove an inner shell electron from atom, the vacancy created in the shell is filled when an electron from higher level drops into it. Suppose vacancy created in innermost K-shell is filled by an electron droping from next higher level L-shell then K_α characteristic x-ray is obtained. If vaccany in K-shell is filled by an electron from M-shell, K_β line is produced and so on.

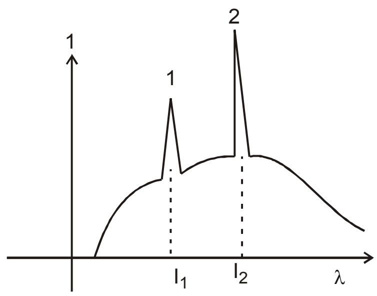
Similarly L_α, L_β,................ M_α, M_β lines are produced.

EXAMPLE 23

Find which is K_α and K_β

Sol. $\Delta E = \dfrac{hc}{\lambda}$, $\quad \lambda = \dfrac{hc}{\Delta E}$

since energy difference of K_α is less than K_β



$\Delta E_{k\alpha} < \Delta K_{k\beta}$

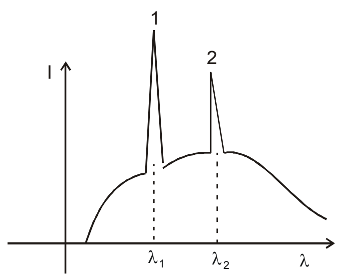
1 is K_β and 2 is K_α

EXAMPLE 24

Find which is K_α and L_α

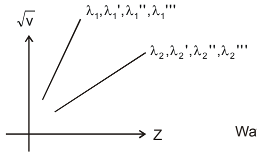
Sol. $\therefore \quad \Delta E_{K\alpha} > \Delta E_{L\alpha}$

1 is K_α and 2 is L_α



11. MOSELEY'S LAW :

Moseley meaured the frequencies of characteristic x-rays for a large number of elements and plotted the square root of frequency against position number in periodic table. He discovered that plot is very closed to a straight line not passing through origin.



Wavelength of charactristic wavelengths.

Moseley's observations can be mathematically expressed as

$$\sqrt{v} = a(Z-b)$$

a and b are positive constrants for one type of x-rays & for all elements (indepedent of Z).

Moseley's Law can be derived on the basis of Bohr's theory of atom, frequency of x-rays is given by

$$\sqrt{v} = \sqrt{CR\left(\frac{1}{n_1^2}-\frac{1}{n_2^2}\right)}.(Z-b)$$

by using the formula $\frac{1}{\lambda} = Rz^2\left(\frac{1}{n_1^2}-\frac{1}{n_2^2}\right)$ with modification for multi electron system.

b $\rightarrow$ known as screening constant or shielding effect, and (Z – b) is effective nuclear charge.

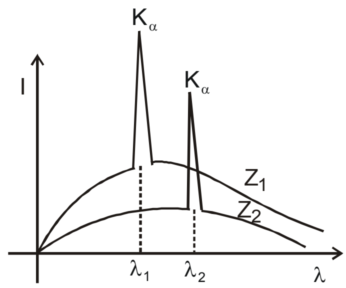
for K_α line

$n_1 = 1,\ n_2 = 2$

$\therefore \quad \sqrt{v} = \sqrt{\frac{3RC}{4}}(Z-b) \qquad \sqrt{v} = a(Z-b)$

Here $a = \sqrt{\frac{3RC}{4}}$, [b = 1 for K_α lines]

EXAMPLE 23



Find in Z_1 and Z_2 which one is greater.

Sol. $\therefore \sqrt{v} = \sqrt{cR\left(\frac{1}{n_1^2}-\frac{1}{n_2^2}\right)}$. (Z – b)

If Z is greater then v will be greater, λ will be less

$\therefore \quad \lambda_1 < \lambda_2$

$\therefore \quad Z_1 > Z_2$

Note

The student can now attempt section E from exercise.

Exercise - 1 Objective Problems | JEE Main

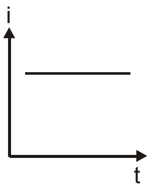
Section A - Photoelectric Effect

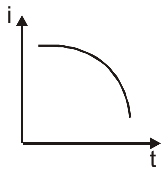
1. If the frequency of light in a photoelectric experiment is doubled, the stopping potential will
(A) be doubled
(B) halved
(C) become more than doubled
(D) become less than double

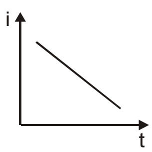
2. The stopping potential for the photo electrons emitted from a metal surface of work function 1.7eV is 10.4 V. Identify the energy levels corresponding to the transitions in hydrogen atom which will result in emission of wavelength equal to that of incident radiation for the above photoelectric effect
(A) n = 3 to 1 (B) n = 3 to 2
(C) n = 2 to 1 (D) n = 4 to 1

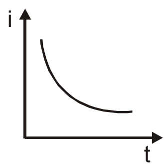
3. When a photon of light collides with a metal surface, number of electrons, (if any) coming out is
(A) only one (B) only two
(C) infinite (D) depends upon factors

4. A point source causes photoelectric effect from a small metal plate. Which of the following curves may represent the saturation photocurrent as a function of the distance between the source and the metal?

(A)


(B)


(C)


(D)


5. The maximum kinetic energy of photoelectrons emitted from a surface when photons of energy 6 eV fall on it is 4eV. The stopping potential is Volts is :
(A) 2 (B) 4
(C) 6 (D) 10

6. Let n_r and n_b be respectively the number of photons emitted by a red bulb and a blue bulb of equal power in a given time.
(A) $n_r = n_b$ (B) $n_r < n_b$
(C) $n_r > n_b$ (D) data insufficient

7. 10^{-3} W of 5000 Å light is directed on a photoelectric cell. If the current in the cell is 0.16 mA, the percentage of incident photons which produce photoelectrons, is
(A) 0.4% (B) .04%
(C) 20% (D) 10%

8. A point source of light is used in photoelectric effect. If the source is removed farther from the emitting metal, the stopping potential :
(A) will increase
(B) will decrease
(C) will remain constant
(D) will either increase or decrease

9. Cut off potentials for a metal in photoelectric effect for light of wavelength λ_1, λ_2 and λ_3 is found to be V_1, V_2 and V_3 volts if V_1, V_2 and V_3 are in Arithmetic Progression and λ_1, λ_2 and λ_3 will be :
(A) Arithmetic Progression
(B) Geometric Progression
(C) Harmonic Progression
(D) None

10. Photons with energy 5eV are incident on a cathode C, on a photoelectric cell. The maximum energy of the emitted photoelectrons is 2eV. When photons of energy 6eV are incident on C, no photoelectrons will reach the anode A if the stopping potential of A relative to C is
(A) 3V (B) –3V
(C) –1V (D) 4V

Section B - Radiation Pressure, Matter Waves + Davisson Germer Experiment

11. A proton and an electron are accelerated by same potential difference have de-Broglie wavelength λ_p and λ_e.
(A) $\lambda_e = \lambda_p$ (B) $\lambda_e < \lambda_p$
(C) $\lambda_e > \lambda_p$ (D) none of these

12. An electron with initial kinetic energy of 100eV is acceleration through a potential difference of 50V. Now the de-Broglie wavelength of electron becomes.
(A) 1 Å (B) $\sqrt{1.5}$Å
(C) $\sqrt{3}$ Å (D) 12.27 Å

13. If h is Planck's constant is SI system, the momentum of a photon of wavelength 0.01 Å is:
(A) 10^{-2} h (B) h
(C) 10^{2} h (D) 10^{12}h

14. When a centimeter thick surface is illuminated with light of wavelength λ, the stopping potential is V. When the same surface is illuminated by light of wavelength 2λ, the stopping potential is V/3. Threshold wavelenth for the metallic surface is
(A) 4λ/3 (B) 4λ
(C) 6λ (D) 8λ/3

15. Out of a photon and an electron, the equation E = pc, is valid for
(A) both (B) neither
(C) photon only (D) electron only

16. If a photocell is illuminated with a radiation of 1240 Å, then stopping potential is found to be 8 V. The work function of the emitter and the threshold wavelength are
(A) 1 eV, 5200 Å (B) 2 eV, 6200 Å
(C) 3 eV, 7200 Å (D) 4 eV, 4200 Å

17. Silver has a work function of 4.7 eV. When ultraviolet light of wavelength 100 mm is incident upon it, a potential of 7.7 V is required to stop the photoelectrons from reaching the collector plate. How much potential will be required to stop the photoelectrons when light of wavelength 200 mm is incident upon silver?
(A) 1.5 V (B) 3.85 V
(C) 2.35 V (D) 15.4 V

18. The kinetic energy of an electron is E when the incident wavelength is λ. To increase the KE of the electron to 2E, the incident wavelength must be
(A) 2λ (B) λ/2
(C) (hcλ)/(Eλ+hc) (D) (hcλ)/(Eλ+hc)

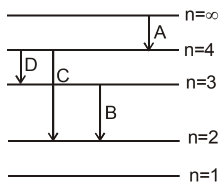
19. If λ_0 stands for mid-wavelength in the visible region, the de Broglie wavelength for 100 V electrons is nearest to
(A) $\lambda_0/5$ (B) $\lambda_0/50$
(C) $\lambda_0/500$ (D) $\lambda_0/5000$

20. Light of wavelength λ strikes a photoelectric surface and electrons are ejected with kinetic energy K. If K is to be increased to exactly twice its original value, the wavelength must be changed to λ such that
(A) λ' < λ/2 (B) λ'>λ/2
(C) λ>λ'>λ/2 (D) λ'=λ/2

Section C -Bohr Model, Bohr Model nuclear motion

21. The angular momentum of an electron in the hydrogen atom is $\frac{3h}{2\pi}$. Here h is Planck's constant. The kinetic energy of this electron is :
(A) 4.53 eV (B) 1.51 eV
(C) 3.4 eV (D) 6.8 eV

22. Consider the following electronic energy level diagram of H-atom : Photons associated with shortest and longest wavelengths would be emitted from the atom by the transitions labelled.



(A) D and C respectively
(B) C and A respectively
(C) C and D respectively
(D) A and C respectively

23. If the electron in a hydrogen atom were in the energy level with n = 3, how much energy in joule would be required to ionise the atom ? (Ionisation energy of H-atom is 2.18×10^{-18} J):

(A) 6.54×10^{-19} (B) 1.43×10^{-19}
(C) 2.42×10^{-19} (D) 3.14×10^{-20}

24. In a hydrogen atom, the electron is in nth excited state. It may come down to second excited state by emitting ten different wavelengths. What is the value of n:

(A) 6 (B) 7
(C) 8 (D) 5

25. Difference between nth and (n + 1)th Bohr's radius of 'H' atom is equal to it's (n – 1)th Bohr's radius. The value of n is :

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

26. The electron in a hydrogen atom makes transition from M shell to L. The ratio of magnitudes of initial to final centripetal acceleration of the electron is

(A) 9 : 4 (B) 81 : 16
(C) 4 : 9 (D) 16 : 81

27. The electron in a hydrogen atom makes a transition $n_1 \rightarrow n_2$ whose n_1 and n_2 are the principal quantum numbers of the two states. Assume the Bohr model to be valid. The frequency of orbital motion of the electron in the initial state is 1/27 of that in the final state. The possible values of n_1 and n_2 are

(A) $n_1 = 4, n_2 = 2$ (B) $n_1 = 3, n_2 = 1$
(C) $n_1 = 8, n_2 = 1$ (D) $n_1 = 6, n_2 = 3$

28. The radius of Bohr's first orbit is a_0. The electron in n^{th} orbit has a radius :

(A) na_0 (B) a_0/n
(C) n^2a_0 (D) a_0/n^2

29. The ionisation potential of hydrogen atom is 13.6 volt. The energy required to remove an electron from the second orbit of hydrogen is :

(A) 3.4 eV (B) 6.8 eV
(C) 13.6 eV (D) 27.2 eV

30. In a sample of hydrogen like atoms all of which are in ground state, a photon beam containing photons of various energies is passed. In absorption spectrum, five dark lines are observed. The number of bright lines in the emission spectrum will be (Assume that all transitions take place)

(A) 5 (B) 10
(C) 15 (D) none of these

Section D -Atomic Collisions

31. A neutron collides head on with a stationary hydrogen atom in ground state

(A) If kinetic energy of the neutron is less than 13.6 eV, collision must be elastic
(B) if kinetic energy of the neutron is less than 13.6 eV, collision may be inelastic.
(C) inelastic collision takes place when initial kinetic energy of neutron is greater than 13.6 eV.
(D) perfectly inelastic collision cannot take place.

32. The electron in a hydrogen atom make a transition from an excited state to the ground state. Which of the following statement is true?

(A) Its kinetic energy increases and its potential and total energies decrease
(B) Its kinetic energy decreases, potential energy increases and its total energy remains the same.
(C) Its kinetic and total energies decrease and its potential energy increases.
(D) Its kinetic potential and total energies decreases.

33. An H atom in ground state is moving with initial kinetic energy K. It collides head on with a He^+ ion in ground state kept at rest but free to move. Find minimum value of K so that both the particles can excite to their first excited state.

(A) 63.75 eV (B) 31.86 eV
(C) 137.50 eV (D) 14.95 eV

34. An electron collides with a hydrogen atom in its ground state and excites it to n = 3. The energy given to hydrogen atom in this inelastic collision is [Neglect the recoiling of hydrogen atom]

(A) 10.2 eV (B) 12.1 eV
(C) 12.5 eV (D) None of these

35. A neutron having kinetic energy 5 eV is incident on a hydrogen atom in its ground state. The collision
(A) must be elastic
(B) must be completely inelastic
(C) may be partially elastic
(D) information is insufficient

36. An electron of energy 11.2 eV undergoes an inelastic collision with a hydrogeon atom in its ground state. [Neglect recoiling of atom as $m_H >> m_e$]. Then in this case
(A) The outgoing electron has energy 11.2 eV
(B) The entire energy is absorbed by the H atom and the electron stops
(C) 10.2 eV of the incident electron energy is absorbed by the H atom and the electron would come out with 1.0 eV energy
(D) None of the above

37. The recoil speed of hydrogen atom after it emits a photon in going from n = 2 state to n =1 state is nearly [Take $R_\infty = 1.1 \times 10^{-1}$ and $h = 6.63 \times 10^{-34}$ Js]
(A) 1.5 ms^{-1} (B) 3.3 ms^{-1}
(C) 4.5 ms^{-1} (D) 6.6 ms^{-1}

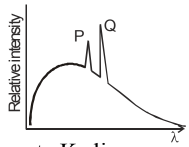
38. The recoil speed of a hydrogen atom after it emits a photon in going from n = 5 state to n = 1 state is -
(A) 4.718 ms^{-1} (B) 7.418 ms^{-1}
(C) 4.178 ms^{-1} (D) 7.148 ms^{-1}

39. A neutron moving with a speed v makes a head-on collision with a hydrogen atom in ground state kept at rset. The minimum kinetic energy of the neutron for which inelastic collision will take place is (assume that mass of proton is neraly equal to the mass of neutron)
(A) 10.2 eV (B) 20.4 eV
(C) 12.1 eV (D) 16.8 eV

40. A hydrogen atom is in 5th excited state. When the electron jumps to ground state, the velocity of recoiling hydrogen atom is-
(A) 1.1 m/s (B) 4.2 m/s
(C) 8.4 m/s (D) 11.2 m/s

Section E – X-rays production, X-Rays Moseley's law, X-Ray Properties

41. In a characteristic X-ray spectra of some atom superimposed on continuous X-ray spectra



(A) P represents K_α line
(B) Q represents K_β line
(C) Q and P represents K_α and K_β lines respectively
(D) Relative positions of K_α and K_β depend on the particular atom

42. Which of the following wavelength falls in a X-rays region?
(A) 10,000 Å (B) 1000 Å
(C) 1 Å (D) 10^{-2} Å

43. The penetrating power of X-ray increases with the
(A) Increases of its velocity
(B) Increase in its intensity
(C) Decrease in its velocity
(D) Increases in its frequency.

44. If the frequency of K_α, K_β and L_α X-rays for a meterial ν_{K_α}, ν_{K_β}, ν_{L_α} respectively, then
(A) $\nu_{K_\alpha} = \nu_{K_\beta} + \nu_{L_\alpha}$ (B) $\nu_{L_\alpha} = \nu_{K_\alpha} + \nu_{K_\beta}$
(C) $\nu_{K_\beta} = \nu_{K_\alpha} + \nu_{L_\alpha}$ (D) none of these

45. In X-ray tube, when the accelerating voltage V is doubled, the different between the wavelength of K_α line and the minimum cut off of continuous X-ray spectum :
(A) remains constant
(B) becomes more than half
(C) becomes half
(D) becomes less than 2 times.

46. The voltage applied to an X-ray tube is 18 kV. The maximum mass of photon emitted by the X-ray tube will be
(A) 2×10^{-13} kg (B) 3.2×10^{-36} kg
(C) 3.2×10^{-32}kg (D) 9.1×10^{-31} kg

47. The wavelength of K_a X-rays of two metals 'A' and 'B' are 4/1875 R and 1/675 R, respectively, where 'R' is Rydberg's constant. The number of elements lying between 'A' and 'B' according to their atomic numbers is

(A) 3 (B) 6
(C)5 (D)4

48. The element which has a K_a X-rays line of wave-length 1.8 Å is

(R = 1.1 × 10^7 m^{-1}, b = 1 and $\sqrt{5/33}$ = 0.39)

(A) Co, Z = 27 (B) Iron, Z = 26
(C) Mn, Z = 25 (D) Ni, Z = 28

49. The energy of a tungsten atom with a vacancy in L shell is 11.3 keV. Wavelength of K_α photon for tungsten is 21.3 pm. If a potential difference of 62 kV is applied across the X-rays tube following characteristic x-rays will be produced.

(A) K, L series (B) only K_α & L series
(C) only L series (D) none

50. When the voltage applied to an X-ray tube increases from V_1 =10kV to V_2 = 20 kV, the wavelength interval between K_α line and cut-off wavelength of continuous spectrum increase by a factor of 3. Atomic number of the metalic target is

(A) 28 (B) 29
(C) 65 (D) 66

Exercise - 2 (Level-I) Objective Problems | JEE Main

Section A - Photoelectric Effect

1. In a photo-emissive cell, with exciting wavelength λ, the maximum kinetic energy of electron is K. If the exciting wavelength is changed to $\frac{3\lambda}{4}$ the kinetic energy of the fastest emitted electron will be :

(A) 3K/4 (B) 4K/3
(C) less than 4K/3 (D) greater than 4K/3

2. The frequency and the intensity of a beam of light falling on the surface of photoelectric material are increased by a factor of two (Treating efficiency of photoelectron generation as constant). This will:

(A) increase the maximum energy of the photoelectrons, as will as photoelectric current by a factor of two
(B) increase the maximum kinetic energy of the photo electrons and would increase the photoelectric current by a factor of two
(C) increase the maximum kinetic energy of the photoelectrons by a factor of greater than two and will have no effect on the magnitude of photoelectric current produced.
(D) not produce any effect on the kinetic energy of the emitted electrons but will increase the photoelectric current by a factor of two

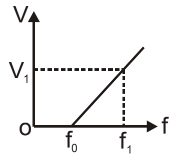
3. Light coming from a discharge tube filled with hydrogen falls on the cathode of the photoelectric cell. The work function of the surface of cathode is 4eV. Which one of the following values of the anode voltage (in Volts) with respect to the cathode will likely to make the photo current zero.

(A) – 4 (B) – 6
(C) – 8 (D) – 10

4. Let K_1 be the maximum kinetic energy of photoelectrons emitted by a light of wavelength λ_1 and K_2 corresponding to λ_2. If $\lambda_1 = 2\lambda_2$, then :

(A) $2K_1 = K_2$ (B) $K_1 = 2K_2$
(C) $K_1 < \frac{K_2}{2}$ (D) $K_1 > 2K_2$

5. In a photoelectric experiment, the potential difference V that must be maintained between the illuminated surface and the collector so as just to prevent any electron from reaching the collector is determined for different frequencies f of the incident illumination. The graph obtained is shown. The maximum kinetic energy of the electrons emitted at frequency f_1 is



(A) hf_1 (B) $\frac{V_1}{(f_1 - f_0)}$
(C) $h(f_1 - f_0)$ (D) $eV_1(f_1 - f_0)$

6. In a photoelectric experiment, the collector plate is at 2.0V with respect to the emitter plate made of copper (φ = 4.5eV). The emitter is illuminated by a source of monochromatic light of wavelength 200 nm.

(A) the minimum kinetic energy of the photoelectrons reaching the collector is 0.
(B) the maximum kinetic energy of the photoelectrons reaching the collector is 3.7eV.
(C) if the polarity of the battery is reversed then answer to part A will be 0.
(D) if the polarity of the battery is reversed then answer to part B will be 1.7eV.

Section B - Radiation Pressure, Matter Waves + Davisson Germer Experiment

7. An electron and a photon possess the same de Broglie wavelength. If E_e and E_{ph} are, respectively, the energies of electron and photon while v and c are their respective velocities, then E_e/E_{ph} =

(A) v/c (B) v/2c
(C) v/3c (D) v/4c

8. An electron is accelerated through a potential difference of V volt. It has a wavelength λ associated with it. Through what potential difference an electron must be accelerated so that its de Broglie wavelength is the same as that of a proton? Take mass of proton to be 1837 times larger than the mass of electron.
(A) V volt (B) 1837 V volt
(C) V/1837 volt (D) $\sqrt{1837}$ V volt

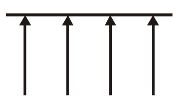
9. If wavelength of photon emitted due to transition of an electron from third orbit to first orbit in a hydrogen atom is λ, then the wavelength of photon emitted due to transition of electron from fourth orbit to second orbit will be
(A) $\frac{128}{27}\lambda$ (B) $\frac{25}{9}\lambda$
(C) $\frac{36}{7}\lambda$ (D) $\frac{125}{11}\lambda$

10. Transitions between three energy levels in a particular atom give rise to three spectral lines of wavelengths, in increasing magnitudes. λ_1, λ_2 and λ_3. Which one of the following equations correctly relates λ_1, λ_2 and λ_3 ?
(A) $\lambda_1 = \lambda_2 - \lambda_3$ (B) $\lambda_1 = \lambda_3 - \lambda_2$
(C) $\frac{1}{\lambda_1} = \frac{1}{\lambda_2} + \frac{1}{\lambda_3}$ (D) $\frac{1}{\lambda_1} = \frac{1}{\lambda_3} + \frac{1}{\lambda_2}$

11. The wavelength of a neutron with energy 1 eV is closest to –
(A) 10^{-2} cm (B) 10^{-4} cm
(C) 10^{-6} cm (D) 10^{-8} cm

12. 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 :
(A) $\lambda_1 = \lambda_2$ (B) $\lambda_1 > \lambda_2$
(C) $\lambda_1 < \lambda_2$ (D) $\lambda_1 > \lambda_2$ or $\lambda_1 < \lambda_2$

13. A plate of mass 10 g is in equilibrium in air due to the force exerted by a light beam on the plate. Calculate power of the beam. Assume plate is perfectly absorbing.



(A) 2×10^7 W (B) 5×10^7 W
(C) 3×10^3 W (D) 3×10^7 W

14. A radiation of wavelength 200 nm is propagating in the form of a parallel surface. The intensity of the beam is 5 mW and its cross–sectional area is 1.0 mm^2. Find the pressure exeted by radiation on the metallic surface if the radiation is completely reflected.
(A) 1.11×10^{-5} N m^{-2}
(B) 2.22×10^{-5} N m^{-2}
(C) 3.33×10^{-5} N m^{-2} (D) None of these

15. In which of the following situations the heavier of the two particles has smaller de Broglie wavelength ? The two particles-
(A) move with the same speed
(B) move with the same linear momentum
(C) move with the same kinetic energy
(D) have fallen through the same height

Section C -Bohr Model, Bohr Model nuclear motion

16. Consider the spectral line resulting from the transition $n = 2 \rightarrow n = 1$ in the atoms and ions given below. The shortest wavelength is produced by :
(A) hydrogen atom
(B) deuterium atom
(C) singly ionized helium
(D) doubly ionized lithium

17. In an atom, two electrons move around the nucleus in circular orbits of radii R and 4R. The ratio of the time taken by them to complete one revolution is : (neglect electric interaction)
(A) 1 : 4 (B) 4 : 1
(C) 1 : 8 (D) 8 : 1

18. The electron in hydrogen atom in a sample is in nth excited state, then the number of different spectrum lines obtained in its emission spectrum will be :
(A) 1 + 2 + 3 + ... + (n – 1)
(B) 1 + 2 + 3 + ... + (n)
(C) 1 + 2 + 3 + ...+ (n + 1)
(D) 1 × 2 × 3 × ....× (n –1)

19. An electron in hydrogen atom first jumps from second excited state to first excited state and then, from first excited state to ground state. Let the ratio of wavelength, momentum and energy of photons in the two cases by x, y and z, then select the wrong answers :
(A) z = 1/x (B) x = 9/4
(C) y = 5/27 (D) z = 5/27

20. An electron is in an excited state in hydrogen-like atom. It has a total energy of –3.4 eV. If the kinetic energy of the electron is E and its de-Broglie wavelength is λ, then
(A) $E = 6.8$ eV, $\lambda = 6.6 \times 10^{-10}$ m
(B) $E = 3.4$ eV, $\lambda = 6.6 \times 10^{-10}$ m
(C) $E = 3.4$ eV, $\lambda = 6.6 \times 10^{-11}$ m
(D) $E = 6.8$ eV, $\lambda = 6.6 \times 10^{-11}$ m

21. If radiation of allowed wavelengths from ultraviolet to infrared is passed through hydrogen agas at room temperature, absorption lines will be observed in the :
(A) Lyman series
(B) Balmer series
(C) Both (A) and (B)
(D) neither (A) nor (B)

22. 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.

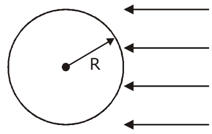
Section D -Atomic Collisions

23. A photon of wavelength 0.1 Å is emitted by a helium atom as a consequence of the emission of photon. The KE gained by helium atom is
(A) 0.05 eV (B) 1.05 eV
(C) 2.05 eV (D) 3.05 eV

24. An electron collides with a fixed hydrogen atom in its ground state. Hydrogen atom gets excited and the colliding electron loses all its kinetic energy. Consequently the hydrogen atom may emit a photon corresponding to the largest wavelength of the Balmer series. The min. K.E. of colliding electron will be
(A) 10.2 eV (B) 1.9 eV
(C) 12.1 eV (D) 13.6 eV

25. A plane light wave of intensity $I = 0.20$ W cm^{-2} falls on a plane mirror surface with reflection coefficient $\rho = 0.8$. The angle of incidence is 45°. In terms of corpuscular theory, find the magnitude of the normal pressure exerted on that surface.
(A) 4 μ N/m^2 (B) 8 μ N/m^2
(C) 2 μ N/m^2 (D) 6 μ N/m^2

26. A plane wave of intensity $I = 0.70$ W cm^{-2} illuminates a sphere with ideal mirror surface. The radius of sphere is $R = 5.0$ cm. From the standpoint of photon theory, find the force that light exerts on the sphere.



(A) 0.18 μN (B) 0.4 μN
(C) 0.5 μN (D) 1.2 μN

27. A particle of mass 3m at rest decays into two particles of masses m and 2m having non-zero velocities. The ratio of the de Broglie wavelengths of the particles (λ_1/λ_2) is
(A) 1/2 (B) 1/4
(C) 2 (D) none of these

28. Assuming that the mass of proton is nearly equal to mass of neutron the minimum kinetic energy in 10^1 eV of a neutron for inelastic head on collision with a ground state hydrogen atom at rest is -
(A) 4 (B) 2
(C) 6 (D) 8

Section E -X–rays production, X–Rays Moseley's law, X–Ray Properties

29. If 10,000 V are applied across an X-ray tube, find the ratio of wavelength of the incident electrons and the shortest wavelength of X-ray coming out of the X-ray tube, given e/m of electron $= 1.8\times10^{11}$C kg^{-1}
(A) 1:10 (B) 10:1
(C) 5:1 (D) 1:5

30. If the potential difference aplied across a Coolidge tube is increased, then
(A) wavelength of K_α will increase
(B) λ_{min} will increase
(C) difference between wavelength of K_α and λ_{min} increases
(D) none of these

31. The wavelength k_α of X-rays produced by the X-ray tube is 0.76 Å. The atomic number of the node material of the tube is
(A) 30 (B) 40
(C) 50 (D) 60

32. The shortest wavelength produced in an X-ray tube operating at 0.5 million volt is

(A) dependent on the target element

(B) about 2.5×10^{-12} m

(C) double of the shortest wavelength produced at a million volt

(D) dependent only on the target material

33. If the K_α radiation of Mo (Z = 42) has a wavelength of 0.71 Å find the wavelength of the corresponding radiation of Cu (Z=29)

(A) 1Å (B) 2Å

(C) 1.52Å (D) 1.25Å

34. In a Coolidge tube experiment, the minimum wavelength of the continuous X-ray spectrum is equal to 66.3 pm, then

(A) electrons accelerate through a potential difference of 12.75 kV in the Coolidge tube

(B) electrons accelerate through a potential difference of 18.75 kV in the Coolidge tube

(C) de-Broglie wavelength of the electrons reaching the anticathode is of the order of 10μm

(D) de-Broglie wavelength of the electrons reaching the anticathode is 0.01 Å.

Exercise - 2 (Level-II) Multiple Correct | JEE Advanced

Section A - Photoelectric Effect

1. 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

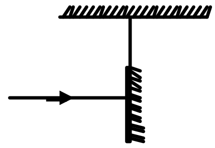
2. In the experiment on photoelectric effect using light having frequency greater than the threshold frequency, the photocurrent will certainly increase when
(A) Anode voltage is incrased
(B) Area of cathode surface is increased
(C) Intensity of incident light is increased
(D) Distance between anode and cathode is increased.

3. Photoelectric effect supports the quantum nature of light because
(A) there is a minimum frequency of light below which no photoelectrons are emitted
(B) the maximum KE of photoelectrons depends only on the frequency of light and not on its intensity.
(C) even when the metal surface is faintly illuminated by light of wavelength less than the threshold wavelength, the photoelectrons leave the surface immediately
(D) electric charge of photoelectrons is quantized.

4. A point source of light is taken away from the experimental setup of photoelectric effect. For this situation, mark out the correct statements(s).
(A) Saturation photocurrent decreases
(B) Saturation photocurrent increases
(C) Stopping potential remains the same
(D) Stopping potential increases

Section B - Radiation Pressure, Matter Waves + Davisson Germer Experiment

5. A small mirror is suspended by a thread as shown in figure. A short pulse of mono-chromatic light rays is incident normally on the mirror and gets reflected. Which of the following statements is/are correct -



(A) Mirror will start to oscillate
(B) Wavelength of reflected rays will be greater than that of incident rays.
(C) Wavelength of reflected rays may be less than that of incident rays
(D) None of these

Section C -Bohr Model, Bohr Model nuclear motion

6. A particular hydrogen like atom has its ground state binding "energy 122.4 eV. 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 91.8 eV can be brought to almost rest by this atom.
(D) An electron of kinetic energy 2.6 eV may emerge from the atom when electron of kinetic energy 125 eV collides with this atom.

7. The electron in a hydrogen atom makes a transition $n_1 \longrightarrow n_2$, where n_1 & n_2 are the principal quantum numbers of the two states. Assume the Bohr model to be valid. The time period of the electron in the initial state is eight times that in the final state. The possible values of n_1 & n_2 are:
(A) $n_1 = 4, n_2 = 2$ (B) $n_1 = 8, n_2 = 2$
(C) $n_1 = 8, n_2 = 1$ (D) $n_1 = 6, n_2 = 3$

8. 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.

Section D - Atomic Collisions

9. 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
(D) the upper energy level is of excitation energy 12.75 eV.

10. 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 cannot take place.

11. When a point light source of power W emitting monochromatic light of wavelength λ is kept at a distance a from a photo-sensitive surface of work function ϕ and area S, we will have
(A) number of photons striking the surface per unit time as W λS/4 πhca^2
(B) the maximum energy of the emitted photoelectrons as (1/λ) (hc-$\lambda\phi$)
(C) the stopping potential needed to stop the most energetic emitted photoelectrons as (e/λ) (hc-$\lambda\phi$)
(D) Photo-emission only if λ lies in the range $0 \le \lambda \le (hc/\phi)$

Section E - X-rays production, X-Rays Moseley's law, X-Ray Properties

12. The potential difference applied to an X–ray tube is increased. As a result, in the emitted radiation :
(A) the intensity increases
(B) the minimum wave length increases
(C) the intensity decreases
(D) the minimum wave length decreases

13. A X-ray tube operates at an accelerating potential of 20 kV. Which of the following wavelengths will be absent in the continuous spectrum of X-ray.
(A) 12 pm (B) 45 pm
(C) 65 pm (D) 95 pm

14. X-ray are produced by accelerating electrons across a given potential difference to strike a meta target of high atomic number. If the electrons have same speed when they strike the target, the X-ray spectrum will exhibit.
(A) a minimum wavelength
(B) a continuous spectrum
(C) some discrete comparatively prominent wavelenght
(D) uniform density over the whole spectrum

15. Which of the following are in the ascending order of wavelength?
(A) H_α , H_β , H_γ .... lines in Balmer series of hydrogen atom.
(B) Lyman limit, Balmer limit, and paschen limit in the hydrogen spectrum
(C) Violet, blue, yellow, and red colours in solar spectrum.
(D) None of the above.

Exercise - 3 | Level-I — Subjective | JEE Advanced

Section A - Photoelectric Effect

1. A parallel beam of uniform, monochromatic light of wavelength 2640 A has an intensity of 200 W/m^2. The number of photons in 1 mm^3 of this radiation are ....

2. When photons of energy 4.25 eV strike the surface of a metal A, the ejected photoelectrons have maximum kinetic energy T_a eV and de Broglie wavelength λ_a. The maximum kinetic energy of photoelectrons liberated from another metal B by photons of energy 4.7 eV is $T_b = (T_a - 1.5)$ eV. If the De Broglie wavelength of these photoelectrons is $\lambda_b = 2\lambda_a$, then find
(a) The work function of a
(b) The work function of b is
(c) T_a and T_b

3. When a monochromatic point source of light is at a distance of 0.2 m from a photoelectric cell, the cut off voltage 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 find
(a) the stopping potential
(b) the saturation current

4. An isolated metal body is illuminated with monochromatic light and is observed to become charged to a steady positive potential 1.0 V with respect to the surrounding. The work function of the metal is 3.0 eV. The frequency of the incident light is ____________________.

5. 663 mW of light from a 540 nm source is incident on the surface of a metal. If only 1 of each 5×10^9 incident photons in absorbed and causes an electron to be ejected from the surface, the total photocurrent in the circuit is ____________.

Section B - Radiation Pressure, Matter Waves + Davisson Germer Experiment

6. What voltage must be applied to an electron microscope to produce electrons of wavelenght 0.4 Å?

7. An electron and a photon have the same de Broglie wavelength. Which one of these has higher kinetic energy?

8. An electron microscope uses electrons accelerated by a voltage of 50 kV. Determine the de Broglie wavelength associated with the electrons. If other factors (such as numerical aperture, etc.) are taken to be roughly the same, how does the resolving power of an electron microscope compare with that of an optical microscope which uses yellow light?

9. An electron of mass "m" and charge "e" initially at rest gets accelerated by a constant electric field E. The rate of change of DeBroglie wavelength of this electron at time t is .....

10. Assume that a particle cannot be confined to a spherical volume of diameter less then DeBroglie wavelength of the particle. Estimate the minimum kinetic energy a proton confined to a nucleus f diameter 10^{-14} m may have.

Section C - Bohr Model, Bohr Model nuclear motion

11. A hydrogen atom in a state having a binding energy 0.85 eV makes a transition to a state of excitation energy 10.2 eV. The wave length of emitted photon is .... nm.

12. A hydrogen atom is in 5^{in} excited state. When the electron jumps to ground state the velocity of recoiling hydrogen atom is .... m/s and the energy of the photon is .... eV.

13. The ratio of series limit wavelength of Balmer series to wavelength of first line of paschen series is ....

14. Imagine an atom made up of a proton and a hypothetical particle of double the mass of an electron but having the same charge as the electron. Apply the Bohr atom model and consider a possible transitions of this hypothetical particle to the first excited level. Find the longest wavelength photon that will be emitted λ (in terms of the Rydberg constant R.)

15. In a hydrogen atom, the electron moves in an orbit of radius 0.5 Å making 10^{16} revolution per second. The magnetic moment associated with the orbital motion of the electron is _____________.

Section D - Atomic Collisions

16. Explain why nearly all H atoms are in the ground state at room temperature and ehnce emit no light.

17. Consider a hydrogen–like atom whose energy in n^{th} excited state is given by

$$E_n = \frac{13.6Z^2}{n^2}$$

When this excited atom makes a transition from excited state to ground state, most energetic photons have energy E_{max} = 52.224 eV and least energetic photons have energy E_{min} = 1.224 eV.
Find the atomic number to atom and the initial state of excitation.

18. A gas of identical hydrogen–like a atoms has some atoms in the lowest (ground) energy level A and some atoms in a particular upper (excited) energy level B and there are no atoms in any ohter energy levvel. The atoms of the gas make transition to higher energy level by absorbing monochromatic light of photon energy 2.55 eV.
Subsequently, the atoms emit radiations 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.
(a) Find the principal quantum number of the initially excited level B.
(b) Find the ionization energy for the gas atoms.
(c) Find the maximum and the minimum energies of the emitted photons.

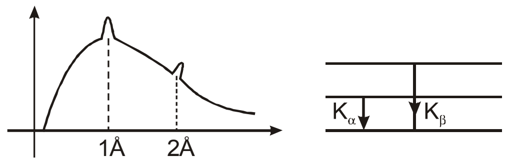
19. A photon collides with a stationary hydrogen atom in ground state inelastically. Energy of the colliding photon is 10.2 eV. Almost instantaneously, another photon collides with same hydrogen atom inelastically with an energy of 15 eV. What will be observed by the detector?

20. A H-atom in ground state is moving with initial kinetic energy K. It collides head on with a He^+ ion in ground state kept at rest but free to move. Find minimum value of K so that both the particles can excite to their first excited state.

Section E - X–rays production, X–Rays Moseley's law, X–Ray Properties

21. Obtain a relation between the frequencies of K_α, K_β and L_α lines for a target material.

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



23. Photoelectrons are emitted when 400 nm radiation is incident on a surface of work function 1.9 eV. These photoelectrons pass through a region containing a-particles. A maximum energy electron combines with an α-particle to form a He^+ ion, emitting a single photon in this process. He^+ ions thus formed are in their fourth excited state. Find the energies in eV atomi structure of the photons, lying in the 2 to 4 eV range, that are likely to be emitted during and after the combination. [Take, h = 4.14×10^{-15} eV–s]

24. A 20 KeV energy electron is brought to rest in an X-ray tube, by undergoing two successive bremsstrahling events, thus emitting two photons. The wavelength of the second photon is 130×10^{-12} m greater than the wavelength of the first emitted photon. Calculate the wavelengths of the two photons.

25. The wavelength of K_α x-ray of tungsten is 21.3 pm. It takes 11.3 KeV to knock out an electron from the L shell of a tungsten atom. What should be the minimum accelerating voltage across ab x-ray tube having tungsten target which allows poduction of K_α x-ray.

Exercise - 3 | Level-II — Subjective | JEE Advanced

Section A - Photoelectric Effect

1. 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.

2. A small 10 W source of ultraviolet light of wavelength 99 nm is held at a distance 0.1 m from a metal surface. The radius of an atom of the metal is approximaterly 0.05 nm. Find :
(i) the number of photons striking an atom per second.
(ii) the number of photoelectrons emitted per second it the efficiency of liberation of photoelectrons is 1%

Section B - Radiation Pressure, Matter Waves + Davisson Germer Experiment

3. Light of wavelength λ from a small 0.5 mW He-Ne laser, source is used in the school laboratory, shines from a spacecraft of mass 1000 kg. Explain why this causes the space-craft to accelerate. Estimate the time needed for the spacecraft to reach a velocity of 1.0 km s^{-1} from rest. The momentum p of a photon of wavelength λ is given by $p = h/\lambda$, where h is Planck's constant.

4. An α-particle and a proton are fired through the same magnetic fields which is perpendicular to their velocity vectors. The α-particle and the proton move such that radius of curvature of their path is same. Find the ratio of their de Broglie wavelengths.

Section C - Bohr Model, Bohr Model nuclear motion

5. A stationary He^+ ion emitted a photon corresponding to the first line its Lyman series. That photon liberated a photoelectron from a stationary hydrogen atom in the ground state. Find the velocity of the photoelectron.

6. An energy of 68.0 eV is required to excite a hydrogen like atom from its second Bohr orbit to the third. The nuclear charge Ze. Find the value of Z, the kinetic energy of the electron in the first Bohr orbit and the wavelength of the electro magnetic radiation required to eject the electron from the first Bohr orbit to infinity.

Section D - Atomic Collisions

7. A neutron of kinetic energy 65 eV collides inelastically with a single ionized helium atom at rest. It is scattered at an angle of 90° with respect of its original direction.
(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.
(Given : Mass of he atom = 4 × (mass of neutron), ionization energy of H atom = 13.6 eV)

8. The radius of hydrogen atom in its ground state is 5.3×10^{-11} m. After collision with an electron it is found to have a radius of 21.2×10^{-11} m. What is the principal quantum number n of the final state of the atom ?

Section E - X–rays production, X–Rays Moseley's law, X–Ray Properties

9. An electron, in a hydrogen like atom, is in an excited state. It has a total energy of –3.4 eV. Calculate:
(i) The kinetic energy &
(ii) The De-Broglie wave length of the electron.

10. A potential difference of 20 KV is applied across an x-ray tube. The minimum wave length of X-rays generated is _________

Exercise - 4 | Level-I Previous Year | JEE Main

1. If the kinetic energy of a free electron doubles, its de-Broglie wavelength changes by the factor **(AIEEE 2005)**

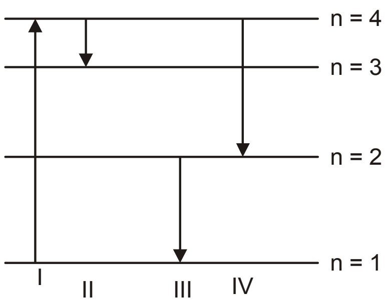
(A) $\frac{1}{2}$ (B) 2

(C) $\frac{1}{\sqrt{2}}$ (D) $\sqrt{2}$

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

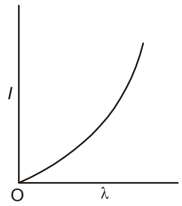
(A) decrease by a factor of 4
(B) increase by a factor of 4
(C) decrease by a factor of 2
(D) increase by a factor of 2

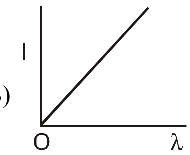
3. The diagram shows the energy levels for an electron in a certain atom. Which transition shown represents the emission of a photon with the most energy? **(AIEEE 2005)**

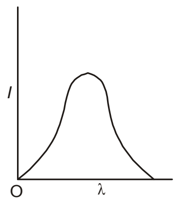


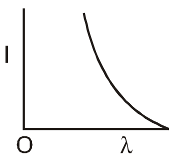
(A) III (B) IV
(C) I (D) II

4. 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) 

5. 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} s (D) 10^{-1} s

6. The threshold frequncy for a metallic surface corresponds to an energy of 6.2 eV and the stopping potential for a radiation incident on this surface is 5 V. The incident radiation lies in **(AIEEE 2006)**

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

7. 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 **[JEE Main 2006]**

(A) v^2 (B) $\frac{1}{m}$

(C) $\frac{1}{v^4}$ (D) $\frac{1}{Ze}$

8. Photon of frequency v has a momentum associated with it. If c is the velocity of light, the momentum is **(AIEEE 2007)**

(A) $\frac{v}{c}$ (B) hvc

(C) $\frac{hv}{c^2}$ (D) $\frac{hv}{c}$

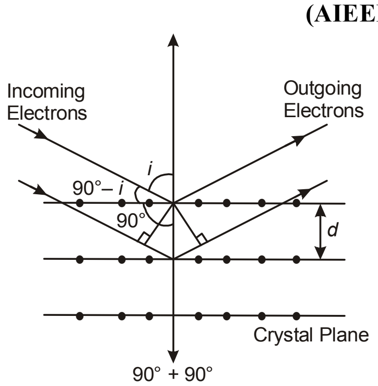
9. Which of the following transitions in hydrogen atoms emit photons of highest frequency? **(AIEEE 2007)**

(A) n = 2 to n = 6 (C) n = 6 to n = 2

(C) n = 2 to n = 1 (D) n = 1 to n = 2

Directions : Questins No. 10, 11, and 12 are based on the following paragraph.

Wave property of electrons implies that they will show diffraction effects Davisson and Germer demonstrated this by diffracting electrons from crystals. The law governing the differaction from a crystal is obtained by requiring that electron waves reflected from the planes of atoms in a crystal interfere constructively (see figure). **(AIEEE 2008)**



10. Electrons accelerated by potential V are diffracted from a crystal. If $d = 1\,\mathring{A}$ and i = 30° V should be about (h = 6.6 × 10^{-34} J-s, m_e =9.1× 10^{-31} kg, e = 1.6 × 10^{-19} C) **(AIEEE 2008)**

(A) 2000 V (B) 50 V

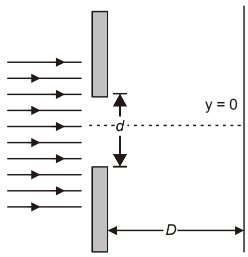
(C) 500 V (D) 1000 V

11. If a strong diffraction peak is observed when electrons are incident at an angle i from the normal to the crystal planes with distance d between them (see figure), de-Broglie wavelength λ_{dB} of electrons can be calculated by the relationship (n is an integer) **(AIEEE 2008)**

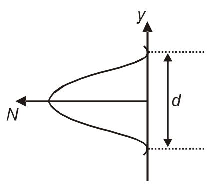
(A) $d\sin i = n\lambda_{dB}$ (B) $2d\cos i = n\lambda_{dB}$

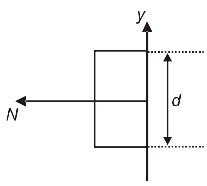
(C) $2d\sin i = n\lambda_{dB}$ (D) $d\cos i = n\lambda_{dB}$

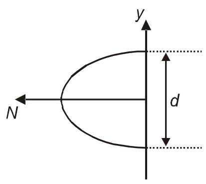
12. In an experiment electrons are made to pass through a narrow slit of width d comparable to their de-Broglie wavelength. They are detected on a screen at a distance D from the slit (see figure).

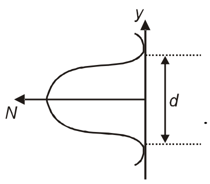


Which of the following graphs can be expected to represent the numberof electrons N detected as a function of the detector position y (y = 0 corresponds to the middle of the slit) ? **(AIEEE 2008)**

(A) 

(B) 

(C) 

(D) 

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

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

(B) T_n is independent of n, $r_n \propto n$

(C) $T_n \propto \frac{1}{n}, r_n \propto n$

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

14. The surface a metal is illuminated with the light of 400 nm. The kinetic energy of the ejected photoelectrons was found to be 1.68 eV. The work function of the metal is (hc = 1240 eV-nm) **(AIEEE 2009)**

(A) 3.09 eV (B) 1.42 eV
(D) 151 eV (D) 1.68 eV

15. The transition from the state n = 4 to a n = 3 in a hydrogen like atom results in ultraviolet radiation. Infrared radition will be obtained in the transition from **(AIEEE 2009)**

(A) $2 \to 1$ (B) $3 \to 2$
(C) $4 \to 2$ (D) $5 \to 4$

16. If a source of power 4 kW produces 10^{20} photons/second, the radiation belong to a part of the spectrum called **(AIEEE 2010)**

(A) X-rays (B) ultraviolet rays
(C) microwaves (D) γ – rays

17. **Statement I :** 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 II : Photoelectrons are emitted with speeds ranging from zero to a maximum value because of the range of frequencies present inthe incident light. **[JEE Main 2010]**

(A) Statement I is true, Statement II is true; Statement II is not a correct explanation for Statement I.
(B) Statement I is true, Statement II is false.
(C) Statement I is false, Statement II is true.
(D) Statement I is true, Statement II is true; Statement II is a correct explanation for Statement I.

18. This question has Statement I and Statement II of the four choices given after the statements, choose the one that best describes the two statements.
Statement I 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 doubled.
Statement II 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)**

(A) Statement I is the true, Statement II is ture, Statement II is the correct explanation of Statement I
(B) Statement I is true, Statement II is true, Statement II is not the correct explanation of Statement I
(C) Statement I is false, Statement II is true
(D) Statement I is true, Statement II is false

19. Energy required for the electron excitation in Li^{2+} from the first to the third Bohr orbit is **(AIEEE 2011)**

(A) 36.3 eV (B) 108.8 eV
(C) 122.4 eV (D) 12.1 eV

20. After absorbing a slowly moving neutron of mass m_N (momentum ~ 0) a nucleus of mass M breaks into two nunlei 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 **(AIEEE 2011)**

(A) 25λ (B) 5λ

(C) $\frac{\lambda}{5}$ (D) λ

21. This question has statement 1 and statement 2 Of the four choices given the statements, choose the one that describes the two statements. **(AIEEE 2012)**

Statement_1 Davission- Germer experiment established the wave nature of electrons.

Statement_2 If electrons have wave nature, they can interfere and show diffraction.

(A) Statement 1 is false, Statement 2 is true.
(B) Statement 1 is true, Statement 2 is false.
(C) Statement 1 is true, Statement 2 is true, Statement 2 is the correct explanation for Statement 1
(D) Statement 1 is true, Statement 2 is true, Statement 2 is not the correct explanation of Statement 1

22. Hydrogen atom is excited from ground state to another state with principle quantum number equal to 4. Then, the number of spectral lines in the emission spectra will be **(AIEEE 2012)**

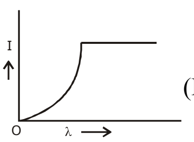
(A) 2 (B) 3
(C) 5 (D) 6

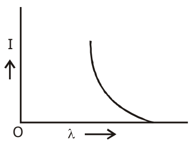
23. A diatomic molecule is made of two masses m_1 and m_2 which are separated by a distance r. If we calculate its rotational energy by applying Bohr's rule of angular momentum quantization, its energy will be given by (n is an integer) **(AIEEE 2012)**

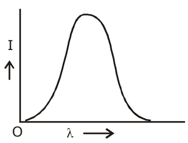
(A) $\frac{(m_1+m_2)^2n^2h^2}{2m_1^2m_2^2r^2}$ (B) $\frac{n^2h^2}{2(m_1+m_2)r^2}$

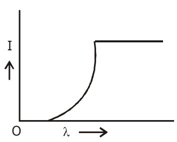
(C) $\frac{2n^2h^2}{(m_1+m_2)r^2}$ (D) $\frac{(m_1+m_2)n^2h^2}{2m_1m_2r^2}$

24. 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 : **[JEE MAIN-2013]**

(A) 

(B) 

(C) 

(D) 

25. In a hydrogen like atom electron make transition from an energy level with quantum number n to another with quantum number (n – 1). If n >> 1, the frequency of radiation emitted it proportional to **[JEE MAIN-2013]**

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

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

(A) $\lambda_1 = \lambda_2 = 4\lambda_3 = 9\lambda_4$
(B) $\lambda_1 = 2\lambda_2 = 3\lambda_3 = 4\lambda_4$
(C) $4\lambda_1 = 2\lambda_2 = 2\lambda_3 = \lambda_4$
(D) $\lambda_1 = 2\lambda_2 = 2\lambda_3 = \lambda_4$

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

(A) 0.8 eV (B) 1.6 eV
(C) 1.8 eV (D) 1.1 eV

28. An an electron makes a transition from a excited state to the ground state of a hydrogen–like stom/ion :

(A) Kinetic energy decreases, potential energy increases but total energy remains same
(B) Kinetic energy and total energy decrease but potential energy increase
(C) Its kinetic energy increases but potential energy and total energy decrease.
(D) Kinetic energy potential energy and total energy decrease

[JEE Main 2015]

29. Radiation of wavelength λ, is incident on a photocell. The fastest emitted electron has speed υ, If the wavelength is changed to $\frac{3\lambda}{4}$, the speed of the fastest emitted electron will be :

[JEE Main 2016]

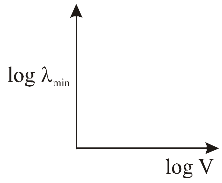
(A) $< \upsilon\left(\frac{4}{3}\right)^{\frac{1}{2}}$ (B) $= \upsilon\left(\frac{4}{3}\right)^{\frac{1}{2}}$

(C) $= \upsilon\left(\frac{3}{4}\right)^{\frac{1}{2}}$ (D) $> \upsilon\left(\frac{4}{3}\right)^{\frac{1}{2}}$

30. 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 characterstic 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]

(A)



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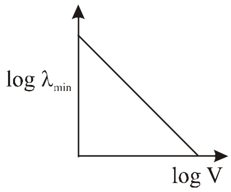

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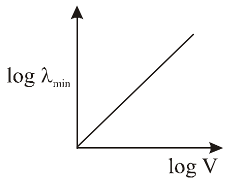

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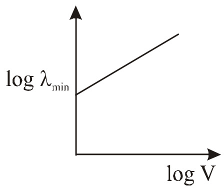


31. A particle A of mass m and initial velocity υ collides with a particle B of mass m/2 which is at rest. The collision is head on and elastic. The ratio of de-Broglie wavelengths λ_A and λ_B after the collision is - **[JEE Main 2017]**

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

(B) $\frac{\lambda_A}{\lambda_B} = 2$ (D) $\frac{\lambda_A}{\lambda_B} = \frac{2}{3}$

32. 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 n^{th} state and the ground state respectively. Let Λ_n be the wavelength of the emitted photon in the transition from the n^{th} state to the ground state. For large n, (A, B are constants)

[JEE Main 2018]

(A) $\Lambda_n^2 \approx \lambda$ (B) $\Lambda_n \approx A + \frac{B}{\lambda_n^2}$

(C) $\Lambda_n \approx A + B\lambda_n$ (D) $\Lambda_n^2 \approx A + B\lambda_n^2$

33. The mass of a hydrogen molecule is 3.32×10^{-27} kg. If 10^{23} hydrogen molecules strike, per second, a fixed wall of area 2 cm^2 at an angle of 45° to the normal, and rebound elastically with a speed of 10^3 m/s, then the pressure on the wall is nearly :

[JEE Main 2018]

(A) 4.70×10^2 N/m^2
(B) 2.35×10^3 N/m^2
(C) 4.70×10^3 N/m^2
(D) 2.35×10^2 N/m

34. 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]**

(A) $v_L/25$ (B) $25\ v_L$
(C) $16\ v_L$ (D) $v_L/16$

35. A silver atom in a solid oscillates in simple harmonic motion in some direction with a frequency of 10^{12}/sec. What is the force constant of the bonds connecting one atom with the other ?
(Mole wt. of silver = 108 and Avagadro number = 6.02×10^{23} gm mole^{-1}) **[JEE Main 2018]**

(A) 5.5 N/m (B) 6.4 N/m
(C) 7.1 N/m (D) 2.2 N/m

Exercise - 4 | Level-II   Previous Year | JEE Advanced

1. 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 4l. Then z′ is **[JEE'2005 (Scr)]**

(A) 11 (B) 44

(C) 6 (D) 4

2. 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.

(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

[JEE' 2005 (Scr)]

3. The potential energy of a particle of mass m is given by

$$V(x) = \begin{Bmatrix} E_0 & 0 \le x \le 1 \\ 0 & x > 1 \end{Bmatrix}$$

λ_1 and λ_2 are the de-Broglie wavelengths of the particle, when $0 \le x \le 1$ and $x > 1$ respectively. If the total energy of particle is $2E_0$, find λ_1/λ_2

[JEE 2005]

4. 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

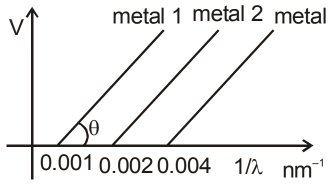
(a) atomic number of the nucleus

(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]

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



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

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

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

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

[JEE 2006]

6. 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]

7. **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

8. Electrons with de-Broglie wavelength λ fall on the target in an X-ray tube. The cut-off wavelength of the emitted X-rays is

[JEE 2007]

(A) $\lambda_0 = \dfrac{2mc\lambda^2}{h}$ (B) $\lambda_0 = \dfrac{2h}{mc}$

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

9. 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

10. Which one of the following statements is **WRONG** in the context of X-rays generated from a X-ray tube?
(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-ray tube
(D) Cut-off wavelength of the continuous X-rays depends on the energy of the electrons in the X-rays tube **[JEE 2008]**

Paragraph for Question No. 11 to 13

In 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 collision). Assume that the Bohr model of atom is exactly valid. **[JEE 2008]**

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

12. 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

13. 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

Paragraph for Questions 14 to 16

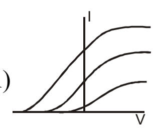
When a particle is restricted to move along x-axis between $x = 0$ and $x = a$, where a is of nanometer dimension, its energy can take only certain specific values. The allowed energies of the particle moving in such a restricted region, correspond to the formation of standing waves with nodes at its 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 = 1, 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 $h=6.6\times10^{-34}$ Js and $e= 1.6 \times 10^{-19}$ C. **[JEE 2009]**

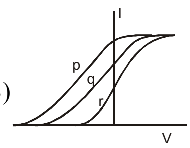
14. The allowed energy for the particle for a particular value of n is proportional to
(A) a^{-2} (B) $a^{-3/2}$
(C) a^{-1} (D) a^2

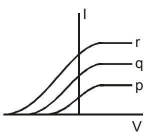
15. If the mass of the particle is $m = 1.0 \times 10^{-30}$ kg and $a = 6.6$ nm, the energy of the particle in its ground state is closest to
(A) 0.8 meV (B) 8 meV
(C) 80 meV (D) 800 meV

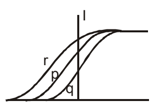
16. The speed of the particle, that can take discrete values, is proportional to
(A) $n^{-3/2}$ (B) n^{-1}
(C) $n^{1/2}$ (D) n

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

(A) 

(B) 

(C) 

(D) 

18. 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_a and λ_p respectively. The ratio $\frac{\lambda_p}{\lambda_\alpha}$, to the nearst integer, is **[JEE 2010]**

Paragraph for questions 19 to 21

The key feature of Bohr's theory of spectrum of hydrogen atoms 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]**

19. 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) $n^2\left(\frac{h^2}{8\pi^2 I}\right)$

20. 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

21. 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

22. 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) 1640 Å
(C) 2430 Å (D) 4687 Å

23. 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]**

24. 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]**

25. A pulse of light of duration 100 ns is absorbed completely by a small object initially at rest. Power of the pulse is 30 mW and the speed of light is 3×10^8 ms^{-1}. The final momentum of the object is **[JEE-2013]**

(A) 0.3×10^{-17} kg ms^{-1}
(B) 1.0×10^{-17} kg ms^{-1}
(C) 3.0×10^{-17} kg ms^{-1}
(D) 9.0×10^{-17} kg ms^{-1}

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

27. 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-2013]**

(A) $\frac{9}{32R}$ (B) $\frac{9}{16R}$

(C) $\frac{9}{5R}$ (D) $\frac{4}{3R}$

28. A metal surface is illuminated by light of two different wavelengths 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 and hc = 1240 eV nm, the work function of the metal is nearly **[JEE Advanced 2014]**

(A) 3.7 eV (B) 3.2 eV
(C) 2.8 eV (D) 2.5 eV

29. If λ_{Cu} is the wavelength of K_α X-ray line of copper (atomic number 29) and λ_{M0} is the wavelength iof the K_α X-ray line of molybdenum (atomic number 42), then the ratio $\lambda_{Cu}/\lambda_{Mo}$ is close to **[JEE Advanced 2014]**

(A) 1.99 (B) 2.14
(C) 0.50 (D) 0.48

30. 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 wavelenght (λ) of incident light and the corresponding stopping potential (V_0) are given below : **[JEE Advanced 2016]**

(2)

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

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

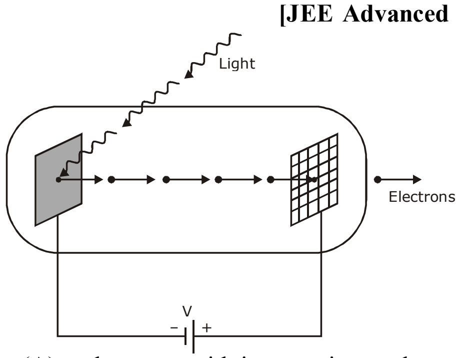
(A) 6.0×10^{-34} (B) 6.4×10^{-34}
(C) 6.6×10^{-34} (D) 6.8×10^{-34}

31. Highly excited states for hydrogen-like atoms (also called Rydberg states) with nucles 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 orbitals 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.

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

33. 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 electrode. 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) λ_e decreases with increase in ϕ and λ_{ph}
(B) λ_e is approximately halved, if d is doubled
(C) For large potential difference (V >> ϕ/e), λ_e approximately halved if V is made four times
(D) λ_e increases at the same rate as λ_{ph} for $\lambda_{ph} < hc/\phi$

34. 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]**

35. A photoelectric material having work-function ϕ_0 is illuminated with light of wavelength $\lambda\left(\lambda < \frac{hc}{\phi_0}\right)$. The fastest photoelectron has a de Broglie wavelength λ_d. A change in wavelength of the incident light by $\Delta\lambda$ results in a change $\Delta\lambda_d$ in λ_d. Then the ratio $\Delta\lambda_d/\Delta\lambda$ is proportional to **[JEE Advanced 2017]**

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

36. 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 me $= 9 \times 10^{-31}$ kg and 1.0 eV $= 1.6 \times 10^{-19}$ J.?

[JEE Advanced 2018]

37. 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]

ANSWER KEYS

Exercise - 1 Objective Problems | JEE Main

1.	C	2.	A	3.	A	4.	D	5.	B	6.	C	7.	B
8.	C	9.	C	10.	B	11.	C	12.	A	13.	D	14.	B
15.	C	16.	B	17.	A	18.	C	19.	D	20.	C	21.	B
22.	C	23.	C	24.	A	25.	D	26.	D	27.	B	28.	C
29.	A	30.	C	31.	A	32.	A	33.	A	34.	B	35.	A
36.	C	37.	B	38.	C	39.	B	40.	B	41.	C	42.	C
43.	D	44.	C	45.	B	46.	C	47.	D	48.	A	49.	C
50.	B												

Exercise - 2 (Level-I) Objective Problems | JEE Main

1.	D	2.	C	3.	D	4.	C	5.	C	6.	B	7.	B
8.	C	9.	A	10.	C	11.	D	12.	D	13.	D	14.	C
15.	A	16.	D	17.	C	18.	B	19.	B	20.	B	21.	A
22.	B	23.	C	24.	C	25.	D	26.	A	27.	D	28.	B
29.	A	30.	C	31.	B	32.	C	33.	B	34.	B		

Exercise - 2 (Level-II) Multiple Correct | JEE Advanced

1.	A,C	2.	B,C	3.	A,B,C	4.	A,C	5.	A,B
6.	A,C,D	7.	A,D	8.	A,C,D	9.	A,C,D	10.	A,C
11.	A,B,D	12.	A,D	13.	A,B	14.	A,B,C	15.	B,C

Exercise - 3 | Level-I Subjective | JEE Advanced

1. 885 2. (a) 2.25 eV (b) 4.2 eV (c) 2.0 eV, 0.5 eV 3. 0.6 Volt, 2.0 mA

4. when the potential is steady, photo electric emission just stop when $h\nu = (3 + 1)$ eV = 4.0 eV

5. $5.76 \times 10^{-11}\ A$ 6. 940.96 V 7. Photon

8. Power of electron microscope is 10^5 times as large as that of the optical microscrope.

9. $-h/e\,Et^2$ 10. 8.6 MeV 11. 487.06 nm 12. 4.26 m/s, 13.2 eV

13. 7 : 36 14. 18/5R 15. 1.257×10^{-23} Am^2 16. By theory

17. Z = 2 & n = 5

18. a. $n_b \approx 2$; b. 14.4 eV ; c. E_{max} = 13.5 eV & E_{min} = 0.7 eV

19. One electron having kinetic energy nearly 11.6 eV

20. 63.75 eV 21. $f_b = f_a - 2f'_\alpha$ 22. 6210 eV

23. during combination = 3.365 eV; after combination = 3.88 eV ($5 \to 3$) & 2.63 eV ($4 \to 3$)

24. 62.5×10^{-12}, 192.5×10^{-12} 25. 69.5 Kev

Exercise - 3 | Level-II — Subjective | JEE Advanced

1. (a) 10^5 s^{-1} ; (b) 286.18 ; (d) 111 s
2. (i) 5/16 photon/sec, (ii) 5/1600 electrons/sec
3. 6×10^{17} sec.
4. $\frac{\lambda_\alpha}{\lambda_p} = \frac{1}{2}$
5. 3.1×10^6 m/s
6. 489.6 eV, 25.28 Å
7. (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
8. n = 2
9. (i) KE = 3.4 eV, (ii) λ = 6.66 Å
10. 0.61 Å

Exercise - 4 | Level-I — Previous Year | JEE Main

1.	C	2.	B	3.	A	4.	D	5.	B	6.	A	7.	B
8.	D	9.	C	10.	B	11.	B	12.	D	13.	B	14.	B
15.	D	16.	A	17.	D	18.	C	19.	B	20.	D	21.	C
22.	D	23.	D	24.	B	25.	B	26.	A	27.	D	28.	C
29.	D	30.	B	31.	C	32.	B	33.	B	34.	A	35.	C

Exercise - 4 | Level-II — Previous Year | JEE Advanced

1.	C	2.	A	3.	$\sqrt{2}$	4.	$\nu = 1.546 \times 10^{18}$ Hz		
5.	A,C	6.	n = 24	7.	B	8.	A	9.	B
10.	B	11.	C	12.	C	13.	A	14.	A
15.	B	16.	D	17.	A	18.	3	19.	D
20.	B	21.	C	22.	A	23.	7	24.	7
25.	B	26.	1	27.	A,C	28.	A	29.	B
30.	B	31.	A,B,D	32.	6	33.	C	34.	5
35.	B	36.	24	37.	3				

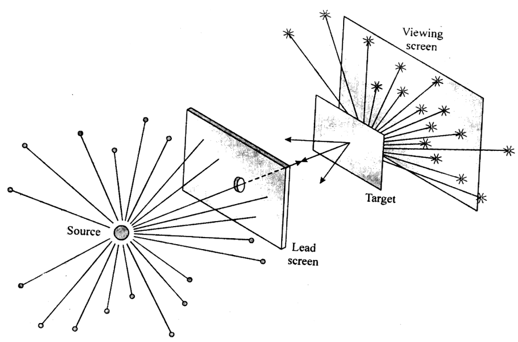
CHAPTER 2

Modern Physics - 2

Section A - RUTHERFORD'S EXPERIMENT, NUCLEAR PROPERTIES (RADIUS, DENSITY, ISOTOPES ETC.)

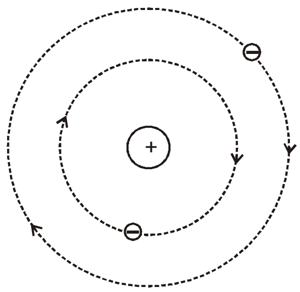
It is the branch of physics which deals with the study of nucleus.

In 1911, Earnest Ruthorford performed a critical experiment that showed that Thomson's model could not be correct. In this experiment a beam of positively charged alpha particles (helium nuclei) was projected into a thin gold foil. It is observed that most of the alpha particles passed through the foil as if it were empty space. But some surprising results are also seen. Several alpha particles are deflected from their original direction by large angles. Few alpha particles are observed to be reflected back, reversing their direction of travel as shown in figure-l.2.



If Thomson model is assumed true that the positive charge is spreaded uniformly in the volume of an atom then the alpha particle can never experience such a large repulsion due to which it will be deflected by such large angles as observed in the experiment. On the basis of this experiment Ruthorford presented a new atomic model.

In this new atomic model it was assumed that the positive charge in the atom was concentrated in a region that was small relative to the size of atom. He called this concentration of positive charge, the nucleus of the atom. Electrons belonging to the atom were assumed to be moving in the large volume of atom outside the nucleus. To explain why these electrons were not pulled into the nucleus, Ruthorford said that electrons revolve around the "nucleus in orbits around the positively charged nucleus in the same manner as the planets orbit the sun. The corresponding atomic model can be approximately shown in figure.



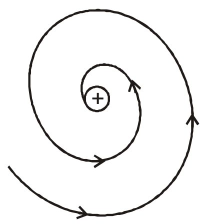
Reason of Failure of model :

1. It could not explain the line spectrum of H-atom.

Justification : According to Maxwell's electromagnetic theory every accelerated moving charged particle radiates energy in the form of electromagnetic waves & therefore duringh revolution of e^- in circular orbit its frequency will contanously vary (i.e. decrease) which will result in the conitnuous emission of lines & therefore spectrum of atom must be continuous but in reality, one obtains line spectrum for atoms.

2. It could not explain the stablity of atoms.

Justification : Since revolving electron will continuously radiates energy & therfore radii of circular path will continuously decrease & in a time of about 10^{-8} sec revolving electron must fall down in a nucleus by adopting a spiral path



Path of electron spiral

1. NUCLEUS :

(a) **Discoverer :** Rutherford

(b) **Constituents :** neutrons (n) and protons (p) [collectively known as nucleons]

1. **Neutron :** It is a neutral particle. It was discovered by J. Chadwick.

Mass of neutron,

$m_n = 1.6749286 \times 10^{-27}$ kg

2. **Proton :** It has a charge equal to +e. It was discovered by Goldstein.

Mass of proton, $m_p = 1.6726231 \times 10^{-27}$ kg

$(m_p \lesssim m_n)$

(c) **Representation :**

$_ZX^A$ or ^A_ZX

where $X \Rightarrow$ symbol of the atom

$Z \Rightarrow$ Atomic number = number of protons

$A \Rightarrow$ Atomic mass number = total number of nucleons.

= no. of protons + no. of neutrons.

Atomic mass number :

It is the nearest integer value of mass represented in a.m.u (atomic mass unit)

1 a.m.u $= \frac{1}{12}$ [mass of one atom of $_6C^{12}$ atom at rest and in ground state]

1.6603×10^{-27} kg ; 931.478 MeV/c²

mass of proton (m_o) = mass of neutron (m_n) = 1 a.m.u.

Some definitions :

(1) **Isotopes :**

The nuclei having the same number of protons but different number of neutrons are called isotopes.

(2) **Isotones :**

Nuclei with the same neutron number N but different atomic number Z are called isotones.

(3) **Isobars :**

The nuclei with the same mass number but different atomic number are called isobars

(d) **Size** of nucleus : Order of 10^{-15} m (fermi)

Radius of nucleus ; $R = R_0A^{1/3}$

where $R_0 = 1.1 \times 10^{-15}$ m (which is an empirical constant)

A = Atomic mass number of atom.

(e) **Density :**

$$\text{density} = \frac{\text{mass}}{\text{volume}} \cong \frac{Am_p}{\frac{4}{3}\pi R^3}$$

$$= \frac{Am_p}{\frac{4}{3}\pi(R_0A^{1/3})^3} = \frac{3m_p}{4\pi R_0^3}$$

$$= \frac{3 \times 1.67 \times 10^{-27}}{4 \times 3.14 \times (1.1 \times 10^{-15})^3}$$

$$= 3 \times 10^{17}\ \text{kg/m}^3$$

Nuclei of almost all atoms have almost same density as nuclear density is independent of the mass number (A) and atomic number (Z).

Note

The student can now attempt section A from exercise.

Section B - MASS DEFECT, BINDING ENERGY, STABILITY

2. MASS DEFECT

It has observed that there is a differene between expected mass and actual mass of a nucleus.

$M_{expected} = z\ m_p + (A - Z)\ m_n$

$M_{observed} = M_{atom} - Zm_e$

It is found that

$M_{observed} < M_{erxpected}$

Hence, mass defect is defined as

Mass defect $= M_{expected} - M_{observed}$

$\Delta m = [Zm_p + (A - Z)m_n - [M_{atom} - Zm_e]$

3. BINDING ENERGY

It is the minimum energy required to break the nucleus into its constituent particles.

or

Amount of energy released during the formation of nucleus by its constituent particles and bringing them from infinite separation.

Binding Energy (B.E.) = Δmc^2

BE $= \Delta m$ (in amu) $\times$ 931.5 MeV/amu

$= \Delta m \times 931.5$ MeV

$= \Delta m \times 931$ MeV

(Also Called Mass energy equivalance)

Note

If binding energy per nucleon is more for a nucleus then it is more stable.

For Example

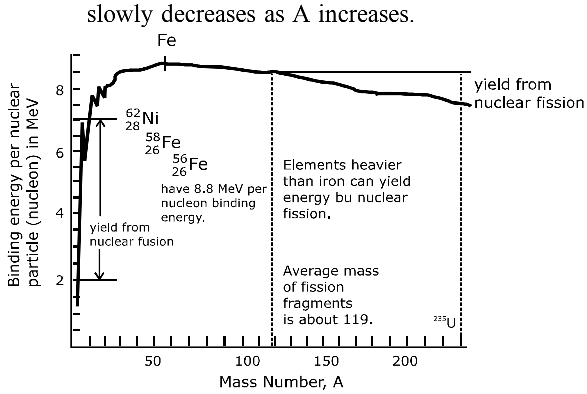
If $$\left(\frac{B.E_1}{A_1}\right) > \left(\frac{B.E_2}{A_2}\right)$$

then nucleus 1 would be more stable.

3.1 Variation of binding energy per nucleon with mass number :

The binding energy per nucleon first increases on an averge and reaches a maximum of about 8.7 MeV for A. 50 $\rightarrow$ 80. For still heavier nuclei, the binding energy per nucleon

slowly decreases as A increases.



Binding energy per nucleon is maximum for $_{26}Fe^{56}$, which is equal to 8.8 MeV. Binding energy per nucleon is more for medium nuclei than for heavy nuclei. Hence, medium nuclei are highly stable.

- The heavier nuclei being unstable have tendency to split into medium nuclei. This process is called **Fission.**
- The Lighter nuclei being unstable have tendency to fuse into a medium nucleus. This process is called **Fusion.**

Note

The student can now attempt section B from exercise.

Section C - RADIOACTIVING LAW

4. RADIOACTIVITY :

It was discovered by Henry Becquerel.

Spontaneous emission of radiations (α, β, γ) from unstable nucleus is called **radioactivity.** Substances which shows radioactivity are known as **radioactive substance.**

Radioactivity was studied in detail by Rutherford.

In radioactive decay, an unstable nucleus emits α particle or β particle. After emission of α or β the remaining nucleus may emit γ- particle, and converts into more stable nucleus.

α- particle :

It is a doubly charged helium nucleus. It contains two protons and two neutrons.

Mass of α - particle = Mass of $_2He^4$ atom – $2m_e$ = 4 m_p

Charge of α - particle = + 2e

β-particle :

(a) **β^- (electron) :**

Mass = m_e ; Charge = – e

(b) **β^+ (positron)**

Mass = m_e ; Charge = + e

positron is an antiparticle of electron.

Antiparticle :

A particle is called antiparticle of other if on collision both can annihilate (destroy completely) and converts into energy. For example : (i) electron (–e, m_e) and positron (+e, m_e) are anti particles, (ii) neutrino (ν) and antineutrino ($\bar{\nu}$) are anti particles.

γ-particle : They are energetic photons of energy of the order of Mev and having rest mass zero.

Note

The student can now attempt section C from exercise.

Section D - α, β, γ DECAY, FISSION & FUSSION

5. RADIOACTIVE DECAY (DISPLACEMENT LAW) :

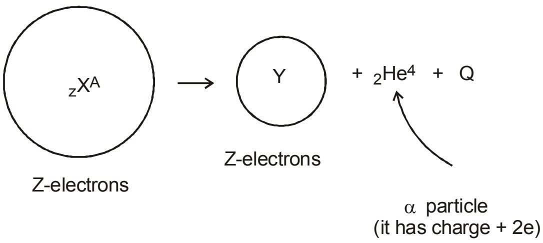
5.1 α-Decay :

$$_{Z}X^{A} \rightarrow {}_{Z-2}Y^{A-4} + {}_{2}He^{4} + Q$$

Q value : It is definied as energy released during the decay process.

Q value = rest mass energy of reactans – rest mass energy of products.

This energy is available in the form of increase in K.E. of the products



Let, M_x = mass of atom $_{Z}X^{A}$

M_y = mass of atom $_{Z-2}Y^{A-4}$

M_{He} = mass of atom $_{2}He^{4}$

Q value = $[(M_x - Zm_e) - \{(M_y - (Z-2)m_e) + (M_{He} - 2m_e)\}]\, c^2 = [M_x - M_y - M_{He}]\, c^2$

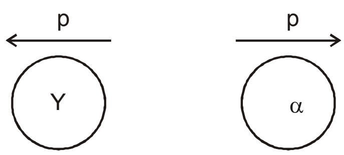
Considering actual number of electrons in α - decay

Q value = $[M_x - (M_y + 2m_e) - (M_{He} - 2m_e)]\, c^2$

$= [M_x - M_y - M_{He}]c^2$

Calculation of Kinetic energy of final products :

As atom X was initially at rest and no external forces are acting, so final momentum also has to be zero. Hence both Y and α - particle will have same momentum in magnitude but in opposite direction.



$p_{\alpha}^{2} = p_{Y}^{2}$ $\qquad 2m_{\alpha}T_{\alpha} = 2\, m_Y\, T_Y$

(Here we are representing T for kinetic energy)

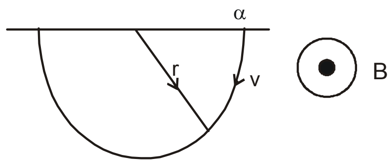
$Q = T_y + T_{\alpha}$ $\qquad m_{\alpha}T_{\alpha} = m_Y T_y$

$$T_{\alpha} = \frac{m_Y}{m_{\alpha} + m_Y}Q \;; \qquad T_Y = \frac{m_{\alpha}}{m_{\alpha} + m_Y}Q$$

$$T_{\alpha} = \frac{A-4}{A}Q \;; \qquad T_Y = \frac{4}{A}Q$$

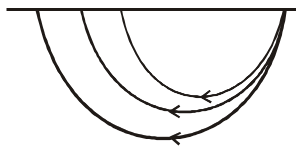
From the above calculation, one can see that all the α-particles emitted should have same kinetic energy. Hence, if they are passed through a region of uniform magnetic field having direction perpendicular to velocity, they should move in a circle of same radius.

$$r = \frac{mv}{qB} = \frac{mv}{2eB} = \frac{\sqrt{2Km}}{2eB}$$



Experimental Observation :

Experimentally it has been observed that all the α-particles do not move in the circle of same radius, but they move in 'circles having different radii.



This shows that they have different kinetic energies. But it is also observed that they follow circular paths of some fixed values of radius i.e. yet the energy of emitted α-particles is not same but it is quantized. The reason behind this is that all the daughter nuclei produced are not in their ground state but some of the daughter nuclei may be produced in their excited states and they emits photon to aquire their ground state.

$$X \longrightarrow Y^{*}\,(\text{excited state}) + \alpha + Q$$

$$\downarrow$$

$$Y + \text{photon } (\gamma \text{ particle})$$

The only difference between Y and Y* is that Y* is in excited state and Y is in ground state.

Let, the energy of emited γ- particles be E

$\therefore$ $Q = T_\alpha + T_Y + E$

where $Q = [M_x - M_Y - M_{He}]\, c^2$

$T_\alpha + T_Y = Q - E$

$$T_\alpha = \frac{m_Y}{m_\alpha + m_Y}(Q - E)\ ;$$

$$T_Y = \frac{m_\alpha}{m_\alpha + m_Y}(Q - E)$$

5.2 β^- – Decay :

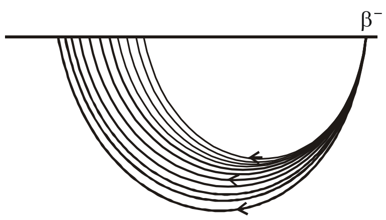
$${}_zX^A \longrightarrow {}_{Z+1}Y^A + {}_{-1}e^0 + Q$$

${}_{-1}e^0$ can also be written as ${}_{-1}\beta^0$

Here also one can see that by momentum and energy conversion, we will get

$$T_e = \frac{m_Y}{m_e + m_Y}Q,\quad T_Y = \frac{m_e}{m_e + m_Y}Q$$

as $m_e << m_Y$, we can consider that all the energy is taken away by the electron. From the above results, we will find that all the β-particles emitted will have same energy and hence they have same radius if passed through a region of perpendicular magnetic field. But, experimental observations were completely different. On passing through a region of uniform magnetic field perpendicular to the velocity, it was observed that β-particles take circular paths of different radius having a continuous spectrum.



To explain this, Paulling has introduced the extra particles called neutrino and antineutrino (antiparticle of neutrino).

$\bar{\nu} \rightarrow$ antineutrino, $\nu \rightarrow$ neutrino

Propeties of antineutrino ($\bar{\nu}$) & neutrino (n) :

(1) They are like photons having rest mass = 0
speed = c
Energy, $E = mc^2$

(2) They are chargeless (neutral)

(3) They have spin quantum number, $s = \pm \frac{1}{2}$

Considering the emission of antineutrino, the equation of β^- - decay can be written as

$${}_ZX^A \longrightarrow {}_{z+1}Y^A + {}_{-1}e^0 + Q + \bar{\nu}$$

Production of antinuetrino along with the electron helps to explain the continueous spectrum because the energy is distributed randomly between electron and $\bar{\nu}$ and it also helps to explain the spin quantum number balnace (p, n and ± e each has spin quantum number ± 12)

During β^- - decay, inside the nucleus a neutron is converted to a proton with emission of an electron and antineutrino.

$$n \rightarrow p + {}_{-1}e^0 + \bar{\nu}$$

Let, M_x = mass of atom ${}_zX^A$
M_Y = mass of atom ${}_{z+1}Y^A$
m_e = mass of electron

Q value = $[(M_x - Zm_e) - \{(M_Y - (z + 1)m_e) + m_e\}]\, c^2 = [M_x - M_Y]\, c^2$

Considering actual number of electrons.

Q value = $[M_x - \{(M_Y - m_e) + m_e\}]\, c^2 = [M_x - M_y]c^2$

5.3 β^+ – Decay :

$${}_ZX^A \rightarrow {}_{Z-1}Y^A + {}_{+1}e^0 + \nu + Q$$

In β^+ decay,inside a nucleus a proton is converted into a neutron, positron and neutrino.

$$p \rightarrow n + {}_{+1}e^0 + \nu$$

As mass increases during conversion of proton to a neutron, hence it requires energy for β^+ decay to take place,

$\therefore$ β^+ decay is rare process. It can take place in the nucleus where a proton can take energy from the nucleus itself.

Q value = $[(M_X - Zm_e) - \{(M_Y - (Z - 1)\, m_e) + m_e\}]\, c^2 = [M_X - M_Y - 2m_e]\, c^2$

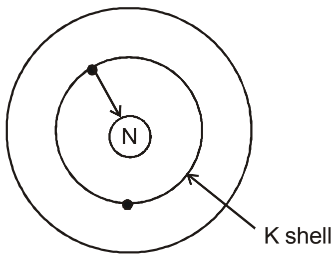
Considering actual number of electrons.

Q value = $[M_X - \{(M_Y + m_e) + m_e\}]\, c^2 = [M_X - M_Y - 2m_e]\, c^2$

5.4 K capture :

It is rare process which is found only in few nucleus. In this process the nuclues captures one of the atomic electrons from the K shell. A proton in the nucleus combines with this electron and converts itself into a neutron. A neutrino is also emitted in the process and is emitted from the nucleus.

$$p + {}_{-1}e^{0} \rightarrow n + \nu$$



If X and Y are atoms then reactions is written as :

${}_{Z}X^{A} \rightarrow {}_{Z-1}Y^{A} + \nu + Q$ + characteristic x-rays of Y.

If X and Y are taken as nucleus, then reactions is written as :

$${}_{Z}X^{A} + {}_{-1}e^{0} \rightarrow {}_{Z-1}Y^{A} + \nu$$

Note

(1) Nuclei having atomic numbers from Z = 84 to 112 shows radioactivity.

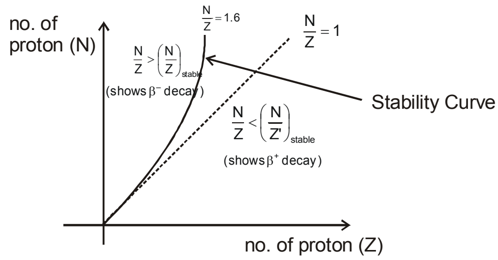
(2) Nuclei having Z = 1 to 83 are stable (only few exceptions are there)

(3) Whenever a neutron is produced, a neutrino is also produced.

(4) Whenever a neutron is converted into a proton, a antineutrino is produced.

6. NUCLEAR STABILITY :

Figure shows a plot of neutron number N versus proton number Z for the nuclides found in nature. The solid line in the figure represents the stable nuclides. For light stable nuclides, the neutron number is equal to the proton number so that ratio N/Z is equal to 1. The ratio N/Z increases for the heavier nuclides and becomes about 1.6 for the heaviest stable nuclides.



The points (Z, N) for stable nuclides fall in a rather well-defined narrow region. There are nuclides to the left of the stability belt as well as to the right of it. The nuclides to the left of the stability region have excess neutrons, whereas, those to the right of the stability belt have excess protons. these nuclides are unstble and decay with time according to the laws of radioactive disintegration. Nuclides with excess neutrons (lying above stability belt) show β^- decay while nuclides with excess protons (lying below stability belt) show β^+ decay and K - capture.

7. NUCLEAR FORCE :

(i) Nuclear forces are basically attractive and are responsible for keeping the nucleons bound in a nucleus in spite of repulsion between the positively charge protons.

(ii) It is the strongest force with in nuclear dimensions ($F_n - 100\ F_e$)

(iii) It is a short range force (acts only inside the nucleus)

(iv) It acts only between neutron-neutron, neutron-proton and proton-proton i.e. between nucleons.

(v) It does not depend on the nature of nucleons.

(vi) An important property of nuclear force is that it is not a central force. The force between a pair of nucleons is not solely determined by the distance between the necleons. For example, the nuclear force depends on the directions of the spins of the nucelons. The force is stronger if the spins of the nucleons are parallel (i.e., both nucleons have m_s = +1/2 or –1/2) and is weaker if the spins are antiparallel (i.e., one nucleon has m_s = +1/2 and the other has m_s = – 1/2). Here m_s is spin quantum number.

8. RADIOACTIVE DECAY : (STATISTICAL LAWS) :

These were given by Rutherford and Soddy.

Rate of radioactive decay $\propto N$

where N = number of active nuclei $= \lambda N$

where λ = decay constant of the radioactive substance.

Decay constant is different for different radioactive substances, but it does not depend on amount of substances and time.

SI unit of λ is s^{-1}

If $\lambda_1 > \lambda_2$ then first substance is more radioactive (less stable) than the second one.

For the case, if A decays to B with decay constant λ

$$A \xrightarrow{\lambda} B$$

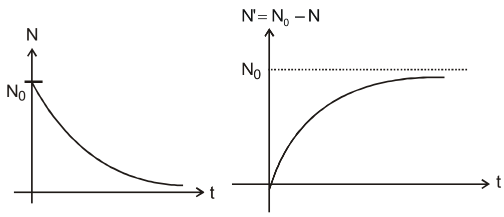
$t = 0 \quad N_0 \quad 0$ where N_0 = number of active nuclei of A at t = 0

$t = t \quad N \quad N'$ where N = number of active nuclei of A at t = t

$$\text{Rate of radioactive decay of A} = -\frac{dN}{dt} = \lambda N$$

$$-\int_{N_0}^{N} \frac{dN}{N} = \int_0^t \lambda dt$$

$\Rightarrow \quad N = N_0\, e^{-\lambda t}$ (it is exponential decay)



Number of nuclei decayed (i.e., the number of nuclei of B formed)

$$N' = N_0 - N = N_0 - N_0 e^{-\lambda t}$$

$$N' = N_0(1 - e^{-\lambda t})$$

8.1 Half Life ($T_{1/2}$) :

It is the time in which number of active nuclei becomes half.

$$N = N_0 e^{-\lambda t}$$

After one half life, $\quad N = \dfrac{N_0}{2}$

$$\frac{N_0}{2} = N_0 e^{-\lambda t} \Rightarrow t = \frac{\ln 2}{\lambda} \Rightarrow \frac{0.693}{\lambda} = t_{1/2}$$

$$t_{1/2} = \frac{\ln 2}{\lambda} = \frac{0.693}{\lambda} \quad \textbf{(to be remembered)}$$

Number of nuclei present after n half lives i.e. after a time $t = n\, t_{1/2}$

$$N = N_0 e^{-\lambda t} \quad = N_0 e^{-\lambda\, n t_{1/2}} \quad = N_0 e^{-\lambda n \frac{\ln 2}{\lambda}}$$

$$= N_0 e^{\ln 2^{(-n)}} \quad = N_0 (2)^{-n} = N_0 (1/2)^n \quad = \frac{N_0}{2^n}$$

$\{n = \dfrac{t}{t_{1/2}}$. It may be a fraction, need not to be an integer$\}$

or

$$N_0 \xrightarrow[\text{half life}]{\text{after 1st}} \frac{N_0}{2} \xrightarrow{2} N_0\left(\frac{1}{2}\right)^2 \xrightarrow{3} N_0\left(\frac{1}{2}\right)^3$$

$$\ldots\ldots\ldots\ldots\ldots\ldots \xrightarrow{n} N_0\left(\frac{1}{2}\right)^n$$

8.2 Activity :

Activity is defined as rate of radioactive decay of nuclei

It is denoted by A or R $\quad A = \lambda N$

If a radioactive substance changes only due to decay then

$$A = -\frac{dN}{dt}$$

As in that case, $N = N_0\, e^{-\lambda t}$

$$A = \lambda N = \lambda N_0 e^{-\lambda t} \Rightarrow A = A_0 e^{-\lambda t}$$

SI unit of activity : becquerel (Bq) which is same as 1 dps (disintegration per second)

The popular unit of activity is curis which is defined as 1 curie $= 3.7 \times 10^{10}$ dps (which is activity of 1 gm Radium)

specific activity : The activity per unit mass is called specific activity.

8.3 Average Life :

$$T_{avg} = \frac{\text{sum of ages of all the nuclei}}{N_0} = \frac{\int_0^\infty \lambda N_0 e^{-\lambda t} dt . t}{N_0} = \frac{1}{\lambda}$$

EXAMPLE 17

A radioactive nucleus can decay be two different processes. The half-life for the first process is t_1 and that for the second process is t_2. Show that the effective half-life t of the nucleus is given by

$$\frac{1}{t}=\frac{1}{t_1}+\frac{1}{t_2}$$

Sol. The decay constant for the first process is $\lambda_1=\frac{\ln 2}{t_1}$ and for the second process it is $\lambda_2=\frac{\ln 2}{t_1}$. The probability that an active nucleus decays by the first process in a time interval it is λ_1 dt. Similarly, the probability that it decays by the second process is λ_2 dt. The probability that it either decays by the first process or by the second process is λ_1 dt + λ_2 dt. If the effective decay constant is λ, this probability is also equal to λ dt. Thus

$$\lambda dt=\lambda_1 dt+\lambda_2\, dt$$

or, $$\boldsymbol{\lambda=\lambda_1+\lambda_2}$$

or, $$\frac{1}{t}=\frac{1}{t_1}+\frac{1}{t_2}\quad \text{(To be remembered)}$$

EXAMPLE 18

A factory produces a radioactive substance A at a constant rate R which decays with a decay constant λ to form a stable substance. Find **(i)** the no. of nuclei of A and **(ii)** Number of nuclei of B, at any time t assuming the production of A starts t = 0. **(iii)** Also find out the maximum number of nuclei of 'A' present at any time during its formation.

Sol. $$\text{Factory}\xrightarrow[\text{constant}]{R}A\xrightarrow[\text{decay}]{\lambda}B$$

Let N be the number of nuclei of A at any time t

$$\therefore\ \frac{dN}{dt}=R-\lambda N\qquad \int_0^N\frac{dN}{R-\lambda N}=\int_0^t dt$$

On solving we will get

$N=R/\lambda\,(1-e^{-\lambda t})$

(ii) Number of nuceli of B at any time t, $N_B=R\,t-N_A=Rt-R/\lambda\,(1-e^{-\lambda t})=R/\lambda\,(\lambda t-1+e^{-\lambda t})$

(iii) Maximum number of nuclei of 'A' present at any time during its formation $=\frac{R}{\lambda}$

EXAMPLE 19

A radioactive substance "A" having N_0 active nuclie at t = 0, decays to another radioactive substance "B" with decay constant λ_1. B further decays to a stable substance 'C' with decay constant λ_2. **(a)** Find the number of nuclei of A, B and C after time t, **(b)** What would be answer of part (a) if $\lambda_1 >> \lambda_2$ and $\lambda_1 << \lambda_2$

Sol. The decay scheme is as shown

$$A\xrightarrow{\lambda_1}B\xrightarrow{\lambda_2}C\ \text{(stable)}$$

t = 0	N_0	0	0
t	N_1	N_2	N_3

Here N_1, N_2 and N_3 represent the nuclei of A, B and C at any time t.

For A, we can write

$$N_1=N_0e^{-\lambda_1 t}\qquad ...(1)$$

For B, we can write

$$\frac{dN_2}{dt}=\lambda_1N_1-\lambda_2N_2\qquad ...(2)$$

or, $$\frac{dN_2}{dt}+\lambda_2N_2-\lambda_1N_1$$

This is a linear differential equation with integrating factor

$$\text{I.F.}=e^{\lambda}2^{t}$$

$$e^{\lambda_2 t}\frac{dN_2}{dt}+e^{\lambda_2 t}\lambda_2N_2=\lambda_1N_1e^{\lambda_2 t}$$

$$\int d(N_2e^{\lambda_2 t})=\int\lambda_1N_1e^{\lambda_2 t}dt$$

$$N_2e^{\lambda_2 t}=\lambda_1N_0\int e^{-\lambda_1 t}e^{\lambda_2 t}dt\qquad ...\text{using (1)}$$

$$N_2e^{\lambda_2 t}=\lambda_1N_0\frac{e^{(\lambda_2-\lambda_1)t}}{\lambda_2-\lambda_1}+C\qquad ...(3)$$

At $t=0,\ N_2=0$ $$0=\frac{\lambda_1N_0}{\lambda_2-\lambda_1}+C$$

Hence $$C=\frac{\lambda_1N_0}{\lambda_1-\lambda_2}$$

Using C in eqn. (3), we get

$$N_2=\frac{\lambda_1N_0}{\lambda_2-\lambda_1}(e^{-\lambda_1 t}-e^{-\lambda_2 t})$$

and $N_1 + N_2 + N_3 = N_0$

$\therefore$ $N_3 = N_0 - (N_1 + N_2)$

(b) For $\lambda_1 >> \lambda_2$

$$N_2 = \frac{\lambda_1 N_0}{-\lambda_1}(-e^{-\lambda_2 t}) = N_0 e^{-\lambda_2 t}$$

For $\lambda_1 << \lambda_2$

$$N_2 = \frac{\lambda_1 N_0}{\lambda_2}(e^{-\lambda_1 t}) = 0$$

9. NUCLEAR FISSION :

In nuclear fission heavy nuclei of A, above 200, break up into two or more fragments of comparable masses. The most attractive bid, from a practical point of view, to achieve energy from nuclear fission is to use ${}_{92}U^{236}$ as the fission material. the technique is to hit a uranium sample by sample by slow moving neutrons (kinetic energy ≈ 0.04 eV, also called thermal neutrons.) A ${}_{92}U^{235}$ nucleus has large probability of absorbing a slow neutron and forming ${}_{92}U^{236}$ nucleus. This nucleus then fissions into two parts. A variety of combinations of the middle-weight nuclei may be formed due to the fission. For example, one may have

$${}_{92}U^{235} + {}_0n^1 \rightarrow {}_{92}U^{236} \rightarrow X + Y + 2{}_0n^1,$$

or

$${}_{92}U^{235} + {}_0n^1 \rightarrow {}_{92}U^{236} \rightarrow X' + Y' + 2{}_0n^1$$

and a number of other combinations.

• On an average 2.5 neutrons are emitted in each fission event.

• Mass lost per reaction 0.2 a.m.u.

• In nuclear fission the total B.E. increases and excess energy is released.

• In each fission event, about 200 MeV of energy is released a large part of which appears in the form of kinetic energies of the two ragements. Neutrons take away about 5 MeV.

Ex. $${}^{235}_{92}U + {}_0n^1 \rightarrow {}^{236}_{92}U \rightarrow {}^{141}_{56}Ba + {}^{92}_{36}Kr + 3{}_0n^1 + \text{energy}$$

Q value = $[(M_U - 92\,m_e + m_n) - \{(M_{Ba} - 56\,m_e) + (M_{Kr} - 36\,m_e) + 3m_n\}]\,c^2 = [(M_U + m_n) - (M_{Ba} + M_{Kr} + 3m_n)]\,c^2$

• A very important and interesting feature of neutron-induced fission is the chain reaction. For working of nuclear reactor refer your text book.

10. NUCLEAR FUSION (THERMO NUCLEAR REACTION) :

(a) Some unstable light nuclei of A below 20, fuse together, the B.E. per nucleon increases and hence the excess energy is released. The easiert thermonuclear reaction that can be handled on earth is the fusion of two deuterons (D – D reaction) or fusion of a deuteron with a triton (D – T reaction).

$${}_1H^2 + {}_1H^2 \rightarrow {}_2He^3 + {}_0n^1 + 3.3\,\text{MeV}(D-D)$$

$$Q\text{ value} = [2((M_D - m_e) - \{(M_{He^3} - 2m_e) + m_n\}]c^2$$

$$= [2M_D - (M_{He^3} + m_n)]c^2$$

$${}_1H^2 + {}_1H^2 \rightarrow {}_1H^3 + {}_1H^1 + 4.0\,\text{MeV}\ (D-D)$$

Q value

$$= [2(M_D - m_e) - \{(M_T - m_e) + (M_H - m_e)\}]c^2$$

$$= [2M_D - (M_T + M_H)]c^2$$

$${}_1H^2 + {}_1H^3 \rightarrow {}_2He^4 + n + 17.6\,\text{MeV}\,(D-T)$$

Q value

$$= [\{(M_D - m_e) + (M_T - m_e)\} - \{(M_{He^4} - 2m_e) + m_n\}]c^2$$

$$= [(M_D + M_T) - (M_{He^4} + m_n)]c^2$$

Note

- In case of fission and fusion, $\Delta m = \Delta m_{atom} = \Delta m_{nucleus}$
- These reactions take place at ultra high temperature ($\simeq 10^7$ to 10^8). At high pressure it can take place at low temperature also. For these reactions to take place nuclei should be brough upto 1 fermi distance which requires very high kinetic energy.
- Energy released in fusion exceeds the energy liberated in the fission of heavy nuclei.

Note

The student can now attempt section D from exercise.

Exercise - 1 Objective Problems | JEE Main

Section A - RUTHERFORD'S EXPERIMENT, NUCLEAR PROPERTIES (RADIUS, DENSITY, ISOTOPES ETC.)

1. Why is a ${}^4_2He$ nucleus more stable than a ${}^4_3Li$ nucleus?

(A) The strong nuclear force is larger when the neutron to proton ratio is higher.

(B) The laws of nuclear physics forbid a nucleus from containing more protons than neutrons.

(C) Forces other than the strong nuclear force make the lithium nucleus less stable.

(D) None of the above.

2. An element A decays into an element C by a two-step process :

$A \to B + He^4_2$ and $B \to C + 2e^0_{-1}$

Then

(A) A and C are isotopes

(B) A and C are isobars

(C) B and C are isotopes

(D) A and B are isobars

3. Which of the following statements is incorrect for nuclear forces ?

(A) These are strongest in magnitude.

(B) They are charge dependent.

(C) They are effective only for short ranges.

(D) They result from interaction of every nucleon with the nearest limited number of nucleons.

4. Fast neutrons can easily be slowed down by

(A) the use of lead shielding

(B) passing them through heavy water

(C) elastic collision with heavy nuclei

(D) applying a strong electric field

5. Order of magnitude of density of uranium nucleus is $[m_p=1.67\times10^{-27}kg]$

(A) $10^{20}kg\ m^{-3}$ (B) 10^{17} kg m^{-3}

(C) 10^{14} kg m^{-3} (D) 10^{11} kg m^{-3}

6. 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

Section B - MASS DEFECT, BINDING ENERGY, STABILITY

7. 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) $Q = 2E_2 + E_1$

8. The binding energies of the atom of elements A & B are E_a & E_b respectively. Three atom of the element B fuse to give one atom of element A. This fusion process is accompained 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) $E_a+3E_b+e=0$

9. Consider the nuclear reaction

$X^{200} \to A^{110} + B^{90}$

If the binding energy per nucleon for X, A and B is 7.4 MeV, 8.2 MeV and 8.2 MeV respectively, what is the energy released?

(A) 200 MeV (B) 160 MeV

(C) 110 MeV (D) 90 MeV

10. A heavy nucleus having mass number 200 gets disintegrated into two small fragments of mass number 80 and 120. If binding energy per nucleon for parent atom is 6.5 M eV and far daughter nuclei is 7 MeV and 8 MeV respectively, then the energy released in the decay will be –

(A) 200 MeV (B) –220 MeV
(C) 220 MeV (D) 180 MeV

11. Consider the nuclear reaction $X^{200} \rightarrow A^{110} + B^{80}$. If the binding energy per nucleon for X, A and B are 7.4 MeV, 8.2 MeV and 8.1 MeV respectively, then the energy released in the reaction -

(A) 70 MeV (B) 200 MeV
(C) 190 MeV (D) 10 MeV

12. Binding energy per nucleon of $_1H^2$ and $2He^4$ are 1.1 MeV and 7.0 MeV respectively. Energy released in the process $_1H^2 + {_1H^2} = {_2He^4}$ is -

(A) 20.8 MeV (B) 16.6 MeV
(C) 25.2 MeV (D) 23.6 MeV

Section C -RADIOACTIVING LAW

13. The radioactivity of a sample is R_1 at time T_1 and R_2 at time T_2. If the half life of the specimen is T. Number of atoms that have disintegrated in time $(T_2 - T_1)$ is proportional to

(A) $(R_1T_1 - R_2T_2)$ (B) $(R_1 - R_2)$ T
(C) $(R_1 - R_2)/T$ (D) $(R_1 - R_2)(T_1 - T_2)$

14. 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.

15. The radioactive sources A and B of half lives of 2 hr and 8 hr respectively, initially contain the same number of radioactive atoms. At the end of 2 hours, their rates of disintegration are in the ratio :

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

16. In a RA element the fraction of initiated amount remaining after its mean life time is :

(A) $1 - \frac{1}{e}$ (B) $\frac{1}{e^2}$
(C) $\frac{1}{e}$ (D) $1 - \frac{1}{e^2}$

17. Two radioactive material A_1 and A_2 have decay constants of 10 λ_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

18. 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 decays before t = 4 days
(B) no nucleus will decays before t = 8 days
(C) all nuclei will decays before t = 16 days
(D) a given nucleus may decay at any time after t = 0.

Section D -α, β, γ DECAY, FISSION & FUSSION

19. The following nuclear reaction is an example of

$$^{12}_{6}C + {^4_2H} \longrightarrow {^{16}_8O} + \text{energy}$$

(A) fission (B) fusion
(C) alpha decay (D) beta decay

20. The rest mass of the deuteron, ^2_1H, 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 Me V
(D) captures a γ-ray photon of energy 3 MeV

21. 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

22. The number of α and β^-–emitted during the radioactive decay chain starting from ${}^{226}_{88}Ra$ and ending at ${}^{206}_{82}Pb$ us

(A) 3α & $6\beta^-$ (B) 4α & $5\beta^-$

(C) 5α & $4\beta^-$ (D) 6α & $6\beta^-$

23. If a nucleus such as ${}^{226}Ra$ that is initially at rest undergoes alpha decay, then which of the following statements is true?

(A) The alpha particle has more kinetic energy than the daughter nucleus.

(B) The alpha particle has less kinetic energy than the daughter nucleus.

(C) The alpha particle and daughter nucleus both have same kinetic energy.

(D) We cannot say anything about kinetic energy of alpha particle and daughter nucleus.

24. In a large sample of ${}^{235}U$ (which is alpha active)

(A) the probability of a nucleus disintegrating during one second is lower in first half life and greater in 2^{nd} half life.

(B) the probability of a nucleus to decay during one sec remains constant for all time.

(C) an appreciable quantity of ${}^{235}U$ remain undecayed even after average life.

(D) None of these

Exercise - 2 (Level-I) Objective Problems | JEE Main

Section A - Rutherford's Experiment, Nuclear Properties (Radius, Density, Isotopes etc.)

1. **Statement-1:** It is easy to remove a proton from $^{40}_{20}Ca$ nucleus as compared to a neutron.
Statement-2: Inside nucleus neutrons are acted on only attractive forces but protons are also acted on by repulsive forces.
(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.

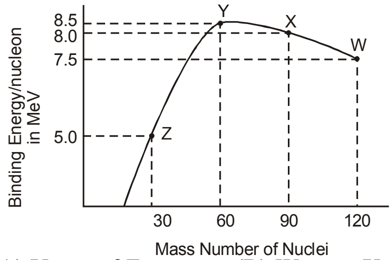
2. The surface area of a nucleus varies with mass number A as
(A) $A^{2/3}$ (B) $A^{1/3}$
(C) A (D) None

3. 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) $M_1 < 10\ (m_n)$

Section B - Mass Defect, Binding Energy, Stability

4. 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

5. Binding energy per nucleon vs. mass number curve for nuclei is shown in the figure. W, X, Y and Z are four nuclei indicated on the curve. The process that would release energy s



(A) Y ⟶ 2Z (B) W ⟶ X + Z
(C) W ⟶ 2Y (D) X ⟶ Y + Z

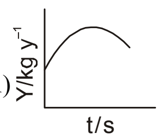
6. What is the power output of $_{92}U^{235}$ reactor if it takes 30 days to use up 2 kg of fuel and if each fission gives 185 MeV of usable energy? Avogadro's number = 6.02×10^{26} per kilomole.
(A) 45 megawatt (B) 58.46 megawatt
(C) 72 megawatt (D) 92 megawatt

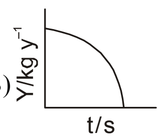
Section C - Radioactiving law

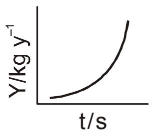
7. There are two radio nuclie A and B. A is an alpha emitter and B is a beta emitter. Their distintegration constants are in the ratio of 1 : 2. What should be the ratio of number of atoms of two at time t = 0 so that probabilities of getting α and β particles are same at time t = 0.
(A) 2 : 1 (B) 1 : 2
(C) e (D) e^{-1}

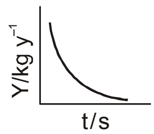
8. A radioactive nuclide can decay simultaneously by two different processes which have decay constants λ_1 and λ_2. The effective decay constant of the nuclide is λ, then :
(A) $\lambda = \lambda_1 + \lambda_2$ (B) $\lambda = 1/2(\lambda_1 + \lambda_1)$
(C) $\frac{1}{\lambda} = \frac{1}{\lambda_1} + \frac{1}{\lambda_2}$ (D) $\lambda = \sqrt{\lambda_1\lambda_2}$

9. 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) 

10. 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) $+\left(\frac{N_1}{N_2}\right)e^{-(\lambda_1-\lambda_2)t}$
(C) $+(N_1\lambda_1e^{-\lambda_1 t}+N_2\lambda_2e^{-\lambda_2 t})$
(D) $+N_1\lambda_1\ N_2\lambda_2e^{-(\lambda_1+\lambda_2)t}$

Section D - α, β, γ DECAY, FISSION & FUSSION

11. A star initially has 10^{40} deutrons. It produces energy via, the processes ${}_1H^2 + {}_1H^2 \longrightarrow {}_1H^3 + p$ & ${}_1H^2 + {}_1H^3 \longrightarrow {}_2He^4 + n$. If the average power radiated by the star is 10^{16} W, the deuteron supply of the star is exhausted in a time of the order of :

(A) 10^6 sec (B) 10^8 sec

(C) 10^{12} sec (D) 10^{16} sec

12. 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

13. A radioactive nucleus undergoes a series of decays according to the scheme

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

If the mass number and atomic number of A are 180 and 72, respectively, then what are these number for A_4?

(A) 172 and 69 (B) 174 and 70

(C) 176 and 69 (D) 176 and 70

Exercise - 2 (Level-II) Multiple Correct | JEE Advanced

Section A - Rutherford's Experiment, Nuclear Properties (Radius, Density, Isotopes etc.)

1. If A, Z, and N denote the mass number, the atomic number, and the neutron number for a given nucleus, we can say that the incorrect statement is

(A) N = Z + A

(B) isobard have the same A but different Z and N

(C) isotopes have the same Z but different A and N

(D) isotopes have the same N but different A and Z

2. Choose correct statement(s) from following-

(A) The binding energy per nucleon decreases as atomic number increases

(B) Density of all nuclei is almost same

(C) Potential difference applied to an X-ray tube is of the order of hundred thousand volt

(D) The ratio of square of velocity and radius $\left(\frac{v^2}{r}\right)$ of an orbiting electron in hydrogen atom is independent of principal quantum number (n)

3. It has been found that nuclides with 2, 8, 20, 50, 82, and 126 protons or neutrons are exceptionally stable. These numbers are referred to as the magic numbers and their existence has led us to

(A) the idea of periodicity in nuclear properties similar to the periodicity of chemical elements in periodic table.

(B) the so-called 'liquid drop model of the nucleus'

(C) the so-called 'shell model of the nucleus'

(D) have a convenient explanation of 'nuclear fission'

Section B - Mass Defect, Binding Energy, Stability

4. Mark out the correct statements(s).

(A) Higher binding energy per nucleon means the nucleus is more stable.

(B) If the binding energy of nucleus were zero, then it would spontaneously break apart.

(C) Binding energy of a nucleus can be negative

(D) Binding energy of a nucleus is always positive.

5. Choose the correct statements from the following :

(A) Like other light nuclei, the $_2He^4$ nuclei also have a low value of the binding energy per nucleon.

(B) The binding energy per nucleon decreases for nuclei with small as well as large atomic number.

(C) The energy required to remove one neutron from $_3Li^7$ to transform it into the isotope $_3Li^6$ is 5.6 MeV, which is the same as the binding energy per nucleon of $_3Li^6$.

(D) When two deuterium nuclei fuse together, they give rise to a tritium nucleus accompanied by a release of energy.

6. The binding energy per nucleon of deuteron and helium atom is 1.1 MeV and 7 MeV respectively. If two deuteron atoms react to from a single helium then the energy released is (Which option is not correct) :

(A) 13.9 MeV

(B) 26.9 MeV

(C) 23.6 MeV

(D) 19.2 MeV

Section C - Radioactiving law

7. 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.

8. A radioactive sample has initial concentration No. of nuclei –

(A) the number of undecayed nuclei present in the sample decays exponentially with time.

(B) the activity (R) of the sample at any instant is directly proportional to the number of undecayed nuclei present in that sample at that time.

(C) the no. of decayed nuclei grows exponentially with time.

(D) the no. of decayed nuclei grow linearly with time.

Section D - α, β, γ DECAY, FISSION & FUSSION

9. A nitrogen nucleus $_7N^{14}$ absorbs a neutron and can transform into lithium nucleus $_3Li^7$ under suitable conditions, after emitting :

(A) 4 protons and 3 neutrons

(B) 5 protons and 1 negative beta particle

(C) 1 alpha particles and 2 beta positive particles

(D) 4 protons and 4 neutrons

10. The instability of the nucleus can be due to various causes. An unstable nucleus emits radiations if possible of 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

11. 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.

12. In an endoergic nuclear reaction an incoming particle collides with stationary nucleus -

(A) kinetic energy of incoming particle is greater than Q-value of reaction in ground frame

(B) kinetic energy of incoming particle is equal to the Q-value of reaction in center of mass frame

(C) linear momentum of particle-nucleus system is conserved

(D) energy is released in the process

Exercise - 3 | Level-I Subjective | JEE Advanced

Section A - Rutherford's Experiment, Nuclear Properties (Radius, Density, Isotopes etc.)

1. Find the density of ${}^{12}_{6}C$ nucleus in 10^{17} kg/m^3.

2. The nuclear radius of ${}^{16}_{8}O$ is 3×10^{-15} m. What is the nuclear radius of ${}^{205}_{82}Pb$?

3. β 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 = 1.2×10^{-12} MeV.m where h is the Plank's constant and C is the velocity of light in air]

4. When two deutrons (${}_1H^2$) 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 deutrim.

Section B - Mass Defect, Binding Energy, Stability

5. Calculate the mass of an α-particle. Its binding energy is 28.2 MeV.

6. Find the binding of ${}^{56}_{20}Fe$. Atomic mass of ${}^{56}Fe$ is 55.9349 u and that of ${}^{1}H$ is 1.00783 u. Mass of neutron = 1.00867 u.

7. Calculate the Q-value in the following decays :
(A) ${}^{19}O \rightarrow {}^{19}F + e + \bar{v}$
(B) ${}^{25}Al \rightarrow {}^{25}Mg + e^{+} + v$
The atomic masses needed are as follows:

${}^{19}O$	${}^{19}F$
19.003576 u	18.998403 u
${}^{25}Al$	${}^{25}Mg$
24.990432 u	24.985839 u

8. The binding energies per nucleon for deuteron (${}_1H^2$) and helium (${}_2He^4$) are 1.1 MeV and 7.0 MeV respectively. The energy released when two deuterons fuse to form a helium nucleus (${}_2He^4$) is ____________.

Section C - Radioactiving law

9. The activity of a radioactive sample falls from 600 s^{-1} to 500 s^{-1} in 40 minutes. Calculate its half-life.

10. The number of ${}^{238}U$ atoms in an ancient rock equals the number of ${}^{206}Pb$ atoms. The half-life of decay of ${}^{238}U$ is 4.5×10^9 y. Estimate the age of the rock assuming that all the ${}^{206}Pb$ atoms are formed from the decay of ${}^{238}U$.

11. An isotopes of Potassium ${}^{40}_{19}K$ has a half life of 1.4 $\times 10^9$ year and decays to Argon ${}^{40}_{18}Ar$ which is stable.
(i) Write down the nuclear reaction representing this decay.
(ii) A sample of rock taken from the moon contains both potassium and argon in the ratio 1/7. Find age of rock

12. 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.

Section D - α, β, γ DECAY, FISSION & FUSSION

13. ${}^{32}P$ beta-decays to ${}^{32}S$. Find the sum of the energy of the antineutrino and the kinetic energy of the β-particle. Neglect the recoil of the daughter nucleus. Atomic mass of ${}^{32}P$ = 31.974 u and that of ${}^{32}S$ = 31.972 u.

14. Potassium- 40 can decay in three modes. It can decay by β^--emission, β^+-emission or electron capture. (A) Write the equations showing the end products. (B) Find the Q-values in each of the three cases. Atomic masses of ${}^{40}_{18}Ar$, ${}^{40}_{19}K$ and ${}^{40}_{20}C$ are 39.9624 u, 39.9640 u and 39.9626 u respectively.

15. ${}^{228}Th$ emits an alpha particle to reduce to ${}^{224}Ra$. Calculate the kinetic energy of the alpha particle emitted in the following decay.
${}^{228}Th \rightarrow {}^{224}Ra^{*} + \alpha$
${}^{224}Ra^{*} \rightarrow {}^{224}Ra + \gamma(217\text{ keV})$.
Atomic mass of ${}^{228}Th$ is 228.028726 u, that of ${}^{224}Ra$ is 224.020196 u and that of ${}^{4}_{2}He$ is 4.00260 u.

16. Find the kinetic energy of the α-particle emitted in the decay ${}^{238}Pu \rightarrow {}^{234}U + \alpha$. The atomic masses needed are as follows:

${}^{238}Pu$	${}^{234}U$	${}^{4}H$
238.04955 u	234.04095 u	4.002603 u

Neglect any recoil of the residual nucleus.

Exercise - 3 | Level-II Subjective | JEE Advanced

Section A - Rutherford's Experiment, Nuclear Properties (Radius, Density, Isotopes etc.)

1. Show that in a nuclear reaction where the outgoing particle is scattered at an angle of 90° with the direction of the bombarding particle, the Q-value is expressed as

$$Q = K_P\left(1+\frac{m_P}{M_O}\right) - K_I\left(1+\frac{m_I}{M_O}\right)$$

Where, I = incoming particle, P = product nucleus, T = target nucleus, O = outgoing particle.

2. 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.

Section B - Mass Defect, Binding Energy, Stability

3. The kinetic energy of an α - 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 α-particle.

4. When thermal neutrons (negligible kinetic energy) are used to induce the reaction ;
${}^{10}_{5}B + {}^{1}_{0}H \rightarrow {}^{7}_{3}Li + {}^{4}_{2}He$ α – particles are emitted with an energy of 1.83 MeV.
Given the masses of boron neutron & He^4 as 10.01167, 1.00894 & 4.00386 u respectively. What is the mass of ${}^{7}_{3}Li$? Assume that particles are free to move after the collision.

Section C - Radioactiving law

5. A small bottle contains powdered beryllium Be & gaseous radon which is used as a source of α-particles. Neutrons are produced when α - particles of the radon react with beryllium. The yield of this reaction is (1/4000) i.e. only one α- particle out of 4000 induces the reaction. Find the amount of radon (Rn^{222}) originally introduced into the source, if it produces 1.2×10^6 neutrons per second after 7.6 days. [$T_{1/2}$ of R_n = 3.8 days]

6. 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.

Section D - α, β, γ DECAY, FISSION & FUSSION

7. 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)

8. An experiment is done to determine the half-life of radioactive substance that emits one β- particle for each decay process. Measurement show that an average of 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.

Exercise - 4 | Level-I Previous Year | JEE Main

1. A nuclear transformation is denoted by $X(n,\alpha) \rightarrow {}^{7}_{3}\text{Li}$. Which of the following is the nucleus of element X ? **(AIEEE 2005)**

(A) ${}^{12}_{6}\text{C}$ (B) ${}^{10}_{5}\text{B}$

(C) ${}^{9}_{5}\text{B}$ (D) ${}^{11}_{4}\text{Be}$

2. 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 **(AIEEE 2005)**

(A) 6 fermi (B) 8 fermi

(C) 4 fermi (D) 5 fermi

3. Starting with a sample of pure ${}^{66}\text{Cu}$, 7/8 of it decays into Zn in 15 min. The corresponding half-life is **(AIEEE 2005)**

(A) 10 min (B) 15 min

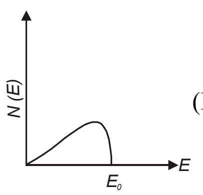
(C) 5 min (D) $7\frac{1}{2}$ min

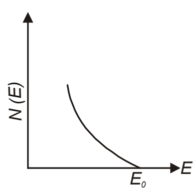
4. When ${}^{7}_{3}\text{Li}$ nuclei are bombarded by protons, and the resultant nuclei are ${}^{8}_{4}\text{Be}$, the emitted particles will be **(AIEEE 2006)**

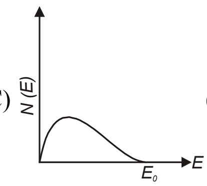
(A) alpha particles (B) beta particles

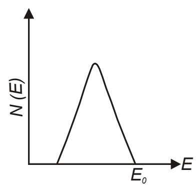
(C) gamma photons (D) neutrons

5. 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) 

6. If the binding energy per nucleon in ${}^{7}_{3}\text{Li}$ and ${}^{4}_{2}\text{He}$ nuclei are 5.60 MeV and 7.06 MeV respectively, then in the reaction $p + {}^{7}_{3}\text{Li} \rightarrow 2\,{}^{4}_{2}\text{He}$, energy of proton must be **(AIEEE 2006)**

(A) 28.24 Mev (B) 17.28 MeV

(C) 1.46 MeV (D) 39.2 MeV

7. An alpha nucleus of energy $\frac{1}{2}mv^2$ bombards a heavy nuclear target of charge Ze. Then the distance of closed approach for the alpha nucleus will be proportional to **(AIEEE 2006)**

(A) v^2 (B) $\frac{1}{m}$

(C) $\frac{1}{v^4}$ (D) $\frac{1}{Ze}$

8. Which of the following transitions in hydrogen atoms emit photons of highest frequency? **[JEE Mains 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

9. In gamma ray emission from a nucleus **(AIEEE 2007)**

(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

10. 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 **(AIEEE 2007)**

(A) $(M_0 - 8M_p)c^2$

(B) $(M_0 - 8M_p - 9M_n)c^2$

(C) M_0c^2

(D) $(M_0 - 17M_n)c^2$

11. 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 **(AIEEE 2007)**

(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

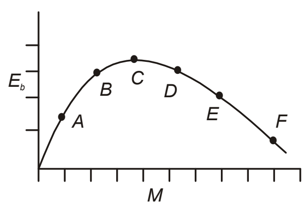
12. **Statement I** Energy is released when heavy nuclei undergo fission of light nuclei undergo fusion.

Statement II For heavy nuclei, binding energy per nucleon increases with increasing Z while for light nuclei it decrease with increasing Z. **(AIEEE 2008)**

(A) Statement I is true, Statement II is true; Statement II is not a correct explanation for Statement I.
(B) Statement I is true, Statement II is false.
(C) Statement I is false, Statement II is true.
(D) Statement I is true, Statement II is true; Statement II is a correct explanation for Statement I.

13. The above is 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 : **(AIEEE 2009)**

(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 ?

(A) (i) and (iv) (B) (i) and (iii)
(C) (ii) and (iv) (D) (ii) and (iii)

14. A radioactive nucleus (initial mass numer A and atomic number Z) emits 3α-particles and 2 positrons. The ratio of number of neutrons to that of protons in the final nucleus will be **(AIEEE 2010)**

(A) $\frac{A-Z-8}{Z-4}$ (B) $\frac{A-Z-4}{Z-8}$

(C) $\frac{A-Z-12}{Z-4}$ (D) $\frac{A-Z-4}{Z-2}$

Directions Question No. 15-16 are based on the following paragraph.

A nucleus of mass $M + \Delta m$ is at rest and decays into two daughter nuclei of equal mass M/2 each. Speed of light is C.

15. The binding energy per nucleon for the parent nucleus is E_1 and that for the daughter nuclei is E_2. Then **(AIEEE 2010)**

(A) $E_2 = 2E_1$ (B) $E_1 > E_2$

(C) $E_2 > E_1$ (D) $E_1 = 2E_2$

16. The speed of daughter nuclei is **(AIEEE 2010)**

(A) $c\frac{\Delta m}{M+\Delta m}$ (B) $c\sqrt{\frac{2\Delta m}{M}}$

(C) $c\sqrt{\frac{\Delta m}{M}}$ (D) $c\sqrt{\frac{\Delta m}{M+\Delta m}}$

17. The half-life of a radioactive substance is 20 min. The approximate time interval $(t_2 - t_1)$ between the time t_2 when 2/3 of it had decayed and time t_1 when 1/3 of it had decayed is **(AIEEE 2011)**

(A) 14 min (B) 20 min
(C) 28 min (D) 7 min

18. **Statement I** 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 II To conserve energy and momentum in β-decay at least three particles must take part in the transformation. **(AIEEE 2011)**
(A) Statement I is false, Statement II is true
(B) Statement I is true, Statement II is false
(C) Statement I is true, Statement II is true; Statement II is the correct explanation of Statement I
(D) Statement I is true, Statement II is true; Statement II is not the correct explanation of Statement I

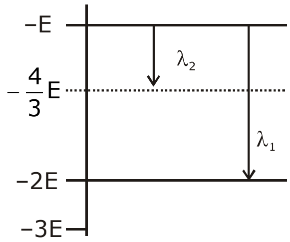
19. Assume that a neutron breaks into a proton and an electron. The energy released during this process is (mass of neutron = 1.6725×10^{-27} kg, mass of proton = 1.6725×10^{-27} kg, mass of electron = 9×10^{-31} kg) **[JEE Main 2012]**
(A) 0.73 MeV (B) 7.10 MeV
(C) 6.30 MeV (D) 5.4 MeV

20. If a simple pendulum has significant amplitude (upto a factor of 1/e of original) only in the period between t = 0 s to t= τs, then τ may be called the average life of the pendulum. When the spherical bob of the pendulum suffers a retardation (due to viscous drag) proportional to its velocity with b as the constant of proportionality, the average life time of the pendulum is (assuming damping is small) in seconds **(AIEEE 2012)**
(A) $\frac{0.693}{b}$ (B) b
(C) $\frac{1}{b}$ (D) $\frac{2}{b}$

21. 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 : **(JEE Main 2016)**
(A) 4 : 1 (B) 1 : 4
(C) 5 : 4 (D) 1 : 16

22. 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 : **(JEE Main 2017)**
(A) $t = \frac{T}{\log(1.3)}$ (B) $t = \frac{T}{2}\frac{\log 2}{\log 1.3}$
(C) $t = T\frac{\log 1.3}{\log 2}$ (D) $t = T \log(1.3)$

23. Some energy levels of a molecule are shown in the figure. The ratio of the wavelengths $r = \lambda_1/\lambda_2$ is given by - **(JEE Main 2017)**



(A) $r = \frac{1}{3}$ (B) $r = \frac{4}{3}$
(C) $r = \frac{2}{3}$ (D) $r = \frac{3}{4}$

24. It is found that if a neutron suffers an elastic collinear collision with deuterium at rest, fractional loss of its energy is P_d; While for its similar collision with carbon nucleus at rest, fractional loss of energy is P_c. The values of P_d and P_c are respectively : **(JEE Main 2018)**
(A) (0,1) (B) (0.89, 0.28)
(C) (0.28, 0.89) (D) (0,0)

Exercise - 4 | Level-II   Previous Year | JEE Advanced

1. Helium nuclie combines to form an oxygen nucleus. The binding energy per nucleon of oxygen nucleus is if $m_0 = 15.834$ amu and $m_{He} = 4.0026$ amu

(A) 10.24 MeV (B) 0 Me V

(C) 5.24 MeV (D) 4 Me V

[JEE 2005]

2. In Young's double slit experiment an electron beam is used to form a fringe pattern instead of light. If speed of the electrons is increased then the fringe width will : **[JEE' 2005 (Scr)]**

(A) increase (B) decrease

(C) remains same

(D) no fringe pattern will be formed

3. Given a sample of Radium - 226 having half-life of 4 days. Find the probability, a nucleus disintegrates within 2 half lives. **[JEE 2006]**

(A) 1 (B) 1/2

(C) 3/4 (D) 1/4

4. Match the following Columns

[JEE 2006]

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

5. In the options given below, let E denote the rest mass energy of a nucleus and *n* a neutron. The correct option is **[JEE 2007]**

(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) $E\left({}^{236}_{92}U\right) = E\left({}^{140}_{56}Ba\right) + E\left({}^{94}_{36}Kr\right) + 2E(n)$

6. Half–life of a radioactive substance A is 4 days. The probability that a nucleus will decay in two half–lives is

[JEE Advanced 2006]

(A) $\frac{1}{4}$ (B) $\frac{3}{4}$

(C) $\frac{1}{2}$ (D) 1

7. 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]

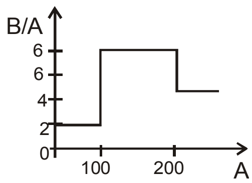
(A) 802 nm (B) 823 nm

(C) 1882 nm (D) 1648 nm

8. 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

9. Assume that the nuclear binding energy per nucleon (B/A) versus mass number (A) is as shown in the figure. Use **[JEE 2008]**



this plot to choose the correct choice(s) given below.

Figure

(A) Fusion of two nuclei with mass numbers lying in the range $1 < A < 50$ 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.

10. A radioactive sample S1 having an activity 5μCi twice the number of nuclei as another sample S2 which as an activity of 10 μC. 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

Paragraph for Questions 11 to 13

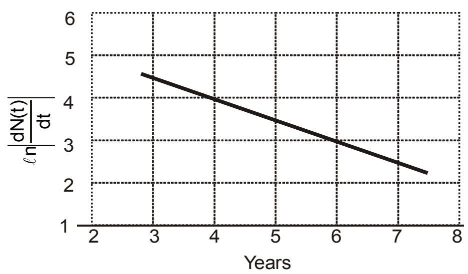
Scientists are working hard to develop nuclear fusion reactor. Nuclei of heavy hydrogen, ${}_1^2H$, known as deuteron and denoted by D, can be thought of as a candidate for fusion reactor. The $D - D$ reaction is ${}_1^2H + {}_1^2H \rightarrow {}_2^3He$ + n energy. In the core of fusion reactor, a gas 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 ; $\frac{e^2}{4\pi\varepsilon_0} = 1.44 \times 10^{-9}$ eVm **[JEE 2009]**

11. In the core of nuclear fusion reactor, the gas becomes plasma because of
(A) strong nuclear force acting between the deuterons
(B) Coulomb force acting between the deuterons
(C) Coulomb force acting between deuteronelectron pairs
(D) the high temperature maintained inside the reactor core

12. 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) 1.0×10^9 K $< T < 2.0 \times 10^9$ K
(B) 2.0×10^9 K $< T < 3.0 \times 10^9$ K
(C) 3.0×10^9 K $< T < 4.0 \times 10^9$ K
(D) 4.0×10^9 K $< T < 5.0 \times 10^9$ K

13. 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 $= 5.0 \times 10^{-3}$ s
(B) deuteron density $= 8.0 \times 10^{14}$ cm^{-3}, confinement time $= 9.0 \times 10^{-1}$ s
(C) deuteron density $= 4.0 \times 10^{23}$ cm^{-3}, confinement time $= 1.0 \times 10^{-11}$ s
(D) deuteron density $= 1.0 \times 10^{24}$ cm^{-3}, confinement time $= 4.0 \times 10^{-12}$ s

14.



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]

15. 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]**

Paragraph for Question 16 and 18

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. $n \rightarrow p + e^- + \bar{v}_e$, around 1930, Pauli explained the observed electron energy spectrum. Assuming the anti-neutrino $(\bar{v}_e)$ 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 x 10^6 eV. The kinetic energy carried by the proton is only the recoil energy.

16. What is the maximum energy of the anti-neutrino?

(A) Zero

(B) Much less than 0.8 x 10^6 eV.

(C) Nearly 0.8 x 10^6 eV.

(D) Much larger than 0.8 x 10^6 eV.

17. 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) $3.0\,eV \le K \le 0.8 \times 10^6 eV$

(C) $3.0\,eV \le K < 0.8 \times 10^6 eV$

(D) $0 \le K < 0.8 \times 10^6 eV$

18. A freshly prepared sample of a radioisotope of half-life 1386 s has activity 10^3 distintegrations per second. Given that ln 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 2013]

Paragraph for Question 19 and 20

The mass of 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 differerce 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 :

${}^{1}_{1}H$	1.007825 u	${}^{2}_{1}H$	2.014102 u	${}^{3}_{1}H$	3.016050 u	${}^{4}_{2}He$	4.002603 u
${}^{6}_{3}Li$	6.015123 u	${}^{7}_{3}Li$	7.016004 u	${}^{70}_{30}Zn$	69.925325 u	${}^{82}_{34}Se$	81.916709 u
${}^{152}_{64}Gd$	151.919803u	${}^{206}_{82}Pb$	205.974455u	${}^{209}_{83}Bi$	208.980388u	${}^{210}_{84}Po$	209.982876u

19. 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.

[JEE 2013]

20. The kinetic energy (in keV) of the alpha particle, when the nucleus ${}^{210}_{84}Po$ at rest undergoes alpha decay, is :

[JEE 2013]

(A) 5319 (B) 5422

(C) 5707 (D) 5818

21. 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 2013]**

List I	List II
(P) Alpha decay	**1.** ${}^{15}_{8}O \to {}^{15}_{7}N + ...$
(Q) β^+decay	**2.** ${}^{238}_{92}U \to {}^{234}_{90}Th + ...$
(R) Fission	**3.** ${}^{185}_{83}Bi \to {}^{184}_{82}Pb + ...$
(S) Proton emission	**4.** ${}^{239}_{94}Pu \to {}^{140}_{57}La + ...$

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

22. The electrostatic energy of Z protons uniformly distributed throughout a spherical nucleus of radius R is given by $E = \frac{3}{5}\frac{Z(Z-1)e^2}{4\pi\varepsilon_0 R}$

The measured masses of the neutron, ${}^{1}_{1}H$, , ${}^{15}_{7}N$ and ${}^{15}_{8}O$ are 1.008665 u, 1.007825 u, 15.000109 u and 15.003065 u, respectively. Given that the radii of both the ${}^{15}_{7}N$ and ${}^{15}_{8}O$ nuclei are same, 1 u = 931.5 MeV/c^2 (c is the speed of light) and $e^2/(4\pi\varepsilon_0)$ = 1.44 MeV fm. Assuming that the difference between the binding energies of ${}^{15}_{7}N$ and ${}^{15}_{8}O$ is purely due to the electrostatic energy, the radius of either of the nuclei is (1 fm = 10^{-15}m) **[JEE–Advanced 2016]**

(A) 2.85 fm (B) 3.03 fm
(C) 3.42 fm (D) 3.80 fm

23. An accident in a nuclear laboratory resulted in depostion 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–Advanced 2016]**

(A) 64 (B) 90
(C) 108 (D) 120

24. The isotope ${}^{12}_{5}B$ having a mass 12.014u undergoues β - decay to ${}^{12}_{6}C, {}^{12}_{6}C$ has an excited state of the nucleus (${}^{12}_{6}C^*$) at 4.041 MeV above its ground state. If ${}^{12}_{5}B$ decays to ${}^{12}_{6}C^*$, 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–Advanced 2016]**

25. ${}^{131}I$ 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 In $2 \approx 0.7$). **[JEE–Advanced 2017]**

26. In a radioactive decay chain, ${}^{232}_{90}Th$ nucleus decays to ${}^{212}_{82}Pb$ 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 ? **[JEE–Advanced 2018]**

(A) $N_\alpha = 5$ (B) $N_\alpha = 6$
(C) $N_\beta = 2$ (D) $N_\beta = 4$

ANSWER KEYS

Exercise - 1 — Objective Problems | JEE Main

1.	A	2.	A	3.	B	4.	B	5.	B	6.	C	7.	B
8.	C	9.	B	10.	C	11.	A	12.	D	13.	B	14.	A
15.	C	16.	C	17.	B	18.	D	19.	B	20.	D	21.	B
22.	C	23.	A	24.	C								

Exercise - 2 (Level-I) — Objective Problems | JEE Main

1.	A	2.	A	3.	C	4.	A	5.	C	6.	B	7.	A
8.	A	9.	D	10.	C	11.	C	12.	B	13.	A		

Exercise - 2 (Level-II) — Multiple Correct | JEE Advanced

1.	B,C,D	2.	B,C	3.	A,C	4.	A,B,D	5.	B,C
6.	A,B,D	7.	A,B,D	8.	A,B,C	9.	C,D	10.	A,C,D
11.	A,B,C	12.	ABC						

Exercise - 3 | Level-I — Subjective | JEE Advanced

1. 2 2. 7.02 fermi 3. 2.48×10^{-12} m 4. 28 MeV

5. 4.0016 u 6. 492 MeV 7. (A) 4.816 MeV (B) 3.254 MeV

8. 23.6 MeV 9. 152 min. 10. 4.5×10^{10} y old

11. (i) $^{40}_{19}K \to ^{40}_{18}Ar + _{+1}e^0 + \nu$, (ii) 4.2×10^9 years 12. $t = \left(\frac{\ln 5}{\ln 2}\right)\tau$ 13. 1.86 MeV

14. (A) $^{40}_{19}K \to ^{40}_{20}Ca + e^- + \bar{\nu}$, $^{40}_{19}K \to ^{40}_{18}Ar + e^+ + \nu$, $^{40}_{19}K + e^- \to ^{40}_{18}Ar + \nu$
(B) 1.3034 MeV, 0.4676 MeV, 1.490 MeV

15. 5.304 MeV 16. 5.58 MeV

Exercise - 3 | Level-II — Subjective | JEE Advanced

2. v = ult 3. 4.87 Mev 4. 7.01366 amu 5. 3.3×10^{-6} g

6. $\Delta T = \dfrac{0.2E_0\left[\alpha t - \frac{\alpha}{\lambda}(1 - e^{-\lambda t})\right]}{mS}$ 7. 6.04×10^9 yrs 8. 1.7×10^{10} years

Exercise - 4 | Level-I — Previous Year | JEE Main

1.	B	2.	A	3.	C	4.	C	5.	C	6.	B	7.	B
8.	C	9.	B	10.	B	11.	B	12.	B	13.	A	14.	B
15.	C	16.	B	17.	B	18.	C	19.	A	20.	D	21.	C
22.	C	23.	A	24.	B								

Exercise - 4 | Level-II — Previous Year | JEE Advanced

1. A 2. B 3. C 4. (A) P,Q ; (B) P,R ; (C) S,P ; (D) P,Q,R

5. A 6. B 7. B 8. (A) R, P ; (B) Q, S ; (C) P ; (D) Q

9.	B,D	10.	A	11.	D	12.	A	13.	B	14.	8	15.	1
16.	C	17.	D	18.	4	19.	C	20.	A	21.	C	22.	C
23.	C	24.	9	25.	5	26.	AC						

CHAPTER 3

Semi Conductor & Logic Gates

PN JUNCTION

1. ENERGY BANDS IN SOLIDS

(i) Overlapped energy levels are termed as energy bands

(ii) The energy band formed by teh overlapping of valency electrons is known as volency energy band.

(iii) The energy band formed by the overlapping of conduction electrons is known as conduction energy band.

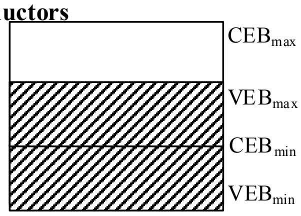
(iv) Electrical conduction in solid can take place only when electron remains present in its conduction energy band.

(v) The minimum energy required for excitting an electrond from valency energy band to conduction energy band is known as forbidden energy gap (ΔEg)

$$\Delta Eg = CEB_{min} - VEB_{max}$$

2. TYPES OF SOLID MATERIALS ON THE BASIS OF FORBIDDEN ENERGY GAP

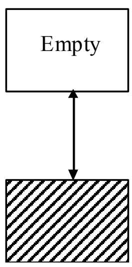
2.1 Conductors



Those solid substances in which forbidden energy gap is zero are known as conductors

2.2 Insulators

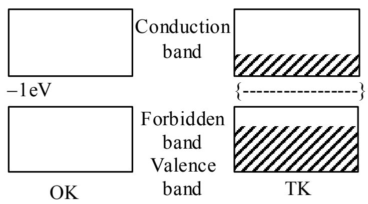
These are solids in which the energy band formation occurs in such a manner, that valence band is completely filled while the conduction band is completely empty. Furthermore the valence band and the conduction band are separated by a large forbidden energy gap $\Delta Eg \geq 6eV$.



The energy band in diamond is shown is Fig. There occurs a forbidden band of width 6 eV between conduction and valence band. No electron can have energy corresponding to the forbidden band. Thus an electron needs at least 6eV to reach the empty conduction band. Such an energy can not be supplied by heat or electric fields that are generally used in laboratories. Therefore diamond is an **insulator.**

2.3 Semiconductors

These are solids in which the forbidden energy gap between the valence band an dthe conduction band is small, of the order of 1eV . At 0 kelvin temperature, the valence band is completely filled and the conduction band is completely empty. At OK, it behaves lie an insulator (electron can not absorb infinitesimal energy because there is a forbidden gap just above the top of the valence band).



At a finitude temperature, (room temperature), some electrons gain energy due to thermal motion and jump from the tope of the valence band to the conduction band. These electrons contribute to the conductions to the conduction of electricity in a semiconductor. The forbidden gap in semiconductor is small ~ 1eV. At finite temperature, some balance electron goes to conduction band. Then the formlessly is in the middle of the gap

The energy gap is some semiconductors is as follows :

E_g (Silicon) = 1.12 eV

E_g (Germanium) = 0.7 eV

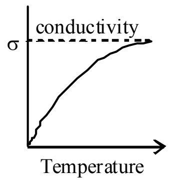
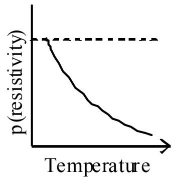
E_g (Indium antimonide) 0.17 eV

E_g (Gallium arsenide) = 1.43 eV

E_g (Tellurium) = 0.33 eV

The energy gap decreases slightly with increases in temperature.

3. COMPARISON BETWEEN CONDUCTORS, INSULATORS AND SEMICONDUCTORS

S.No.	Conductors	Insulators	Semiconductors
1.	Valence band is partially filled or valence band andconduction band overlap	Completely empty conduction band separated from completely filled valence	At OK, the conductive band is empty while valence band is full Separated by small energy gap
2.	There is no forbidden energy gap	The forbidden gap is large Eg (diamond) ~ 6 eV Eg (diamond) ~ 6 eV	Separated by small energy gap Eg (si)
3.	At room temperature , all electrons remains in the partially , filled valence band or over lapped band	At room temperatue, electrons do not get sufficient thermal energy to cross over the forbidden energy band remains empty	At room temperature, may electrons have sufficient energy to go to conduction band. (see Fig 46)
4.	Conducts electric current. Very small resistivity ρ (ohm. meter) ρ (Cu) = 1.7×10^{-8} Ω m ρ (Ag) = 1.6×10^{-8} Ωm The conductively is high σ 10^7 to 10^8 ohm/m (or siemen /m)	Does not conduct electric current (negligible conduction) Very large resistively (ohm meter) ρ (glass) ~ $10^{11} - 10^{12}$ Ωm ρ (diamond) ~ 10^{14} Ω m Very low conductivity $\sigma \sim 10^{-10}$ to 10^{-14} Ωm Verylow conductivity $\sigma \sim 10^{-10}$ to 10^{-15} ohm /m (or siemen/m)	May conduct electric current but conducton is small. Medium resistivity and medium conductivity ρ (Si) = 2100 Ωm ρ (Ge) = 0.47 Ωm σ (Ge) ~ 2.13 σ (Si) ~ 4.7×10^{-4} (ohm/m).
5.	Only electrons are the current carriers Number of free electrons (in Cu) ~ 10^{28} per m	No current carriers (the electric conduction is almost zero for all practical purposes, see σ mentioned before)	Both electrons and holes contribute to current conduction. Numner of free electrons (at room temperature) is in Ge ~ 10^{19} per m^3 in Si ~ 10^{16} per m^3
6.	Conductivity decreases with temperature.	Conductivity negligibly small however increases slightly at very high temperatures 	Conductivily increases with temperature (the resistivity/ resistance decreases with temperature).  The temperature coefficient of a semiconductor is negative

4. COMMENT : BAND STRUCTURE AND OPTICAL PROPERTIES

The optical properties of a solid are closely related with their energy band structure. The photons of visible light have energies between about 1eV and 3 eV , as sin the case of insulators like mica, diamond, then visible light from valence band can not go to conduction band. The such solids are transparent to visible light. In case of semiconductors, since band gap is ~ 1 eV , the visible light is readily absorbed and these are usually opaque, to visible light,. Infrared photons have energies less than 1eV and therefore infrared light is not absorbed by Si or Ge. The metals are usually opaque, because electrons in the partially filled band can readily absorbs visible light photon without leaving the valence band. The ultraviolet photons energies are large and if they are more than the Eg of insulators, then those insulators will absorb UV radiation. Thus some special glasses are although transparent for visible light are opaque for UV light.

5. Types of Semiconductors

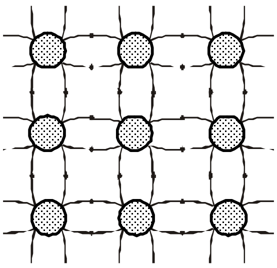
The semiconductor are of two type

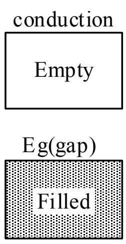
(1) A semiconductor in a pure form is called intrinsic semiconductor. The imputity must be less than 0.01 ppm (parts per million), i.e., less than 1 in 10^8 parts of semiconductor. At low temperature, the electrons are present in valence bonds of the semiconductor.As the tem perature is increased a few electrons are raised to conduction bond .

- In intrinsic semiconductors:-

$$n_e^{(0)} = n_n^{(0)} = n_i = AT^{3/2} e^{-\Delta Eg/2KT}$$

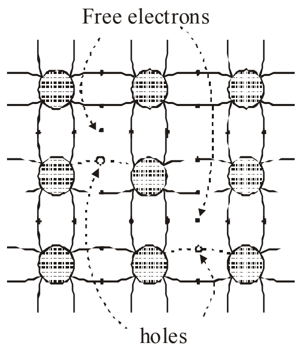
Where $n_e^{(0)}$ is electron density in conduction band, $n_e^{(0)}$ is hole density in valance band and n_i is the density of intrinsic carriers.

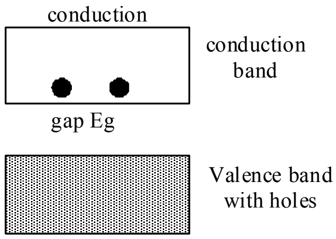




At absolute zero all the valence electrons are tightly bound and no free electron is available for electrical condition. In the band picture, at absolute zero temperature. The conduction band is completely empty while, the the valence band **a perfect insulator at absolute zero.**

At room temperature (~ 300K), some of the electrons may gain sufficient thermal energy and move away from the influence of the nucleus, i.e., the covalent bond may be broken. The electron, so obtained is free to move in the crystal and conduct electricity (see Fig). The vacancy created in the covalent bond is called a **hole.**





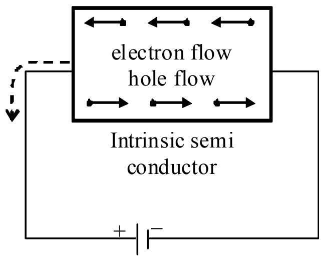
When a covalent band is broken, the electron hole pair is created.Thus in intrinsic semiconductor

Number of holes = number of free electrons

$n_h = n_e$

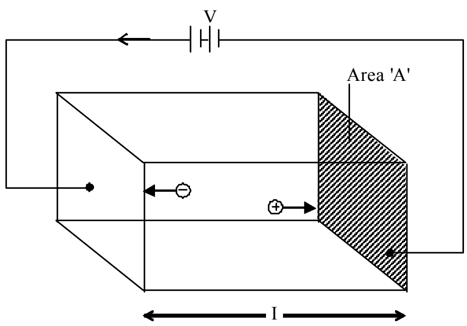
6. CONDUCTION IN INTRINSIC SEMICONDUCTORS

In intrinsic semiconductor , the number of free electrons and holes are equal. Both electrons and holes contribute in current conduction. For the purpose of flow of current , a hole , behaves like a positively charged particle having some



effective mass. Therefore while the electron moves from negative electrode a of the battery to the positive electrode though the semiconductor, the hole moves in opposite side. The holes exist only inside a semiconductor. There are no holes in a metal. There , electric conduction through holes takes place inside the semiconductor only. Outside, in the metal wires, the electric current flow is due to electrons only. (In cell current flow is due to the motion of positive and negative ions).

In an instrinsic semiconductor the current flow occurs due to the motion of both, the electrons and the holes,. Let e = magnitude of charge on the electrons, n_h= number density of holes, μ_e = mobility of electrons an μ_b = mobility of



holes, then the conductivity of intrinsic semiconductor is $\sigma = e\ (n_e\mu_e + n_h\ \mu_h)$ onsider a block of semiconductor of length ℓ, area of cross section A and having density of electron and holes as n_e and n_h respecitively when a potential difference say V is applied across it, current I flows through it as shown in fig. The current I is made of electron current I_e and hople current I_h.

Thus, $I = I_e + I_h$ .....(i)

If v_e is drift velocity of electrons,

then $I_e = en_e Av_e$ .....(ii)

Similarly , the hole current is given by

$I_h = en_e\ Av_h$ .....(iii)

Using equations (ii) and (iii), the equation (i) becomes

$I = eA\ (n_e v_e + n_h v_h)$ .....(iv)

if R is the resistance offered by the simiconductor to the flow of current, then

$I = \frac{V}{R}$ or $\frac{V}{R} = eA\ (n_e v_e + n_h v_h)$ .....(v)

The electric field set up across the semiconductor is given by

$E = \frac{V}{\ell}$ or $V = E\ell$

Therefore, equation (v) becomes

$$\frac{E\ell}{R} = eA\ (n_e v_e + n_h v_h)$$

or $$\frac{E\ell}{R\frac{A}{\ell}} = e\ (n_e v_e + n_h v_h)$$

But $R\frac{A}{\ell} = \rho$ = resistivity of the material of semiconductor

Therefore, $\frac{E}{\rho} = e\ (n_e n_e + n_h v_h)$ .....(vi)

Mobnility of electrons or holes is defined as the frigt velocity acquired per unit electric field. Therefore, mobility of electrons and holes is given by

$$\mu_e = \frac{v_e}{E} \quad \text{and} \quad \mu_h = \frac{v_h}{E}$$

From equation (vi) ,we have

$$\frac{1}{\rho} = e\left\{n_e.\frac{ve}{E} + n_h.\frac{v_h}{E}\right\}$$

or $\sigma = e\ (n_e\ \mu_e + n_h\ \mu_h)$ ....(vii)

where $\sigma = \frac{1}{\rho}$ is called conductivity of the material of semiconductor and μ_e and μ_h are electron and hole mobilities respectively.

Comment

(i) In pure semiconductors, at any temperature t, the carrier concentration $n_e = n_h = n$ and the conductivity σ is determined by the value of E_g (width of the forbidden band) (see relations given above).

(ii) In metal , however , the value of n is almost the same at different temperatures. The resistance arises due to interaction of free (conduction) electrons with the lattice vibrations (see, chapter 3, 3-5 also).

(iii) At absolute zero, n = 0, σ = 0 i.e., the pure semiconductor behaves like a perfect insulator.

However, as temperature increases both n and s increses.In germanium at T 300 K, $n_e = n_h = 2.5 \times 10^{19}$ per m^3.The higher is the temperature , higher is the conductivity and lower is the resistivity.

(iv) The temperature coefficient of the resistance of a semiconductor is negative .

(v) Pure semiconductors are of little use (may be used as heat or light sensitive resistance).

7. EXTRINSIC SEMICONDUCTORS

A semiconductor in which impurities have been added in a controlled manner is called extrinsic semiconductor . The process of deliberately adding impurities to a semiconductor is called doping. The impurity atoms are either from V group (such as arsinic (as), antimony (Sb), phosphorus (P) etc. or from III group (such as Aluminium (AI) , gallium (Ga) , indium (In) etc. There are two types of extrinsic semiconductors,

(i) N-type (extrinsic) semiconductor and

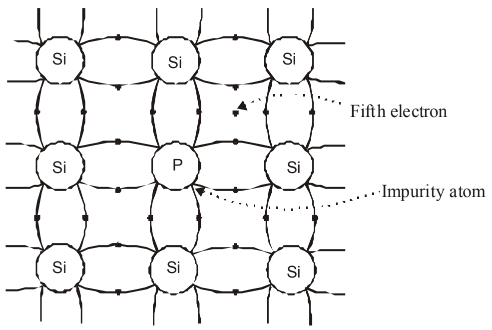
(ii) P-type (extrinsic) semiconductor.

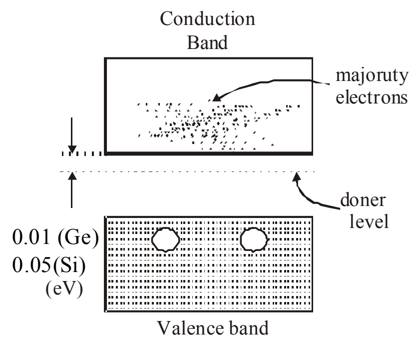
The conductivity of extrinsic semiconductor is controlled by the amont of doping, I part of a donor impurityper 10^9 parts of germanium increases its conductivity by a factor of neraly10^3.

The compounds of trivalent and penta valent elements also behave like semiconductors, (indium antimonide), In P, GaP.

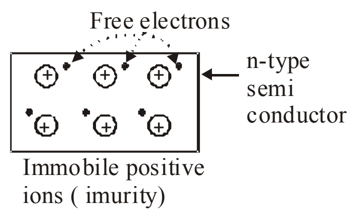
7.1 N-Type Semiconductor

N- Type (n- type) semiconductor is obtained by adding a small amount of pentavent (V group) impurity to a sample of intrinsic semiconductor. The pentavalent impurities are P (phophorus Z + 15), As (Z = 3), Sb (Z = 51), Bi (Z = 83).



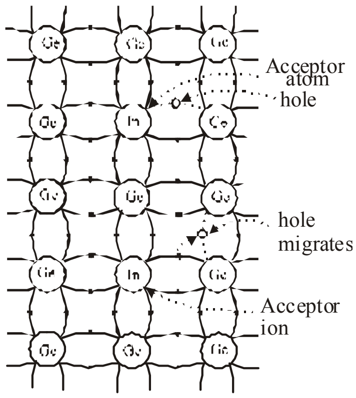


In the energy band pricture we say that impurity atoms, produce donor energy levels just below the conduction band . Ther electrons from these levels jump to the conduction band easily by gaining thermal energies (at room temperature). There may also break some covalent bonds producing electron hole paire, but their number is small. So in this type of extrinisc semiconductor, there are a large number of free electrons (donated by impurity atoms) and a negligible number of holes from cavalent cond breaking.

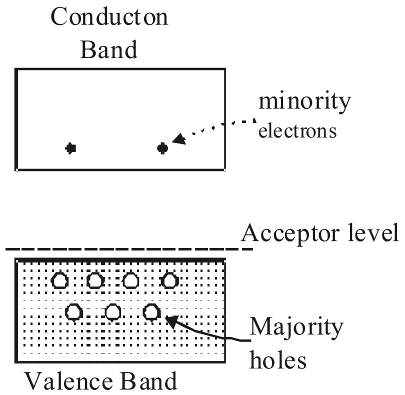


The impurity atom on donating electrons becomes positive ions. However the over all charge on the semiconductor is zero. The negative charge of the immobile positive charge of the immobile positive ions. The majority charge carriers are electrons (negative charge) . Therefore, this type of extrinsic semiconductor is called n - type. The Fermi level does not lie in the middle of band gap, but it shifts towards the conduction band. The few hole s formed by covalent bond breaking are called minority charrge carriers. The conductivity of th n-type semiconductors is controoled by the amoutn of impurity atoms added in it. Since

7.2 P-Type Semiconductor



P-type (pype) semiconductor is obtained by adding a small amount of trivalent (III groupe) impurity to intrinsic semiconductor. The impurities may be Boron (Z = 5), AI (Z = 13, Ga (Z – 31) In (Z = 49), TI (Z = 81). For each acceptor ion there exist a hole in this type of semiconductor, there are a large number of holes present. The majority charge carriers are holes. Therefore it is called a p-type semicondutor.

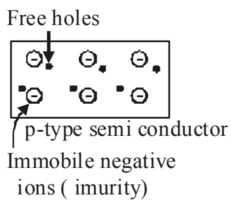


In the band picture, we say that acceptor energy levels lie just above the valence band. These levels accepts electrons from the valence band and creates holes. The breaking of covalent bonds may create electron-hole pairs but their number is very little. The majority carriers are holes. The minority carriers are electron. The conduction takes place mainly through the motion of holes

$$n_h >> n_e$$

$$\sigma_p \approx e\mu_h n_h$$

The overall charge on p-type semiconductor is zero. It is represented as shown in Fig. The positive charge of free



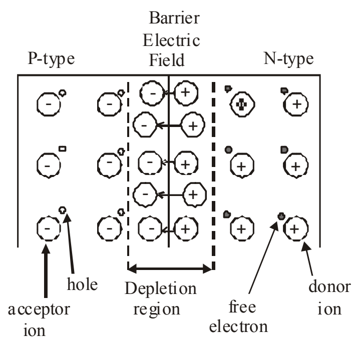
holes is balanced by the negative charge of immobile impurity ions.

COMMENT

When temprature is increased, covalent bonds break. This increases minority charge carriers. At very high temperature, it may happen that electron-hole numbers obtained from bond breaking, far excceds the cahrge carrirers from impurities . Then the semiconductor behaves like intrinsic semiconductor. The critical temperature at which this happens is 85°C for germanium and 200°C for silicon.

8. PN JUNCTION

When a piece of p-type material and piece of n-type matrial are joined in such a manner that cyrstal structure remains continuous at the boundary, then a pn junction is formed. It



is also called a pn junction (PN junction) diode. A PN junction can not be made by simply pushing the two pieces together as it would not lead to a single crystal structure .There are special fabricaton techniques to form a PN junction. Immediately after a PN junction is formed, the following process are initiated :

(i) The negative ions on P-sides and positive ions on N-sides are immobile.The majority holes from P region diffuse into N region, and the majority electrons from N region diffuse into P region.

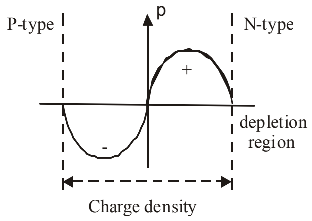
(ii) Due to the above, the electrons and holes at the juction region recombine and disappear (i.e., cavalent bonds are completed).

(iii) As a result, a layer of negative ions on P-side and a layer of positive ions on N-side is formed at the junction. In this region, due to recombination of electrons and holes, depletion of free charge carriers occurs. So this region is called depletion region. The charge density on the two sides of the junction (due to ion layers) is shown in Fig.

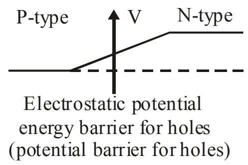
(iv) The uncompensated ion layers in the depletion region generates an electric field in this region. The electric field points from N side to P side. This electric field prevents further tdiffusion of holes from P-sides. It also prevents further diffusion of electrons from the N side to P side . The electric field is called barrier electric field.

(v) The barrier electric field gives rise to a difference of potentail from one side to the other side. This is called barrier potential (or potential barrier). For silicon PN junction the barrier potential is about 0.7 V while for germanium PN junction, it is about 0.3V.

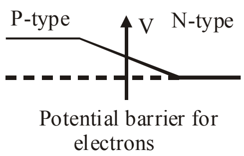
(A)



(B)



(C)



(vi) For holes the potential on the N-sides is higher . Holes can not cross the deplection region because of this barrier potential . Fig 60 (B). For electrons the potential barrier is shown in Fig. 60(C)

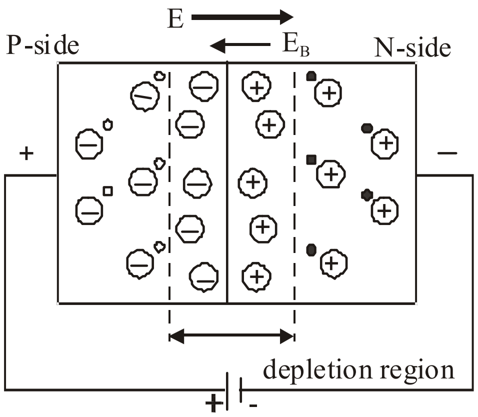
(vii) On the average the potential barrier height in PN junction is ~ 0.5 V and the width of the depletion region ~1 μm or 10–6 m. The barrier electric field is thus

$$E = \frac{V}{d} = \frac{0.5}{10^{-6}}$$

$$= 5 \times 10^{5} \text{ volt /m}$$

9. PN JUNCTION WITH FORWARD BIAS

(i) When the positive terminal of a battery is connected to the P-side and the negative terminal to the N-side of a PN-junction, then it is said to be forward biased (Fig).



(ii) The holes are repelled from the positive terminal and compelled to move towards the junction. The electrons are also repelled from the negative terminal and move towards the junction . This **reduces the depletion region** for a forward biased PN-junction

(iii) **The potential barrier is reduced . More charge carries diffuse across the junction.**

(iv) In the P-type material, near the positive terminal , an electron breaks the covalent bond and goes to battery. As a result a hole is created in P-sides . At the same time an electron enters the N-sides from the negative terminal. The currrent in the P - region airses due to flow of the holes while the currrent in the N-regioon is due to electrons.

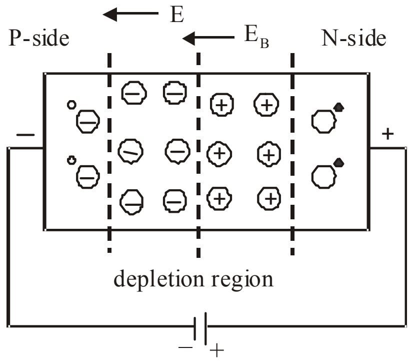
(v) The electric field at the barrier, due to the battery is from P side to N side (forward bias). This is in opposition to the barrier electric field.

(vi) If battery potential is increased, the potential barrier is further reduced. More majority carriers diffuse across the junction. The current increases

10. PN JUNCTION WITH REVERSE BIAS

(i) When the positive terminal of a battery is connected to the N-side and the negative termanl is connected to the P-side of thePN junction , then it is said to be reverse biased.

(ii) The holes in the P-region are attracted towards the negative terminal and the electrons in the N-region are attracted twowards the positive termanl . Thus the majority carriers move away from the juction. The depletion region increases for a reverse biased PN- junction,



(iii) The barrier potential increases, This makes it more difficult for the majority carriers to diffuse across the junction .

(iv) A very little current called reverse saturation current flows due to minority carrier flow.It is of the order of nanoamperes (10^{-9}A)for silicon and microamperes (10^{-6} A) for germanium PN -diodes.

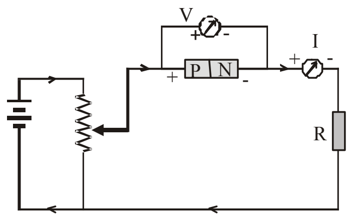
(v) In reverse bias situation , the junction behaves like a highresistivity material sanwiched in between two regions.

(vi) The effective capacitance of PN junction in the reverse bias condition is of the order of few pico farads.

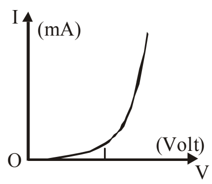
11. PN JUNCTION DIODE CHARACTERISTICS

Forward bias characteristics

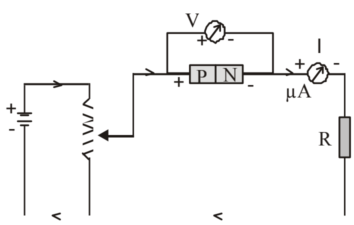
The circuit diagram for studying the V-I characteristics of a PN junction diode in forward bias is shown in Fig. In forward bias the depletion region decreases, the barrier potentail decreases, and current folws due to diffusion of charge carriers across the junction. Majority holes from P side cross over to N side, and majority electrons from N side cross over to P side, The current voltage chracteristics is shown in Fig.



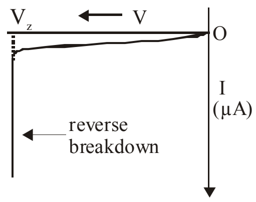
The diode current is negligibly small for first few tenths of a volt. The reason is that the diode does not conduct will till the external voltageV, overcomes the barrier potential . The voltage at which the current starts to increse repidly is called cut-in or Knee voltage (V_o) of the diode. For a silicon diode V_o ~7volt and for germanium V_o junction diode in reverse bias is shown in Fig.



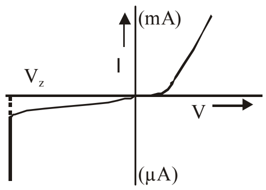
In reverse bias state, the depletion region increases and potential barrier also increases. The majority holes in P region and majority electrons in N region , now do not cross the junction . They donot give rise to any current.



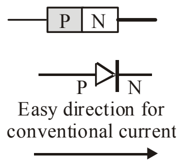
In reverse bias a very smal current flows. This arises due to the flow of minority charge carriers across the junction . The reverse current is only few μ A for germanium diodes and only a few nA for silicon diodes. It remains small and almost constant for all reverse bias voltages less than the break down voltage V_Z. At breakdown, the current increses rapidly for small increase in voltage



The full charactaristics, forward and reverse bias are shown in Fig. The PN junction diode thus is a unidirectional device. Large current (mA) flows in one direction, but neglible current flows in the reverse direction. The symbol used for PN junction diode is shown in Fig.



The equation for diode current is



$$I = I_o \left(e^{eV/kT} - 1 \right)$$

Where I_o is called saturation current, V is positive for forward and negative for reverse bias, k is Boltzmann constant, T is temperature and e = 1.6 $\times 10^{-19}$ C.

12. REVERSE BREAK DOWN

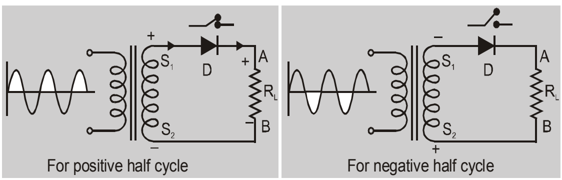
If the reverse bias voltage is made too high, the current through the PN junction increases rapidly at V_Z(seefig). The voltage at which this happens is called **breakdown voltage** or **Zener voltage.** There two mechnism which causes this breakdown. One is called avalanche breakdown **Zener breakdown** and the other is called avalanche 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 miniority 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.**

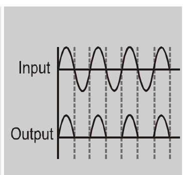
Avalanche break down:- The covalent bonds where the junction break down liberating a large number of electron hole pairs.Then the reverse current increases abruptly to high value .This is called avalanche break down and may damage the junction.This phenomenon is used to Zener diode and used in voltage regulator.

13. RECTIFIER

It is device which is used for converting alternating current into direct current.

13.1 Half wave rectifier

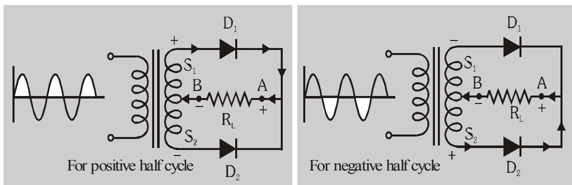


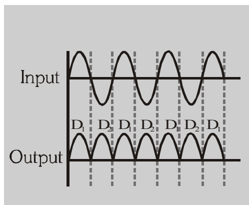


During the first half (positive) of the input signal. Let S_1 is at positive and S_2 is at negative potential. So, the PN junction diode D is forward biased. The current flows through the load resistance R_L and output voltage is obtained. During the second half (negative) of the input signal, S_1 and 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.

13.2 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.

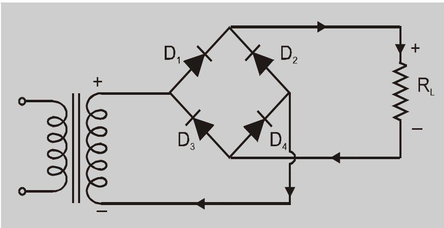
In this case diode D_1 is forward biased and D_2 is reverse biased. So only D_1 conducts and hence the flow of current in the load resistance R_L is from A to B.

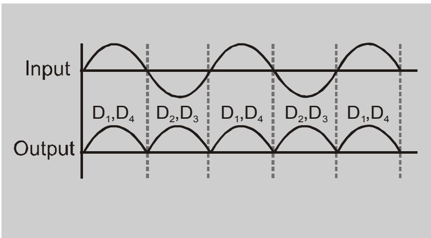
During the negative half of the input signal :

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.

13.3 Bridge Rectifier





During positive half cycle

D_1 and D_4 are foward biased $\rightarrow$ on switch

D_2 and D_3 are reverse biased $\rightarrow$ off switch

During negative half cycle

D_2 and D_3 are foward biased $\rightarrow$ on switch

D_1 and D_4 are reverse biased $\rightarrow$ off switch

Form Factor

$$F = \frac{I_{rms}}{I_{dc}} \quad \text{or} \quad \frac{E_{rms}}{E_{dc}}$$

for full wave rectifier $F = \dfrac{\pi}{2\sqrt{2}}$

for half wave rectifier $F = \dfrac{\pi}{2}$

Ripple and ripple factor

In the output of rectifier A.C. & D.C. components are present. They are called ripple & there ratio is called ripple factor. For good rectifier ripple factor must be very low.

Total output current

$$I_{rms} = \sqrt{I^2_{ac} + I^2_{dc}}$$

I_{ac} = rms value of AC component

Ripple factor $\quad r = \dfrac{I_{ac}}{I_{dc}} \quad r \quad r = \sqrt{\dfrac{I^2_{rms}}{I^2_{dc}} - 1}$

$= \sqrt{F^2 - 1}$

1. For half wave rectifier

$$I_{rms} = \frac{I_0}{2}, \qquad I_{dc} = \frac{I_0}{\pi} \quad r = 1.21$$

2. For full wave or bridge wave rectifier

$$I_{rms} = \frac{I_0}{\sqrt{2}}, \qquad I_{dc} = \frac{2I_0}{\pi} \qquad r = 0.48$$

Rectifier efficiency

$$\eta\% = \frac{P_{dc}}{P_{ac}} = \frac{I^2_{dc}\ R_L}{I^2_{rms}\ (R_F + R_L)} \times 100$$

Half wave rectifier

$$\eta = 40.6\left(\frac{R_L}{R_L + R_f}\right)\% \text{ if } \frac{R_f}{R_L} << 1$$

$\eta = 40.6\%$

Special Note If $R_f = R_L$

$\eta = 20.3\%$

Full wave rectifier or bridge wave rectifier

$$\eta = 81.2 \times \frac{R_L}{R_L + R_f}\% \qquad \text{If } \frac{R_f}{R_L} << 1$$

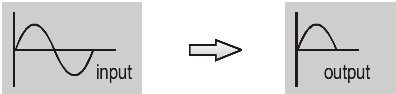
$\eta = 81.2\%$

If $R_f = R_L$

$\eta = 40.6\%$

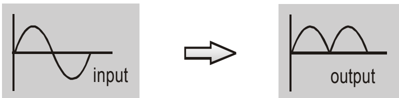
Ripple Frequency : Output frequency of rectifier known as ripple frequency $f_{out} = f_{ripple}$

(i) For half wave rectifier



input frequency = 50Hz ripple frequency = 50Hz

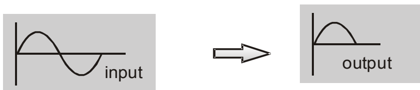
(ii) for full wave rectifier



input frequency = 50Hz ripple frequency = 100Hz

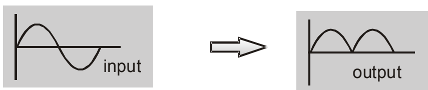
Pulse

(i) For half wave rectifier



number of pulse = 2 number of pulse = 1

(ii) For full wave rectifier



number of pulse = 2 number of pulse = 2

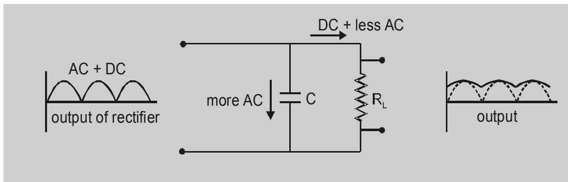
Comparison Between Rectifiers

	Half-wave	**Centre-tap**	**Bridge**
Number of Diodes	1	2	4
Transformer necessary	No	Yes	No
Peak secondary voltage	V_m	V_m	V_m
Peak load Current, I_m	$\frac{V_{in}}{r_d + R_L}$	$\frac{V_{in}}{r_d + R_L}$	$\frac{V_{in}}{2r_d + R_L}$
RMS Current, I_{rms}	$\frac{I_m}{2}$	$\frac{I_m}{\sqrt{2}}$	$\frac{I_m}{\sqrt{2}}$
DC current, I_{dc}	$\frac{I_m}{\pi}$	$\frac{2\,I_m}{\pi}$	$\frac{2\,I_m}{\pi}$
Ripple factor, r	1.21	0.482	0.482
Rectification efficiency (max)	40.6%	81.2%	81.2%
Lowest ripple frequency, f_r	f_i	$2f_i$	$2f_i$

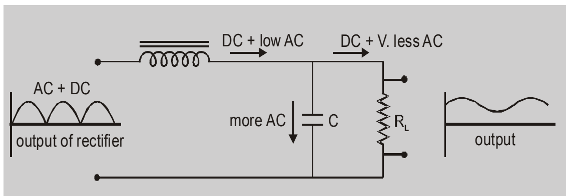
13.4 FILTER CIRCUIT

To reduce A.C. Components

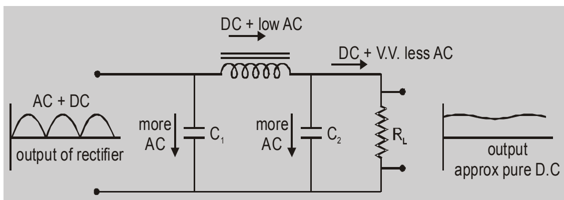
Capacitor Filter



L - C Filter



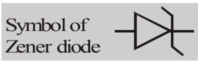
π - Filter (Best Filter)



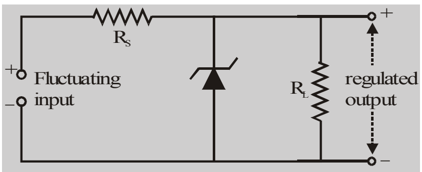
13.5 SOME SPECIAL DIODES

(i) ZENER DIODE

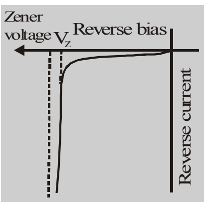
A properly doped crystal diode which has sharp break down voltage is known as Zener diode.



It is always connected in reverse biased condition manner. Used as a voltage regulation

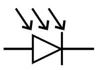


In forward biased it works as a simple diode.



(ii) Photodiode

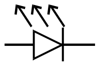
A junction diode made from "light or photo sensitive semiconductor" is called a "photo diode"

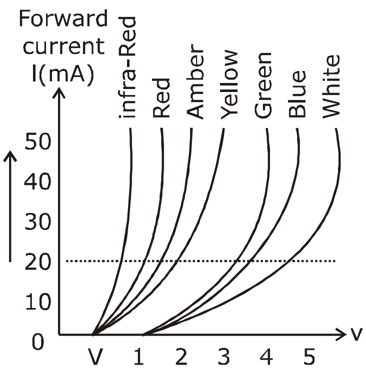
its symbol . When light of energy "hν" falls on the photodiode (Here hν > energy gap) more electrons move from valence band, to conduction band, due to this current in circuit of photodiode in **"Reverse bias"**, increases. As light intensity is increased, the current goes on increases so photo diode is used, **"to detect light intensity"** for example it is used in "Vedio camera".

(iii) Light emitting diode (L.E.D)

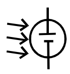
When a junction diode is **"forward biased"** energy is released at junction in the form of light due to recombination of electrons and holes. In case of Si or Ge diodes, the energy released is in infra-red region.

In the junction diode made of GaAs, InP etc energy is released in visible region such a junction diode is called "light emitting diode" (LED) Its symbol





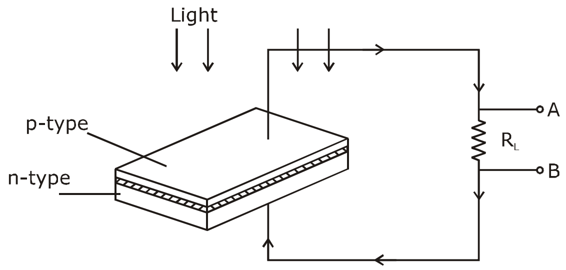
(iv) Solar cell

Solar cell is a device for converting solar energy into electrical. A junction diode in which one of the P or N sections is made very thin (So that the light energy falling on diode is not greatly asorbed before reaching the junction) can be used to convert light energy into electric energy such diode called as solar cell. Its symbol 

(i) It is operated into photo voltaic mode i.e., generation of voltage due to the bombardment of optical photon.

(ii) **No external bias is applied.**

(iii) Active junction area is kept large, because we are intrested in more power. Materials most commonly used for solar cell is Si, As, Cds, CdTe, CdSe, etc.



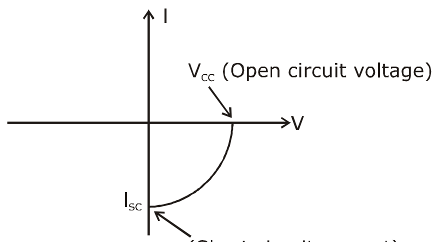


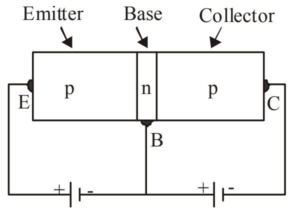
Fig. : I-V characteristics of solar cell

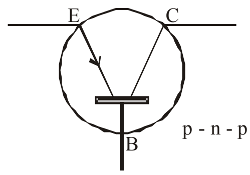
14. TRANSISTOR

A transistor is an electronic device formed by p and n type of semiconductor which is used in place of a triode valve. It was discovered in 1948 by American scientists Bardeen, shockley and Barattain. Transistors are of two types: p-n-p transistor and n-p-n transistor.

14.1 p-n-p Transistor :

It consists of a very thin slice of n-type semiconductor sandwiched between two small crystals of p-type semiconductor (fig). The central slice is called the 'base' while the left and right crystals are called the 'emitter' and the 'collector' respectively. The emitter is given a positive potential negative potential with respect to the base. Thus , the emitter -base (p-n) junction on the left is under forward-bias (high resistance). The symbol for this transistor is shown in Fig. 12(b) in which the direction of the arrow indicates the direction of current (direction of flow of holes).

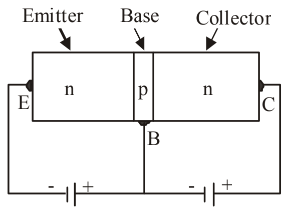




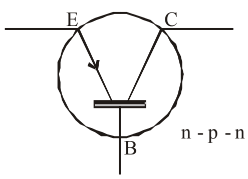
14.2 n-p-n Transistor :

It consists of a very thin slice of p-type semiconductor (fig). In this transistor the meter is given a negative potential while the collector is given a positive potential with respect to the base. Again, the emitter -base (n-p) junction on the left is under forward-bias, while the base collector (p-n) junction on the right is denser reverse- bias. *The symbol for the n-p-n transistor is shown in Fig. (b) in which the direction of the arrow indicates the direction of current (opposite of the direction of flow of electrons).

(a)



(b)

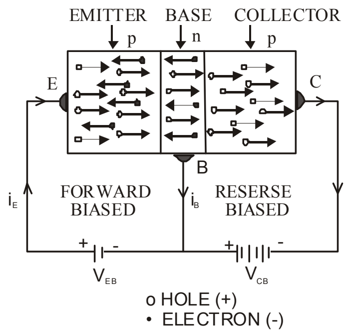


A transistor can be connected in a circuit in three difference ways. They are :

(i) common-base configuration, (ii) common-emitter configuration and (iii) common-collector configuration. The work 'common' is related with that electrode which is common in input and output circuits. This common electrode is generally grounded. Hence the above three configurations of connection are also called respectively as grounded -base configuration, grounded-emitter configuration of connection are also called configuration . Each configuration has its own characteristics.

14.3 Working of p-n-p Transistor

A 'common-base ' circuit of a p-n-p transistor is shown in Fig. 14. The emitter- base (p-n) junction on the left is given a small forward bias (fraction of a volt) while the base-collector (n-p) junction is given a large reverse-bias (a few volts).



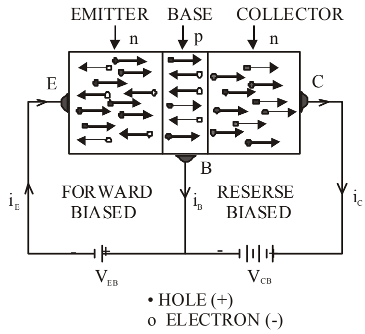
Holes are the charge-carriers with in the p-n-p transistor, while electrons are the charge-carriers in the external circuit. The small current which leaves the base terminal B is called the 'i_B 'base-current' the larger current which leaves the collector terminal is called the 'collector -current ' i_C.Both these currents combine to enter the emitter terminal E and constitute the emitter-current i_E. Clearly,

$$i_E = I_B + i_C$$

The base being very thin, the number of hole-electron combinations in it is very small, and almost all the holes entering the base from the emitter reach the collector. Hence the collector-current i_C is only very slightly less than the emitter current i_E.

14.4 Working of n-p-n Transistor

A circuit known as 'common-base' circuit of n-p-n transistor is shown in Fig. The two n-regions contain the mobile electrons while the central thin p-region contains the mobile (positive) holes. The emitter-base by means of a battery V_{EB}, while the base-collector (p-n)junction on the right has been given a large reverse-bias by means of battery V_{CB}.



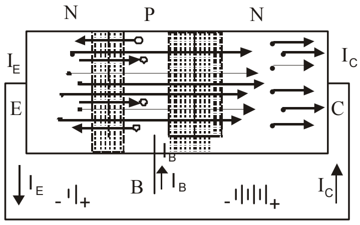
The electrons are the charge-carriers with in the n-p-n transistor as will as in the external circuit (whereas hole sate the charge-carriers with in p-n-p transistor). The small current entering the base terminal B is the base current i_B, while the larger current entering that collector terminal C is the collector-current i_C. Both currents combine to leave the emitter terminal E and constitute the emitter current i_E. Thus

$$i_E = i_B + i_C$$

14.5 TRANSISTOR ACTION

There are four possible ways of biasing the two PN junctions (emitter junction and collectro junction) of a transistor .These are tabulated below.

Emitter junction bias	**Collector junction bias**	**Transistor operation**
Forward	Reverse	Active
Forward	Forward	Saturation
Reverse	Reverse	Cut off
Reverse	Forward	inverted



$I_E = I_C + I_B$
$I_B << I_C$, and
$I_B << I_E$

Thus I_C is always less than I_E, but the difference is small. Since the emitter junction is forward biased its resistance is small, while the collectro jucntion is reverse biased, therefore its resistance is large. Thus , a transistor is a device which transfers I_E current from low resistance circuit to a high resistance circuit ($I_C \sim I_E$). Thus it is, transfer + resistor = transistor

(The name transistor originated from the above action of the transistor).

14.6 CHARACTERISTIC OF TRANSISTOR

To study about the characterstics of transistor we have to make a circuit [i.e. $J_{EB} \rightarrow$ Forward bias and $J_{CB} \rightarrow$ Reverse bias] we need four terminals. But the transistor have three terminals. By keeping one of the terminal of transistor is common in input and output both. So the transistor is connected in three ways in circuit.

(i) Common base connector

(ii) Common emitter

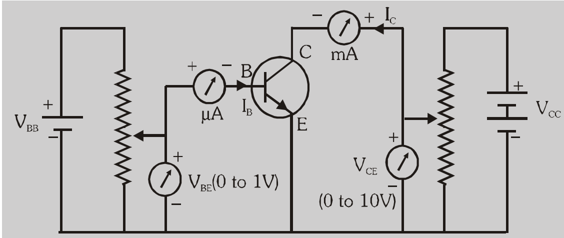
(iii) Common collector

In these three common emitter is widely used and common collector is rarely used.

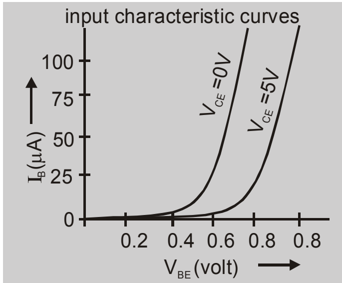
Common emitter characterstics of a transistor

(i) 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.



Circuit diagram for characteristics curves of n-p-n transistor (CE)



(i) Keep the collector-emitter voltage (V_{CE}) constant (say V_{CE} = 1V)

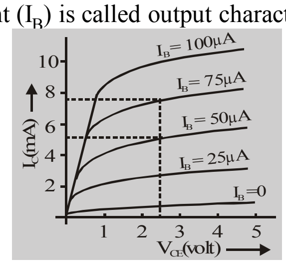
(ii) Now change emitter base voltage by R_1 and note the corresponding value of base current (I_B).

(iii) Plot the graph between V_{EB} and I_B.

(iv) A set of such curves can be plotted at different V_{CE} (say V_{CE} = 2V)

(ii) 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 = 10μA)

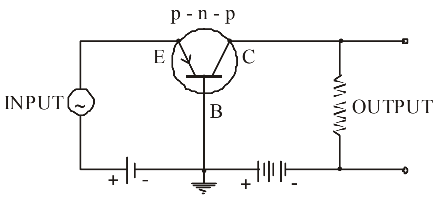
(ii) Now change the collector-emitter voltage (V_{CE}) using variable resistance R_2 and note the corresponding values of collector current (I_C).

(iii) Plot the graph between (V_{CE} versus I_C)

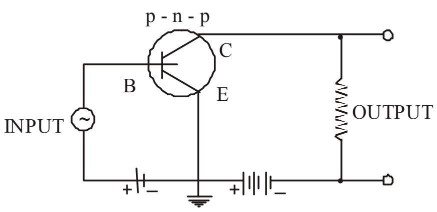
(iv) A set of such curves can be plotted at different fixed values of base current (say 0, 20 μA, 30 μA etc.)

15. TRANSISTOR CONFIGURATION AND ITS USE AS AN AMPLIFIER

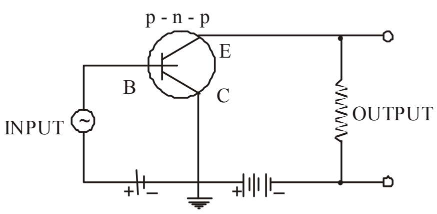
A junction diode cannot amplify a signal. A transistor consisting of two p-n junctions, one forward-biased and the other reverse-biased ,can , however , be used for amplifying a weak signal The forward-biased junction has a low-resistance path whereas the reverse-biased junction has a high-resistances path. The weak input signal is applied across the forward-biased (low resistance) junction and the output currents are signal is taken appears with a much higher voltage. The transistor thus acts as an amplifier



(a) COMMON-BASE



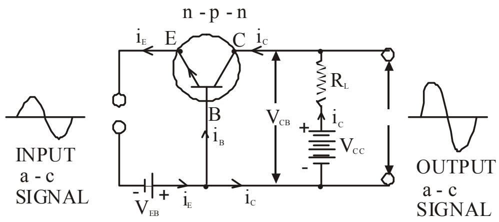
(b) COMMON-EMITTER



(b) COMMON-COLLECTOR

When a transistor is to be operated as amplifier, three different basic circuit connection are possible, as illustrated inFig. These are (a) common-base (b) common emitter and (c) common-collector circuits.

15.1 Transistor as Common-Base Amplifier



Common-Base Amplifier using an n-p-n Transistor :

Fig. shows the common-base amplifier circuit using an n-p-n transistor. The base is made common to the input and the output circuits. The emitter-base input circuit is forward-biased by a low-voltage battery V_{EB} so that the resistance of the input circuit is small . The collector -base output circuit is reverse-biased by means of a high-voltage battery VCC so the at the resistance of the output circuit is quite large. R_L is a load resistance connected in the collector-base circuit. The weak input a-c voltage signal is applied across the emitter-base circuit and the amplified output signal is obtained across the collector-base circuit. Let i_E , i_B and i_C be the emitter -current and collector-current irrespectively when no a-c voltage signal is applied to the input circuit. (The arrows represent the direction of hole current, that is conventional current which is opposite to the direction of electron current). By Kirchhoff's first law, we have

$$i_E = i_B + i_C \qquad .....(1)$$

Due to the collector- current i_C, the voltage drop across R_L is $i_C R_L$. Therefore, the collector-to- base voltage (potential difference between collector and base)V_{CB} would be given by

$$V_{CB} = V_{CC} - i_C R_L \qquad .....(2)$$

When the input a-c voltage signal is applied across the emitter-base circuit, it changes the emitter-base voltage and hence the emitter-current i_E which, in turn , changes the collector current i_C.

Consequently , the collector to base voltage V_{CB} varies in accordance with equation (2) . This variation in V_{CB} , when the input signal is applied, appears as an amplified output.

Phase Relationship between Input and Output voltage Signals in CB circuit :

The output voltage signal is in phase with the input voltage signal in the common -base amplifier.

15.2 Gains in Common-Base Amplifier :

The various gains in a common-base amplifier are as follow:

(i) **a-c Current Gain :** It is defined as the ratio of the change i the colllector-current to the change in the emitter-current at a constant collector-to-base voltage, and is denoted by α. Thus

$$\alpha\ (a-c)\left(\frac{\Delta i_C}{\Delta i_E}\right)_{V_{CB}}$$

The value of α is slightly less than 1 (actually, there is a little current loss).

(ii) **a - c Voltage Gain:** It is defined as the ratio of the changes in the output voltage to thechange in the input voltage , and is denoted by A_V .

Suppose, on applying an a-c input voltage signal, the emitter current changes by Δi_C and correspondingly the collector-current changes by Δi_C . If R_{in} and R_{out} be the resistances of the input and the output circuits respectively, then

$$A_V = \frac{\Delta i_C \times R_{out}}{\Delta i_E \times R_{in}} = \frac{\Delta i_C}{\Delta i_E} \times \frac{R_{out}}{R_{in}}$$

Now , $\Delta i_C / \Delta i_E$ is the a-c current-gain and R_{out} / R_{in} is called the 'resistance gain'.

$\because A_V = \alpha \times$ resistance gain

Since the resistance gain is quite high, A_V is also quite high although α is slightly less than 1.

(iii) **a-c Power Gain:** it is defined as the ratio of the change in the output power to the change in the input power. Since power = current x voltage, we have

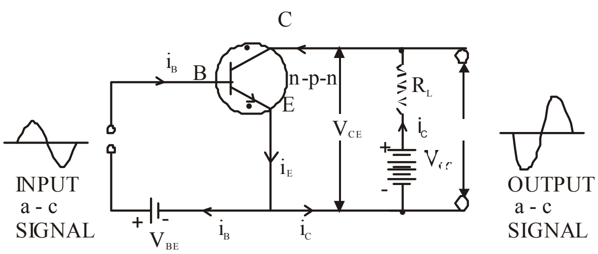
a-c power gain = a-c current gain $\times$ a-c voltage-gain

$= \alpha^2 \times$ resistance gain

15.3 Transistor as Common-Emitter Amplifier :

Common-Emitter Amplifier using an n-p-n Transistor: Fig.shows the common-emitter amplifier circuit using an n-p-n transistor. The emitter is made common to the input and the output circuits.

The input (base-emitter) circuit is forward-biased by a low-voltage battery V_{BE} so theat the resistance of the input circuit is small. The output (collector-emitter) circuit is reverse-biased by means of a high voltage battery V_{CC} so that the resistanc eof the outputcircuit is high. R_L is a load resistanc econnected in the collector-emitter output circuit. The weak input a-c signal is applied across the base-emitter circuit and the camplified output signal is obtained across the collector -emitter circuit.



Let i_E, i_B and i_C be the emitter-current, base-current and collector- current respecitively when no a-c voltage signal is applied to the input curcuit. (The arrows represent the direction of the hole current, that is conventional current which is opposite to the direction of electron current.) By Kirchhoff's first law, we have

$$i_E = i_B + i_C =$$

Due to the collector current i_C (Which is only slightly smaller that i_E), the voltage drop across R_L is i_C R_L. Therefore , the collector -to -emitter voltage (potential between collector and emitter) V_{CE} would be given by

$$V_{CE} = V_{CC} - i_C R_L$$

When the input a-c voltage signal is applied across the base-emitter circuit, it changes the base-emitter voltage and hence the emitter -current i_E which, in turn , changes the collector current iC. Consequently, the collector-to-emitter voltage V_{CE} varies in accordance with equation. (ii). This variation in V_{CE} , when the input signal is applied , appears as an amplidied output.

15.4 Phase Relationship between Input an Output Voltage Signals :

In a common-emitter amplifier the input voltage signal and the output voltage signal obtained across the collector and the emitter are out of phase with each other.

The output voltage signal is 180° out of phase with the input voltage signal in the common-emitter amplifier.

15.5 GAINS IN COMMON-EMITTERAMPLIFIER

The various gains in a common-emitter amplifier are as follows:

(i) d-c Current Gains: it is defined as the ratio of the collector current to the base current, and is denoted by β (d-c) . Thus

$$\beta\ (d\text{-}c) = \frac{i_C}{i_B}$$

In a typical transistor , a small base- current (10μA) produces a large collector -current (500μA). Thus

$$\beta\ (d\text{-}c) = \frac{500}{10} = 50$$

(ii) a-c Current Gain: It is defined as the ratio of the change in the collector -current to the change in the in the base -current at a constant collector to emitter voltage , and is denoted by β (a-c) . Thus

$$\beta\ (a\text{-}c) = \left(\frac{\Delta i_C}{\Delta i_B}\right)_{V_{CE}}$$

(iii) Voltage gain : Suppose , on applying an a-c input voltage signal, the input base-current changes by Δi_B and correspondingly the output collector-current changes by Δi_C. If R_{in} and R_{out} be the resistance of the input an dthe output circuits respectively , then

$$A_V = \frac{\Delta i_C \times R_{out}}{\Delta i_B \times R_{in}} = \frac{\Delta i_C}{\Delta i_B} \times \frac{R_{out}}{R_{in}}$$

Now, $\Delta i_C/\Delta i_B$ is the a-c current gain (a-c) and R_{out} / R_{in} is the resistance gain

∴ A_V= β (a-c) × resistance gain.

Since β (a-c) >> α (a-c), the a-c voltage gain in common-emitter amplifier is larger compared to that is common -base amplifier., although the resistance gain is smaller .

From equation (i) and (ii), it follows that

$A_V = g_m \times R_{out}$

(iv) a-c Power Gain : It is defined as the ratio of the change in the output power to the change in the input power.

Since power = current × voltage , we have

a-c power gain = a-c current gain × a-c voltage gain

= β (a-c) × A_V

= β (a -c) × { β (a-c) x resistance gain}

= β^2 (a-c) × resistance gain.

Since β (a-c) >> α (a-c) , the a-c power gain in common-emitter amplifier is extremely large compared to that in common-base amplifier.

15.6 RELATION BETWEEN α AND β

CB current gain (α)

CB current gain (α) is the ratio of output current to the input current in common base configuration of a transistor.

$$\alpha_{dc} = \frac{I_C}{I_E}$$

$$\alpha_{ac} = \frac{\Delta I_C}{\Delta I_E}$$

CE current gain (β)

CE current gain (β) is the ratio of the output current to the input current in emitter cofiguration of the transistor.

$$\beta_{dc} = \frac{I_C}{I_B}$$

$$\beta_{ac} = \frac{\Delta I_C}{\Delta I_B}$$

The CB current gain α and CE current gain β are related by the rollowing relations.

$$\frac{1}{\alpha} = 1 + \frac{1}{\beta}$$

$$\alpha = \frac{\beta}{\beta+1}$$

$$\beta = \frac{\alpha}{1-\alpha}$$

The above relations are applicable for both dc and ac current gains.

Comment. The value or α is always less than 1. α ~ 0.9 to 0.99 or more. The value of β is always much greater than 1.β ~ 95 to 999 or so.

16. POINT TO REMEMBER

(1) The electrical conductivity in materials is on account of these free electrons.

(2) In semiconductors the number of free electrons is less than that in conductors but more than that in insulators.

(3) Diode can be used as rectifier, modulator, detector.

(4) Voltage gain = $A_V = A_R.A_i$

(5) Energy gap for Ge and Si are respectively 0.7 eV and 1.1 eV.

(6) Holes contribute to current flow.

(7) In Junction diode P-part behaves like a plate and N-part behaves like a cathode.

(8) On account of current in diode being unidirectional , it is also known as a valve.

(9) Fermi energy depends on the nature of the material.

(10) The number of electrons emitted by an emitter depends more on work-function than on temperature.

(11) The work function of cathode decreases by mixing impurity in it.

(12) **Common-base configuration**

(i) Current amplification factor α_c

= Rate of $\alpha = 0.95 - 0.99$

(ii) Voltage amplification factor = α

R_L = load resistance, R_i = Input resistance

(iii) Power amplification factor = current amplification x voltage amp. factor = α^2

(13) **Common - emitter configuration**

(i) Current amplification factor = β, Range of β = 50 to 200

(ii) Voltage amplification = βR_L

(iii) Power application = $\beta^2 R_L$

Logic Gates

INTRODUCTION

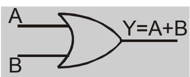
- A logic gate is a digital circuit which is based on certain logical relationship between the input and the output voltages of the circuit.
- The logic gates are built using the semiconductor P-N junction diodes and transistors.
- Each logic gate is represented by its characteristic symbol.
- The operation 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



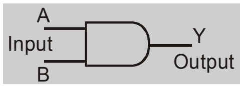
The **Boolean expression** of OR gate is Y = A+B, read as Y equals A ORing B.

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

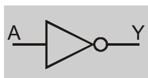
It is read as Y equals ANDing B

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

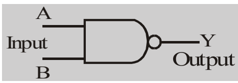
'NOT gate have only one input'

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



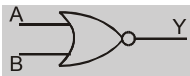
The **Boolean expression** of NAND gate is $Y = \overline{A.B}$

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 $Y = \overline{A + B}$

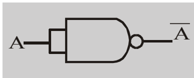
Truth table of a NOR gate

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.

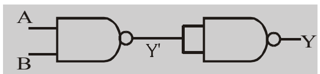
- **The NOT gate from a NAND gate :-** When all the inputs of a NAND gate are connected together, as shown in the figure, we obtain a NOT gate



Truth table of a single input NAND gate

A	B=(A)	Y
0	0	1
1	1	0

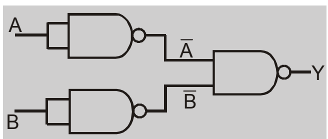
- **The AND gate from a NAND gates :-** If a NAND gate is followed by a NOT gate (i.e., a single input NAND gate), the resulting circuit is an AND gate as shown in figure and truth table given show how an AND gate has been obtained from NAND gates.



Truth table

A	B	Y'	Y
0	0	1	0
0	1	1	0
1	0	1	0
1	1	0	1

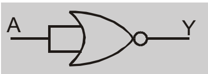
- **The OR gate from NAND gates :-** If we invert the inputs A and B and then apply them to the NAND gate, the resulting circuit is an OR gate.



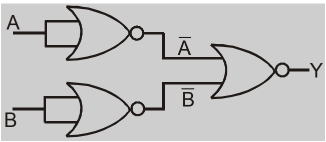
Truth table

A	B	$\bar{A}$	$\bar{B}$	Y
0	0	1	1	0
0	1	1	0	1
1	0	0	1	1
1	1	0	0	1

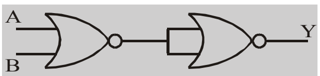
- **The NOT gate from NOR gates :-** When all the inputs of a NOR gate are connected together as shown in the figure, we obtain a NOT gate



- **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.



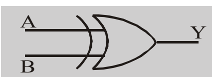
- **The OR gate from NOR gate :-** If a NOR gate is followed by a single input NOR gate (NOT gate), the resulting circuit is an OR gate.



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



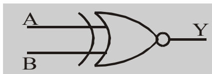
The **Boolean expression** of XOR gate is $Y = A.\bar{B} + \bar{A}.B$ or $Y = A \oplus B$

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

$Y = A.B + \bar{A}.\bar{B}$ 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

Laws of Boolean Algebra

Basic OR, AND, and NOT operations are given below :

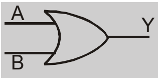
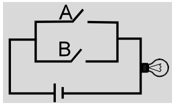
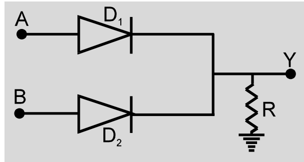
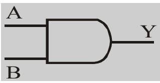
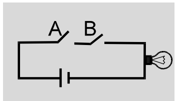
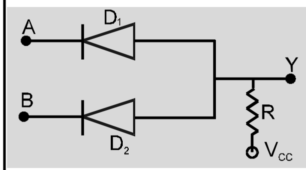
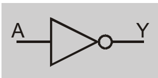
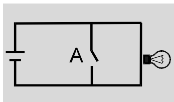
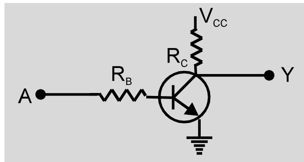
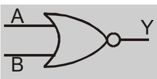
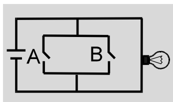
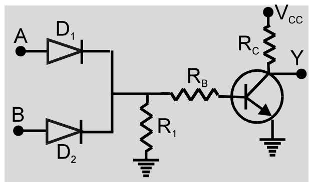
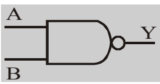
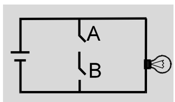
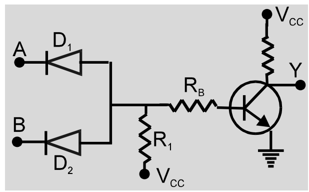
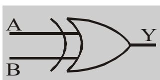
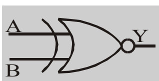
OR	AND	NOT
$A + 0 = A$	$A . 0 = 0$	$A + \bar{A} = 1$
$A + 1 = 1$	$A . 1 = A$	$A . \bar{A} = 0$
$A + A = A$	$A . A = A$	$\bar{\bar{A}} . A = A$

Boolean algebra obeys commutative, associative and distributive laws as given below :

- **Commutative laws :**

$A + B = B + A$;

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 or Inverter		$Y = \overline{A}$	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 $Y = \overline{A}.B + A\overline{B}$	A B Y 0 0 0 0 1 1 1 0 1 1 1 0		
XNOR (Exclusive NOR)		$Y = A \odot B$ or $Y = A.B + \overline{A}.\overline{B}$ or $Y = \overline{A \oplus B}$	A B Y 0 0 1 0 1 0 1 0 0 1 1 1		

A.B = B.A

- **Associative laws :**
  A + (B + C) = (A + B) + C
  A. (B . C) = (A. B) . C
- **Distributive laws :**
  A. (B + C) = A.B + A.C
- **Some other useful identities :**
  (i) A + AB = A
  (ii) A . (A + B) = A
  (iii) $A + (\bar{A}B) = A + B$
  (iv) $A.(\bar{A} + B) = A.B$
  (v) A +(B.C) = (A + B). (A + C)
  (vi) $(\bar{A} + B).(A + C) = \bar{A}.C + B.A + B.C$
- **De Morgan's theorem :**
  First theorem : $\overline{A+B} = \bar{A}.\bar{B}$
  Second theorem : $\overline{A.B} = \bar{A} + \bar{B}$

NUMBER SYSTEMS

Decimal Number system

The base of this system is 10 and in this system 10 numbers [0,1,2,3,4,5,6,7,8,9] are used.

Ex. 1396, 210.75 are decimal numbers.

Binary Number System

The base of this system is 2 and in this system 2 numbers (0 and 1) are used.

Ex. 1001, 1101.011 are Binary numbers.

Binary to decimal conversion

We can write any decimal number in following form

$2365.75 = 2000 + 300 + 60 + 5 + 0.7 + 0.05$

$= 2 \times 1000 + 3 \times 100 + 6 \times 10 + 5 \times 1 + 7 \times \frac{1}{10} + 5 \times \frac{1}{100}$

$= 2 \times \mathbf{10^3} + 3 \times \mathbf{10^2} + 6 \times \mathbf{10^1} + 5 \times \mathbf{10^0} + 7 \times \mathbf{10^{-1}} + 5 \times \mathbf{10^{-2}}$

Similarly we can write any binary number in following form

$10101.11 = 1 \times \mathbf{2^4} + 0 \times \mathbf{2^3} + 1 \times \mathbf{2^2} + 0 \times \mathbf{2^1} + 1 \times \mathbf{2^0} + 1 \times \mathbf{2^{-1}} + 1 \times \mathbf{2^{-2}}$

$= 1 \times 16 + 0 \times 8 + 1 \times 4 + 0 \times 2 + 1 \times 1 + 1 \times \frac{1}{2} + 1 \times \frac{1}{4}$

$= 16 + 4 + 1 + \frac{1}{2} + \frac{1}{4} = 21.75$

EXAMPLE 1

Convert binary number 1011.01 into decimal number.

$1011.01 = 1 \times 2^3 + 0 \times 2^2 + 1 \times 2^1 + 1 \times 2^0 + 0 \times 2^{-1} + 1 \times 2^{-2}$

$= 8 + 2 + 1 + \frac{1}{4} = 11.25$

EXAMPLE 2

Convert binary number 1000101.101 into decimal number.

$1000101.101 \equiv 1 \times 2^6 + 0 \times 2^5 + 0 \times 2^4 + 0 \times 2^3 + 1 \times 2^2 + 0 \times 2^1 + 1 \times 2^0 + 1 \times 2^{-1} + 0 \times 2^{-2} + 1 \times 2^{-3}$

$= 64 + 4 + 1 + \frac{1}{2} + \frac{1}{8} = 69 + 0.5 + 0.125 = 69.625$

EXAMPLE 3

Convert the following binary numbers into decimal numbers –

(a) 101 (b) 110.001
(c) 11111 (d) 1011.11

Ans. : (a) 5 (b) 6.125 (c) 31 (d) 11.75

DECIMAL TO BINARY CONVERSION

You should remember this table for decimal to binary conversion

2^{-3}	2^{-2}	2^{-1}	2^0	2^1	2^2
2^3	2^4	2^5	2^6	2^7	2^8
2^9	2^{10}	0.125	0.25	0.5	1
2	4	8	16	32	64
128	256	512	1024		

EXAMPLE 4

Convert the decimal number 25 into its binary equivalent

Sol. $25 = 16+8+1 \equiv 2^4 + 2^3 + 2^0 = 1 \times 2^4 + 1 \times 2^3 + 0 \times 2^2 + 0 \times 2^1 + 1 \times 2^0 \Rightarrow (25)_{10} = (11001)_2$

EXAMPLE 5

Convert 69 into its binary equivalent

Sol. $69 = 64 + 4 + 1 = 1 \times 2^6 + 1 \times 2^2 + 1 \times 2^0$
$\Rightarrow (69)_{10} = (1000101)_2$

EXAMPLE 6

Convert 13.5 into its binary equivalent

$13.5 = 8 + 4 + 1 + 0.5 = 1 \times 2^3 + 1 \times 2^2 + 0 \times 2^1 + 1 \times 2^0 + 1 \times 2^1 \Rightarrow (13.5)_{10} = (1101.1)_2$

EXAMPLE 7

Convert the following decimal numbers into binary numbers

(a) 6 (b) 65 (c) 106 (d) 268 (e) 8.125

Ans. (a) 110 (b) 1000001 (c) 1101010 (d) 100001100

(e) 1000.001

Exercise - 1 Objective Problems | JEE Main

1. In conductors -
(A) conduction band is completely empty but forbidden energy gap is small
(B) conduction and valence bands are overlapped
(C) valence band is completely filled but the conduction band is completely empty
(D) no energy band is present

2. The forbidden energy gap of a germanium semiconductor is 0.75 eV. The minimum thermal energy of electrons reaching the conduction band from the valence band should be -
(A) 0.5 eV (B) 0.75 eV
(C) 0.25 eV (D) 1.5eV

3. The energy of a photon of sodium light ($\lambda = 5890Å$) equals the band gap of a semiconductor. The minimum energy required to create an electron-hole pair is -
(A) 0.026 eV (B) 0.31 eV
(C) 2.1eV (D) 6.4 eV

4. The forbidden energy band gap in conductors, semiconductors and insulators are EG_1, EG_2 and EG_3 respectively. The relation among them is -
(A) $EG_1 = EG_2 = EG_3$
(B) $EG_1 < EG_2 < EG_3$
(C) $EG_1 > EG_2 > EG_3$
(D) $EG_1 < EG_2 > EG_3$

5. On increasing temperature the specific resistance of a semiconductor -
(A) decreases
(B) increases
(C) remains constant
(D) becomes zero

6. Which of the following statements is not 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

7. Wires P and Q have the same resistance at ordinary (room) temperature. When heated, resistance of P increases and that of Q decreases. We conclude that -
(A) P and Q are conductors of different materials
(B) P is N-type semiconductor and Q is P-type semiconductor
(C) P is semiconductor and Q is conductor
(D) P is conductor and Q is semiconductor

8. In a good conductor the energy gap between the conduction band and the valence band is -
(A) Infinite (B) Wide
(C) Narrow (D) Zero

9. In a semiconducting material the mobilities of electrons and holes are μ_e and μ_h respectively. Which of the following is true ?
(A) $\mu_e > \mu_h$ (B) $\mu_e < \mu_h$
(C) $\mu_e = \mu_h$ (D) $\mu_e < 0; \mu_h > 0$

10. Those materials in which number of holes in valence band is equal to number of electrons in conduction band are called
(A) conductors
(B) Intrinsic semiconductors
(C) p-type semiconductors
(D) n-type semiconductors

11. In p-type semiconductor holes move in
(A) forbidden region (B) conduction band
(C) valence band (D) all the above regions

12. Which of the following statement is wrong ?
(A) Resistance of extrinsic semiconductors can be changed as required
(B) In n-type semiconductor the number of electrons increases in valence band
(C) In p-type semiconductors the number of holes increases in valence band
(D) In pure semiconductor fermi band is situated in between the valence band and conduction band

13. P-type semiconductor is formed when -
A. As impurity is mixed in Si
B. $A\ell$ 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

14. 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

15. Fermi level of energy of an intrinsic semiconductor lies -
(A) In the middle of forbidden gap
(B) Below the middle of forbidden gap
(C) Above the middle of forbidden gap
(D) Outside the forbidden gap

16. If n_e and v_d be the number of electrons and drift velocity in a semiconductor. When the temperature is increased -
(A) n_e increases and v_d decreases
(B) n_e decreases and v_d increases
(C) Both n_e and v_d increases
(D) Both n_e and v_d decreases

17. The electron mobility in N-type germanium is 3900 $cm^2/v.s$ and its conductivity is 6.24 mho/cm, then impurity concentration will be if the effect of cotters is negligible -
(A) 10^{15} cm^3 (B) $10^{13}/cm^3$
(C) $10^{12}/cm^3$ (D) $10^{16}/cm^3$

18. In semiconductor the concentrations of electrons and holes are $8 \times 10^{18}/m^3$ and $5 \times 10^{18}/m^3$ respectively. If the mobilities of electrons and hole are 2.3 m^2/volt-sec and 0.01 m^2/volt-sec respectively, then semiconductor is -
(A) N-type and its resistivity is 0.34 ohm-metre
(B) P-type and its resistivity is 0.034 ohm-metre
(C) N-type and its resistivity is 0.034 ohm-metre
(D) P-type and its resistivity is 3.40 ohm-metre

19. A potential difference of 2V is applied between the opposite faces of a Ge crystal plate of area 1 cm^2 and thickness 0.5 mm. If the concentration of electrons in Ge is $2 \times 10^{19}/m^3$ and mobilities of electrons and holes are $0.36 \frac{m^2}{volt-sec}$ and $0.14 \frac{m^2}{volt-sec}$ respectively, then the current flowing through the plate will be -
(A) 0.25 A (B) 0.45 A
(C) 0.56 A (D) 0.64 A

20. A potential barrier of 0.50 V exists across a P-N junction. If the depletion region is 5.0×10^{-7} m wide, the intensity of the electric field in this region is -
(A) 1.0×10^6 V/m (B) 1.0×10^{5} V/m
(C) 2.0×10^5 V/m (D) 2.0×10^6 V/m

21. If no external voltage is applied across P-N junction, there would be -
(A) No electric field across the junction
(B) An electric field pointing from N-type to P-type side across the junction
(C) An electric field pointing from P-type to N-type side across the junction
(D) A temporary electric field during formation of P-N junction that would subsequently disappear

22. No bias is applied to a P-N junction, then the current -
(A) Is zero because the number of charge carriers flowing on both sides is same
(B) Is zero because the charge carriers do not move
(C) Is non-zero
(D) None of these

23. Just before the reverse breakdown in a semiconductor diode -
(A) The forward current is much larger then the reverse current
(B) The forward current is much less then the reverse current
(C) The forward current is equal to the reverse current
(D) The reverse current is much large than the forward current

24. The main cause of avalanche breakdown is -
(A) collision ionisation
(B) high dopring
(C) recombination of electron and holes
(D) none of these

25. The main cause of Zener breakdown is -
(A) the base semiconductor being germanium
(B) production of electron-hole pair due to electric field
(C) low doping
(D) high doping

26. Which of the following statements is correct ?
(A) The deplection region of P-N junction diode increases with forward biasing
(B) The depletion region of P-N junction diode decreases with reverse biasing
(C) The depletion region of P-N junction diode does not change with biasing
(D) The deplection region of P-N junction diode decreases with forward biasing

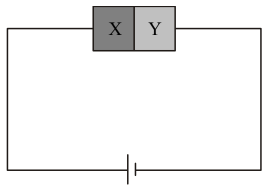
27. When reverse bias in a junction diode is increased, the width of depletion layer -
(A) increase (B) decreases
(C) does not change (D) fluctuate

28. A semiconductor device is connected in a series circuit with a battery and resistance. A current is found to pass through the circuit. If the polarity of the battery is reversed, the current drops almost to zero. The device may be -
(A) A P-type semiconductor
(B) An N-type semiconductor
(C) A PN-junction
(D) An intrinsic semiconductor

29. The approximate ratio of resistances in the forward and reverse bias of the PN-junction diode is -
(A) $10^2 : 1$ (B) $10^{-2} : 1$
(C) $1 : 10^{-4}$ (D) $1 : 10^4$

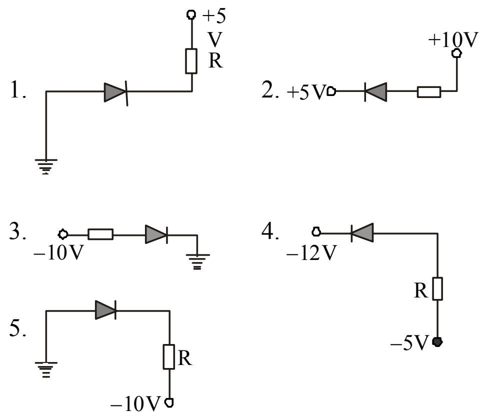
30. The dominant mechanisms for motion of charge carriers in forward and reverse biased silicon P-N junctions are -
(A) Drift in forward bias, diffusion in reverse bias
(B) Diffusion in forward bias, drift in reverse bias
(C) Diffusion in both forward and reverse bias
(D) Drift in both forward and reverse bias

31. A semiconductor X is made by doping a germanium crystal with arsenic (Z = 33). A second semiconductor Y is made by doping germanium with indium (Z = 49). The two are joined end to end and connected to a battery as shown. Which of the following statements is correct ?



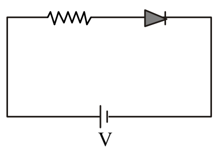
(A) X is P-type, Y is N-type and the junction is forward biased
(B) X is N-type, Y is P-type and the junction is forward biased
(C) X is P-type, Y is N-type and the junction is reverse biased
(D) X is N-type, Y is P-type and the junction is revese biased

32. In the given figure, which of the diodes are forward biased ?



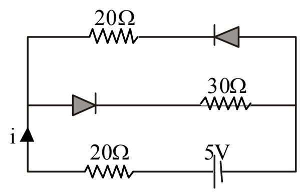
(A) 1, 2, 3 (B) 2, 4, 5
(C) 1, 3, 4 (D) 2, 3, 4

33. For the given circuit of PN-junction diode, which of the following statements is correct -



(A) In forward biasing the voltage across R is V
(B) In forward biasing the voltage across R is 2V
(C) In reverse biasing the voltage across R is V
(D) In reverse biasing the voltage across R is 2V

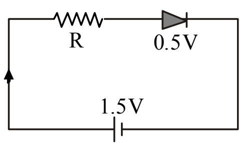
34. Current in the circuit will be -



(A) $\frac{5}{40}$ A (B) $\frac{5}{50}$ A

(C) $\frac{5}{10}$ A (D) $\frac{5}{20}$ A

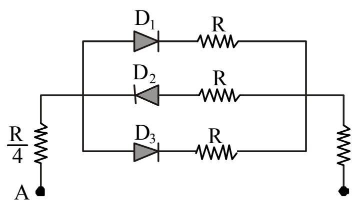
35. The diode used in the circuit shown in the figure has a constant voltage drop of 0.5 V at all currents and a maximum power rating of 100 milli watts. What should be the value of the resistor R, connected in series with the diode for obtaining maximum current -



(A) 1.5 Ω (B) 5 Ω

(C) 6.67 Ω (D) 200 Ω

36. 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) – 10 V, – 5 V (ii) – 5V, – 10 V

(iii) – 4V, – 12 V

(A) (i) < (ii) < (iii) (B) (iii) < (ii) < (i)

(C) (ii) = (iii) < (i) (D) (i) = (iii) < (ii)

37. Mobility of electrons in Germanium of N types & their conductivity are 3900 cm^2/volt-sec & 5 mho/cm respectively. If effect of holes are negligible then concentration of impurity will be-

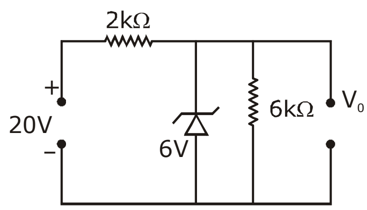
(A) 8×10^{15} per cm^3

(B) 9.25×10^{14} per cm^3

(C) 6×10^{13} per cm^3

(D) 9×10^{13} per cm^3

38. What is the value of output voltage V_0 in the circuit shown in the figure ?

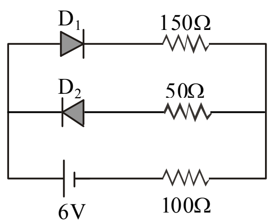


(A) 6 V (B) 14 V

(C) 20 V (D) 26 V

Passage based questions : (39-40)

The circuit shown in diagram contains two diodes each with a forward resistance of 50 ohm and with infinite reverse resistance. If the battery voltage is 6V then –



39. Current through 100 Ω resistance is -

(A) 0 (B) 0.02 amp

(C) 0.03 amp (D) none of these

40. Current through 50 Ω resistance is -

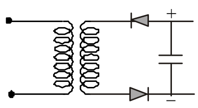
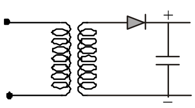
(A) 0

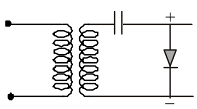
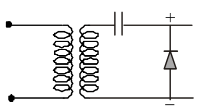
(B) 0.02 amp

(C) 0.03 amp

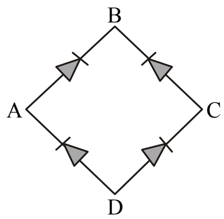
(D) none of these is moderate

41. Which is the correct diagram of a half-wave rectifier?

(A)  (B) 

(C)  (D) 

42. In the diagram, the input is across the terminals A and C and the output is across the terminals B and D, then the output is -

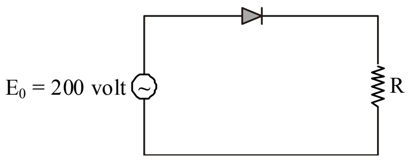


(A) zero (B) same as input
(C) full wave rectifier (D) half wave rectifier

43. If a full wave rectifier circuit is operating from 50 Hz mains, the fundamental frequency in the ripple will be -
(A) 50 Hz (B) 70.7 Hz
(C) 100 Hz (D) 25 Hz

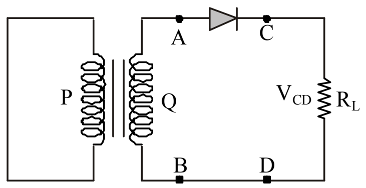
44. In a full wave rectifiers input ac current has a frequency ν. The output frequency of current is
(A) $\nu/2$ (B) ν
(C) 2ν (D) None of these

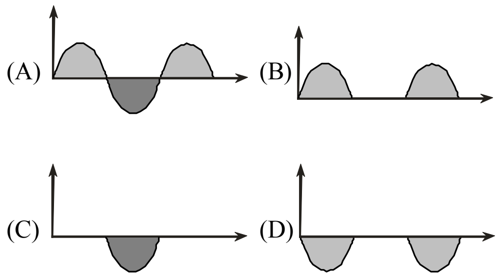
45. A sinusoidal voltage of peak value 200 volt is connected to a diode and resistor R in the circuit shown so that half wave rectification occurs. If the forward resistance of the diode is negligible compared to R then rms voltage (in volt) across R is approximately -



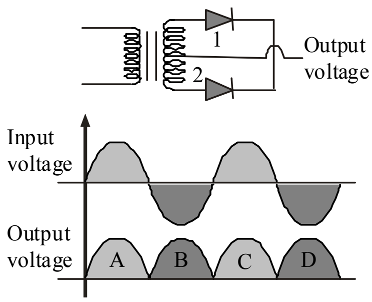
(A) 200 (B) 100
(C) $\frac{200}{\sqrt{2}}$ (D) 280

46. In the half-wave rectifier circuit shown. Which one of the following wave forms is true for V_{CD}, the output across C and D?



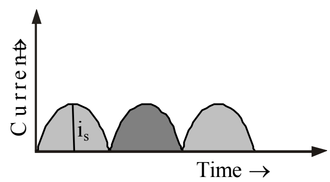


47. A full wave rectifier circuit along with the input and output voltage is shown in the figure.



The contribution to output voltage from diode – 2 to -
(A) A, C (B) B, D
(C) B, C (D) A, D

48. The output current versus time curve of a rectifier is shown in the figure. The average value of the output current in this case is -



(A) 0 (B) i_0/π
(C) $2i_0/\pi$ (D) i_0

49. 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 and hence high mobility of energy

50. For a common base transistor if the values of I_f and I_c are 10^3 μA and 0.96 mA respectively then the value of I_E will be -

(A) 0.04 mA (B) 4 mA

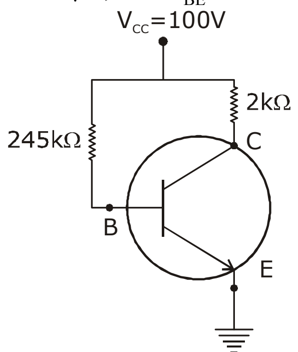
(C) 0.4 mA (D) 0.004 mA

51. The dc current gain of a transistor in CB configuration is 0.99 . Find its dc current gain in CE configuration.

(A) 99 (B) 400

(C) 300 (D) 50

52. In a common emitter transistor circuit, the base current is 40 μA, then V_{BE} is -



(A) 2 V (B) 0.2 V

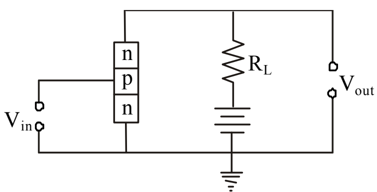
(C) 0.8 V (D) Zero

53. A transsitor is operated in CE configuration at V_{CC} = 2 V such that a change in base current from 100 μA to 200 μA produces a change in the collector current from 9mA to 16.5 mA. The value of current gain, β is -

(A) 45 (B) 50

(C) 60 (D) 75

54. An n-p-n transistor circuit is arranged as shown in fig. It is -



(A) a common-base amplifier circuit

(B) a common-emitter amplifier circuit

(C) a common-collector amplifier circuit

(D) none of the above

55. What is the voltage gain in a common-emitter amplifier, where input resistance is 3Ω and load resistance 24Ω ? Take β = 0.6 -

(A) 8.4 (B) 4.8

(C) 2.4 (D) 1.2

56. Compared to CB amplifier, the CE amplifier has -

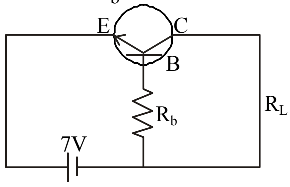
(A) lower input resistance

(B) higher output resistance

(C) lower current amplification

(D) higher current amplification

57. In the given transistor circuit, the base current is 35 μA. The value of R_b is -



(A) 100 kΩ (B) 200 kΩ

(C) 300 kΩ (D) 400 kΩ

58. I. In a P-N-P type common base amplifier the input and output are in same phase.

II. In a P-N-P common base amplifier input and output are out of phase.

III. In a N-P-N- common base amplifier the input and output are in same phase.

IV. In a N-P-N common base amplifier input and output are out of phase.

State if -

(A) I and III are correct (B) II and III are correct

(C) I and IV are correct (D) II and IV are correct

59. In a transistor the base is made very thin and is lightly doped with an impurity because-

(A) to enable the collector to collect 95% of the holes or electrons coming from the emitter side

(B) to enable the emitter to emit small number of holes or electrons

(C) to save the transistor from higher current effects

(D) none of the above

60. In an NPN transistor 10^{10} electrons enter the emitter in 10^{-6}s. 2% of the electrons are lost in the base. The current transfer ratio will be-

(A) 0.95 (B) 0.96

(C) 0.97 (D) 0.98

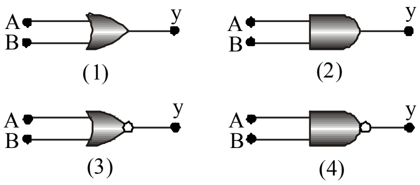
61. In an NPN transistor the values of base current and collector current are 100μA and 9 mA respectively, the emitter current will be-

(A) 9.1 mA (B) 18.2 mA
(C) 9.1μ A (D) 18.2 μA

62. For a common base amplifier, the values of resistance gain and voltage gain are 3000 and 2800 respectively. The current gain will be -

(A) 0.93 (B) 0.83
(C) 0.73 (D) 0.63

63. Given below are four logic gate symbol (figure). Those for OR, NOR and NAND are respectively -



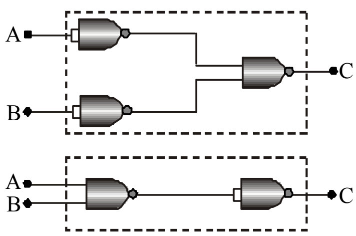
(A) 1, 4, 3 (B) 4, 1, 2
(C) 1, 3, 4 (D) 4, 2, 1

64. The following truth table corresponds to the logic gate -

A	0	0	1	1
B	0	1	0	1
X	0	1	1	1

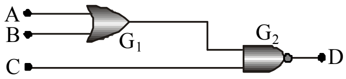
(A) NAND (B) OR
(C) AND (D) XOR

65. The combination of 'NAND' gates shown here under (figure) are equivalent to –



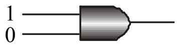
(A) An OR gate and an AND gate respectively
(B) An AND gate and a NOT gate respectively
(C) An AND gate and an OR gate respectively
(D) An OR gate and a NOT gate respectively

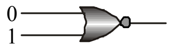
66. For the given combination of gates, if the logic states of inputs A, B, C are as follows A = B = C = 0 and A = B = 1, C = 0 then the logic states of output D are -

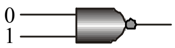


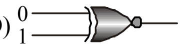
(A) 0, 0 (B) 0, 1
(C) 1, 0 (D) 1, 1

67. Which of the following gates will have an output of 1 ?

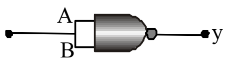
(A) 

(B) 

(C) 

(D) 

68. This symbol represents -

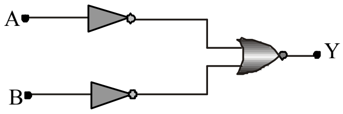


(A) NOT gate (B) OR gate
(C) AND gate (D) NOR gate

69. The output of a NAND gate is 0 -

(A) If both inputs are 0
(B) If one input is 0 and the other input is 1
(C) If both inputs are 1
(D) Either if both inputs are 1 or if one of the inputs is 1 and the other 0

70. Which logic gate is represented by the following combination of logic gates -



(A) OR (B) NAND
(C) AND (D) NOR

71. The output of OR gate is 1 -

(A) If both inputs are zero
(B) If either or both inputs are 1
(C) Only if both input are 1
(D) If either input is zero

72. An oscillator is nothing but an amplifier with

(A) Positive feedback (B) Negative feedback
(C) Voltage gain (D) No feedback

73. In which of the configurations of a transistor, the power gain is highest ?

(A) Common base (B) Common emitter
(C) Common collector (D) Same in all the three

Exercise - 2 | Objective Problems | JEE Main

1. Which of the following statement is true ?
(A) In insulators the conduction band is completely empty
(B) In conductor the conduction band is completely empty
(C) In semiconductor the conduction band is partially empty at low temperature
(D) In insulators the conduction band is completely filled with electrons

2. The materials resistance of which decreases with increases in temperature (i.e. the temperature coefficient of resistance is negative) are called -
(A) conductors (B) insulators
(C) semiconductors (D) all of the above

3. The diffusion current in a p-n junction is from -
(A) p-side to n-side
(B) n-side to p-side
(C) p-side to n-side if the junction is forward biased and in the opposite direction if it is reverse biased
(D) n-side to p-side if the junction is forward biased and in the opposite direction if it is reverse based

4. In n-type semiconductors the Fermi energy level is displaced -
(A) towards the valence band
(B) towards the conduction band
(C) not displaced
(D) and it does not depend on quantity of impurity

5. If n-type semiconductor is heated then -
(A) the number of electrons increases and the number of holes decreases
(B) the number of holes increases and the number of electrons decreases
(C) at the number of electrons and holes both remains equal
(D) the number of both electrons and holes increases

6. Forbidden energy gap of a silicon semiconductor is 1.12 eV. In order to generate electron-hole pairs in it, the maximum wavelength of the incident photons will be -
(A) 11080Å (B) 11250Å
(C) 12370Å (D) 14400Å

7. If the two ends of a p-n junction are joined by a conducting wire, then -
(A) there will be no current in the circuit
(B) there will be steady current from n-side to p-side
(C) there will be steady current from p-side to n-side
(D) there will be a steady current in the circuit

8. In a p-type semiconductor, the acceptor level is 57 meV, above the valence band. The maximum wavelength of light required to produce a hole will be (Planck's constant h = 6.6×10^{-34} Joule × sec) -
(A) 57Å (B) 57×10^{-3}Å
(C) 217100 Å (D) 11.61×10^{-23} Å

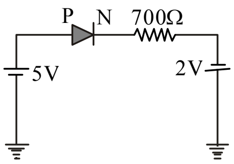
9. A doped semiconductor has impurity levels 32 meV below the conduction band. The semiconductor is -
(A) N-type (B) P-type
(C) N-P junction (D) none of the above

10. The mean free path of a conduction electron in a metal is 5×10^{-8} m. The electric field, required to be applied across the conductor so as to impart 1eV energy to the conduction electron, will be -
(A) 1×10^{-7} V/m (B) 2×10^{7} V/m
(C) 3×10^{7} V/m (D) 4×10^{7} V/m

11. Which of the following statements is correct ?
(A) when forward bias is applied on a p-n junction then current does not flow in the circuit
(B) rectification of alternating current can not be achieved by p-n junction
(C) when reverse bias is applied on a p-n junction then it acts as a conductor
(D) some potential gap developed across the p-n junction when it is formed

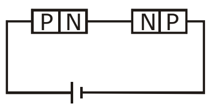
12. In semiconductor the concentrations of electrons and holes are $8 \times 10^{18}/m^3$ and $5 \times 10^{18}/m^3$ respectively. If the mobilities of electrons and holes are 2.3 m^2/V-s and 0.01 m^2/V-s respectively, then semiconductor is -
(A) N-type and its resistivity is 0.34 ohm-metre
(B) P-type and its resistivity is 0.034 ohm-metre
(C) N-type and its resistivity is 0.034 ohm-metre
(D) P-type and its resistivity is 3.40 ohm-metre

13. The current through an ideal PN junction shown in the following circuit diagram will be -

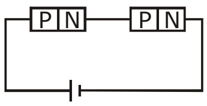


(A) 5 mA (B) 10 mA
(C) 70 mA (D) 100 mA

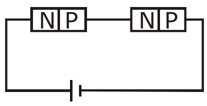
14. Two identical p-n junction may be connected in series with a battery in three ways (fig). The potential drops across the p-n junctions are equal in -

(A) circuit 1 and 2


circuit 1

(B) circuit 2 and 3


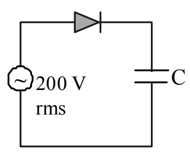
circuit 2

(C) circuit 3 and 1


circuit 3

(D) circuit 1 only

15. In the figure, an A.C. of 200 rms voltage is applied to the circuit containing diode and the capacitor and it is being rectified. The potential across the capacitor C will be -



(A) 500V (B) 200V
(C) 283V (D) 141V

16. Which of the following statements is wrong ?

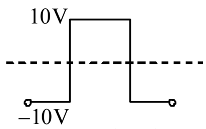
(A) The resistance of a semiconductor decreases with the increases of temperature

(B) In electric field the displacement of holes is opposite in direction to that of electrons

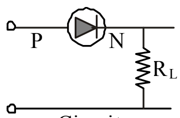
(C) The resistance of conductor decreases with the increase of temperature

(D) N-type semiconductors are neutral

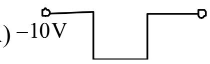
17. If the following input signal is sent through a P-N junction diode, then the output signal across R_L will be -

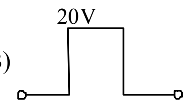


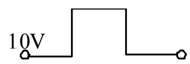
Input signal

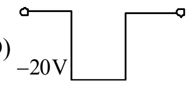


Circuit

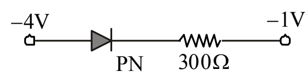
(A) 

(B) 

(C) 

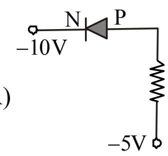
(D) 

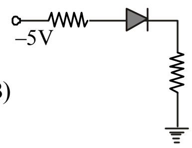
18. The value of current in the following diagram will be –

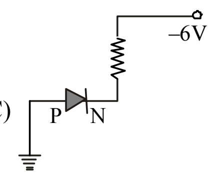


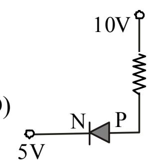
(A) 0.10 Ac (B) 10^{-2} A
(C) 1 A (D) 0 A

19. In which of the following figures the junction diode is in reverse bias

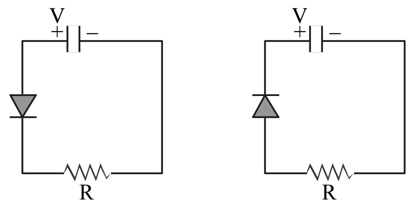
(A) 

(B) 

(C) 

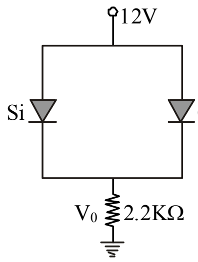
(D) 

20. Two identical capacitors A and B are charged to the same potential V and are connected in two circuits at t = 0 as shown in figure. The charge of the capacitors at a time t = CR are respectively -



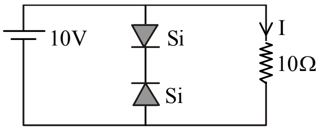
(A) VC, VC (B) VC/e, VC
(C) VC, VC/e (D) VC/e, VC/e

21. In the circuit shown in figure, Voltage V_0 is–



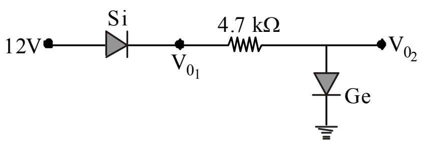
(A) 11.7 volt (B) 11.3 volt
(C) 0 (D) None

22. Determine current I in the configuration –



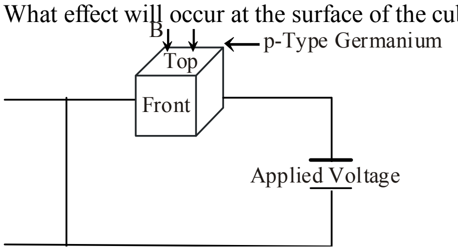
(A) 1 amp (B) 0 amp
(C) less than 1 amp (D) None

23. In the given circuit V_{0_1} & V_{0_2} are -



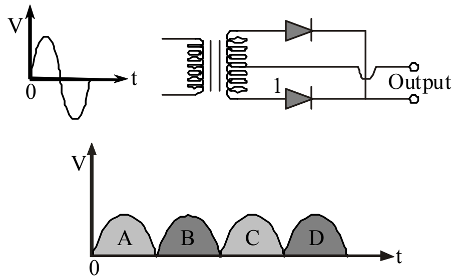
(A) 11.3 V & 0.3 V (B) 0.3 V & 11.3 V
(C) 11.3 V & 11.3 V (D) 0.3 V & 0.3 V

24. A cube of germanium is placed between the poles of a magnet and a voltage is applied across opposite faces of the cube as shown in Figure. Magnetic field is directed vertical downward in the plane of the paper :
What effect will occur at the surface of the cube ?



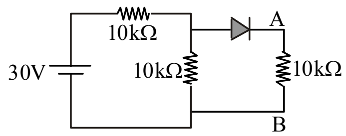
(A) The top surface of cube will become negatively charged
(B) The front surface of the cube will become positively charged
(C) The front surface of the cube will become negatively charged
(D) Both top and front surface of cube will become positively charged

25. A full wave rectifier circuit along with the output is shown in the following diagram. The contribution(s) from the diode (1) is (are) -



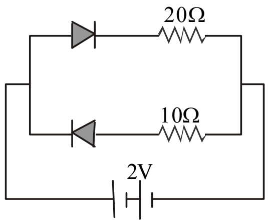
(A) C (B) A,C
(C) B,D (D) A, B, C, D

26. In the given figure potential difference between A and B is -



(A) 0 (B) 5 volt
(C) 10 volt (D) 15 volt

27. In figure the current supplied by the battery is -



(A) 0.1 A (B) 0.2 A
(C) 0.3 A (D) 0.4 A

28. In a p-n junction -
(A) new holes and conduction electrons are produced continuously throughout the material
(B) new holes and conduction electrons are produced continuously throughout the material except in the depletion region
(C) holes and conduction electrons recombine continuously throughout the material
(D) holes and conduction electrons recombine continuously throughout the material except in the depletion region

29. Temperature coefficient of resistance for a pure semiconductor is -
(A) 0
(B) negative
(C) positive
(D) depends on nature of semiconductor

30. A conducting wire of Copper and Germenium are cooled from room temperature to temperature 80K, then their resistance will :–
(A) increase
(B) decrease
(C) copper's increase and Germenium's decrease
(D) copper's decrease and Germenium's increase

31. Consider an n–p–n transistor amplifier in common–emitter configuration. The current gain of the transistor is 100. If the collector current changes by 1 mA, what will be the change in emitter current
(A) 1·1 mA (B) 1·01 mA
(C) 0·01 mA (D) 10 mA

32. In semiconducting material the mobilities of electrons and holes are μ_e and μ_h respectively. Which of the following is true :–
(A) $\mu_e > \mu_h$ (B) $\mu_e < \mu_h$
(C) $\mu_e = \mu_h$ (D) $\mu_e < 0$; $\mu_h > 0$

33. In a transistor the base is very lightly doped as compared to the emitter because by doing so -
(A) The flow across the base region is mainly because of electrons
(B) The flow across the base region is mainly because of holes
(C) Recombination is decreased in teh base region
(D) Base current is high

Exercise - 3 Previous Year | JEE Mains

1. If temperature increases, conductivity of semiconductor will be – **[AIEEE-2002]**
(A) increases (B) decreases
(C) remain unchanged (D) none of these

2. At 0K, silicon behave as – **[AIEEE-2002]**
(A) super conductor (B) conductor
(C) Insulator (D) none of these

3. The energy band gap is maximum in – **[AIEEE-2002]**
(A) Metals (B) Superconductors
(C) Insulators (D) Semiconductors

4. The part of a transistor which is most heavily doped to produce large number of majority carriers is – **[AIEEE-2002]**
(A) Emitter (B) Base
(C) Collector
(D) Can be any of the above three

5. In the middle of the depletion layer of a reverse-biased p-n junction, the – **[AIEEE-2003]**
(A) Potential is maximum
(B) Electric field is maximum
(C) Potential is zero
(D) Electric field is zero

6. The difference in the variation of resistance with temperature in a metal and a semiconductor arises essentially due to the difference in the – **[AIEEE-2003]**
(A) Variation of the number of charge carriers with temperature
(B) Type of bonding
(C) Variation of scattering mechanism with temperature
(D) Crystal structure

7. A strip of copper and another of germanium are cooled from room temperature of 80 K. The resistance of – **[AIEEE-2003]**
(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

8. When npn transistor is used as an amplifier –
(A) electrons move from collector base
(B) holes move from emitter to base
(C) electrons move from base to collector
(D) holes move from base to emitter

9. A piece of copper and another of germanium are cooled from room temperature of 77 K, the resistance of – **[AIEEE-2004]**
(A) copper increases and germanium
(B) each of them decreases
(C) each of these increases
(D) copper decreases and germanium increases

10. 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

11. 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

12. 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

13. 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) 25 Hz
(C) 100 Hz (D) 70.7 Hz

14. In a common base amplifier the phase difference between the input signal voltage and output voltage is – **[AIEEE-2005]**
(A) $\frac{\pi}{4}$ (B) π (C) 0 (D) $\frac{\pi}{2}$

15. 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) $\frac{5}{8}$ (D) $\frac{4}{5}$

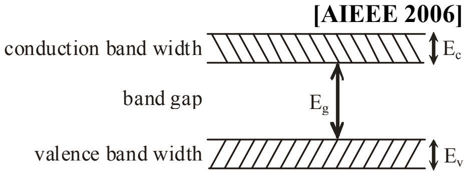
16. A solid which is not transparent to visible light and whose conductivity increases with temperature is formed by – **[AIEEE-2006]**

(A) Vander Waals binding
(B) Metallic binding
(C) Ionic binding
(D) Covalent binding

17. In a common base mode of a transistor, the collector current is 5.488 mA for an emitter current of 5.60 mA. The value of the base current amplification (β) will be – **[AIEEE-2006]**

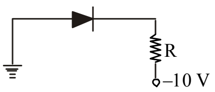
(A) 51 (B) 48
(C) 49 (D) 50

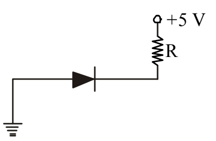
18. If the lattics constant of this semiconductor is decreased, then which of the following is correct – **[AIEEE 2006]**

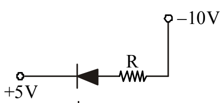


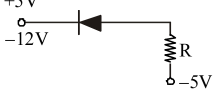
(A) E_c and E_v decrease, but E_g increases
(B) All E_c, E_g, E_v decrease
(C) All E_c, E_g, E_v increase
(D) E_c and E_v increase, but E_g decreases

19. In the following, which one of the diodes is reverse biased – **[AIEEE-2006]**

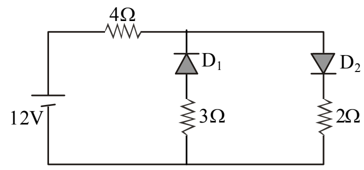
(A) 

(B) 

(C) 

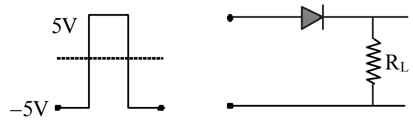
(D) 

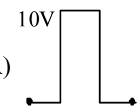
20. The circuit has two oppositely connected ideal diodes in parallel. What is the current flowing in the circuit ? **[AIEEE-2006]**

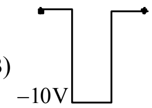


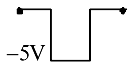
(A) 2.31 A (B) 1.33 A
(C) 1.71 A (D) 2.00 A

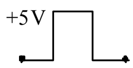
21. If in a p-n junction diode, a square input signal of 10 V is applied as shown. Then the output signal across R_L will be – **[AIEEE-2007]**



(A) 

(B) 

(C) 

(D) 

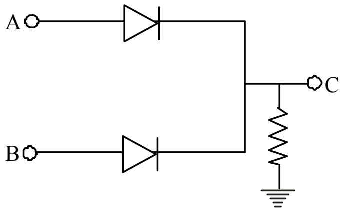
22. Carbon, silicon and germanium have four valence electrons each. At room temperature which one of the following statements is most appropriate ? **[AIEEE-2007]**

(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

23. A working transistor with its three legs marked P, Q and R is tested using a multimeter. No conduction is found between P and Q. By connecting the common (negative) terminal of the multimeter to R and the other (positive) terminal to P or Q, some resistance is seen on the multimeter. Which of following is true for the transistor ? **[AIEEE-2008]**

(A) It is a pnp transistor with R as collector
(B) It is a pnp transistor with R as emitter
(C) It is an npn transistor with R as collector
(D) It is an npn transistor with R as base

24. In the circuit below, A and B represent two inputs and C represents the output. **[AIEEE-2008]**

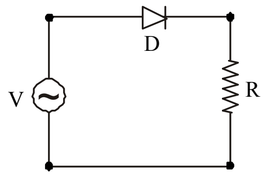


The circuit represents

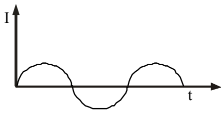
(A) AND gate (B) NAND gate

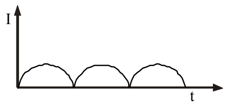
(C) OR gate (D) NOR gate

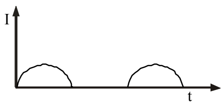
25. An p-n junction (D) shown in the figure can act as a rectifier. An alternating current source (V) is connected in the circuit. **[AIEEE-2009]**

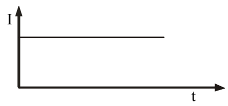


The current (I) in the resistor R can be shown by -

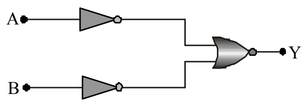
(A) 

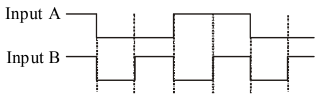
(B) 

(C) 

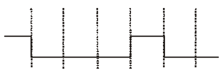
(D) 

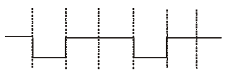
26. The logic circuit shown below has the input waveforms 'A' and 'B' as shown. Pick out the correct output waveform. **[AIEEE-2009]**

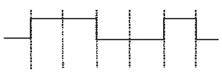


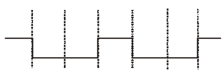


Output is -

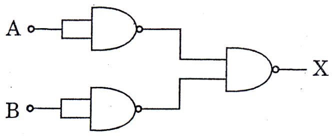
(A) 

(B) 

(C) 

(D) 

27. The combination of gates shown below yields

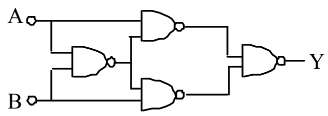


(A) NAND gate (B) OR gate

(C) NOT gate (D) XOR gate

[AIEEE-2010]

28. Truth table for system of four NAND gates as shown in figure is- **[AIEEE-2012]**



(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	1
0	1	0
1	0	0
1	1	1

(D)

A	B	Y
0	0	0
0	1	1
1	0	1
1	1	0

29. 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 ± 0.01 V while measuring the current of 5 mA at 300 K, what will be the error in the value of current in mA? **[JEE MAIN 2014]**

(A) 0.5 mA (B) 0.05 mA

(C) 0.2 mA (D) 0.02 mA

30. The forward biased diode connection is :

(A) 

(B) 

(C) 

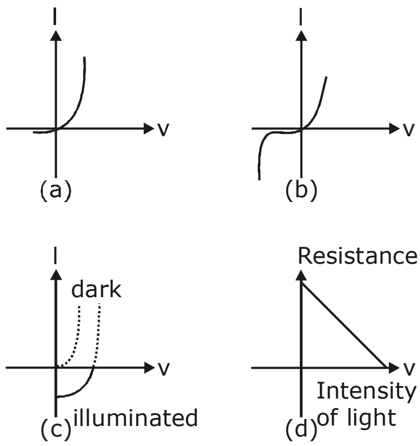
(D) 

[JEE MAIN 2014]

31. The temperature dependence of resistances of Cu and undoped Si in the temperature range 300–400 K, is best described by : **[JEE MAIN 2016]**

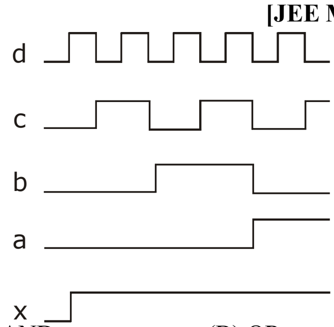
(A) Linear increase for Cu, exponential increase for Si.
(B) Linear increase for Cu, exponential decrease for Si.
(C) Linear decrease for Cu, linear decrease for Si.
(D) Linear increase for Cu, linear increase for Si.

32. Identify the semiconductor devices whose characteristics are given below, in the order (1), (2), (3), (4) : **[JEE MAIN 2016]**



(A) Zener diode, Simple diode, Light dependent resistance, Solar cell
(B) Solar cell, Light dependent resistance, Zener diode, Simple diode
(C) Zener diode, Solar cell, Simple diode, Light dependent resistance
(D) Simple diode, Zener diode, Solar cell, Light dependent resistance

33. 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]**



(A) AND (B) OR
(C) NAND (D) NOT

34. For a common emitter configuration, if α and β have their usual meanings, the incorrect relationship between α and β is : **[JEE MAIN 2016]**

(A) $\alpha = \dfrac{\beta}{1-\beta}$ (B) $\alpha = \dfrac{\beta}{1+\beta}$

(C) $\alpha = \dfrac{\beta^2}{1+\beta^2}$ (D) $\dfrac{1}{\alpha} = \dfrac{1}{\beta} + 1$

ANSWER KEYS

Exercise - 1 Objective Problems | JEE Main

1.	B	**2.**	B	**3.**	C	**4.**	B	**5.**	A	**6.**	C	**7.**	D
8.	D	**9.**	A	**10.**	B	**11.**	C	**12.**	B	**13.**	C	**14.**	C
15.	A	**16.**	A	**17.**	D	**18.**	A	**19.**	D	**20.**	A	**21.**	B
22.	A	**23.**	A	**24.**	A	**25.**	B	**26.**	D	**27.**	A	**28.**	C
29.	D	**30.**	B	**31.**	D	**32.**	B	**33.**	A	**34.**	B	**35.**	B
36.	C	**37.**	A	**38.**	A	**39.**	B	**40.**	A	**41.**	B	**42.**	C
43.	C	**44.**	C	**45.**	B	**46.**	B	**47.**	B	**48.**	C	**49.**	D
50.	A	**51.**	A	**52.**	B	**53.**	D	**54.**	B	**55.**	B	**56.**	D
57.	B	**58.**	A	**59.**	A	**60.**	D	**61.**	A	**62.**	A	**63.**	C
64.	B	**65.**	A	**66.**	D	**67.**	C	**68.**	A	**69.**	C	**70.**	C
71.	B	**72.**	A	**73.**	B								

Exercise - 2 Objective Problems | JEE Main

1.	A	**2.**	B,C	**3.**	A	**4.**	B	**5.**	D	**6.**	A	**7.**	A
8.	C	**9.**	A	**10.**	B	**11.**	D	**12.**	A	**13.**	B	**14.**	B
15.	C	**16.**	C	**17.**	C	**18.**	D	**19.**	B	**20.**	B	**21.**	A
22.	A	**23.**	A	**24.**	B	**25.**	B	**26.**	C	**27.**	A	**28.**	A,D
29.	B	**30.**	D	**31.**	B	**32.**	A	**33.**	C				

Exercise - 3 Previous Year | JEE Mains

1.	A	**2.**	C	**3.**	C	**4.**	A	**5.**	B	**6.**	A	**7.**	B
8.	C	**9.**	D	**10.**	B	**11.**	A	**12.**	C	**13.**	C	**14.**	C
15.	A	**16.**	D	**17.**	C	**18.**	D	**19.**	B,C	**20.**	D	**21.**	D
22.	D	**23.**	D	**24.**	C	**25.**	C	**26.**	A	**27.**	B	**28.**	D
29.	C	**30.**	C	**31.**	**B**	**32.**	**D**	**33.**	**B**	**34.**	A,D		

CHAPTER 4

COMMUNICATION SYSTEM

1. COMMUNICATION SYSTEM

A communication system is the set-up used in the transmission of information from one place to another. The present day communication system are electrical, electronic or optical in nature.

In principle, a communication system consists of the following three parts :

(i) Transmitter (ii) Communication Channel (iii) Receiver

A schematic model of an electrical communication system is shown in Figure 1.

Figure (1)

(i) A transmitter : transmits the information after modifying it to a form suitable for transmission. The key to communication system is to obtain an electrical signal (voltage or current), which contains the information. For example, a *microphone* converts speech signals into electrical signals. Similarly, *piezoelectric sensors* convert pressure variations into electrical signals. Light signals are converted into electrical signals by *photo detectors*. The devices like microphone, piezoelectric sensors and photo detectors, which convert a physical quantity (called information, here) into electrical signal are known as **Transducers**. Such an electrical signal contains the information to be transmitted.

We define a **signal** as a single valued function of time (that conveys the information). This function has a unique value at every instant of time.

Most of the speech or information signals cannot be transmitted directly over long distances. These signals have to be loaded or superimposed on a high frequency wave, which acts as the *carrier wave*. This process is known as *modulation*. The signal so obtained is called modulated signal/wave. The power of the signal is boosted signal using a *suitable amplifire*. The modulated signal is then radiated into space with the help of an antenna called *transmitting antenna*. The arrangement is shown in Fig.2

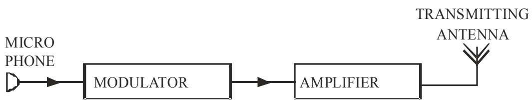


Figure 2

(ii) Communication Channel :
The communication channel carries the modulated wave from the transmitter to the receiver. In ordinary conversation, the air through which sound travels from the speaker to the listener serves as the communication channel. In case of telephony and telegraphy, communication channel is the *transmission lines*, which connect the transmitter and the receiver. In radio communication (or wireless communication), the *free space* through which the modulated signal travels serves as the communication channel.

(iii) The receiver : In the radio communication or wireless communication, the receiver consists of

(a) a pick up antenna to pick the signal,

(b) a demodulator, to separate the low frequency audio signal from the modulated signal,

(c) an amplifier, to boost up suitably the audio signal, and

(d) the transducer, like loud speaker to convert the audio signal (in the form of electrical pulses) into sound waves.

The receiver part of the communication system is shown schematically in Fig.3

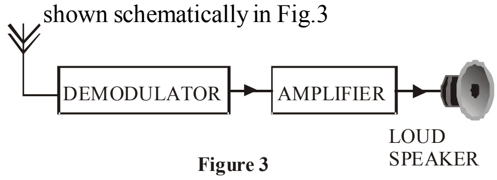


Figure 3

2. ANTENNA

An antenna plays a vital role in a communication system. It is used in both, the transmission and reception of radio frequency signals. Infact, an antenna is a structure that is capable of radiating electromagnetic waves or receiving them, as the case may be. Basically, an antenna is generally a metallic object, often a wire or collection of wires, used to convert high frequency current into electromagnetic waves and vice-versa. Thus, a transmitting antenna converts electrical energy into electromagnetic waves, whereas a receiving antenna converts electromagnetic waves into electrical energy. Apart from their different function, transmitting and receiving antennas behave idenically i.e. their behaviour is reciprocal. When a transmitting antenna is held vertically, the electromagnetic waves produced are polarized vertically.

A **Hertz** antenna is a straight conductor of length equal to half the wavelength of radio signals to be transmitted or received i.e. $l = \lambda/2$.

A **Marconi** antenna is a straight conductor of length equal to a quarter of the wavelength of radio signals to be transmitted or received i.e. $l = \lambda/4$. It is held vertically with its lower end touching the ground. The ground provides a reflection of the voltage and current distributions set up in the antenna. The electromagnetic waves emitted from (Marconi) antenna ground system are the same as those emitted from Hertz antenna, which is not grounded.

The design of an antenna depends on frequency of carrier wave and directivity of the beam etc. Two common types of antenna are :

(i) **Dipole antenna,** shown in Fig.4 is used in transmission of radio waves. It is *omni directional*.

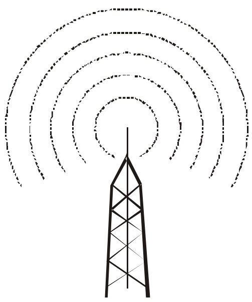


Figure 4

(ii) **Dish type antenna,** shown in Fig.5 is a directional antenna. Such an antenna has a parabolic reflector with an active element, called the **dipole** or **horn feed** at focus of the reflector. The dish type antenna can transmit waves in a particular direction. Also, it can receive only those waves which are directed towards it. For transmission, the signal is fed to the active element, which directs it on to the reflector. The signal is then transmitted in the form of a parallel beam as shown in Fig.5. For reception, the waves directed towards the dish are reflected on to the active element, which converts them into electrical signals. The dish type antennas are commonly used in radar and satellite communication.

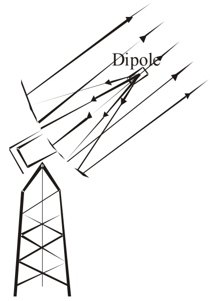


Figure 5

3. MESSAGE SIGNALS

Message signals are electrical signals generated from the original information to be transmitted, using an appropriate transducer. *A message signal is a single valued function of time that conveys the information*. This function has a unique value at every instant of time. These signals are of two type

(i) Analog signals

(ii) Digital signals

(i) **Analog signals.** An analog signal is that in which current or voltage value varies continuously with time. In the simplest form of an analog signal, amplitude of the signal varies sinusoidally with time. It is represented by the equation

$E = E_0 \sin(\omega t + \phi)$

where E_0 is max. value of voltage, called the amplitude, T is time period and $\omega = \frac{2\pi}{T}$ is angular frequency of the signal.

In fig.6, ϕ represents the phase angle. Such signals can have all sorts of values at different instants, but these values shall remain within the range of a maximum value $(+E_0)$ and a minimum value $(-E_0)$.

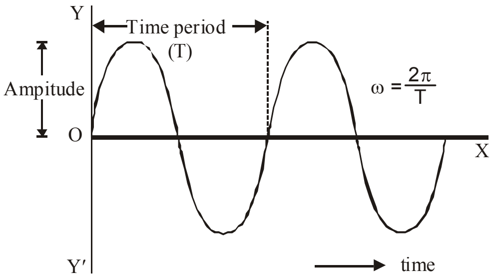


Figure 6

Examples of analog signals are speech, music, sound produced by a vibrating tuning fork, variations in light intensity etc. These are converted into current/ voltage variations using suitable transducers. The information bearing signals are called **base band signals.**

(ii) Digital signals. A digital signal is a discontinuous function of time, in contrast to an analog signal, wherein current or voltage value varies continuously with time.
Such a signal is usually in the form of *pulses*. Each pulse has two levels of current or voltage, represented by 0 and 1. Zero (0) of a digital signal refers to open circuit and (1) of a digital signal refers to closed circuit. Zero (0) is also referred to as 'No' or space and (1) is referred to as 'Yes' or mark. Both 0 and 1 are called bits.
A typical digital signal is shown in Fig.7.
The significant characteristics of a digital signal are :

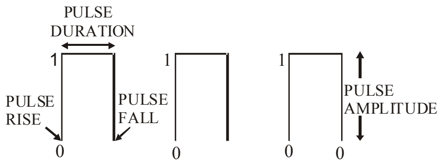


Figure 7

Pulse amplitude ; Pulse Duration or Pulse Width and Pulse Position, representing the time of rise and time of fall of the pulse amplitude, as shown in Fig.7.

Examples of digital messages are :
(i) letters printed in this book
(ii) listing of any data,
(iii) output of a digital computer,
(iv) Electronic transmission of a document at a distant place via telephone line i.e. FAX etc.

An analog signal can be converted suitably into a digital signal and vice-versa.
Note. As stated above, a digital signal is represented by binary digits 0 and 1 called bits. A group of bits is called a binary word or a byte. A byte made of 2 bits can give four code combinations : 00, 01, 10 ; 11.

4. TYPES OF COMMUNICATIONS SYSTEMS

There is no unique way of classifying communication systems. However, for the sake of convenience, we can classify them broadly on the basis of -
(i) nature of information source,
(ii) mode of transmission,
(iii) type of transmission channel used,
(iv) type of modulation employed, as detailed below :

(a) Based on nature of information source
(i) Speech transmission as in radio
(ii) Picture as well as speech transmission as in television
(iii) Facsimile transmission, as in FAX
(iv) Data transmission as in computers

(b) Based on mode of transmission
(i) Analog communication, where the modulating signal is analog. The carrier wave may be sinusoidal or in the form of pulses. For example, in telegraphy, telephony, radio network, radar, television network, teleprinting, telex etc.
(ii) Digital communicatoin, where the modulating signal is digital in nature. For example, Fax, mobile phone network, e-mail, teleconferencing, telemetry, communication satellites and global positioning system are all digital communication systems.

(c) Based on transmission channel
(i) Line communication
1. Two wire transmission line
2. Co-axial cable transmission
3. Optical fibre cable communication
(ii) Space communication

(d) Based on the type of modulation
(i) For sinusoidal continuous carrier waves, the types of modulation are :
1. Amplitude Modulation (AM)
2. Frequency Modulation (FM)
3. Phase Modulation

(ii) For pulsed carrier waves, the modes of modulation are :
1. Pulse Amplitude Modulation (PAM)
2. Pulse Time Modulation (PTM). It includes
– Pulse Position Modulation (PPM),
– Pulse Width modulation (PWM),
– Pulse Duration Modulation (PDM)
3. Pulse Code Modulation (PCM)

5. AN IMPORTANT STEP IN COMMUNICATIONS MODULATION AND ITS NEED

Suppose we wish to transmit an electrical signal in the audio frequency (AF) range (20 Hz to 20 kHz) over a long distance. We cannot do it, as such because of the following reasons :

1. Size of the antenna or aerial. An antenna or aerial is needed both for transmission and reception. Each antenna should have a size comparable to the wavelength of the signal, (atleast $\lambda/4$ in size), so that time variation of the signal is properly sensed by the antenna. For an audio frequency signal of frequency ν = 15 kHz, the wavelength, $\lambda = \frac{c}{\nu} = \frac{3\times10^8}{15\times10^3}$ = 20000 m. The length of the antenna = $\frac{\lambda}{4} = \frac{20000}{4}$ = 5000 metre. To set up an antenna of vertical height 5000 metre is practically impossible. Therefore, we need to use high frequencies for transmission.

2. Effective Power radiated by antenna. Theoretical studies reveal that power P radiated from a linear antenna of length l is

$$P \propto \frac{1}{l^2}$$

As high powers are needed for good transmission, l should be small i.e. antenna length should be small, for which wavelength λ should be small or frequency ν should be high.

3. Mixing up of signals from different transmitters. Suppose many people are talking at the same time. We just cannot make out who is talking what. Similarly, when many transmitters are transmitting baseband information signals simultaneously, they get mixed up and there is no way to distinguish between them. The possible solution is, communication at high frequencies and allotting a band of frequencies to each user. This is what is being done for different radio and T.V. broadcast stations.

All the three reasons explained above suggest that there is a need for transmissions at high frequencies. This is achieved by a process, called modulation, where in we superimpose the audio frequency baseband message or information signals (called the modulating signals) on a high frequency wave (called, the carrier wave). The resultant wave is called the modulated wave, which is transmitted.

In the process of modulation, some specific characteristic of the carrier wave is varied in accordance with the information or message signal.

The carrier wave may be
(i) Continuous (sinusoidal) wave, or
(ii) Pulse, which is discontinuous

A continuous sinusoidal carrier wave can be expressed as $E = E_0 \sin(\omega t + \phi)$.

Three distinct characteristics of such a wave are : amplitude (E_0), angular frequency (ω) and phase angle (ϕ). Any one of these three characteristics can be varied in accordance with the modulating baseband (AF) signal, giving rise to the respective Amplitude Modulation ; Frequency Modulation and Phase Modulation.

Notes. Phase modulation is not of much practical importance. We shall, therefore, confine ourselves to the study of amplitude and frequency modulations only. Again, the significant characteristics of a pulse are : Pulse Amplitude, Pulse Duration or Pulse Width and Pulse Position (representing the time of rise or fall of the pulse amplitude). Any one of these characteristics can be varied in accordance with the modulating baseband (AF) signal, giving rise to the respective, Pulse Amplitude Modulation (PAM), Pulse Duration Modulation (PDM) or Pulse Widhth Modulation (PWM) and Pulse Position Modulation (PPM).

6. AMPLITUDE MODULATION

When a modulating AF wave is superimposed on a high frequency carrier wave in a manner that the frequency of modulated wave is same as that of the carrier wave, but its amplitude is made proportional to the instantaneous amplitude of the audio frequency modulating voltage, the process is called amplitude modulation (AM).

Let the instantaneous carrier voltage (e_c) and modulating voltage (e_m) be represented by

$$e_c = E_c \sin \omega_c t \quad ....(1)$$
$$e_m = E_m \sin \omega_m t \quad ....(2)$$

Thus, in amplitude modulation, amplitude A of modulated wave is made proportional to the instantaneous modulating voltage e_m

i.e. $A = E_c + k\,e_m$ ....(3)

where k is a constant of proportionality.

In amplitude modulation, the proportionality canstant k is made equal to unity. Therefore, max. positive amplitude of AM wave is given by

$A = E_c + e_m = E_c + E_m \sin \omega_m t$ ....(4)

It is called top envelope

The maximum negative amplitude of AM wave is given by

$-A = -E_c - e_m$

$= -(E_c + E_m \sin \omega_m t)$ ....(5)

This is called bottom envelope

The modulated wave extends between these two limiting envelopes, and its frequency is equal to the unmodulated carrier frequency. Fig.8(a) shows the variation of voltage of carrier wave with time. Fig.8(b) shows one cycle of modulating sine wave and Fig.8(c) shows amplitude modulated wave for this cycle.

As is clear from Fig.8(c)

$$E_m = \frac{E_{max} - E_{min}}{2}$$

$$E_c = \frac{E_{max} + E_{min}}{2} \quad ....(6)$$

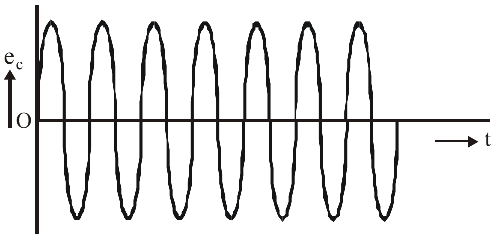


Fig.8(a) CARRIER WAVE

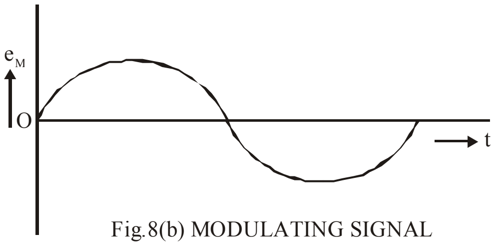


Fig.8(b) MODULATING SIGNAL

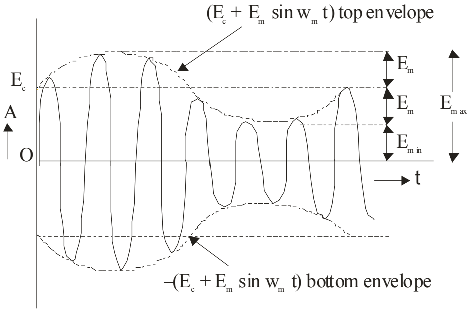


Fig.8(c) AMPLITUDE MODULATED WAVE

In amplitude modulation, the degree of modulation is cefined by a term, called modulation index or modulation factor or depth of modulation represented by m_a. It is equal to the ratio of amplitude of modulating signal to the amplitude of carrier wave i.e.

$$m_a = \frac{E_m}{E_c} = \frac{E_{max} - E_{min}}{E_{max} + E_{min}} \quad ....(7)$$

Obviously, modulation index (m_a) is a number lying between 0 and 1. Often, m_a is expressed in percentage and is called the percentage modulatoion. **Importance** of moduation index is that it determines the quality of the transmitted signal. When modulation index is small, veriation in carrier amplitude will be small. Therefore, audio signal being transmitted will be weak. As the modulataion index increases, the audio signal on reception becomes clearer.

6.1 Frequency Spectrum of AM wave

A detailed study of amplitude modulation reveals that the amplitude modulated wave consists of three discrete frequencies, as shown in Fig.9. Of these, the central frequency is the the carrier frequency (f_c), which has the highest amplitude. The other two frequencies are placed symmetrically about it. Both these frequencies have equal amplitudes-which never exceeds half the carrier amplitude. These frequencies are called side band frequencies.

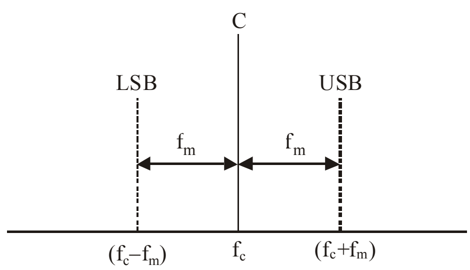


Figure 9

$f_{SB} = f_c \pm f_m$

$\therefore$ Frequency of lower side band is

$f_{LSB} = f_c - f_m$ ....(8)

and frequency of upper side band is

$f_{USB} = f_c + f_m$ ....(9)

Band width of amplitude modulated wave is

$= f_{USB} - f_{LSB}$

$= (f_c + f_m) - (f_c - f_m) = 2f_m$ ....(10)

Band width = twice the frequency of the modulating signal

6.2 Power and Current Relations in AM wave

Average power/cycle in the unmodulated carrier wave is

$$P_c = \frac{E_c^2}{2R} \quad ....(11)$$

where R is resistance (of antenna) in which power is dissipated.

It can be shown that total power/cycle in the modulated wave is

$$P_t = P_c\left(1+\frac{m_a^2}{2}\right) \quad ....(12)$$

$$\therefore \quad \frac{P_t}{P_c} = 1 + \frac{m_a^2}{2}$$

But $P_t = I_t^2 R$ and $P_c = I_c^2 R$

$$\therefore \quad \frac{I_t^2}{I_c^2} = \left(1+\frac{m_a^2}{2}\right)$$

$$\text{or} \quad \frac{I_t}{I_c} = \sqrt{1+\frac{m_a^2}{2}} \quad ....(13)$$

7. FREQUENCY MODULATION

When a modulating AF wave is superimposed on a high frequency carrier wave in such a way that the amplitude of modulated wave is same as that of the carrier wave, but its frequency is varied in accordance with the instantaneous value of the modulating voltage, the process is called frequency modulation (FM).

Let the instantaneous carrier voltage (e_c) and modulating voltage (e_m) be represented by

$e_c = E_c \sin \omega_c t$ ....(15)

$e_m = E_m \sin \omega_m t$ ....(16)

Fig.10(a) represents the variation of carrier voltage with time, and Fig.10(b) represents the variation of modulating AF voltage with time.

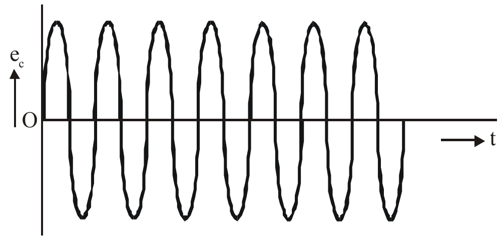


Fig.10(a) CARRIER WAVE

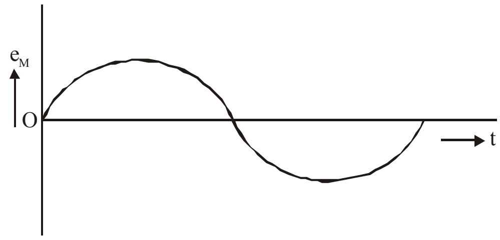


Fig.10(b) MODULATING SIGNAL

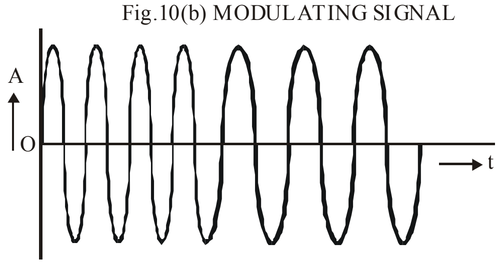


Fig.10(c) FM Wave (exaggerated)

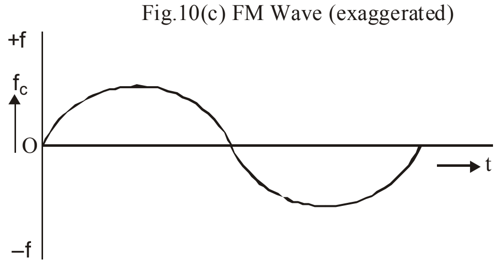


Fig.10(d) Frequency vs time in FM wave

In frequency modulation, the amount by which carrier frequency is varied from its unmodulated value ($f_c = \omega_c/2\pi$) is called the **deviation.** This deviation is made proportional to the instantaneous value of the modulating voltage. The rate at which the frequency variation takes place is equal to the modulating frequency. Fig.10(c) represents an exaggerated view of frequency modulated wave. Fig.10(d) shows the frequency variation with time in the FM wave. This is identical to the variation of the modulating voltage with time, Fig.10(b). Note that

(i) All signals having same amplitude will change the carrier frequency by the same amount, whatever be their frequencies

(ii) All modulating signals of same frequency, say 1 kHz, will change the carrier frequency at the same rate of 1000 times, per second-whatever be their individual amplitudes

(iii) The amplitude of the frequency modulated wave remains constant at all times, being equal to the amplitude of the carrier wave

If f is frequency of FM wave at any instant t and f_c is constant frequency of the carrier wave, then deviation (in frequency), $\delta = (f - f_c)$....(17)

By definition of frequency modulation,

$$\delta \propto e_m$$

or $\delta \propto E_m \sin \omega_m t$

$$\delta = k\, E_m \sin \omega_m t \quad \text{....(18)}$$

where k is a constant of proportionality, Using (17), we get

$$\delta = f - f_c = k\, E_m \sin \omega_m t$$

or $f = f_c + k\, E_m \sin \omega_m t$ ....(19)

The deviation will be maximum, when

$$(\sin \omega_m t)_{max} = \pm 1$$

$\therefore$ From (19), $f_{max} = f_c \pm k\, E_m$ ....(20)

or $d_{max} = f_{max} - f_c = \pm k\, E_m$ ....(21)

The **modulation index** (m_f) of a frequency modulated wave is defined as the ratio of maximum frequency deviation to the modulating frequency i.e.

$$m_f = \frac{\delta_{max}}{f_m} = \frac{\pm k\, E_m}{f_m} \quad \text{....(22)}$$

Clearly, modulating index increases, as modulating frequency (f_m) decreases. m_f has no units, it being the ratio of two frequencies. The instantaneous amplitude of frequency modulated wave is given by

$$A = A_0 \sin \theta$$

where θ is the function of carrier angular frequency (ω_c) and modulating angular frequency (ω_m). Infact,

$$\theta = \left(\omega_c t + \frac{\delta}{f_m} \sin \omega_m t\right) \quad \text{....(23)}$$

The **frequency spectrum** of FM wave is far more complex than the frequency spectrum of AM wave. Infact,

(i) The output of an FM wave consists of carrier frequency (f_c) and almost an infinite number of side bands, whose frequencies are ($f_c \pm f_m$), ($f_c \pm 2f_m$), ($f_c \pm 3f_m$),... and so on. The sidebands are thus separated from the carrier by f_m, $2f_m$, $3f_m$ ....etc i.e. they have a recurrence frequency of f_m.

(ii) The number of sidebands depends on the modulation index (m_f). The number of sidebands increases, when frequency deviation (δ) is increased, keeping (f_m) constant. Similarly, number of sidebands decreases, when frequency of modulating signal (f_m) is increased keeping frequency deviation constant

(iii) The sidebands are disposed symmetrically about the carrier. Further, sidebands at equal distances from the carrier have equal amplitudes.

(iv) As the distance of sidebands from carrier frequency increases, their amplitude decreases. Therefore, number of significant sideband pairs is limited

(v) In frequency modulated wave, the information (audio signal) is contained in the sidebands only. Since the sidebands are separated from each other by the frequency of the modulating signal (f_m), therefore,

Band width = $2n \times (f_m)$ ....(24)

where n is the number of the particular sideband pair.

8. COMPARISON OF AMPLITUDE F MODULATION AND FREQUENCY MODULATION

Following are some of the **advantages of frequency modulation** over the amplitude modulation :

(i) FM transmission is far more efficient compared to AM transmission. This is because amplitude of FM wave is constant, whatever be the modulation index. Therefore, transmitted power is constant. Amplifiers used in FM transmission handle constant power and are more efficient. Further, all the power transmitted in FM is useful, whereas in AM transmission, most of the power goes waste in the transmitted carrier, which contains no useful information.

(ii) FM reception is almost immune to noise as compared to AM reception. This is because noise is a form of amplitude variation in transmitted signal. Therefore, by using amplitude limiters in the FM receivers, we can almost eliminate noise. Noise can also be reduced by increasing the frequency deviation in FM wave. This feature is not available in the AM wave.
Further, FM broadcasts operate in VHF and UHF frequency ranges—where the noise is much less than in MF and HF ranges for AM broadcasts.

(iii) With the use of space wave in FM broadcasts, radius of operation is limited to slightly more than the line of sight transmission. This reduces the chances of adjacent channel interference.
The chances of interference reduce further by standard frequency allocations by the International Radio Consultative Committee (IRCC). This provides a guard band between commercial FM stations.
Some of the **disadvantages of frequency modulation** are :

(i) The channel width required in FM transmission is almost 10 times as large as that needed in AM transmission. Therefore, much wider frequency channel is required in FM transmission

(ii) The equipment used in FM transmission and reception is far more complex than the equipment used in AM transmission and reception

(iii) As FM reception is limited to 'line of sight', the area of reception of FM is much smaller than that for AM
Range of frequencies allotted for commercial FM radio and T.V. broadcasts is given in Table 10.1 :

TABLE 10.1

Nature of Broadcast	Frequency Band
FM radio	88–108 MHz
VHF T.V	47–230 MHz
UHF T.V	470–960 MHz

9. PROPAGATION OF ELECTROMAGNETIC WAVE

An antenna at the transmitter in communication using radio waves, radiates the electromagnetic waves which travel through space and reach the receiving antenna at the otehr end. Several factors affect the propagation of em waves and the path, they follow.

9.1 TRANSMISSION MEDIUM OR COMMUNICATION CHANNEL

The **transmission medium** or **communication channel** is a link through which information/message signal may propagate from the source to the destination, without any noise or distortion. It is a sort of electronic roadways along which signals travel.
Broadly, transmission media have been divided into two types :
(i). Guided Transmission Medium
(ii) Unguided Transmission Medium

(i) Guided Transmission Medium. It is that communication medium or channel which is used in signal communication, for point to point contact between the transmitter and receiver. For example, parallel wire lines, twisted pair and co-axial cable are guided transmission media. Optical fibres are other examples of guided transmission medium. Guided transmission medium is used in **line communication.**

(ii) Unguided Transmission Medium. It is that communication medium which is used, where there is no point to point contact between the transmitter and receiver. Free space is an example of unguided transmission medium. It is used in **space communication** and **satellite communication.**
The characteristics and quality of transmission medium depend upon
(a) nature of transmission medium,
(b) nature of signal
Thus, basically there are two types of communications (1) Space communication (2) Line communication.

9.2. GROUND WAVE

The antennas should have a size comparable to the wavelength λ of the signal (at least – $\lambda/4$) to radiate signals with high efficiency. At longer wavelengths (i.e., at lower frequencies), the antennas have large physical size and they are located on or very near to the ground. In standard AM broadcast, ground based vertical the propagation of the signal. The mode of propagation is called surface wave propagation and the wave glides over the surface of the earth. A wave induces current in the ground over which it passes and it is attenuated as a result of absorption of energy by the earth. The attenuation of surface waves increases very rpidly with increase in frequency. The maximum range of coverage depends on the transmitted power and frequency (less than a few MHz).

Table:- Different layers of atmosphere and their interaction with the propagating electromagnetic waves

Name of the Stratum (layer)		Approximate height over earth's surface	Exists during	Frequencies most affected
Troposphere		10 km	Day and night	VHF (up to several GHz)
D (part of stratosphere)	Parts of ionosphere	65-75 km	Day only	Reflects LF, absorbs MF and HF to some degree
E (part of stratosphere)		100 km	Day only	Helps surface waves, reflects HF
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
F_2 (Thermosphere)		300 km at night, 250-400 km during daytime	Day and night	Efficiently reflects HF waves, particularly at night

9.2 BEHAVIOUR OF ATMOSPHERE TOWARDS ELECTROMAGNETIC WAVE

The behaviour of atmosphere is different for electromagnetic waves of different frequencies. The atmosphere is transparent to electromagnetic waves of visible region of wavelength range 4000 Å to 8000 Å, as we can see the sun and the stars through it clearly. The electromagnetic waves belonging to infrared region of wavelength range 8×10^{-7} m to 3×10^{-5} m are not allowed to pass through atmosphere rather they get reflected by atmosphere. The ozone layer of earth's atmosphere blocks the electromagnetic waves of ultraviolet region of wavelength range 6 Å to 4000 Å.

The behaviour of earth's atmosphere towards electromagnetic waves of wavelength 10^{-3} m and higher is of special interest in space communication. The lower part of atmosphere is more or less transparent to electromagnet waves of wavelength 20 m and higher used in radiocommunication but the top most layer, the ionosphere does not allow these waves to penetrate but reflects, above 40 MHz, the ionosphere bends any incident electromagnetic wave but dies not reflect it back towards earths.

9.4 RADIOWAVES

The radiowaves are the electro-magnetic waves of frequency ranging from few kilo hertz to nearly few hundred mega hertz (i.e. 3 kHz to about 300 GHz, where 1 GHz = 109 Hz). These waves are used in the field of radio communication. With reference to the frequency range and wavelength range the radiowaves have been divided into following categories ; See Table 12-1.

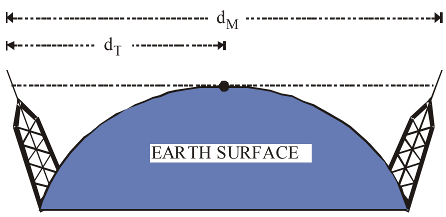
Table 12-1

S. No.	Frequency band	Frequency range	Wavelength range	Main use
1	Very-Low Frequency (VLF)	3 kHz to 30 kHz	10 km to 100 km	Long distance point to point communication
2	Low Frequency (LF)	30 kHz to 300 kHz	1 km to 10 km	Marine and navigational purposes
3	Medium Frequency (MF)	300 kHz to 3 MHz	100 m to 1 km	Marine and broadcasting purposes
4	High Frequency (HF)	3 MHz to 30 MHz	10 m to 100 m	Communication of all types
5	Very-High Frequency (VHF)	30 MHz to 300 MHz	1 m to 10 m	T.V., Radar and air navigation
6	Ultra-High-Frequency (UHF)	300 MHz to 3000 MHz	10 cm to 1 m	Radar and microwave commnication
7	Super-High-Frequency (SHF)	3 GHz to 30 GHz	1 cm to 10 cm	Radar,radio relays and navigation purposes
8	Extremely-High-Frequency (EHF)	30 GHz to 300 GHz	1 mm to 1 cm	Optical fibre communication

9.5 SPACEWAVE PROPAGATION

It is that mode of propagation in which the radiowaves emitted from the transmitting antenna reach the receiving antenna through space. These radiowaves are called space waves. The space waves are the radiowaves of frequency range from 54 MHz to 4.2 GHz. The space waves travel in straight line from transmitting antenna to receiving antenna.

Therefore, the space waves are used for the **line of sight communication** as well as for the **satellite communication.** The space wave propagation is used for **television broadcast, microwave link** and **satellite communication.**

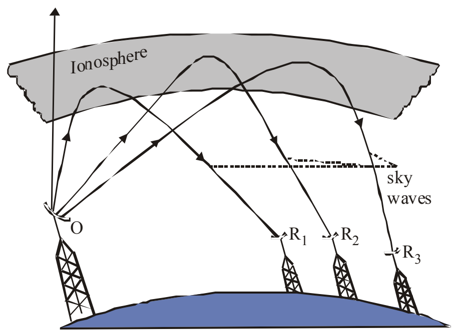


If the frequency of the radiowaves is greater than 54 MHz ; then the waves can not travel along the surface of earth as they get absorbed by the earth. Hence, their propagation cannot be like ground wave propagation. Morcover, these waves cannot be reflected by ionosphere, hence their propagation cannot be like sky wave propagation. The communication through space wave between transmitter and receiver is limited to line of sight path. The line of sight communication is limited by (i) the line of sight distance and (ii) the curvature of the earth. The space waves following the line of sight propagation get blocked at some point by the curvature of the earth as illustrated in Fig.14.

Here, d_T is called the radio horizon of the transmitting atenna, d_M is called the maximum line of sight distance between the two antennas. The line of sight distance is that distance between transmitting antenna and receiving antenna at which they can see each other. It is also called **range of communication (d_M).** The range of space wave communication can be increased by increasing the heights of transmitting antenna and receiving antenna.

9.6 SKY WAVE

Long distance communication can be achieved by ionospheric reflection of radio waves back towards the earth. Sky wave propagation and is used by short wave broadcast services. The ionospheer is so called because fo the presence of the large number of ions or charged particles. It extends from a height of ~ 65 km to about 400 km above the earth's surface. Ionisation occurs due to the absorption of the ultraviolet and other high energy radiation coming from the sun by air molecules. The ionosphere is further subdivided into several layers, the details of which are given in table 3. The degree of ionisaton varies with the height. The density of atmosphere decreases with height. At great heights, the solar rdiation is intense but there are frew molecules to be ionised. Close to the earth, even though the molecular concentration is very high, the radaition intensity is low so that the ionisation is again low. However, at some intermediate heights, there occurs a peak of ionisation density. The ionospheric 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. These phenomena are shown in the figure. The phenomenon of bending of em waves so that they are diverted towards the erath is similar to total internal reflection in optics.



IMPORTANT TERMS FOR SKY WAVE PROPAGATION

(a) Plasma frequency and critical frequency. Plasma frequency is an important parameter in radiocommunication via the ionosphere. The plasma frequency ν is related to the electron density N (in m^{-3}) of a layer of ionosphere by a relation $\nu = 9$

The plasma frequency at the peak of a layer is called **critical frequency** (ν_c).

Critical frequency ν_c. It is that highest frequency of radio wave, which when sent straight (i.e. normally) towards the layer of ionosphere gets reflected from ionosphere and returns to the earth. If the frequency of the radiowave is more than critical frequency, it will not be reflected by ionosphere. The critical frequency of a sky wave for reflection from a layer of atmosphere is given by $\nu_c = 9(N_{max})^{1/2}$, where N_{max} is the maximum number density of electron/m^3. The number density per cubic metre of electrons for D, E, F_1 and F_2 layers are 10^9, 10^{11}, 5×10^{11} and 8×10^{11} respectively.

(b) Maximum usable frequency (MUF). It is that highest frequency of radio waves which when sent at some angle towards the ionosphere, gets reflected from that and returns to the earth.

Quantitatively, MUF = = ν_c sec i

where i is the angle between normal and the direction of incidence of waves. The frequency normally used for ionosphere transmission is known as **optimum working frequency** (OWF), which is taken to be 15% of MUF.

(c) Skip distance. It is the smallest distance between the transmitting antenna and the point R_v where the sky wave of a fixed frequency, but not more than critical frequency is first received after reflection from ionosphere. In Fig.15, OR_1 = skip distance. If the angle of incidence of sky wave on the layer of ionosphere is large, then after reflection they will be reaching the earth at longer distance from the transmitting antenna. It means, the larger is the angle of incidence of sky wave, the greater is the value of skip distance on the surface of earth. This shows that the transmission path of sky waves is limited by the skip distance. The skip distance is given by the relation

$$D_{skip} = 2h\sqrt{\left(\frac{\nu_{max}}{\nu_c}\right)^2 - 1}$$

where h is the height of reflecting layer of atmosphere, ν_{max} is the maximum frequency of electromagnetic waves and ν_c is the critical frequency for that layer of ionosphere.

Note. Skip zone in radio communication is that range where there is no reception of either ground wave of sky wave.

(d) Fading. It is the variation in the strength of a signal at a receiver due to interference of waves. Fading is more at high frequencies. Fading causes an error in data transmission and retrieval.

The signals received due to sky wave propagation are subjected to **fading** in which the strength of the signal varies with time. It is so because, at the receiver, a large number of waves reach, following different number of paths.

(e) Refractive index μ of a layer in sky wave propagation is given by

$$\mu = \sqrt{1 - \frac{81.45\ N}{\nu^2}}$$

where N is the number density of electrons/m^3 of the layer of atmosphere under study and ν is the frequency of electromagnetic wave in Hz).

Relative permittivity or dielectric constant of the layer of atmosphere under study is given by

$$\epsilon_r = 1 - \frac{81.45\ N}{\nu^2}$$

10. RELATION BETWEEN COVERAGE DISTANCE AND HEIGHT OF TRANSMITTING ANTENNA

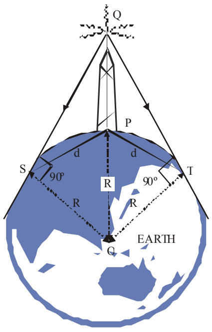
Suppose PQ is a T.V. transmitting angenna of height h located at P on the surface of earth. Due to finite curvature of earth, the T.V. signal transmitted from Q cannot be received beyond the tangent points T and S on earth (Fig.16). The effective reception range of the T.V. broadcast is essential the region from S to T on earth which is covered by the line of sight during T.V. transmission.

Let SP = TP = d (distance to the horizon). This distance is limited by the curvature of earth. Therefore, The T.V. signals will be received on earth in a circle of radius d.

Here, R = radius of earth

= OS = OT = OP; PQ = h

or d = $\sqrt{2hR}$

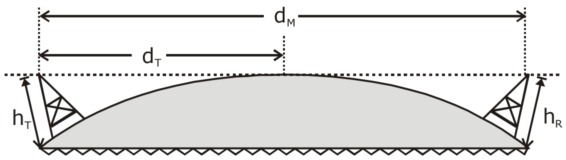


For T.V. signals, area covered

$= \pi d^2 = \pi\ 2Rh$

Population covered = population density × area covered

Hence maximum line-of-sight distance between two antennas will be calculated as follows



$$d_M = \sqrt{2R.h_T} + \sqrt{2R.h_R}$$

where d_M : maximum line-of-slight distance between the two antennas

d_T : Radio horizon of transmitting antenna

h_T : Height of transmitting antenna

h_R : Height of receiving antenna

Example 1 : A transmitting antenna at the top of a tower has a height 32 m and the height of the receiving antenna is 50 m. What is the maximum distance between them for satisfactory communication in the line of sight mode. Given radius of earth 6.4×10^5 m.

Sol. $d = \sqrt{2Rh_T} + \sqrt{2Rh_R}$

$d = \sqrt{2 \times 6.4 \times 10^6 \times 32} + \sqrt{2 \times 6.4 \times 10^6 \times 50}$

$= 64 \times 10^2 \times \sqrt{10} + 8 \times 10^3 \times \sqrt{10}$ m

$= 144 \times 10^2 \times \sqrt{10}$ m = 45.5 km

Exercise - 1 Objective Problems

1. A digital signal –
(A) is less reliable than analog signal
(B) is more reliable than analog signal
(C) is equally reliable as the analog signal
(D) none of the above

2. Modern communication systems use –
(A) analog circuits
(B) digital circuits
(C) combination of analog and digital circuits
(D) none of the above

3. 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

4. The process of changing some characteristic of a carrier wave in accordance with the intensity of the signal is called –
(A) amplification (B) rectification
(C) modulation (D) none of these

5. 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) 30 m
(C) 300 m (D) 3000 m

6. The types of modulation which are possible, are –
(A) one only (B) two only
(C) three only (D) none of these

7. In amplitude modulation –
(A) only the amplitude is changed but frequency remains same
(B) both the amplitude and frequency change equally
(C) both the amplitude and frequency change unequally
(D) none the these

8. Modulation factor determines –
(A) only the strength of the transmitted signal
(B) only the quality of the transmitted signal
(C) both the strength and quality of the signal
(D) none of the above

9. Degree of modulation –
(A) can take any value
(B) should be less than 100%
(C) should exceed 100%
(D) none of these

10. If the maximum and minimum voltages of an AM wave are $V_{max.}$ and $V_{min.}$ respectively then modulation factor –

(A) $m = \frac{V_{max.}}{V_{max.} + V_{min.}}$ (B) $m = \frac{V_{min.}}{V_{max.} + V_{min.}}$

(C) $m = \frac{V_{max.} + V_{min.}}{V_{max.} - V_{min.}}$ (D) $m = \frac{V_{max.} - V_{min.}}{V_{max.} + V_{min.}}$

11. The AM wave contains three frequencies, viz.:
(A) $\frac{f_c}{2}, \frac{f_c + f_s}{2}, \frac{f_c - f_s}{2}$
(B) $2f_c$ $2(f_c + f_s)$, $2(f_c - f_s)$
(C) f_c, $(f_c + f_s)$, $(f_c - f_s)$
(D) f_c, f_c, f_c

12. In AM wave, carrier power is given by –

(A) $P_c = \frac{2E_c^2}{R}$ (B) $P_c = \frac{E_c^2}{R}$

(C) $P_c = \frac{E_c^2}{2R}$ (D) $P_c = \frac{E_c^2}{\sqrt{2}R}$

13. Fraction of total power carried by side bands is given by –

(A) $\frac{P_s}{P_T} = m^2$ (B) $\frac{P_s}{P_T} = \frac{1}{m^2}$

(C) $\frac{P_s}{P_T} = \frac{2+m^2}{m^2}$ (D) $\frac{P_s}{P_T} = \frac{m^2}{2+m^2}$

14. Which of the following is/are the limitations of amplitude modulation?
(A) Clear reception
(B) High efficiency
(C) Small operating range
(D) Good audio quality

15. What is the frequency above which radiation of electrical energy is particle ?
(A) 0.2 kHz (B) 2 kHz
(C) 20 kHz (D) 20 kHz

16. What type of modulation is employed in India for radio transmission?
(A) Pulse modulation
(B Frequency modulation
(C) Amplitude modulation
(D) None of these

17. 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) 10 kHz (C) 20 kHz (D) 200 KHz

Exercise - 2 Objective Problems

1. Polarization in electromagnetic wave is caused by -
(A) reflection
(B) refraction
(C) transverse nature of e.m. waves
(D) longitudinal nature of e.m. waves

2. The velocity of electromagnetic waves in a dielectric medium ($\epsilon_r = 4$, $\mu_r = 4$) is -
(A) 3×10^8 metre/second
(B) 1.5×10^8 metre/second
(C) 6×10^8 metre/second
(D) 7.5×10^7 metre/second

3. If refractive index of core & cladding are μ_1 & μ_2 respectively then :
(A) $\mu_1 > \mu_2$ (B) $\mu_2 > \mu_1$
(C) $\mu_1 = \mu_2$ (D) None of these

4. If critical frequency is 40 MHz then calculate maximum density of electron-
(A) 20×10^{12} (B) 20×10^{14}
(C) 20×10^{10} (D) None of these

5. Communication satellites revolve at a height of (over earth's surface) ;
(A) 6 Re (B) 5 Re
(C) 7 Re (D) None of these

6. The distance between consecutive maxima and minima is given by -
(A) $\lambda / 2$ (B) 2λ
(C) λ (D) $\lambda / 4$

7. Through which mode of propagation, the radio waves can be sent from one place to another
(A) Ground wave propagation
(B) Sky wave propagation
(C) Space wave propagation
(D) All of them

8. The frequencies of electromagnetic waves employed in space communication vary over a range of -
(A) 10^4 Hz to 10^7 Hz (B) 10^4 Hz to 10^{11} Hz
(C) 1 Hz to 10^4 Hz (D) 1 Hz to 10^{11} Hz

9. The wavelength of electromagnetic waves employed for space communication lie in the range of -
(A) 1 mm to 30 m (B) 1 mm to 300 m
(C) 1 mm to 3 km (D) 1 mm to 30 km

10. The radio waves of frequency 300 MHz to 3000 MHz belongs to -
(A) High frequency band
(B) Very high frequency band
(C) Ultra high frequency band
(D) Super high frequency band

11. 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

12. In which frequencies range space waves are normally propagated -
(A) HF (B) VHF
(C) UHF (D) SHF

13. For television broadcasting, the frequency employed is normally -
(A) 30 – 300 M Hz (B) 30 – 300 G Hz
(C) 30 – 300 K Hz (D) 30 – 300 Hz

14. The sound waves after being converted into electrical waves are not transmitted as such because -
(A) they travel with the speed of sound
(B) the frequency is not constant
(C) they are heavily absorbed by the atmosphere
(D) the height of antenna has to be increased several times

15. The process of superimposing signal frequency (i.e. audio wave) on the carrier wave is known as -
(A) transmission (B) reception
(C) modulation (D) detection

16. In an amplitude modulated wave for audio-frequency of 500 cycles/second, the appropriate carrier frequency will be -
(A) 50 cycles/sec (B) 100 cycles/sec
(C) 500 cycles/sec (D) 50,000 cycles/sec

17. The T.V. transmission tower in Delhi has a height of 240 m. The distance, up to which the broadcast can be received, (taking the radius of earth to be 6.4×10^6 m) is -
(A) 100 km (B) 60 km
(C) 55 km (D) 50 km

Exercise - 3 Previous Year Problems | JEE MAIN

1. This question has Statement-1 and Statement-2. Of the four choices given after the statements, choose the one that best describes the two statements. **[AIEEE-2011]**

Statement-1 :
Sky wave signals are used for long distance radio communication. These signals are in general, less stable than ground wave signals.

Statement -2 :
The state of ionosphere varies from hour to hour, day to day and season to season.

(A) Statement -1 is true, Statement -2 is false
(B) Statement -1 is true, Statement -2 is true and Statement -2 is the correct explanation of Statement -1.
(C) Statement -1 is true, Statement -2 is true and Statement – 2 is **not** the correct explanation of Statement – 1.
(D) Statement -1 is false, Statement -2 is true.

2. Which of the following four alternatives is not correct ? We need modulation- **[AIEEE-2011]**
(A) to reduce the time lag between transmission and reception of the information signal
(B) to reduce size of antenna
(C) to reduce the fractional band width, that is, the ratio of the signal band width to the centre frequency
(D) to increase the selectivity

3. 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 upto which it can detect object located on the surface of the earth **[AIEEE-2012]**
(Radius of earth = 6.4×10^6 m) is-
(A) 16 km (B) 40 km
(C) 64 km (D) 80 km

4. Choose the correct statement: **[AIEEE-2016]**
(A) In amplitude modulation the frequency of the high frequency carrier wave is made to vary in proportion to the amplitude of the audio signal.
(B) In frequency modulation the amplitude of the high frequency carrier wave is made to vary in proportion to the amplitude of the audio signal.
(C) In frequency modulation the amplitude of the high frequency carrier wave is made to vary in proportion to the frequency of the audio signal.
(D) In amplitude modulation the amplitude of the high frequency carrier wave is made to vary in proportion to the amplitude of the audio signal.

5. In amplitude modulation, sinusoidal carrier frequency used is denoted by ω_c and the signal frequency is denoted by ω_m. The band width $(\Delta\omega_m)$ of the signal is such that $\Delta\omega_m << \omega_c$. Which of the following frequencies is not contained in the modulated wave? **[AIEEE-2017]**
(A) $\omega_c - \omega_m$ (B) ω_m
(C) ω_c (D) $\omega_m + \omega_c$

6. 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 ? **[AIEEE-2018]**
(A) 2×10^6 (B) 2×10^3
(C) 2×10^4 (D) 2×10^5

ANSWER KEYS

Exercise - 1 Objective Problems

1.	B	**2.**	B	**3.**	B	**4.**	C	**5.**	C	**6.**	C	**7.**	A
8.	C	**9.**	B	**10.**	D	**11.**	C	**12.**	C	**13.**	D	**14,**	C
15.	C	**16.**	C	**17.**	B								

Exercise - 2 Objective Problems

1.	C	**2.**	D	**3.**	A	**4.**	A	**5.**	A	**6.**	D	**7.**	D
8.	B	**9.**	D	**10.**	C	**11.**	C	**12.**	C	**13.**	A	**14.**	C
15.	C	**16.**	D	**17.**	C								

Exercise - 3 Previous Year Problems

1.	D	**2.**	A	**3.**	D	**4.**	**D**	**5.**	**B**	**6.**	**D**