MAR GREGORIOS COLLEGE
OF ARTS & SCIENCE

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DEPARTMENT OF ELECTRONICS & COMMUNICATION SCIENCE

SUBJECT NAME: BASIC PHYSICS-II

SUBJET CODE: TBG4A

SEMESTER: IV

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BASIC PHYSICS II

UNIT – 1

OPTICS: Interference – Newton's rings – Measurement of wavelength and radius of curvature by Newton's rings with theory – Diffraction – Elementary theory of formation of spectra by transmission grating (normal incidence) – Determination of wavelength – Polarization – Optical activity – Brewster's law – Determination of specific rotatory power – Half shade polarimeter – Uses of polarized light.

UNIT – 2

MODERN PHYSICS: Photo electricity: Photoelectric emission – Einstein's theory – Millikan's experiment – Photoelectric cell – Photovoltaic cell – Photoconductive cell.

NUCLEAR PHYSICS :Properties of nuclei – size, charge, mass & spin – Binding Energy – Nuclear fission and fusion – liquid drop model – Semi empirical mass formula – Shell model – magic numbers.

RADIO ACTIVITY: Natural radioactivity – Artificial radioactivity – Radio isotopes – Uses of radio isotopes – Nuclear reaction – Q value of a reaction.

UNIT 3

LASER PHYSICS – Introduction- Principle of spontaneous emission and stimulated emission. Population inversion, pumping. Eienstein's A and B coefficients-derivation. Types of Lasers- Ruby Laser, Nd-YAG, Semiconductor lasers-Applications of lasers.

UNIT 4

MEDICAL PHYSICS – Doppler effect – Blood flow meter – Determination of upward and downwardtransit time – A-scan, B-scan and M-scan – X-rays – Introduction – Units of X-rays – Diagnostictechnologies of X-rays – Radiography.

UNIT 5

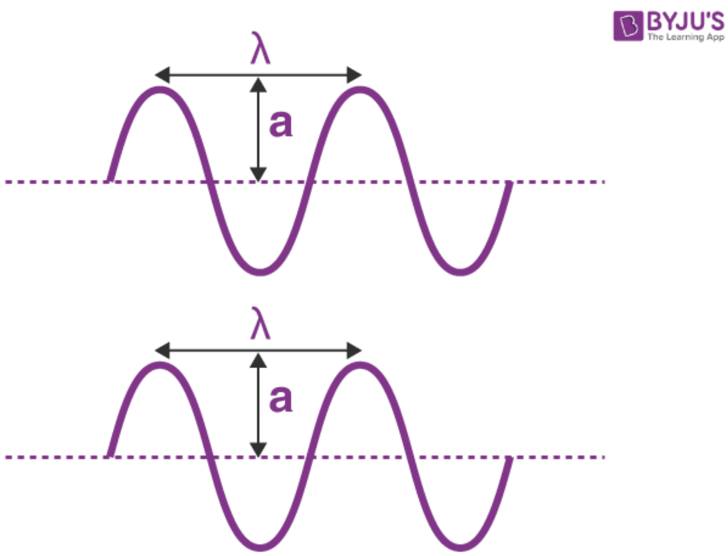
FIBER OPTICS – Introduction – Principle and structure of optical fibers – Propagation of light throughoptical fibers – types of optical fibers – Optical fiber communication system (block diagram) – FiberOptic Sensors – Medical Applications of Optical fibers- Endoscope- Engineering Applications of Opticalfibers- Telecommunications-Computer Networks- Cable television – Advantages.

UNIT – 1- OPTICS

Interference

Interference is a natural phenomenon that happens at every place and at every moment. Yet we don't see interference patterns everywhere. Interference is the phenomenon in which two waves superpose to form the resultant wave of the lower, higher or same amplitude. The most commonly seen interference is the optical interference or light interference. This is because light waves are randomly generated every which way by most sources. This means that light waves coming out of a source do not have a constant amplitude, frequency or phase.The most common example of interference of light is the soap bubble which reflects wide colours when illuminated by a light source.Example, incandescent bulbs generate a wide range of frequencies of light, including all colours of the rainbow. Moreover, the light coming out of the bulb is randomly generated every moment in all directions. This means that the starting point of the wave generated may be a maximum, a minimum or any point in between. There is no way of predicting which phase the wave will start. Such a source is said to be incoherent.

Coherent Sources



Two sources are said to be coherent when the waves emitted from them have the same frequency and constant phase difference.Interference from such waves happen all the time, the randomly phased light waves constantly produce bright and dark fringes at every point. But, we cannot see them since they occur randomly. A point that has a dark fringe at one moment may have a bright fringe at the next moment. This cancels out the effect of the interference effect, and we see only an average brightness value. The interference is not said to be sustained since we cannot observe it.

Characteristics of Coherent Sources

Coherent sources have the following characteristics:

1. The waves generated have a constant phase difference
2. The waves are of a single frequency

Coherent Source Example

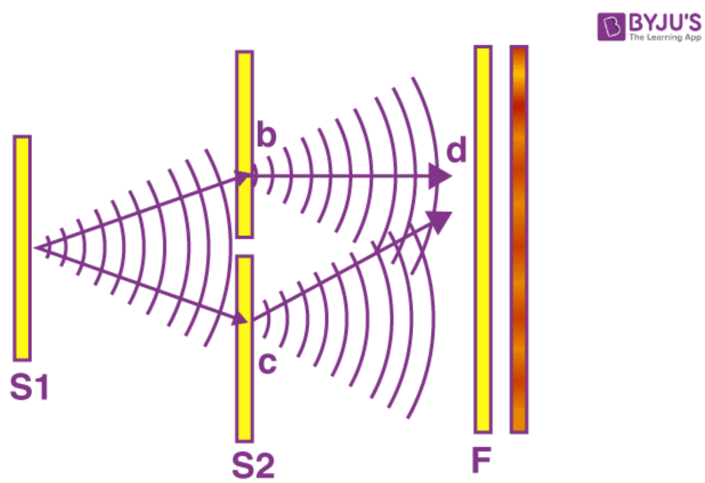
- Laser light is an example of coherent source of light. The light emitted by the laser light has the same frequency and phase.
- Sound waves are another example of coherent sources. The electrical signals from the sound waves travel with the same frequency and phase.

Types of Interference

Interference of light waves can be either constructive interference or destructive interference.

- **Constructive interference:** Constructive interference takes place when the crest of one wave falls on the crest of another wave such that the amplitude is maximum. These waves will have the same displacement and are in the same phase.
- **Destructive interference:** In destructive interference the crest of one wave falls on the trough of another wave such that the amplitude is minimum. The displacement and phase of these waves are not the same.

Young's Double Slit Experiment



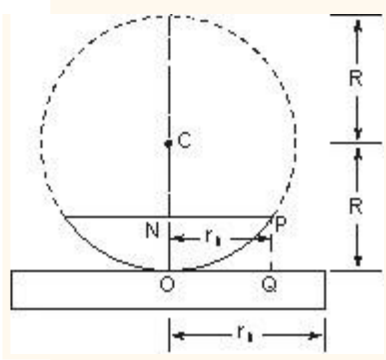
The great scientist Young's performed an experiment to prove the wave nature of light by explaining the phenomenon of interference of light. In the Young's double slit experiment, two coherent sources were generated using diffracted light from a single slit. Note that the waves must have a constant phase difference, so the two slits need not be placed symmetrically from the first slit to observe an interference pattern. Lasers are commonly used as coherent sources and use a phenomenon called Simulated Emission to generate highly coherent light. Small sources of light are at least partially coherent. This is why we can observe interference patterns on soap bubbles and appreciate the iridescence of butterfly wings. While sunlight is incoherent overall, small portions on small areas are generally partially coherent.

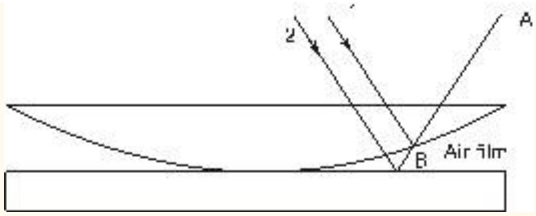
Conditions for Interference of Light Waves
For sustained interference of light to occur, the following conditions must be met:

1. Coherent sources of light are needed.
2. Amplitudes and intensities must be nearly equal to produce sufficient contrast between maxima and minima.
3. The source must be small enough that it can be considered a point source of light.
4. The interfering sources must be near enough to produce wide fringes.
5. The source and screen must be far enough to produce wide fringes.
6. The sources must emit light in the same state of polarization.
7. The sources must be monochromatic.

NEWTON'S RINGS

When a plane-convex lens of large focal length is placed as a plane glass plate, A thin film of air is formed between the lower surface of the plate. The thickness of the air film is very small at the point of contact and gradually increased from the centre upwards. If a monochromatic light is allowed to fall normally on this film, a set of alternate dark and bright fringes will be seen in the film. The fringes are concentric circle with their centre dark. These circles or rings are called Newton Rings.Newton Rings are formed as a result of interference between light wave reflected from the upper and lower surfaces of the air film.





Newton's Rings by Reflected Light

Suppose the radius of curvature of the lens is R and the thickness of the air film is 't' at a distance OQ=r, from the point of contact O. The effective path difference between the interfering rays is

$$2\mu t\, cosr + \frac{\lambda}{2}$$

For the bright fringes

$$2\mu t\, cosr + \frac{\lambda}{2} = n\lambda$$

$$2\mu t\, cosr = (2n-1)\frac{\lambda}{2} \qquad \ldots\ldots\ldots(1)$$

For μ=1 and for normal incidence r=0
So,

$$cosr = 1$$

$$2t = (2n-1)\frac{\lambda}{2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

For the dark rings

$$2\mu t \cos r + \frac{\lambda}{2} = (2n+1)\frac{\lambda}{2}$$

$$2\mu t \cos r = n\lambda$$

$$again\ for\ \mu = 1\ and\ \cos r = 1$$

$$2t = n\lambda \qquad \ldots\ldots\ldots(3)$$

It is clear that a bright or dark fringe of any order n depend upon the thickness of the air film. Since t is constant along a circle with its centre at the point of contact, the fringe are in the form of concentric circle.

Diameter of Bright Rings

$Let\ r_n\ be\ the\ radius\ of\ newton\ rings\ corresponding\ to\ a\ point\ P\ where\ the\ firm\ thickness\ is\ t.$

$From\ the\ figure$

$$(PN)^2 = ON \times NE = ON \times (2R - ON)$$

$$(PN)^2 = PQ \times (2R - PQ)$$

$$(PN)^2 = T(2R - t) = 2Rt - t^2$$

$$r_n^2 = 2Rt$$

$$2t = \frac{r_n^2}{R} \qquad \ldots\ldots\ldots\ldots(4)$$

Substituting the value of t in eqn. (2)

For bright rings

$$\frac{r_n^2}{R} = (2n-1)\frac{\lambda}{2}$$

$$r_n^2 = \frac{(2n-1)}{2}\lambda R$$

$$r_n = \sqrt{\frac{(2n-1)}{2}\lambda R} \qquad \dots\dots\dots\dots(5)$$

and $D_n = 2r_n$ *where D is diameter of nth bright ring.*

So from eqn. 5

$$D_n^2 = 2(2n-1)\lambda R$$

$$D_n = \sqrt{2\lambda R}\,\sqrt{(2n-1)}$$

$$D_n \propto \sqrt{(2n-1)}$$

Thus the diameters of bright rings are proportional to the square root of the odd number

$$D_1 = \sqrt{1}\,, D_2 = \sqrt{3}\,, D_3 = \sqrt{5}$$

The separations between successive rings are 0.732:0.504:0.410

Diameter of Dark Rings

From equation (3) and (4)

$$\frac{r_n^2}{R} = n\lambda$$

$$r_n = \sqrt{nR\lambda}$$

If D is the diameter of dark ring

$$D_n = 2r_n = 2\sqrt{nR\lambda} = \sqrt{4n\lambda R}$$

$$D_n \propto \sqrt{n}$$

Thus the diameters of dark ring are proportional to the square root of natural number

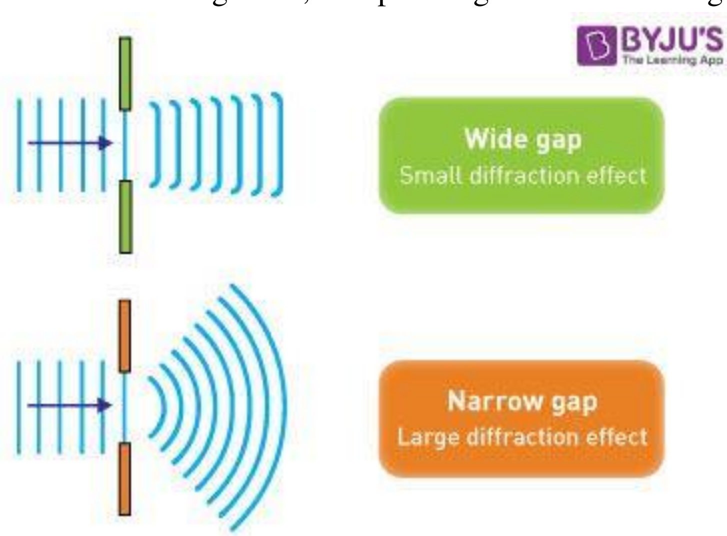
$$D_1 = \sqrt{1}, D_2 = \sqrt{2}, D_3 = \sqrt{3}\ldots\ldots\ldots$$

Diffraction :

Diffraction of light is defined as the bending of light around corners such that it spreads out and illuminates areas where a shadow is expected. In general, it is hard to separate diffraction from interference since both occur simultaneously. The silver lining which we witness in the sky is caused due to diffraction of light. When the sunlight passes through or encounters the cloud, a silver lining is seen in the sky.When the double-slit in Young's experiment is replaced by a single narrow slit, a broad pattern with a bright region at the centre is seen. On both sides of the centre, there are alternating dark and bright regions. The intensity becomes weaker away from the centre.

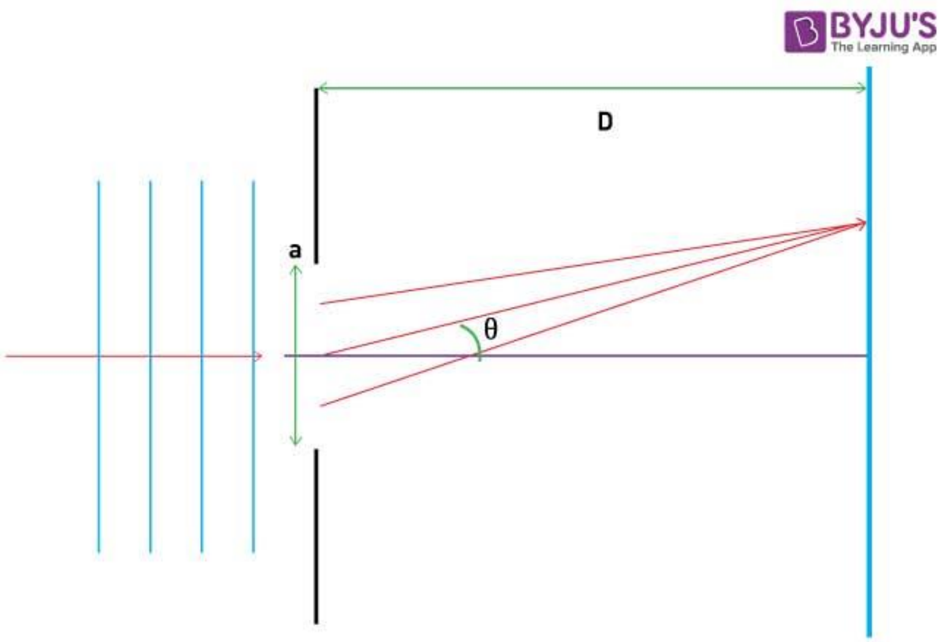
Single Slit Diffraction:

In the single-slit diffraction experiment, we can observe the bending phenomenon of light or diffraction that causes light from a coherent source to interfere with itself and produce a distinctive pattern on the screen called the diffraction pattern. Diffraction is evident when the sources are small enough that they are relatively the size of the wavelength of light. You can see this effect in the diagram below. For large slits, the spreading out is small and generally unnoticeable.

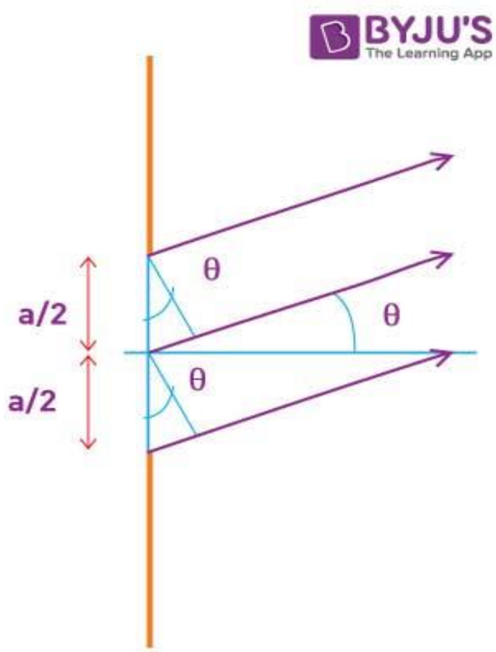


Single Slit Diffraction Formula

We shall assume the slit width a << D. x`D is the separation between slit and source.



We shall identify the angular position of any point on the screen by ϑ measured from the slit centre which divides the slit by a/2 lengths. To describe the pattern, we shall first see the condition for dark fringes. Also, let us divide the slit into zones of equal widths a/2. Let us consider a pair of rays that emanate from distances a/2 from each other as shown below.



The path difference exhibited by the top two rays shown is:

$\Delta L = a/2 \sin\Theta$

This is a calculation valid only if D is very large.
We can consider any number of ray pairings that start from a distance a/2 from one another such as the bottom two rays in the diagram. Any arbitrary pair of rays at a distance a/2can be considered. For a dark fringe, the path difference must cause destructive interference; the path difference must be out of phase by $\lambda/2$. (λ is the wavelength)
For the first fringe,

$\mathbf{\Delta L} = \lambda/2 = a/2 \sin\Theta$
$\boldsymbol{\lambda} = a \sin \theta$

For a ray emanating from any point in the slit, there exists another ray at a distance a/2 that can cause destructive interference.Thus, at $\boldsymbol{\theta = \sin^{-1}\lambda/a}$, there is destructive interference as any ray emanating from a point has a counterpart that causes destructive interference. Hence, a dark fringe is obtained.
For the next fringe, we can divide the slit into 4 equal parts of a/4 and apply the same logic. Thus, for the second minima:

$\lambda/2 = a/4 \sin\Theta$
$2\lambda = a\sin\Theta$

Similarly, for the **nth fringe**, we can divide the slit into 2n parts and use this condition as:

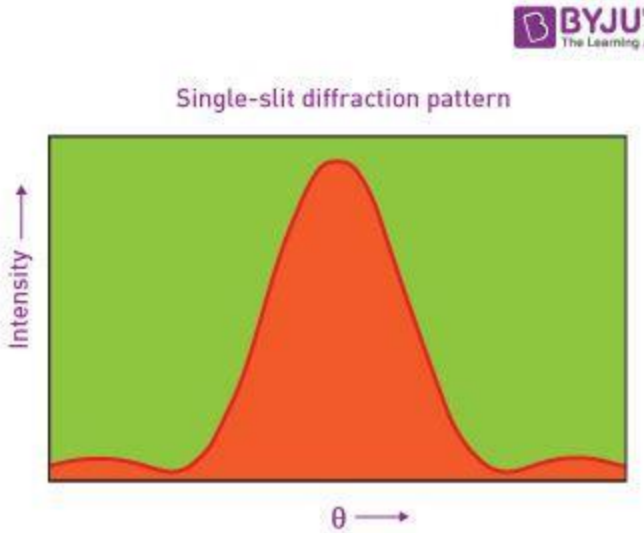
$\mathbf{n\lambda} = a \sin \theta$

The Central Maximum
The maxima lie between the minima and the width of the central maximum is simply the distance between the 1st order minima from the centre of the screen on both sides of the centre.
The position of the minima given by y (measured from the centre of the screen) is:

$\tan\theta \approx \theta \approx y/D$

For small ϑ,
$\mathbf{\sin\theta \approx \theta}$
$\Rightarrow \boldsymbol{\lambda} = a \sin \theta \approx a\theta$
$\Rightarrow \boldsymbol{\theta} = y/D = \lambda/a$
$\Rightarrow \mathbf{y} = \lambda D/a$
The width of the central maximum is simply twice this value
⇒ **Width of central maximum** = $2\lambda D/a$
⇒ **Angular width of central maximum** = $2\theta = 2\lambda/a$

The diffraction pattern and intensity graph is shown below.



Diffraction grating explanation with Theory

Sound is propagated in the form of waves. Sound produced in an adjoining room reaches us after bending round the edges of the walls. Similarly, waves on the surface of water also bend round the edges of an obstacle and spread into the region behind it. This bending of waves around the edges of an obstacle is called diffraction.

Diffraction grating

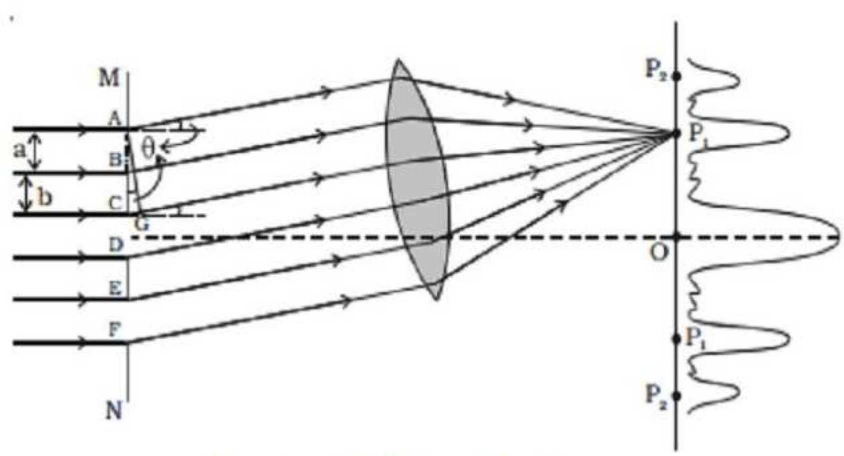


Fig Diffraction grating

An arrangement consisting of a large number of equidistant parallel narrow slits of equal width separated by equal opaque portions is known as a diffraction grating.The plane transmission grating is a plane sheet of transparent material on which opaque rulings are made with a fine diamond pointer. The modern commercial form of grating contains about 6000 lines per centimetre.The rulings act as obstacles having a definite width '*b*' and the transparent space between the rulings act as slit of width '*a*'. The combined width of a ruling and a slit is called grating element (e). Points on successive slits separated by a distance equal to the grating element are called corresponding points.

Theory

MN represents the section of a plane transmission grating. AB, CD, EF … are the successive slits of equal width *a* and BC, DE … be the rulings of equal width b. Let e = *a* + *b*.Let a plane wave front of monochromatic light of wave length λ be incident normally on the grating. According to Huygen's principle, the points in the slit AB, CD … etc act as a source of secondary wavelets which spread in all directions on the other side of the grating.

Let us consider the secondary diffracted wavelets, which makes an angle θ with the normal to the grating.The path difference between the wavelets from one pair of corresponding points A and C is CG = (*a* + b) sin θ. It will be seen that the path difference between waves from any pair of corresponding points is also (*a* + *b*) sin θ

The point P1 will be bright, when

$(a + b) \sin\theta = m\lambda$ where m = 0, 1, 2, 3

In the undiffracted position θ = 0 and hence sin θ = 0.

$(a + b) \sin\theta = 0$, satisfies the condition for brightness for m = 0. Hence the wavelets proceeding in the direction of the incident rays will produce maximum intensity at the centre O of the screen. This is called zero order maximum or central maximum.

If $(a + b) \sin\theta_1 = \lambda$, the diffracted wavelets inclined at an angle θ_1 to the incident direction, reinforce and the first order maximum is obtained.

Similarly, for second order maximum, $(a + b) \sin\theta_2 = 2\lambda$

On either side of central maxima different orders of secondary maxima are formed at the point P1, P2.

In general, $(a + b) \sin\theta = m\lambda$ is the condition for maximum intensity, where m is an integer, the order of the maximum intensity.

$$\sin\theta = \frac{m\lambda}{a+b} \quad \text{or} \quad \sin\theta = Nm\lambda$$

When white light is used, the diffraction pattern consists of a white central maximum and on both sides continuous coloured images are formed.

where N = 1/a+b , gives the number of grating element or number of lines per unit width of the grating.

In the undiffracted position, θ = 0 and hence sin θ = 0. Therefore sin θ = Nmλ is satisfied for m= 0 for all values of λ. Hence, at O all the wavelengths reinforce each other producing maximum intensity for all wave lengths. Hence an undispersed white image is obtained.
As θ increases, (a + b) sin θ first passes through λ/2 values for all colours from violet to red and hence darkness results. As θ further increases, (*a* + b) sin θ passes through λ values of all colours resulting in the formation of bright images producing a spectrum from violet to red. These spectra are formed on either side of white, the central maximum.

Experiment to determine the wavelength of monochromatic light using a plane transmission grating.

The wavelength of a spectral line can be very accurately determined with the help of a diffraction grating and spectrometer.

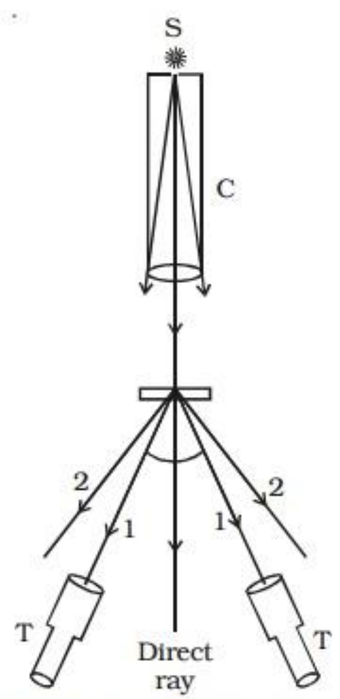


Fig 5.22 Diffraction of monochromatic light

Initially all the preliminary adjustments of the spectrometer are made. The slit of collimator is illuminated by a monochromatic light, whose wavelength is to be determined. The telescope is brought in line with collimator to view the direct image. The given plane transmission grating is then mounted on the prism table with its plane is perpendicular to the incident beam of light coming from the collimator. The telescope is slowly turned to one side until the first order diffraction image coincides with the vertical cross wire of the eye piece. The reading of the position of the telescope is noted.Similarly the first order diffraction image on the other side, is made to coincide with the vertical cross wire and corresponding reading is noted. The difference between two positions gives

2θ. Half of its value gives θ, the diffraction angle for first order maximum. The wavelength of light is calculated from the equation $\lambda = \sin\theta / Nm$. Here N is the number of rulings per metre in the grating.

Determination of wavelengths of spectral lines of white light

Monochromatic light is now replaced by the given source of white light. The source emits radiations of different wavelengths, then the beam gets dispersed by grating and a spectrum of constituent wavelengths is obtained as shown in the figure below.

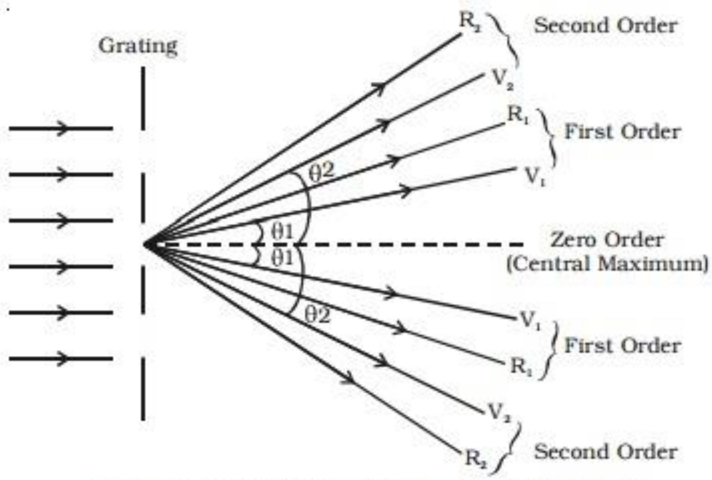


Fig 5.23 Diffraction of white light

knowing N, wave length of any line can be calculated from the relation

$$\lambda = \frac{\sin\theta}{Nm}$$

Difference between interference and diffraction

	Interference	Diffraction
1.	It is due to the superposition of secondary wavelets from two different wavefronts produced by two coherent sources.	It is due to the superposition of secondary wavelets emitted from various points of the same wave front.
2.	Fringes are equally spaced.	Fringes are unequally spaced.
3.	Bright fringes are of same intensity	Intensity falls rapidly
4.	Comparing with diffraction, it has large number of fringes	It has less number of fringes.

Polarization

Polarization, in Physics, is defined as a phenomenon caused due to the wave nature of electromagnetic radiation. Sunlight travels through the vacuum to reach the Earth, which is an example of an electromagnetic wave. These waves are called electromagnetic waves because they form when an electric field that interacts with a magnetic field.

Transverse waves are waves, i.e. movement of the particles in the wave is perpendicular to the direction of motion of the wave.

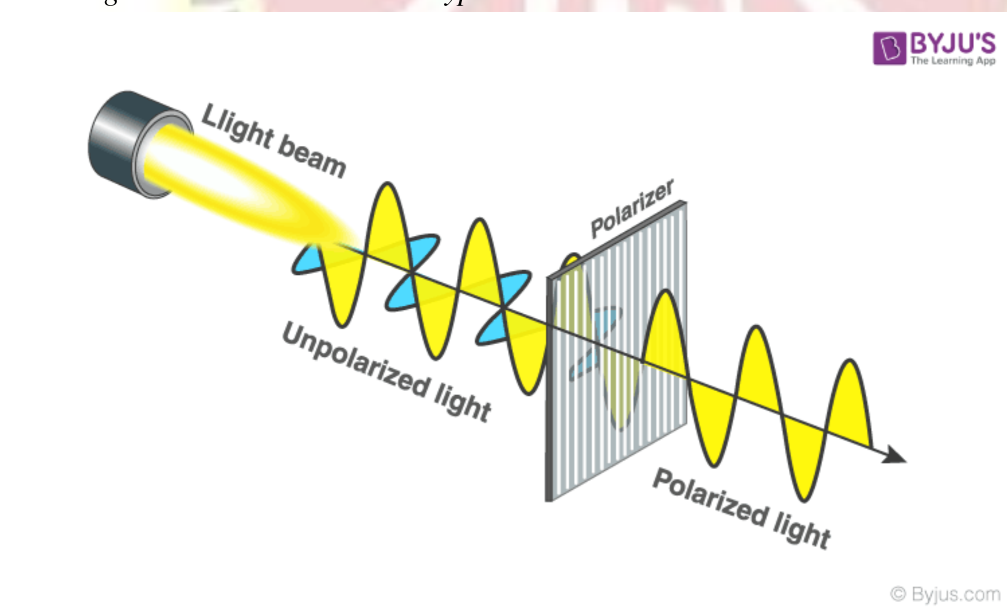
Example: ripples in water, when you throw a stone.

Longitudinal waves are when the particles of the medium travel in the direction of motion of the waves.

Example: the motion of sound waves through the air.

Light is the interaction of electric and magnetic fields travelling through space. The electric and magnetic vibrations of a light wave occur perpendicularly to each other. The electric field moves in one direction and magnetic in another though always perpendicularly. So, we have one plane occupied by an electric field, the magnetic field perpendicular to it, and the direction of travel which is perpendicular to both. These electric and magnetic vibrations can occur in numerous planes. A light wave that is vibrating in more than one plane is known as unpolarized light. The light emitted by the sun, by a lamp or a tube light are all unpolarised light sources. As you can see in the image below, the direction of propagation is constant, but the planes on which the amplitude occurs is changing.

The image here shows its various types:



The other kind of wave is a polarized wave. Polarized waves are light waves in which the vibrations occur in a single plane. Plane polarized light consists of waves in which the direction of vibration is the same for all waves. In the image above, you can see that a Plane polarized light vibrates on only one plane. The process of transforming unpolarized light into the polarized light is known as polarization.

Types of Polarization

Following are the three types of polarization depending on the transverse and longitudinal wave motion:

- Linear polarization
- Circular polarization
- Elliptical polarization

Linear Polarization

In linear polarization, the electric field of light is limited to a single plane along the direction of propagation.

Circular Polarization

There are two linear components in the electric field of light that are perpendicular to each other such that their amplitudes are equal, but the phase difference is $\pi/2$. The propagation of the occurring electric field will be in a circular motion.

Elliptical Polarization

The electric field of light follows an elliptical propagation. The amplitude and phase difference between the two linear components are not equal.

Methods Used in the Polarization of Light

There are a few methods used in the polarization of light:

- Polarization by Transmission
- Polarization by Reflection
- Polarization by Scattering
- Polarization by Refraction

Polarization Applications

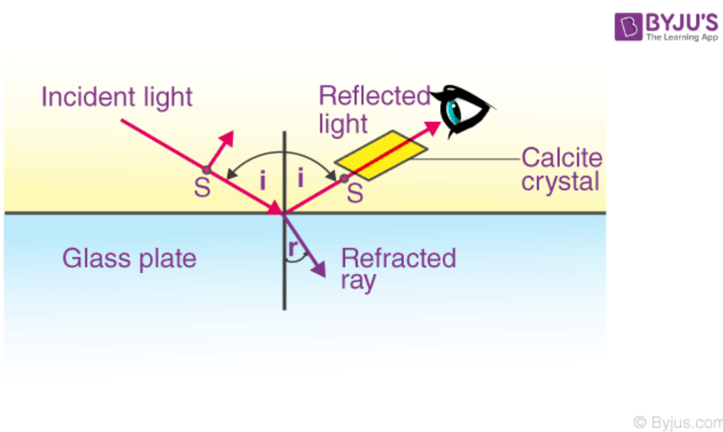
Following are the applications of polarization:

- Polarization is used in sunglasses to reduce the glare.
- Polaroid filters are used in plastic industries for performing stress analysis tests.
- Three-dimensional movies are produced and shown with the help of polarization.
- Polarization is used for differentiating between transverse and longitudinal waves.
- Infrared spectroscopy uses polarization.
- It is used in seismology to study earthquakes.
- In Chemistry, the chirality of organic compounds is tested using polarization techniques.

Optical activity

Optical activity is the ability of a chiral molecule to rotate the plane of plane-polairsed light, measured using a polarimeter. A simple polarimeter consists of a light source, polarising lens, sample tube and analysing lens.

Brewster's Law: According to Brewster's law,When an unpolarized light of known wavelength is incident on a transparent substance surface, it experiences maximum plan polarization at the angle of incidence whose tangent is the refractive index of the substance for the wavelength.Brewster's law is a relationship of light waves at the maximum polarization angle of light. This law is named after Sir David Brewster, a Scottish physicist, who proposed the law in the year 1811. The law states that the p-polarized rays vanish completely on different glasses at a particular angle.Further, the polarization angle is also called Brewster's angle. It is an angle of incidence where the ray of light having a p-polarization transmitted through a dielectric surface that is transparent without any reflection. While the unpolarized light at this angle is transmitted, the light is reflected from the surface.



Brewster was able to determine that the refractive index of the medium is numerically equal to the tangent angle of polarization.

Brewster's Law Formula

$\mu = \tan i$

Where,

μ = Refractive index of the medium.

i = Polarization angle.

From Snell's Law:

$\mu = \sin i / \sin r$……..(1)

From Brewster's Law:

$\mu = \tan i = \sin i / \cos i$……..(2)

Comparing both formulas: (1) and (2)

$\cos i = \sin r = \cos(\pi/2 - r)$

$i = \pi/2 - r$, or $i + r = \pi/2$

As, i+ r = π/2<ABC is also equal to the π/2. Therefore, the reflected and the refracted rays are at right angles to each other.

Application of Brewster's Law

One general example of the application of Brewster's law is polarized sunglasses. These glasses use the principle of Brewster's angle. The polarized glasses reduce glare that is reflecting directly from the sun and also from the horizontal surfaces like road and water. Photographers also use the same law to reduce the reflection from reflective surfaces by using a polarizing filter for the lens.

Half Shade Polarimeter

In essence, the polarimeter consists of a collimated linearly polarized light source (S, L and P) that is passed through the sample tube T (which will rotate the polarization if the sample is optically active), and then polarized (A) and seen through a telescope E.

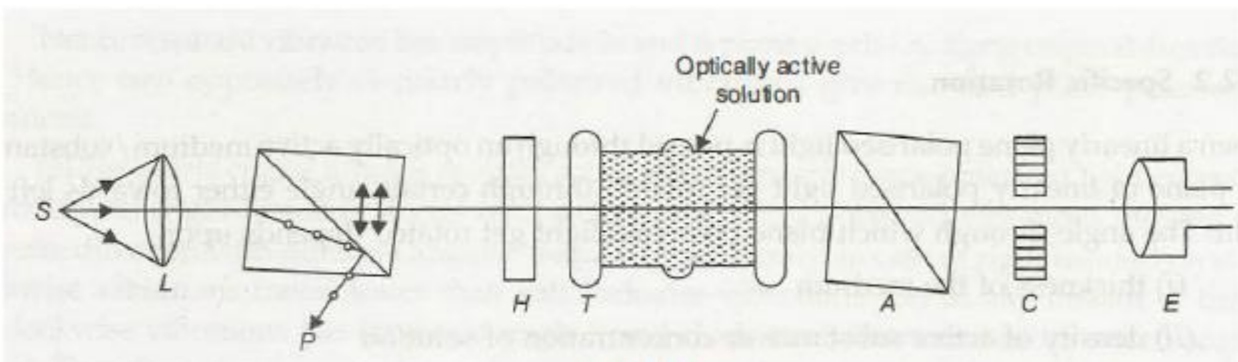
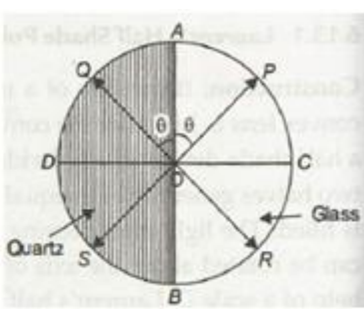


FIGURE 6.22

In this basic setup (without the half-shade A) you are looking for the maximum and minimum brightness, which then tells you that the analyzer A is precisely aligned with the output rotation.

The half-shade H goes between the polarized light source and the sample, and it consists of two half-disks of equally absorptive material. One half, ACB, is glass, and it lets the polarized light pass through unchanged. The other half, ADB, is made of quartz, with the optical axes along AOB and DOC, and it is cut to <u>half-wave-plate</u> thickness; in essence, this means that if the original polarization was along SOP, in the quartz half it gets reflected over into ROQ, i.e. orthogonal to SOP.



In this version of the polarimeter, you're looking for the point where both halves are exactly equal in brightness, i.e. where the analyzer is at exactly 45° from the polarization of both halves of the image.The usefulness of the half-shade is on the sensitivity of the apparatus. The normal

polarimeter requires the experimenter to look for the maximum or minimum brightness, but more importantly you're taking variations around a point where the signal looks quadratic, so even large changes in the angle won't change the output by that much.
It is not possible to accurately judge the position of maximum brightness without using half-shade plate, which may lead you an inaccurate measurement of the optical activity of the experimental liquids. The half-shade plate leads you to accurate measurement of optical activity by helping you to determine the exact position of the equal brightness of the two halves.Without using half shade device your eye cannot judge the exact position of extinction of light when the two nicols are placed in the crossed position.

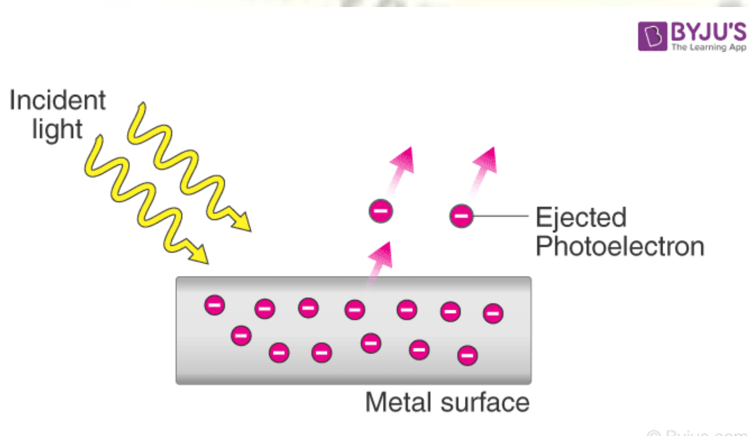
The uses of polarization are:

1) To differentiate between transverse and longitudinal waves.
2)Used in sunglasses to cut of unwanted reflected light.
3)Used to check chirality of organic compounds.
4)They are used in 3D movies and 3D glasses.

UNIT – II

Introduction: Photoelectric Effect and Why does it Occur?

The photoelectric effect is a phenomenon in which electrons are ejected from the surface of a metal when light is incident on it. These ejected electrons are called **photoelectrons**. It is important to note that the emission of photoelectrons and the kinetic energy of the ejected photoelectrons is dependent on the frequency of the light that is incident on the metal's surface. The process through which photoelectrons are ejected from the surface of the metal due to the action of light is commonly referred to as **photoemission**.The photoelectric effect occurs because the electrons at the surface of the metal tend to absorb energy from the incident light and use it to overcome the attractive forces that bind them to the metallic nuclei. An illustration detailing the emission of photoelectrons as a result of the photoelectric effect is provided below.



Theory: Photoelectric Effect: The Concept of Photons

The photoelectric effect cannot be explained by considering light as a wave. However, this phenomenon can be explained by the particle nature of light, in which light can be visualized as a stream of particles of electromagnetic energy. These 'particles' of light are called **photons**. The energy held by a photon is related to the frequency of the light via Planck's equation:

$$E = h\nu = hc/\lambda$$

Where,

- E denotes the energy of the photon
- h is Planck's constant
- ν denotes the frequency of the light
- c is the speed of light (in a vacuum)
- λ is the wavelength of the light

Thus, it can be understood that different frequencies of light carry photons of varying energies. For example, the frequency of blue light is greater than that of red light (the wavelength of blue light is much shorter than the wavelength of red light). Therefore, the energy held by a photon of blue light will be greater than the energy held by a photon of red light.

Threshold Energy for the Photoelectric Effect

For the photoelectric effect to occur, the photons that are incident on the surface of the metal must carry sufficient energy to overcome the attractive forces that bind the electrons to the nuclei of the metals. The minimum amount of energy required to remove an electron from the metal is called the **threshold energy** (denoted by the symbol Φ). For a photon to possess energy equal to the threshold energy, its frequency must be equal to the **threshold frequency** (which is the minimum frequency of light required for the photoelectric effect to occur). The threshold frequency is usually denoted by the symbol ν_{th} and the associated wavelength (called the threshold wavelength) is denoted by the symbol λ_{th}. The relationship between the threshold energy and the threshold frequency can be expressed as follows.

$$\Phi = h\nu_{th} = hc/\lambda_{th}$$

Relationship between the Frequency of the Incident Photon and the Kinetic Energy of the Emitted Photoelectron

Therefore, the relationship between the energy of the photon and the kinetic energy of the emitted photoelectron can be written as follows.

$$E_{photon} = \Phi + E_{electron}$$

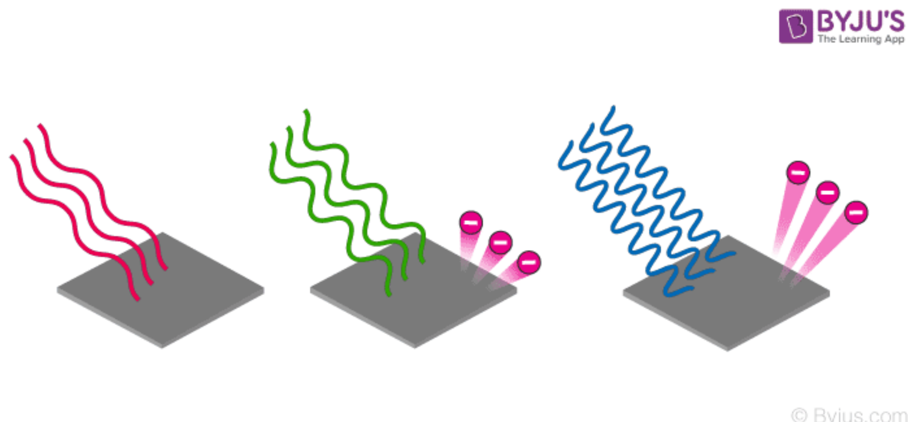
$$\Rightarrow h\nu = h\nu_{th} + \tfrac{1}{2}m_e v^2$$

Where,

- E_{photon} denotes the energy of the incident photon, which is equal to $h\nu$
- Φ denotes the threshold energy of the metal surface, which is equal to $h\nu_{th}$

- $E_{electron}$ denotes the kinetic energy of the photoelectron, which is equal to $\frac{1}{2}m_e v^2$ (m_e = mass of electron = $9.1*10^{-31}$ kg)

If the energy of the photon is less than the threshold energy, there will be no emission of photoelectrons (since the attractive forces between the nuclei and the electrons cannot be overcome). Thus, the photoelectric effect will not occur if $\nu < \nu_{th}$. If the frequency of the photon is exactly equal to the threshold frequency ($\nu = \nu_{th}$), there will be an emission of photoelectrons, but their kinetic energy will be equal to zero. An illustration detailing the effect of the frequency of the incident light on the kinetic energy of the photoelectron is provided below.



From the image, it can be observed that:

- The photoelectric effect does not occur when the red light strikes the metallic surface because the frequency of red light is lower than the threshold frequency of the metal.
- The photoelectric effect occurs when green light strikes the metallic surface and photoelectrons are emitted.
- The photoelectric effect also occurs when blue light strikes the metallic surface. However, the kinetic energies of the emitted photoelectrons are much higher for blue light than for green light. This is because blue light has a greater frequency than green light.

It is important to note that the threshold energy varies from metal to metal. This is because the attractive forces that bind the electrons to the metal are different for different metals. It can also be noted that the photoelectric effect can also take place in non-metals, but the threshold frequencies of non-metallic substances are usually very high.

History of the Photoelectric Effect

The photoelectric effect was first introduced by Wilhelm Ludwig Franz Hallwachs in the year 1887 and the experimental verification was done by Heinrich Rudolf Hertz. They observed that when a surface is exposed to electromagnetic radiation at a higher threshold frequency, the radiation is absorbed and the electrons are emitted. Today, we study photoelectric effect as a phenomenon which involves a material absorbing electromagnetic radiation and releasing electrically charged particles.To be more precise, light incident on the surface of a metal in the photoelectric effect causes electrons to be ejected. The electron ejected due to the photoelectric effect is called a photoelectron and is denoted by e^-. The current produced as a result of the ejected electrons is called photoelectric current.

Einstien's Contributions towards the Photoelectric Effect

The photoelectric effect is the process that involves the ejection or release of electrons from the surface of materials (generally a metal) when light falls on them. The photoelectric effect is an important concept that enables us to clearly understand the quantum nature of light and electrons.

After continuous research in this field, the explanation for the photoelectric effect was successfully explained by Albert Einstein. He concluded that this effect occurred as a result of light energy being carried in discrete quantized packets. For this excellent work, he was honoured with the Nobel prize in 1921.

According to Einstein, each photon of energy E is

$E = h\nu$

Where E = Energy of photon in joule

h = planks constant (6.626×10^{-34} J.s)

ν = frequency of photon in Hz

Properties of the Photon

- For a photon, all the quantum numbers are zero.
- A photon does not have any mass, charge and they are not reflected in a magnetic and electric field.
- The photon moves in the speed of light at empty space.
- During the interaction of matters with radiation, radiation behaves as it is made up of small particles called photons.
- Photons are virtual particles. The photon energy is directly proportional to its frequency and inversely proportional to its wavelength.
- The momentum and energy of the photons are related as given below

$E = p.c$ where

p = magnitude of the momentum

c = speed of light.

Definition of Photoelectric Effect

The phenomenon of metals releasing electrons when they are exposed to the light of the appropriate frequency is called the photoelectric effect, and the electrons emitted during the process are called photoelectrons.

Principle of Photoelectric Effect

The law of conservation of energy forms the basis for the photoelectric effect.

Minimum Condition for Photoelectric Effect

Threshold Frequency (γ_{th})
It is the minimum frequency of the incident light or radiation that will produce a photoelectric effect i.e. ejection of photoelectrons from a metal surface is known as threshold frequency for the metal. It is constant for a specific metal but may be different for different metals.
If γ = frequency of incident photon and γ_{th}= threshold frequency, then,

- If $\gamma < \gamma_{Th}$, there will be no ejection of photoelectron and, therefore, no photoelectric effect.
- If $\gamma = \gamma_{Th}$, photoelectrons are just ejected from the metal surface, in this case, the kinetic energy of the electron is zero
- If $\gamma > \gamma_{Th}$, then photoelectrons will come out of the surface along with kinetic energy

Threshold Wavelength (λ_{th})
During the emission of electrons, a metal surface corresponding to the greatest wavelength to incident light is known threshold wavelength.
$\lambda_{th} = c/\gamma_{th}$
For wavelengths above this threshold, there will be no photoelectron emission. For λ = wavelength of the incident photon, then

- If $\lambda < \lambda_{Th}$, then the photoelectric effect will take place and ejected electron will possess kinetic energy.
- If $\lambda = \lambda_{Th}$, then just photoelectric effect will take place and kinetic energy of ejected photoelectron will be zero.
- If $\lambda > \lambda_{Th}$, there will be no photoelectric effect.

Work Function or Threshold Energy (Φ)
The minimal energy of thermodynamic work that is needed to remove an electron from a conductor to a point in the vacuum immediately outside the surface of the conductor is known as work function/threshold energy
$\Phi = h\gamma_{th} = hc/\lambda_{th}$
The work function is the characteristic of a given metal. If E = energy of an incident photon, then

1. If $E < \Phi$, no photoelectric effect will take place.
2. If $E = \Phi$, just photoelectric effect will take place but the kinetic energy of ejected photoelectron will be zero
3. If E > photoelectron will be zero
4. If $E > \Phi$, the photoelectric effect will take place along with possession of the kinetic energy by the ejected electron.

Photoelectric Effect Formula
According to the Einstein explanation of the photoelectric effect is:

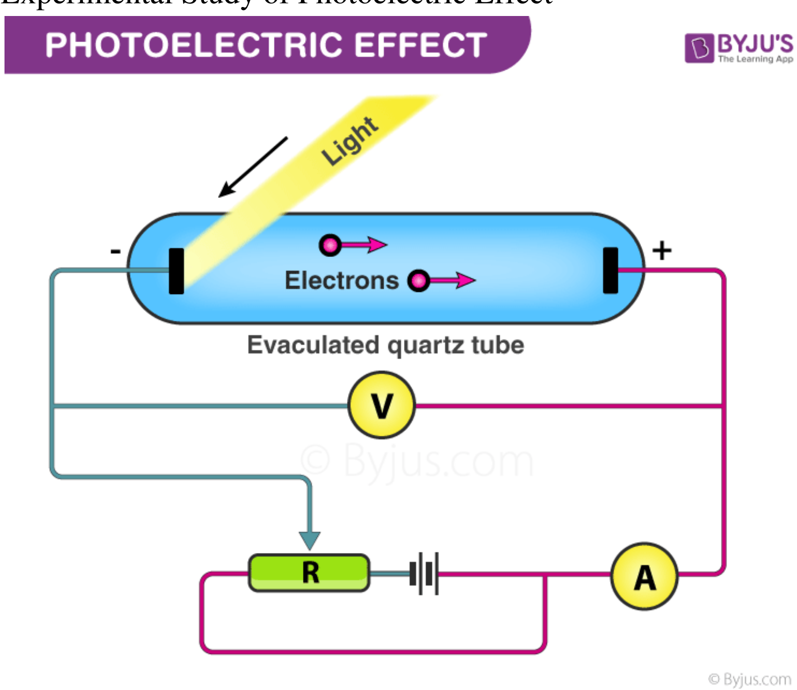
The energy of photon = energy needed to remove an electron + kinetic energy of the emitted electron
i.e. $h\nu = W + E$
Where,

- h is Planck's constant.
- ν is the frequency of the incident photon.
- W is a work function.
- E is the maximum kinetic energy of ejected electrons: $1/2\ mv^2$.

Laws Governing the Photoelectric Effect

1. For a light of any given frequency; ($\gamma > \gamma_{Th}$) photoelectric current is directly proportional to the intensity of light
2. For any given material, there is a certain minimum (energy) frequency, called threshold frequency, below which the emission of photoelectrons stops completely, no matter how high is the intensity of incident light.
3. The maximum kinetic energy of the photoelectrons is found to increase with the increase in the frequency of incident light, provided the frequency ($\gamma > \gamma_{Th}$) exceeds the threshold limit. The maximum kinetic energy is independent of the intensity of light.
4. The photo-emission is an instantaneous process.

Experimental Study of Photoelectric Effect



Photoelectric Effect: Experimental Setup

The given set up D experiment is used to study the photoelectric effect experimentally. In an evacuated glass tube. Two zinc plates C and D are enclosed. Plates C acts as anode and D acts as a photosensitive plate.Two plates are connected to a battery B and ammeter A. If the radiation is incident on the plate D through a quartz window W electrons are ejected out of the plate and current flows in the circuit this is known as photocurrent. Plate C can be maintained at desired potential (+ve or – ve) with respect to plate D.

Characteristics Of Photoelectric Effect

- The threshold frequency varies with material, it is different for different materials.
- The photoelectric current is directly proportional to the light intensity.
- The kinetic energy of the photoelectrons is directly proportional to the light frequency.
- The stopping potential is directly proportional to the frequency and the process is instantaneous.

Factors affecting Photoelectric Effect

With the help of this apparatus, we will now study the dependence of the photoelectric effect on the following factors.

1. The intensity of incident radiation.
2. A potential difference between metal plate and collector.
3. Frequency of incident radiation.

Effects of Intensity of Incident Radiation on Photoelectric Effect

The potential difference between the metal plate and collector and frequency of incident light is kept constant and the intensity of light is varied:

The electrode C i.e. collecting electrode is made positive with respect to D (metal plate). For a fixed value of frequency and the potential between the metal plate and collector, the photoelectric current is noted in accordance with the intensity of incident radiation.It shows that photoelectric current and intensity of incident radiation both are proportional to each other the photoelectric current gives an account of the number of photoelectrons ejected per sec.

Effects of Potential Difference between metal plate and collector on Photoelectric Effect

The frequency of incident light and intensity is kept constant and the potential difference between the plates is varied:

Keeping the intensity and frequency of light constant, the positive potential of C is increased gradually. Photoelectric current increases when there is a positive increase in the potential between the metal plate and collector up to a characteristic value.There is no change in photoelectric current when potential increased higher than the characteristic value for any increase in the accelerating voltage. This maximum value of the current is called as saturation current.

Effect of Frequency on Photoelectric Effect

The intensity of light is kept constant and the frequency of light is varied:

For a fixed intensity of incident light, variation in the frequency of incident light produces linear in the variation cut off potential/stopping potential of the metal. It shown cut off potential (Vc) is linearly proportional to the frequency of incident lightThe kinetic energy of the photoelectrons increases directly proportionally to the frequency of incident light to completely stop the photoelectrons. We should reverse and increase the potential between the metal plate and collector in (negative value) so the emitted photoelectron can't reach the collector.

Einstein's Photoelectric Equation

According to Einstein's theory on photoelectric effect is, when a photon collides inelastically with electrons, the photon is absorbed completely or partially by the electrons. So if an electron in a metal absorbs a photon of energy, it uses the energy in the following ways.

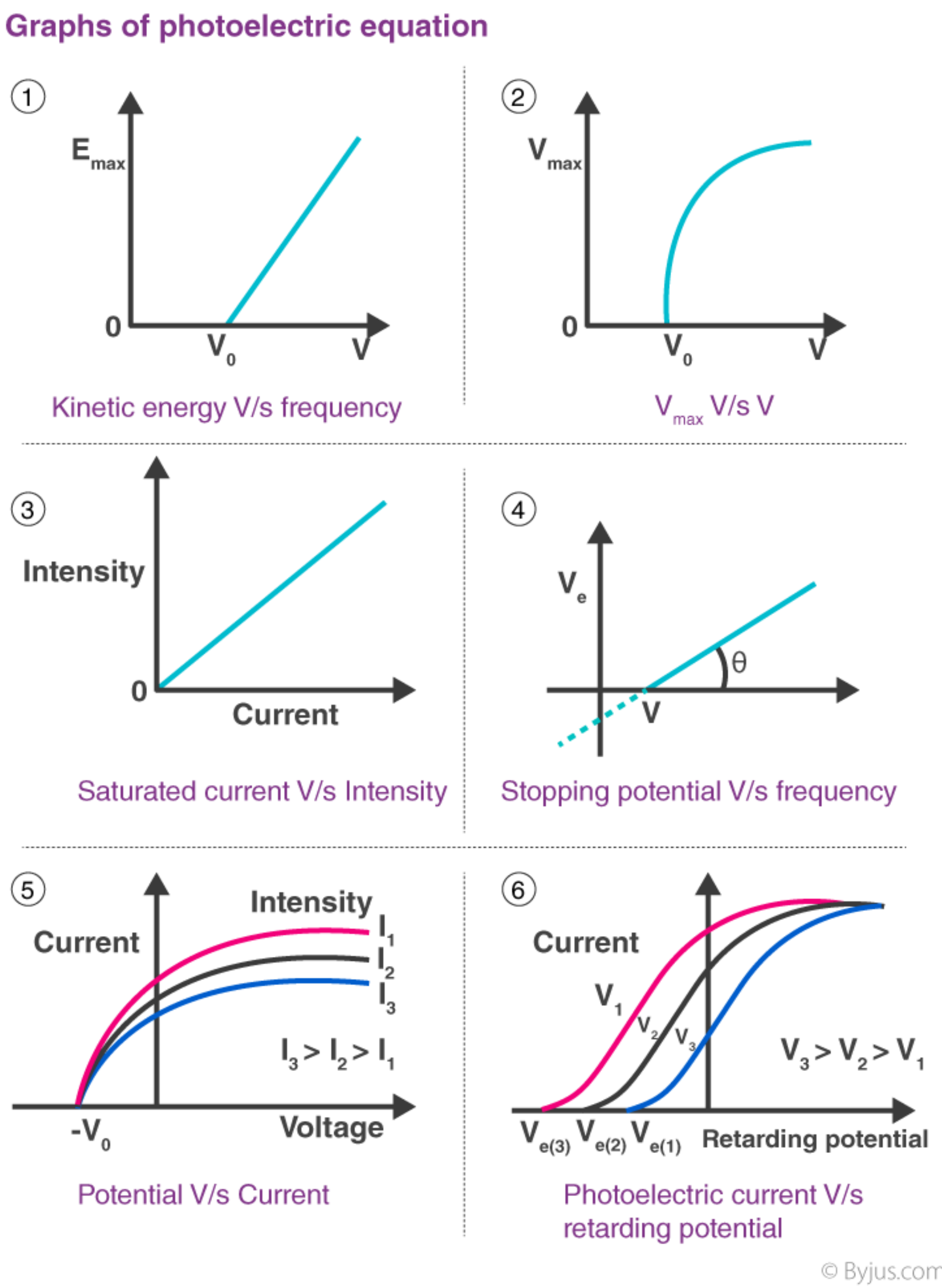
Some energy Φ_0 is used to making the surface electron free from the metal. It is known as the work function of the material. Rest energy will appear as kinetic energy (K) of the emitted photoelectrons.

Einstein's Photoelectric Equation explains the following concepts

- The frequency of the incident light is directly proportional to the kinetic energy of the electrons and the wavelengths of incident light are inversely proportional to the kinetic energy of the electrons.
- If $\gamma = \gamma_{th}$ or $\lambda = \lambda_{th}$ then $v_{max} = 0$.
- $\gamma < \gamma_{th}$ or $\lambda > \lambda_{th}$: There will be no emission of photoelectrons.
- The intensity of the radiation or incident light refers to the number of photons in the light beam. More intensity means more photons and vice-versa. Intensity has nothing to do with the energy of the photon. Therefore, the intensity of the radiation is increased, the rate of emission increases but there will be no change in kinetic energy of electrons. With an increasing number of emitted electrons, the value of photoelectric current increases.

Different Graphs of Photoelectric Equation

- Kinetic energy V/s frequency
- V_{max} V/s v
- Saturated Current V/s Intensity
- Stopping potential V/s frequency
- Potential V/s current: (γ = constant)
- Photoelectric current V/s Retarding potential



Photoelectric Equation Graphs

Applications of Photoelectric Effect

- Used to generate electricity in Solar Panels. These panels contain metal combinations that allow electricity generation from a wide range of wavelengths.
- **Motion and Position Sensors:** In this case, a photoelectric material is placed in front of a UV or IR LED. When an object is placed in between the Light-emitting diode (LED) and sensor, light is cut off and the electronic circuit registers a change in potential difference

- Lighting sensors such as the ones used in smartphones enable automatic adjustment of screen brightness according to the lighting. This is because the amount of current generated via the photoelectric effect is dependent on the intensity of light hitting the sensor.
- Digital cameras can detect and record light because they have photoelectric sensors that respond to different colors of light.
- **X-Ray Photoelectron Spectroscopy (XPS):** This technique uses x-rays to irradiate a surface and measure the kinetic energies of the emitted electrons. Important aspects of the chemistry of a surface can be obtained such as elemental composition, chemical composition, the empirical formula of compounds and chemical state.
- Photoelectric cells are used in burglar alarms.

Problems on Photoelectric Effect

1. In a photoelectric effect experiment, the threshold wavelength of incident light is 260 nm and E (in eV) = 1237/λ (nm). Find the maximum kinetic energy of emitted electrons.

Solution:

$K_{max} = hc/\lambda - hc/\lambda_0 = hc \times [(\lambda 0 - \lambda)/\lambda\lambda 0]$

$\Rightarrow K_{max} = (1237) \times [(380 - 260)/380\times 260] = 1.5$ eV

Therefore, the maximum kinetic energy of emitted electrons in the photoelectric effect is 1.5 eV.

2. In a photoelectric experiment, the wavelength of the light incident on metal is changed from 300 nm to 400 nm and (hc/e = 1240 nm-V). Find the decrease in the stopping potential.

Solution:

$hc/\lambda_1 = \phi + eV_1$ . . . . (i)

$hc\lambda_2 = \phi + eV_2$ . . . . (ii)

Equation (i) – (ii)

$hc(1/\lambda_1 - 1/\lambda_2) = e \times (V_1 - V_2)$

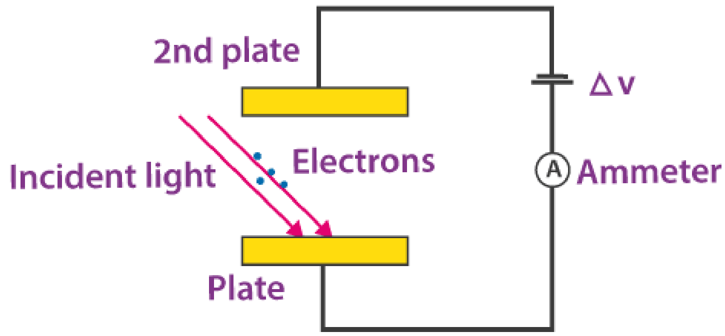
$\Rightarrow V_1 - V_2 = (hc/e) \times [(\lambda 2 - \lambda 1)/(\lambda 1 - \lambda 2)]$

$= (1240 \text{ nm V}) \times 100\text{nm}/(300\text{nm} \times 400\text{nm})$

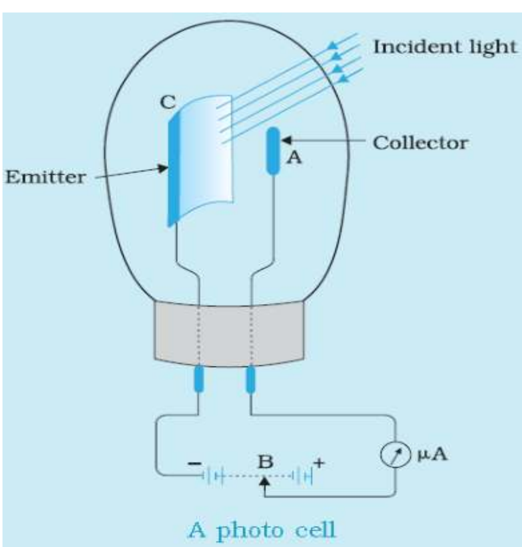
$= 12.4/12 \approx 1$V.

Therefore, the decrease in the stopping potential during the photoelectric experiment is 1V.

3. when ultraviolet light with a wavelength of 230 nm shines on a particular metal plate, electrons are emitted from plate 1, crossing the gap to plate 2 and causing a current to flow through the wire connecting the two plates The battery voltage is gradually increased until the current in the ammeter drops to zero, at which point the battery voltage is 1.30 V.



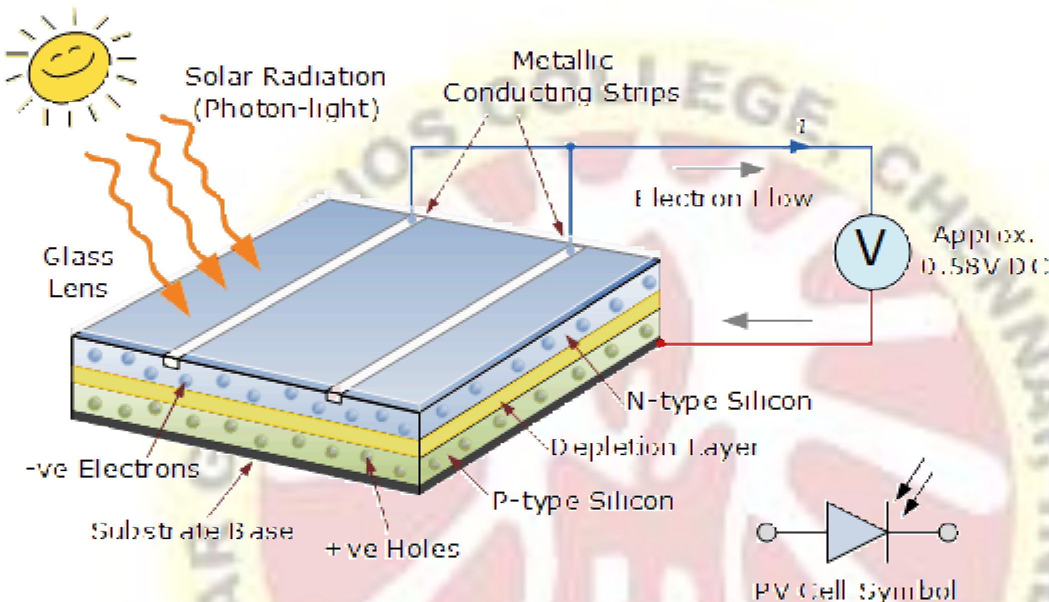
a) What is the energy of the photons in the beam of light, in eV?
b) What is the maximum kinetic energy of the emitted electrons, in eV?
Solution:
Assuming that the wavelength corresponds to the wavelength in vacuum
f = \frac{c}{\lambda }f=λc
f = \frac{3\times 10^{8}}{2.40\times 10^{-7} }f=2.40×10−73×108
$f = 1.25 \times 10^{15}$ Hz
The energy of photon E = hf
$E = (4.136 \times 10^{-15})(1.25 \times 10^{15})$
note: Planck's constant in eV s = 4.136×10^{-15} eV s
E = 5.17 eV.
b) The maximum kinetic energy related to the emitted electron is stopping potential. In this case, stopping potential is 1.30V. SO the maximum kinetic energy of the electrons is 1.30V.
Photo-emissive Cell



A photo cell

A photocell is a technological application of the photoelectric effect.A photocell consists of a semi-cylindrical photo-sensitive metal plate C (emitter) and a wire loop A(collector) supported in an evacuated glass or quartz bulb. It is connected to the external circuit having a high-tension battery B and microammeter (μA). When light of suitable wavelength falls on the emitter C, photoelectrons are emitted. These photoelectrons are drawn to the collector A.A photocell converts a change in intensity of illumination into a change in photocurrent.

Photovoltaic Solar Cell Construction



Solar Power from the Sun

The silicon wafer of the photovoltaic solar cell facing the sun consist of the electrical contacts and is coated with an anti-reflective coating that helps absorb the sunlight efficiently. The electrical contacts provide the connection between the semiconductor material and the external electrical load, such as a light bulb or battery. When sunlight shines on a PV cell, photons of light strike the surface of semiconductor material and liberate electrons from the materials atom structure. Certain doping chemicals are added to the semiconductors composition to help to establish a path of the freed electrons.This creates a flow of electrons forming an electrical current which starts to flow over the surface of the photovoltaic solar cell. Metallic strips are placed across the surface of the photovoltaic cell to collect these electrons which forms the positive connection. The back of the PV cell, the side away from the incoming sunlight, consists of a layer of aluminium or molybdenum metal which forms the negative connection to the cell. Then a photovoltaic solar cell has two electrical connections for conventional current flow, one positive, and one negative.The type of solar power produced by a photovoltaic solar cell is called direct current or DC the same as from a battery. Most photovoltaic solar cells produce a “no load” open circuit voltage (nothing connected to it) of about 0.5 to 0.6 volts when there is no external circuit connected. This output voltage (V_{OUT}) depends very much on the load current (I) demands of the PV cell. For example on very cloudy or dull day the current demand would be low and so the cell could provide the full output voltage, V_{OUT} but at a reduced output current. But as the current demand of the load increases a brighter light (solar radiation) is needed at the junction to maintain a full output voltage, V_{OUT}.However, there is a physical limit to the maximum current that a single photovoltaic solar cell can provide no matter how intense or bright the suns radiation is. This is called the maximum deliverable current and is symbolised as I_{MAX}. The I_{MAX} value of a single photovoltaic solar cell depends upon the size or surface area of the cell (especially the PN-junction), the amount of direct sunlight hitting the cell, its efficiency of converting this solar power into a current and of course the type of semiconductor material that the cell is manufactured from either silicon, gallium arsenide, cadmium sulphide, cadmium telluride etc.Most commercially available photovoltaic solar cells have solar power ratings which indicate the maximum deliverable solar power, P_{MAX} that the cell can provide in watts and is equal to the product of the cell voltage V multiplied by the maximum cell current I and is given as:

$$P_{MAX} = V_{OUT} \times I_{MAX}$$

Where: W is in Watts, V is in Volts, and I is in Amperes

Photovoltaic Solar Cell Problem No1

Calculate the maximum output current of a single 0.5v silicon photovoltaic cell with a maximum rated power output of 1.75 Watts at full sun.

$$P_{MAX} \quad V_{OUT} \quad I_{MAX}$$

$$\therefore I_{MAX} = \frac{P_{MAX}}{V_{OUT}} = \frac{1.75}{0.5} = 3.5\text{amps}$$

Note that this is the maximum theoretical current as the true or real current is determined by the rate of the incoming solar photons. The amount of electrical power generated by a photovoltaic cell depends on solar irradiance and other conditions such as temperature and cloud cover. The power rating of a photovoltaic cell, expressed in watts (W), is the maximum or peak power that a cell can deliver at full sun with the PV cell uncovered. Lets try another example.

Photovoltaic Solar Cell Problem No2

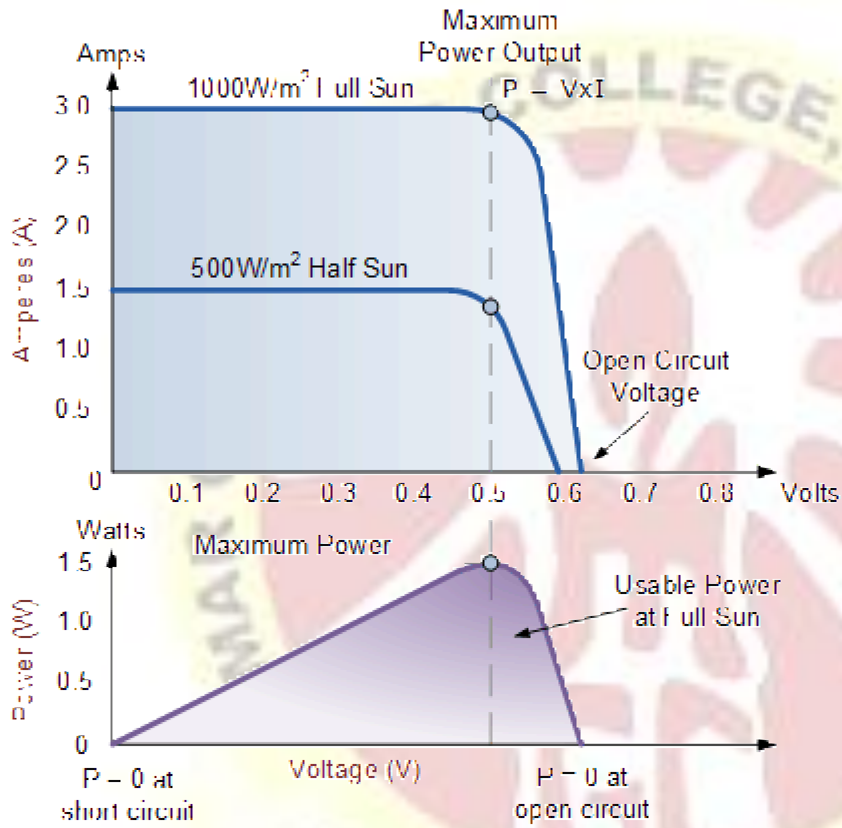
At full sun a 0.58 volt photovoltaic solar cell produces an output current of 1.73 amperes. Calculate the maximum power output of the photovoltaic cell in watts.

$$P \quad V_{OUT} \times I_{OUT}$$

$$P \quad V \times I \quad 0.58V \times 1.73A \quad 1.0\text{Watts}$$

Various manufacturers refer to a photovoltaic solar cells output power at full sun as its: “maximum output power”, “peak power”, “rated power”, “maximum power point” or other such terms but they all mean the same.As we have said before, standard sunlight conditions on a clear day at the equator at midday are assumed to give an irradiance of 1,000 watts of solar energy per square meter (1000 W/m^2 or $1kW/m^2$) and this is generally referred to as a “Full Sun” condition. That is maximum irradiance onto the photovoltaics surface. Less than full sun will reduce the current output of the cell by a proportional amount. For example, if only one-half of the suns energy (500 W/m^2) is available, the amount of output current is roughly cut in half because the solar cell only has half the brightness to generate electricity.Manufacturers of the photovoltaic solar cells produce current-voltage (I-V) curves as shown below which gives the current and voltage at which the photovoltaic cell generates the maximum power output and are based on the cell being under standard conditions of sunlight and temperature with no shading.

Photovoltaic Solar Cell I-V Characteristics



The power available from a photovoltaic solar cell at any point along the curve is expressed in watts and is calculated by multiplying the voltage times the current as we have seen above, watts = volts x amps. For maximum output power from a cell the face of the photovoltaic should be pointed as straight toward the sun as possible.In order to produce more electrical power from a photovoltaic solar cell we need to either increase the photovoltaic effect, the energy of photons, or produce a different type of cell that is more efficient at converting the solar energy into electricity. At the present time, most commercial photovoltaic solar cells are manufactured from silicon, the same material from which sand is made.

Photo-Conductive Cell :

The photoconductive cell is a two terminal semiconductor device whose terminal **resistance** will vary (linearly) with the intensity of the incident light. For obvious reasons, it is frequently called a photoresistive device.The photoconductive materials most frequently used include cadmium sulphide (CdS) and cadmium selenide (CdSe). Both materials respond rather slowly to changes in light intensity. The peak spectral response time of CdS units is about 100 ms and 10 ms for CdSe cells. Another important difference between the two materials is their temperature sensitivity. There is large change in the resistance of a cadmium selenide cell with changes in ambient temperature, but the resistance of cadmium sulphide remains relatively stable. The spectral response of a cadmium sulphide cell closely matches thatof the human eye, and the cell is therefore often used in applications where human vision is a factor, such as street light control or automatic iris control for cameras.The essential elements of a photoconductive cell are the ceramic substrate, a layer of photoconductive material, metallic electrodes to connect the device into a circuit and a moisture re-sistant enclosure.

The circuit symbol and construction of a typical photoconductive cell are shown.

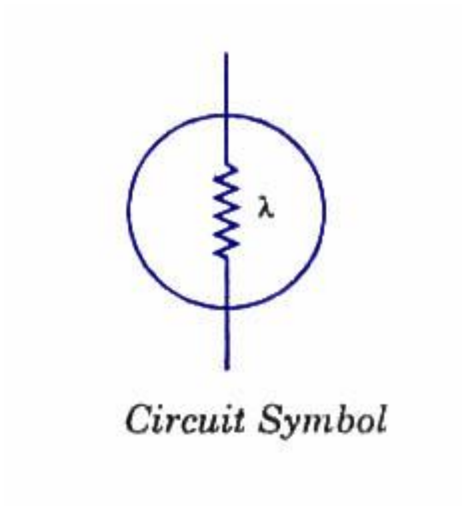


photo-conductive-cell-circuit-symbol

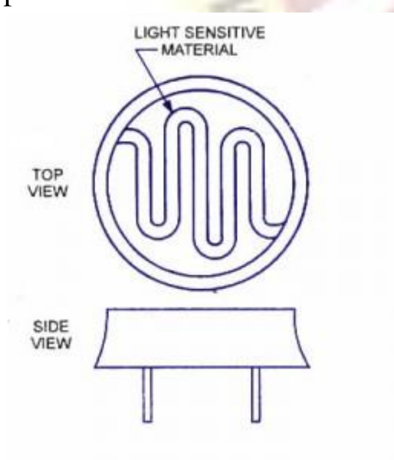


photo-conductive-cell-construction

Light sensitive material is arranged in the form of a long strip, zigzagged across a disc shaped base with protective sides. For added protection, a glass or plastic cover may be included. The two ends of the strip are brought out to connecting pins below the base.

Photoconductive cell circuit:

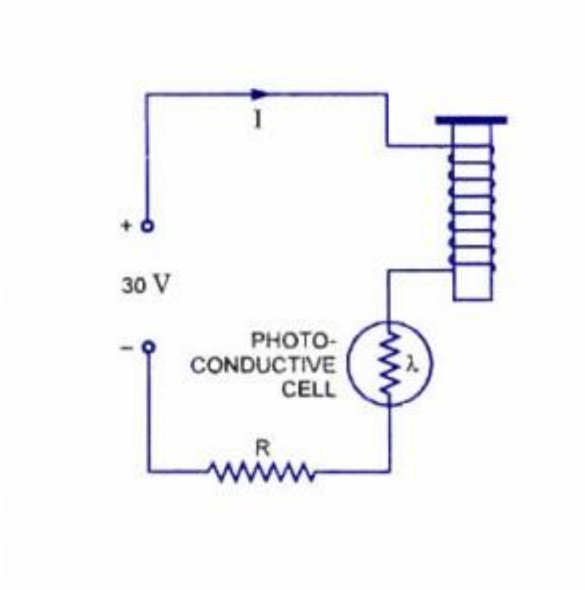
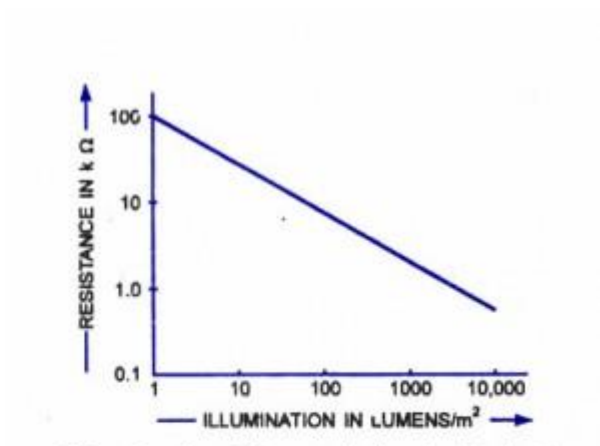


photo-conductive-cell-circuit

Characteristics of a Photoconductive cell:



Illumination Characteristic of a Typical Photoconductive Cell

photo-conductive-cell-characteristics

The illumination characteristics of a typical photoconductive cell are shown from which it is obvious that when the cell is not illuminated its resistance may be more than 1 00 kilo ohms. This resistance is called the dark resistance. When the cell is illuminated, the resistance may fall to a few hundred ohms. Note that the scales on the illumination characteristic are logarithmic to cover a wide ranges of resistance and illumination that are possible. Cell sensitivity may be expressed in terms of the cell current for a given voltage and given level of illumination. The major drawback of the photoconductive cells is that temperature variations cause substantial variations in resistance for a substantial variations in resistance for a particular light intensity.

Therefore such a cell is unsuitable for analog applications. The photoconductive cell used for relay control is shown as circuit above When the cell is illuminated, its resistance is low and the relay current is at its maximum. When the cell is dark, its high resistance reduces the current down to a level too low to energize the relay. Resistance R is included to limit the relay current to the desired level when the resistance of the cell is low. Photoconductive cells are used to switch transistors on and off, as illustrated in figure. When the cell shown in figure is dark, the transistor base is biased above its emitter level, and the device is turned on. When the cell is illuminated, the lower resistance of the cell in series with R biases the transistor base voltage below its emitter level. Thus, the device is turned off.

Atomic Masses

The mass of an atom is extremely small. It means the mass of a carbon atom ^{12}C is about 1.99×10^{-26} kg. So, kilogram is not a convenient unit to measure such small mass. A different mass unit (atomic mass unit) is used for expressing atomic masses this is known as atomic mass unit.This unit is the atomic mass unit (u), defined as $1/12^{th}$ of the mass of carbon (^{12}C) atom.

1 a.m.u. = 1.66×10^{-27} kg.

Discovery of Neutron

In 1932 by James Chadwick observed emission of neutral radiation when beryllium nuclei were bombarded with alpha-particles (or helium nuclei).It was found that this neutral radiation could knock out protons from light nuclei such as those of helium, carbon and nitrogen. The only neutral radiation known at that time was photons (electromagnetic radiation).Application of the principles of conservation of energy and momentum showed that if the neutral radiation consisted of photons, the energy of photons would have to be much higher than is available from the bombardment of beryllium nuclei with α-particles.This phenomenon can be explained by assuming that the neutral radiation consists of a new type of neutral particles called neutrons.

Basic Properties of Neutron

- $m_n = 1.00866$ u $= 1.6749 \times 10^{-27}$ kg
- A free neutron, unlike a free proton, is unstable.
- It decays into a proton, an electron and a antineutrino (another elementary particle), and has a mean life of about 1000s. It is, however, stable inside the nucleus.

Composition of Nucleus

The composition of a nucleus can now be described using the following terms and symbols:

Z - atomic number = number of protons

N - neutron number = number of neutrons

A - mass number = Z + N = total number of protons and neutrons

One also uses the term nucleon for a proton or a neutron.

Number of nucleons in an atom is its mass number A.

Nuclear species or nuclides are shown by the notation where X is the chemical symbol of the species.For example, the nucleus of gold is denoted by$_{79}Au^{197}$. It contains 197 nucleons, of which 79 are protons and the rest 118 are neutrons.

Size of the Nucleus

It has been found that a nucleus of mass number A has a radius $R = R_o A^{1/3}$

Where, $R_o = 1.2 \times 10^{-15}$ m.

This means the volume of the nucleus, which is proportional to R^3 is proportional to A.

Nuclear Density

The density of nucleus is a constant, independent of A, for all nuclei. The density of nuclear matter is approximately 2.3×10^{17} kg m^{-3}.

Mass – Energy Equivalence

Einstein showed from his theory of special relativity that it is necessary to treat mass as another form of energy.Einstein gave the famous mass-energy equivalence relation $E = mc^2$.Here the energy equivalent of mass m is related by the above equation and c is the velocity of light in vacuum and is approximately equal to 3×10^8 m s^{-1}.

Size of the Nucleus

By performing scattering experiments in which fast electrons, instead of α-particles, are projectiles that bombard targets made up of various elements, the sizes of nuclei of various elements have been accurately measured.

It has been found that a nucleus of mass number A has a radius then, $R = R_o A^{1/3}$

Where $R_o = 1.2 \times 10^{-15}$ m

This means the volume of the nucleus (which is proportional to R^3) is proportional to A. So the density of nucleus is a constant and independent of A.

Isotopes

The nuclei of isotopes of a given element contain the same number of protons, but differ from each other in their number of neutrons.

Isobars

All nuclides with same mass number are called isobars.

Isotones

Nuclei of different atom containing same number of neutrons are called isotones.

Energy Equivalence of One Atomic Mass Unit

1 a.m.u. represents the average mass of a nucleon and 1 a.m.u. = 931.25 eV.

Nuclear binding energy

The nucleus is made up of neutrons and protons so, it may be expected that the mass of the nucleus is equal to the total mass of its individual protons and neutrons. However, the nuclear mass is found to be always less than this.

For example, the nucleus of an oxygen atom ($^{16}O_8$) has 8 neutrons and 8 protons

So,

Mass of 8 neutrons = 8 × 1.00866 u,

Mass of 8 protons = 8 × 1.00727 u,

Mass of 8 electrons = 8 × 0.00055 u

Therefore the expected mass of $^{16}O_8$ nucleus is 8 × 2.01593 u = 16.12744 u

But, the atomic mass of $^{16}O_8$ found from mass spectroscopy experiments is seen to be 15.99493u.

Mass Defect

It is the difference between the sum of the masses of protons and neutrons forming a nucleus and actual mass of the nucleus.

Binding Energy

As, some mass disappears in the formation of a nucleus in the form of mass defect. This loss in mass reappears in the form of energy called binding energy.In other words, binding energy is the energy which should be supplied to the nucleus in order to break it up into its constituent particles.

$$\text{Binding Energy} = \left[Zm_p + (A-Z)m_n - m_n\right]c^2 \ or \ \text{Binding Energy} = \left[Zm_H + (A-Z)m_n - m({}_zX^A)\right]c^2$$

Here, c is the velocity of light in ms^{-1}

$m\left({}_ZX^A\right)$ is the mass of the atom,

m_H is mass of the hydrogen atom,

m_N is mass of the nucleus

m_p is mass of the proton

m_n is mass of the neutron

Binding Energy per Nucleon

It is the ratio of the binding energy of a nucleus to the number of the nucleons.

Binding energy per nucleon = (Total binding energy)/(Number of nucleon)

Binding Energy Curve and its Features

Binding energy per nucleon as the average energy per nucleon needed to separate a nucleus into its individual nucleons.

Binding energy curve is a plot of the binding energy per nucleon versus the mass number for large nuclei.

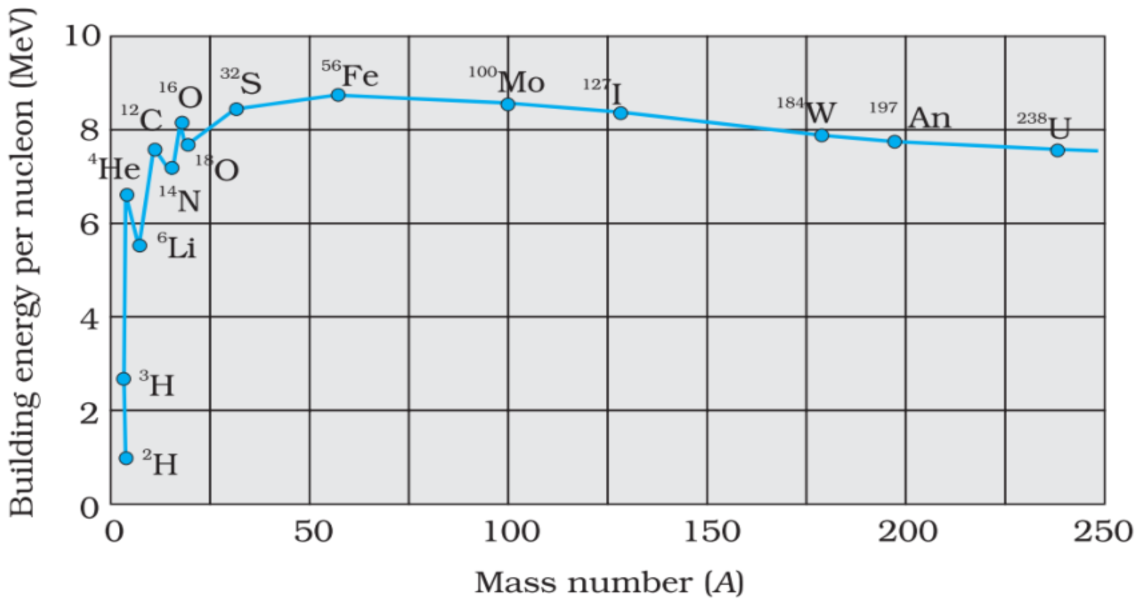


FIGURE The binding energy per nucleon as a function of mass number.

The main features of this curve are given below:

(i) The binding energy per nucleon (E_{bn}) is practically constant, i.e. practically independent of the atomic number for nuclei of middle mass number (30 < A < 170). The curve has a maximum of about 8.75 MeV for A = 56 and has a value of 7.6 MeV for A = 238.

(ii) Binding energy per nucleon is lower for both light nuclei (A<30) and heavy nuclei (A>170).

From above two observations we can draw the conclusions given below:

(a) The force is attractive and sufficiently strong to produce a binding energy of a few MeV per nucleon.

(b) The constancy of the binding energy in the range 30 < A < 170 is a consequence of the fact that the nuclear force is short-ranged.

(c)A very heavy nucleus, say A = 240, has lower binding energy per nucleon compared to that of a nucleus with A = 120. Thus if a nucleus A = 240 breaks into two A = 120 nuclei, nucleons get more tightly bound. This implies energy would be released in the process.

(d) Consider two very light nuclei (A ≤ 10) joining to form a heavier nucleus. The binding energy per nucleon of the fused heavier nuclei is more than the binding energy per nucleon of the lighter nuclei. This means that the final system is more tightly bound than the initial system. Again energy would be released in such a process of fusion. This is the energy source of the sun.

Nuclear Force

For average mass nuclei the binding energy per nucleon is approximately 8 MeV, which is much larger than the binding energy in atoms.Therefore, to bind a nucleus together there must be a strong attractive force of a totally different kind.This force is nuclear force (strongest force in nature). It is strong enough to overcome the repulsion between the (positively charged) protons and to bind both protons and neutrons into the tiny nuclear volume.

Some important features of the nuclear binding force are given below:

(i) The nuclear force is much stronger than the Coulomb force acting between charges or the gravitational forces between masses. The nuclear binding force has to dominate over the Coulomb repulsive force between protons inside the nucleus. This happens only because the nuclear force is much stronger than the coulomb force. The gravitational force is much weaker than even Coulomb force.

(ii) The nuclear force between two nucleons falls rapidly to zero as their distance is more than a few femtometres. This leads to saturation of forces in a medium or a large-sized nucleus, which is the reason for the constancy of the binding energy per nucleon. A rough plot of the potential energy between two nucleons as a function of distance is shown in the figure given below. The potential energy is a minimum at a distance r_0 of about 0.8 fm. This means that the force is attractive for distances larger than 0.8 fm and repulsive if they are separated by distances less than 0.8 fm.

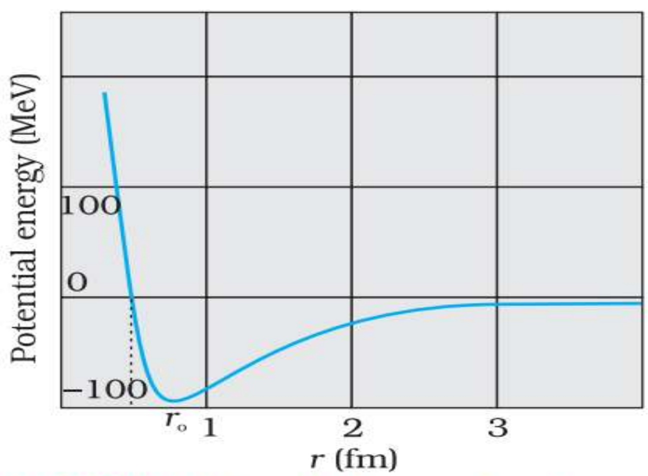


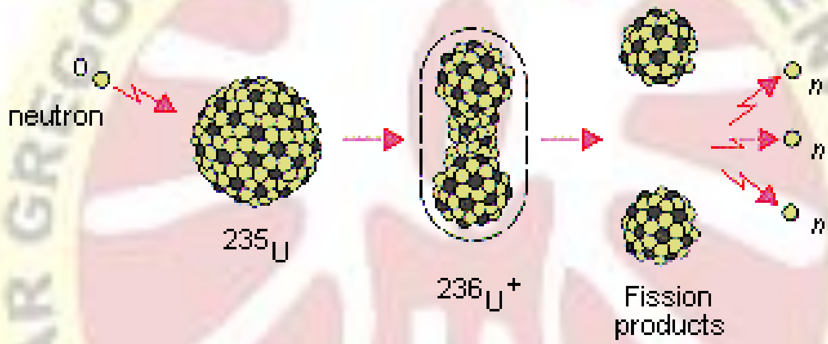
FIGURE Potential energy of a pair of nucleons as a function of their separation. For a separation greater than r_0, the force is attractive and for separations less than r_0, the force is strongly repulsive.

(ii) The nuclear force between neutron-neutron, proton-neutron and proton-proton is approximately the same. The nuclear force does not depend on the electric charge.

Nuclear Fission and Nuclear Fusion

Nuclear Fission

The graph of binding energy per nucleon suggests that nuclides with a mass larger than about 130 amu should spontaneously split apart to form lighter, more stable, nuclides. Experimentally, we find that spontaneous fission reactions occur for only the very heaviest nuclides — those with mass numbers of 230 or more. Even when they do occur, these reactions are often very slow. The half-life for the spontaneous fission of ^{238}U, for example, is 10^{16} years, or about two million times longer than the age of our planet!By irradiating samples of heavy nuclides with slow-moving thermal neutrons it is possible to induce fission reactions. When ^{235}U absorbs a thermal neutron, for example, it splits into two particles of uneven mass and releases an average of 2.5 neutrons, as shown in the figure below.



Nuclear Fuel

Nuclear fuel is the fissionable material used in nuclear reactor. Generally, U-233, U- 235 and Pu-239 is taken as nuclear fuel in form of cylindrical rods arranged in regular pattern in the active reactor core. However, the volume of core is filled with material of light nuclei called moderator. The geometry of core is such that on average out every three neutrons produced per fission. one neutron is used to trigger next fission. However, other neutrons are lost without undergoing any fission.

Basic components of Nuclear Reactor

- Following are the essential components of a nuclear reactor −
    - **Nuclear fuels** − Such as Uranium (^{233}U, ^{235}U), thorium (Th^{232}), plutonium (Pu^{239}).
    - **Moderators** − Used to control the emitted neutrons. E.g. heavy water, beryllium, graphite, etc.
    - **Coolant** − It is used to cool the reactor. E.g. water, steam, helium, CO_2, air, molten metals, etc.

- **Control rods** – It is used to run and stop the fission reaction. E.g. cadmium or boron rods are used for such purpose.

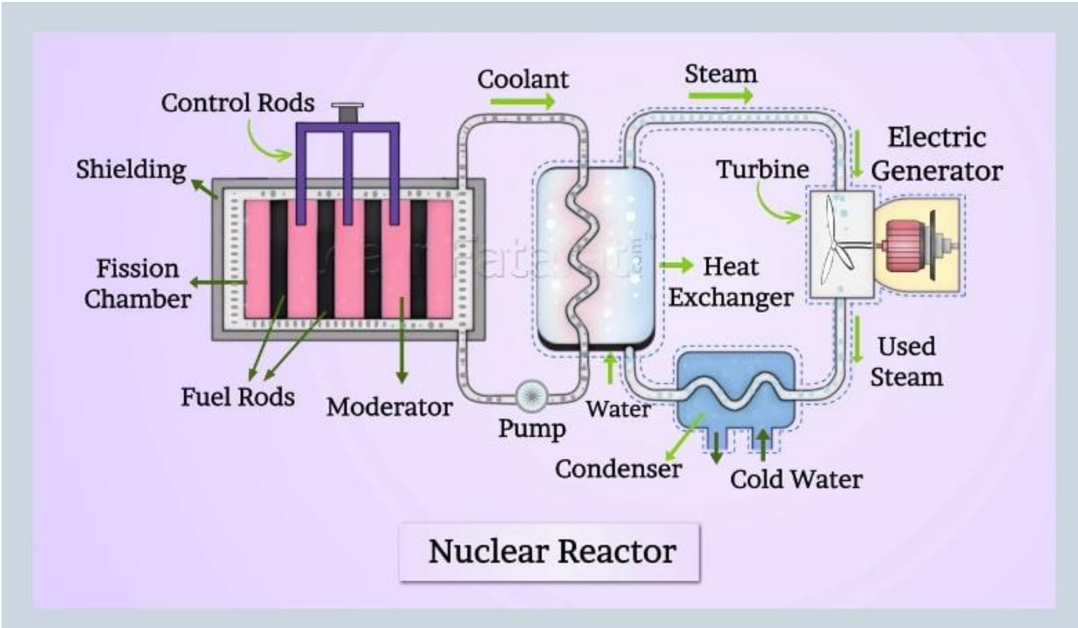
Moderator
Slow moving neutron have more tendency to facilitate fission reaction rather than the fast moving neutrons. Average energy of neutron produced in fission of U-235 is 2 MeV. these are the fast neutrons and have low tendency to cause fission. In order to facilitate fission reaction there is need to slow down the neutrons. The job is done by moderator in nuclear reactor, by transferring the energy with elastic collision to lighter nuclei. In nuclear reactors water, solid graphite or heavy water are used as moderators.

Control Rods
Nuclear reaction if not controlled can cause massive explosion. Multiplication factor K helps us to determine if reaction is in control or not. K=1 is required for sustained energy production. If K exceeds unity control rods made of boron or cadmium are inserted in the reactor core upto desirable length. The rods have the ability to absorb neutrons. Therefore, the nuclear reaction can be controlled thereby bringing down the multiplication factor down unity.

Safety Rod
In addition to control rods, the reactors are provided with safety rods. These rods can be inserted into reactor in order to bring value of K below unity. Hence, it keeps power generation safe.

Coolant
Heat produced in the core is absorbed by coolant. Later this energy is passed to water in heat exchanger. Thus, it produces steam. The steam is used to drive turbine coupled with electric generator and thus, electric energy is produced. In general water or heavy water is used as coolant. In case of high temperature, liquid sodium is used as coolant.

Shielding
Nuclear fission produces hazardous radiations, therefore, nuclear reactor is kept in concrete walls of 2 m to 2.5 m thick. This prevents radiations from reaching outside environment.



Working

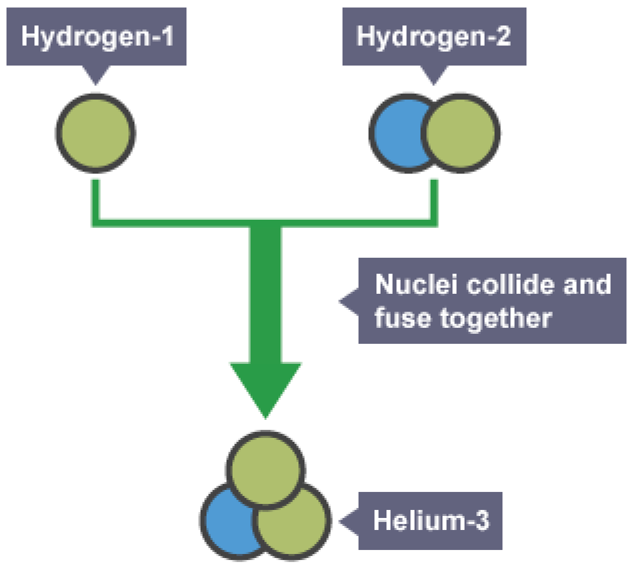
The cadmium rods are slowly removed so that slow moving neutrons can cause fission of U-235 nuclei generating energy . In the primary-loop, coolant absorb energy . The energy is transported at high temperature and pressure to the steam generator in secondary loop where evaporation of water takes place. Evaporation provides high-pressure steam to operate the turbine and in turn, drives the electric generator. The low-pressure steam from the turbine is cooled and condensed to water and forced back into the steam generator.

Advantages and disadvantages of nuclear reactor

It is advantageous because in very small quantity of fuel it produce large energy . However, the disadvantage is that there is problem of disposal of radioactive nuclear waste and maintenance of equipment.

Nuclear fusion

Nuclear fusion is when two small, light nuclei join together to make one heavy nucleus. Fusion reactions occur in stars where two hydrogen nuclei fuse together under high temperatures and pressure to form a nucleus of a helium isotope. There are a number of different nuclear fusion reactions happening in the Sun. The simplest is when four hydrogen nuclei become one helium nuclei.



$4\,{}_1^1H \rightarrow {}_2^4He$

The combined mass of four hydrogen nuclei is 6.693×10^{-27} kilograms (kg). The mass of one helium nucleus is 6.645×10^{-27} kg. This means that there is a missing amount of mass equalling 0.048×10^{-27} kg. The missing mass is converted to energy, which radiates away. This is seen happening in the Sun. In all nuclear reactions a small amount of the mass changes to energy. This may not seem like a lot of energy but this energy is a result of the fusion of only four hydrogen nuclei.

A 250 millilitre (ml) glass of water will contain around 1.6 × 1025 hydrogen atoms. Complete fusion of all these hydrogen nuclei would release about 17,200,000,000,000 joules (J) of energy. It is estimated that the sun releases 3.8×10^{26} joules of energy every second.

However, the issue with fusion is that it requires the fusing of nuclei, which are positive particles. As two nuclei approach each other, they will repel because they have the same charge. The fusion of the nuclei has to happen quickly so that the repulsion of the charges does not have time to stop it from happening. A way that particles can travel that quickly is by being in a hot gas or in plasma, like in the Sun. In fact, for fusion to occur, the temperature of the hot gas or plasma needs to be at least 150,000,000 degrees Celsius (°C).

Liquid Drop Model

Similarities:

1) As a drop of the liquid consist of large number of molecules which are present in the same volume, similarly nucleus is made-up of large number of protons and neutrons present in the same nuclear volume.

2) As the drop of liquid is homogeneous in density, charge etc. same is for the nucleus.

3) As a drop of liquid cannot be compressed, similarly nucleus also cannot be compressed.

4) In the case of drop of the liquid, the forces between all the molecules is same. Similarly nuclear forces in all the nucleons is nearly same.

5) When a very little amount of liquid is added to a drop. The drop of the liquid grows in size. Similarly projectiles (Light Particles) can be added to the nucleus forming the compound nucleus.
6) Small drops of the liquid combine to form a big drop of the liquid. Similarly small nuclei combine forming big nucleus. This is known as nuclear fusion phenomenon.
7) A very big drop of the liquid breaks up into smaller droplets. Similarly heavy nucleus breaks up into smaller. This phenomenon is called nuclear fission.
8) As in a drop of liquid evaporation phenomenon take place. Similarly in the nuclear reaction emission of the nucleons take place. For example The Atomic transmutation reaction, the particles are ejected out.
9) As in a drop of the liquid the molecules are moving continuously due to thermal motion of the molecules. Similarly in the nucleus, the nucleons (Protons and Neutrons) are moving because of K.E.

Merits:

1)It explain the phenomenon of nuclear fission.
2)It explain the nuclear fusion phenomenon.
3)It helps in calculating binding energy of the nuclei.
4) It support the Bohrs theory of the formation of compound nucleus.

Limitations:

1) This model cannot explain the extra stability of the nuclei having the number of protons and neutrons 2, 8, 20, 28, 50, 82 and 126 i.e. inert gases.
2) The model is true only for elements having mass number, between 20 and 150 (20 - 150)

Semi-empirical mass formula

The binding energy is usually plotted as B/A or binding energy per nucleon. This illustrates that the binding energy is overall simply proportional to A, since B/A is mostly constant.

There are however corrections to this trend. The dependence of B/A on A (and Z) is captured by the ***semi-empirical mass formula***. This formula is based on first principle considerations (a model for the nuclear force) and on experimental evidence to find the exact parameters defining it. In this model, the so-called **liquid-drop** model, all nucleons are uniformly distributed inside a nucleus and are bound together by the nuclear force while the Coulomb interaction causes repulsion among protons. Characteristics of the nuclear force (its short range) and of the Coulomb interaction explain part of the semi-empirical mass formula. However, other (smaller) corrections have been introduced to take into account variations in the binding energy that emerge because of its quantum-mechanical nature (and that give rise to the **nuclear shell model**).

The semi-empirical mass formula is
$M(Z,A)=Zm(^{1}H)+Nm_{n}-B(Z,A)/c^{2}$

where the binding energy B(Z, A) is given by the following formula:

$$B(A,Z) = a_v A - a_s A^{2/3} - a_c Z(Z-1)A^{-1/3} - a_{sym}\frac{(A-2Z)^2}{A} + \delta a_p A^{-3/4}$$

volume surface Coulomb symmetry pairing

Volume term

The first term is the volume term $a_v A$ that describes how the binding energy is mostly proportional to A. The binding energy is a measure of the interaction among nucleons. Since nucleons are closely packed in the nucleus and the nuclear force has a very short range, each nucleon ends up interacting only with a few neighbors. This means that independently of the total number of nucleons, each one of them contribute in the same way. Thus the force is not proportional to $A(A - 1)/2 \sim A^2$ (the total # of nucleons one nucleon can interact with) but it's simply proportional to A. The constant of proportionality is a fitting parameter that is found experimentally to be $a_v =$ 15.5MeV.This value is smaller than the binding energy of the nucleons to their neighbors as determined by the strength of the nuclear (strong) interaction. It is found that the energy binding one nucleon to the other nucleons is on the order of 50 MeV. The total binding energy is instead the difference between the interaction of a nucleon to its neighbor and the kinetic energy of the nucleon itself. As for electrons in an atom, the nucleons are fermions, thus they cannot all be in the same state with zero kinetic energy, but they will fill up all the kinetic energy levels according to Pauli's exclusion principle. This model, which takes into account the nuclear binding energy and the kinetic energy due to the filling of shells, indeed gives an accurate estimate for a_v.

Surface term

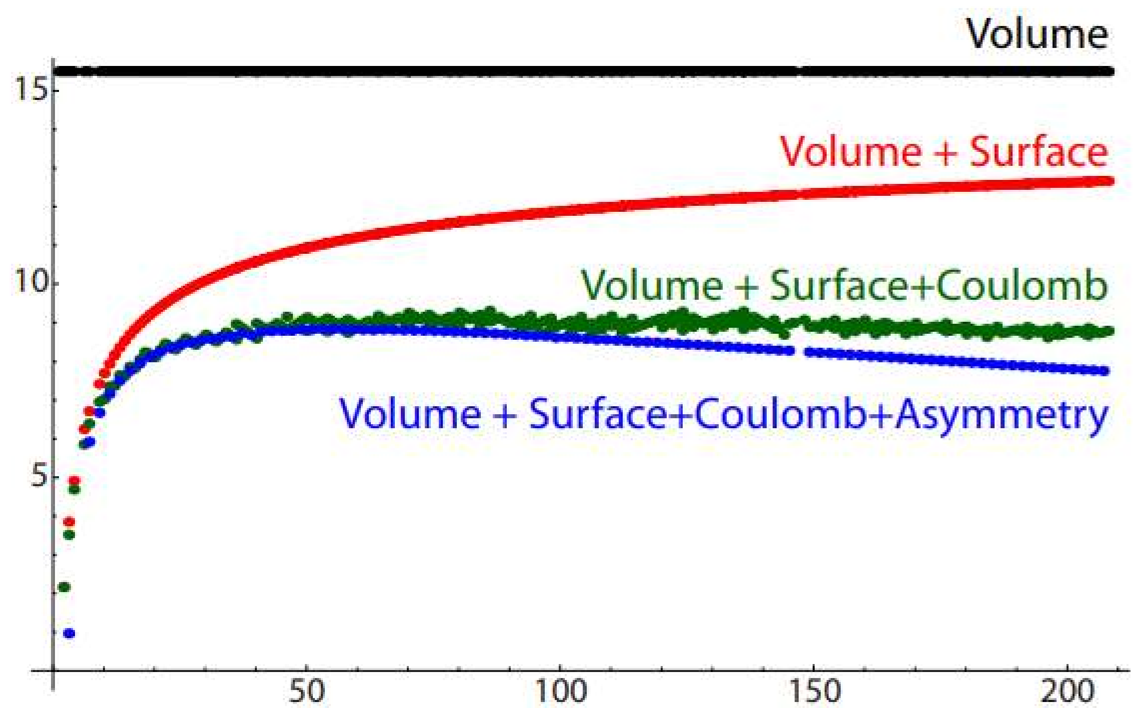
The surface term, $-a_s A^{2/3}$, also based on the strong force, is a correction to the volume term. We explained the volume term as arising from the fact that each nucleon interacts with a constant number of nucleons, independent of A. While this is valid for nucleons deep within the nucleus, those nucleons on the surface of the nucleus have fewer nearest neighbors. This term is similar to surface forces that arise for example in droplets of liquids, a mechanism that creates surface tension in liquids.Since the volume force is proportional to $B_V \propto A$, we expect a surface force to be

$\sim (B_V)^{2/3}$ .Also the term must be subtracted from the volume term and we expect the coefficient a_s to have a similar order of magnitude as a_v.

Coulomb term

The third term $-a_c Z(Z-1)A^{-1/3}$ derives from the Coulombinteraction among protons, and of

course is proportional to Z. This term is subtracted from the volume term since the Coulomb repulsion makes a nucleus containing many protons less favorable (more energetic).To motivate the form of the term and estimate the coefficient a_c, the nucleus is modeled as a uniformly charged sphere.



Symmetry term

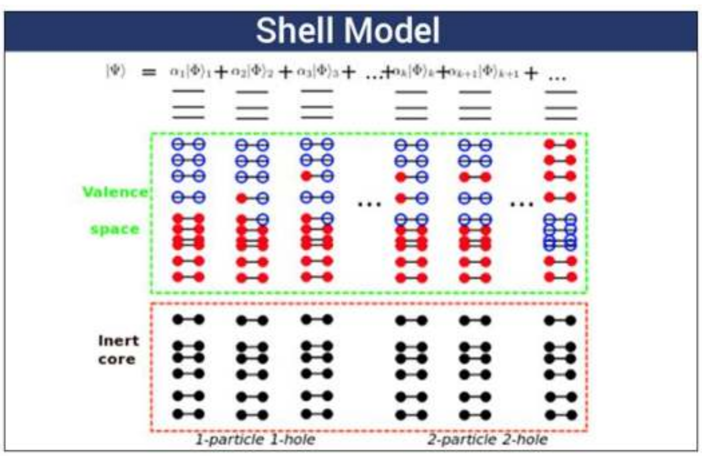
The Coulomb term seems to indicated that it would be favorable to have less protons in a nucleus and more neutrons. However, this is not the case and we have to invoke something beyond the liquid-drop model in order to explain the fact that we have roughly the same number of neutrons and protons in stable nuclei. There is thus a correction term in the SEMF which tries to take into account the symmetry in protons and neutrons. This correction (and the following one) can only be explained by a more complex model of the nucleus, the **shell model**, together with the quantum-mechanical *exclusion principle*, that we will study later in the class. If we were to add more neutrons, they will have to be more energetic, thus increasing the total energy of the nucleus. This increase more than off-set the Coulomb repulsion, so that it is more favorable to have an approximately equal number of protons and neutrons. The shape of the symmetry term is (A−2Z)2A. It can be more easily understood by considering the fact that this term goes to zero for A = 2Z and its effect is smaller for larger A (while for smaller nuclei the symmetry effect is more important). The coefficient is a_{sym} = 23 MeV.

Pairing term

The final term is linked to the physical evidence that like-nucleons tend to pair off. Then it means that the binding energy is greater (δ > 0) if we have an even-even nucleus, where all the neutrons and all the protons are paired-off. If we have a nucleus with both an odd number of neutrons and of protons, it is thus favorable to convert one of the protons into a neutrons or vice-versa (of course, taking into account the other constraints above). Thus, with all other factor constant, we have to subtract (δ < 0) a term from the binding energy for odd-odd configurations. Finally, for even-odd configurations we do not expect any influence from this pairing energy (δ = 0).

Nuclear Shell Model

- It basically explains the distribution of energy levels into different atom shells and nucleus atom shells. A shell is described as the energy level where particles having the same energy exist. In this model, all the nuclear particles are paired one-to-one, neutron with a neutron, and proton with a proton. The paired neutrons and protons in nuclear energy levels are filled when the number of neutrons or protons is equal to 2, 8,20,28,50,82, or 126. These are the magic numbers that show the most stable nuclei.



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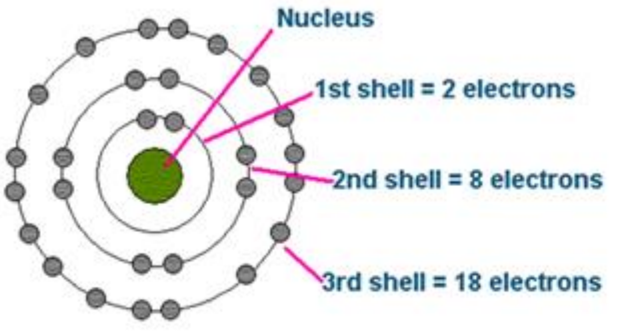
- The unpaired ones are responsible for the properties of a nucleus and valence electrons are responsible for different chemical properties of elements. With the help of the shell model, we can accurately predict the properties of nuclei such as angular momentum. But, for nuclei which are in a highly unstable state, the shell model needs to be modified or replaced with other models such as the collective model, liquid-drop model, and compound nucleus model.

- Shell Model of the Atom
- It explains the arrangement of different electrons present around the nucleus of an atom as per energy levels.



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- **Shell Model of the Atom**
-

Atomic Number = number of electrons in an atom

- The atomic shell model explains the structure of atoms. The negatively charged fundamental particles which are known as electrons are considered to occupy diffuse shells in the space that surrounds the positively charged nucleus. The shell which is closest to the nucleus is the first shell.
- The shells are designated as:

K	First shell
L	Second shell
M	Third shell and so on

- The sequence in which the electrons occupy the shell is given as:
- 2, 8, 18, 32, 50, 72, 98.
- The atomic shell model also helps in understanding the chemical properties of the atoms.
- The maximum number of electrons that can occupy the energy level in an atom is found by using the following formula:

Electron capacity = $2n^2$

- Where n is the principal quantum number.
- Following is the table for the shell levels and their electron capacity:

Energy Level	Shell Designation	Maximum no.of electrons
1	K	2
2	L	8
3	M	18
4	N	32
5	O	50
6	P	72

- **Difference Between Shell Structure of Nuclei and Shell Structure of Atom**

Shell Structure of Nuclei	**Shell Structure of Atom**
Energy Level starts from Zero state	Energy Level starts from the first state
Magic Numbers, Z= 2,8,20,28,50,82,126 and so on	Magic Numbers, Z = 2,10,18,36,54,86 and so on
The average potential of Nuclei is different from that of an atom	The average Potential varies.
Particles of the shell structure of nuclei are neutrons and protons	Particles of the shell structure of an atom are electrons

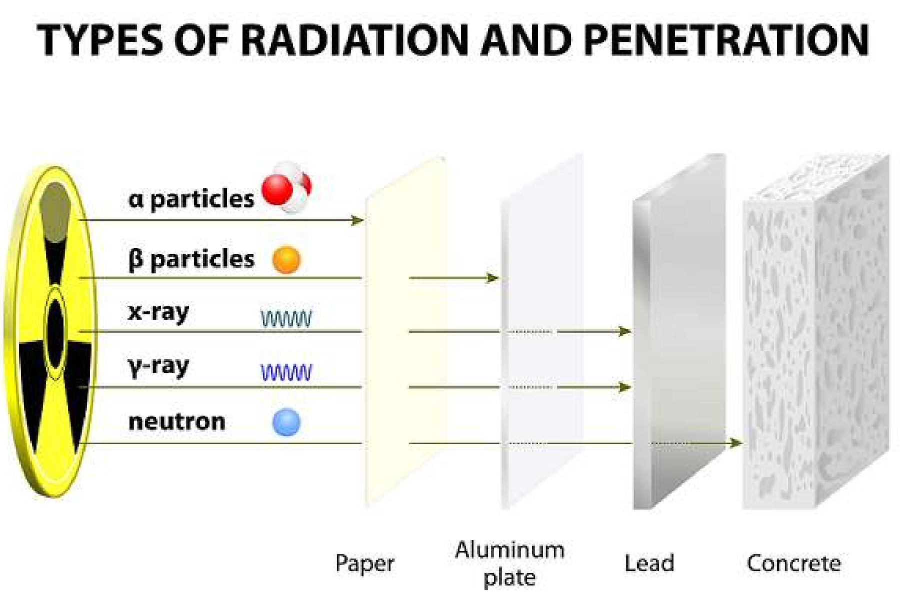
- Magic Numbers in Nuclear Structure
- When a nucleus has an even number of protons and neutrons, such a nucleus is more stable than with the odd numbers. This number is known as "magic numbers" and they offer stability to the atom. Following is the sequence of magic number:
- 2, 8, 20, 28, 50, 82, 126.
- When nuclei will have both neutron number and proton number equal to one of the magic numbers, they are known as "doubly magic". Calcium is an example of a nucleus that has a doubly magic number.

Radioactivity

- The process of emission of particles from nuclei because of the nuclear instability; is known as radioactivity.
- The substance that releases such energy/rays is known as radioactive substance.
- The invisible rays released from such radioactive substance are known as radioactive rays.
- Likewise, radioactivity is a nuclear phenomenon that happens (naturally) because of the nuclear instability of atoms.
- In 1896 Henri Becquerel first observed the phenomena of radioactivity, but the term 'radioactivity' was coined by Marie Curie.
- Marie Curie discovered the radioactive elements namely Polonium and Radium in 1898.
- For her discovery, Marie Curie won the Nobel Prize.

Radioactive Rays

- After long years of experiment, Ernest Rutherford along with his colleague (Hans Geiger and his student Ernest Marsden), discovered alpha rays, beta rays, and gamma rays.



- These rays emitted as the result of the disintegration of atoms.

Alpha (α) Particles

- Alpha particles are usually composed of two protons and two neutrons, which are tightly bound together.
- Alpha particles are being released during radioactive decay (or alpha decay) from the nucleus radio nuclides.

- The alpha particles are identical to the nucleus of either normal helium atom or doubly ionized helium atom.
- In comparison to other particles (i.e. Gamma and Beta), alpha particles are heavy and slow. Therefore, alpha particles have very small range in the air.
- Because of slow speed, Alpha particles have very weak penetrating powers; these particles are even stopped by a thin paper sheet (see image given above).
- Because of having the double positive charge, alpha particles are highly ionizing.

Beta (β) Particles

- Beta particles are the fast moving electrons emitted by some radio nuclides during the radioactive decay (also known as beta decay).
- Beta particles are of much lighter weight and carry a single negative charge.
- Beta particles are rarely ionizing than the alpha particles.
- Because of having lighter weight, beta particles can travel much farther than alpha particles; however, beta particles can be stopped by several sheet of papers or one sheet of aluminum.
- Beta particles are negatively charged and get attracted towards positively charged particles.

Gamma (γ) Particles

- Gamma particles are the bundle of high energy namely electromagnetic energy (photon) emitted by the radioactive elements during the radioactive decay.
- Among all three particles (alpha, beta, and gamma), gamma particles are the most energetic photons.
- Gamma particles, which are the form of electromagnetic radiation(EMR), originate from the nucleus.
- The wavelengths of gamma are the shortest among all three.
- Gamma particles have no charge and they are neutral; therefore, they are unaffected by magnetic and electric fields.

Uses of Radioactive Elements

- Radioactive elements are used in
    - Medical field (treatment of many diseases)
    - Industrial process
    - Energy production – Nuclear reactors

NATURAL RADIOACTIVITY:-

Nuclear reactions which occur spontaneously are said to be an example of natural radioactivity. There are three naturally occurring radioactive series among the elements in the periodic table. These are known as the uranium series, the actinium series and the thorium series, each named after the element at which the series start (except the actinium series which starts with a different uranium isotope). Each series decays through a number of unstable nuclei by means of alpha and beta emmission, until each series end on a different stable istope of lead.

ARTIFICIAL RADIOACTIVITY:-

Not all nuclear reactions are spontaneous. These reactions occur when stable isotopes are bombarded with particles such as neutrons. This method of inducing a nuclear reaction to proceed is termed artificial radioactivity. This meant new nuclear reactions, which wouldn't have been viewed spontaneously, could now be observed. Since about 1940, a set of new elements with atomic numbers over 92 (the atomic number of the heaviest naturally occurring element, Uranium) have been artificially made. They are called the transuranium elements.

Uses of Radioisotopes

Applications of radioisotope

The applications of radioisotopes have played a significant role in improving the quality of life of human beings. The whole world is aware of the benefits of the radiation, but the phobia of nuclear weapons on Hiroshima and Nagasaki (August 6 and 9, 1945) and the nuclear accidents occurred in Chernobyl in Russia (April 25–26, 1986) and Fukushima in Japan (March 2011) was so deep in the mind of the common man that we can still struggle to come out of it. Major problems arrived by workers in nuclear fields are due to lack of legalization, shortage of resources, and knowledge about nuclear society and safe guards. To minimize these problems the international organization such as International Atomic Energy Agency (IAEA) and International Commission on Radiation Protection (ICRP), identify requirements and provide the infrastructure that can support nuclear technology [20].

Radiotracer (radioisotopes)

Radiotracers are widely used in medicine, agriculture, industry, and fundamental research. Radiotracer is a radioactive isotope; it adds to nonradioactive element or compound to study the dynamical behavior of various physical, chemical, and biological changes of system to be traced by the radiation that it emits. The tracer principle was introduced by George de Hevesy in 1940 for which he was awarded the Nobel prize.

Radioisotope production

The sustainability of radioisotope production is one of the critical areas that receive great attention. There are more than 160 different radioisotopes that are used regularly in different fields; these isotopes are produced either in a medium or in high-flux research reactors or particle accelerators (low or medium energy).

Reactor radioisotope	**Half-life**	**Applications**
Bismuth-213	45.59 min	It is an alpha emitter (8.4 MeV). Used for cancer treatment, e.g., in the targeted alpha therapy (TAT)
Cesium-131	9.7 days	It emits photon radiation in the X-ray range (29.5–33.5 keV). Used in brachytherapy of malignant tumors
Cesium-137	30 years	Used in medical devices (sterilization) and gauges (661.64 keV)
Chromium-51	28 days	Used in Diagnosis of gastrointestinal bleeding and to label platelets (320 keV)
Cobalt-60	5.27 years	Used for controlling the cancerous growth of cells (1173.2 keV)
Dysprosium-165	2 h	Used for synovectomy treatment of arthritis (95 keV)
Erbium-169	9.4 days	Used for relieving arthritis pain in synovial joints (8 keV)
Holmium-166	26 h	Diagnosis and treatment of liver tumors (81 keV)
Iodine-125	60 days	Used in cancer brachytherapy and radioimmunoassay (35 keV)
Iodine-131	8 days	Widely used in treating thyroid cancer and in imaging the thyroid, diagnosis, and renal blood flows (284 keV)
Iridium-192	74 days	Used as an internal radiotherapy source for cancer treatment. Strong beta emitter for high-dose rate brachytherapy (317 keV)
Iron-59	46 days	Used in studies of iron metabolism in the spleen (1095 keV)
Lead-212	10.6 h	Used in TAT for cancers (239 keV)
Molybdenum-99	66 h	Used as the parent in a generator to produce technetium-99 m (740 keV)
Palladium-103	17 days	Used to make brachytherapy permanent implant seeds for early-stage prostate cancer. Emits soft X-rays (362 keV)
Potassium-42	12.36 h	Used for potassium distribution in bodily fluids and to locate brain tumors (1524 keV)
Radium-223	11.4 days	Used to treat prostate cancers that have spread to the bones
Rhenium-186	3.71 days	Used for therapeutic purpose to relief pain in bone cancer. Beta emitter with weak gamma for imaging (137 keV)
Samarium-153	47 h	Effective in relieving the pain of secondary cancers lodged in the bone, sold as Quadra met. Beta emitter (103 keV)
Selenium-75	120 days	Used to study the production of digestive enzymes (265 keV)
Sodium-24	15 h	Used for studies of electrolytes within the body (2754 keV)
Ytterbium-169	32 days	Used for cerebrospinal fluid studies in the brain (63 keV)

Reactor radioisotope	Half-life	Applications
Radioisotopes produced by accelerators		
Cobalt-57	272 days	Used as a marker to estimate organ size and for in vitro diagnostic kits (122 keV)
Copper-64	13 h	Used for PET imaging studies of tumors and also cancer therapy (511 keV)
Copper-67	2.6 days	Beta emitter, used in therapy
Fluorine-18	110 min	Used as fluorothymidine (FLT)
Gallium-67	78 h	Used for tumor imaging and locating inflammatory lesions (infections)
Indium-111	2.8 days	Brain studies, infection, and colon transit studies
Iodine-123	13 h	Used for diagnosis of thyroid function
Rubidium-82	1.26 min	Convenient PET agent in myocardial perfusion imaging
Strontium-82	25 days	Used as the parent in a generator to produce Rb-82
Thallium-201	73 h	Used for location of low-grade lymphomas

Medicine

Radiotracer has become an indispensable and sophisticated diagnostic tool in medicine and radiotherapy purposes.

Diagnostic purpose

The most common radioactivity isotope used in radioactive tracer is technetium (^{99}Tc). Tumors in the brain are located by injecting intravenously ^{99}Tc and then scanning the head with suitable scanners.^{131}I and most recently ^{132}I and ^{123}I are used to study malfunctioning thyroid glands. Kidney function is also studied using compound containing ^{131}I. ^{33}P is used in DNA sequencing. Tritium (^{3}H) is frequently used as a tracer in biochemical studies. ^{14}C has been used extensively to trace the progress of organic molecule through metabolic pathways.

A most recent development is positron emission tomography (PET), which is a more precise and accurate technique for locating tumors in the body. A positron emitting radionuclide (e.g., ^{13}N, ^{15}O, ^{18}F, etc.) is injected to the patient, and it accumulates in the target tissue. As it emits positron which promptly combines with nearby electrons, it results in the simultaneous emission of two γ-rays in opposite directions. These γ-rays are detected by a PET camera and give precise indication of their origin, that is, depth also. This technique is also used in cardiac and brain imaging.

Compound X-ray tomography or CT scans. The radioactive tracer produces gamma rays or single photons that a gamma camera detects. Emissions come from different angles, and a computer uses them to produce an image. CT scan targets specific area of the body, like the neck or chest, or a specific organ, like the thyroid [22].

Therapeutic

The most common therapeutic use of radioisotopes is ^{60}Co, used in treatment of cancer. Sometimes wires or sealed needles containing radioactive isotope such as ^{192}Ir or ^{125}I are directly placed into the cancerous tissue. The radiations from the radioisotopes attack the tumor as long as needle/wire is in place. When the treatment is complete, these are removed. This technique is frequently used to treat mouth, breast, lung, and uterine cancer. ^{131}I is used to treat thyroid for cancers and other abnormal conditions of thyroid. ^{32}P is used to treat excess of red blood cells produced in the bone marrow.

Agricultural research

Development of high yielding varieties of plants, oil seeds, and other economically important crops and protection of plant against the insects are the thrust area of agricultural research.

New varieties of crops

The irradiated seeds of wheat, rice, maize, cotton, etc., are undergoing profound genetic changes in order to improve crop varieties and mutation breeding. These varieties of crops are more disease resistant and have high yields. Several countries all over the world produce new variety of crops from radiation-induced mutants.

Eradication of insect and pests

The best technique for the control of insects and pests is sterile insect technique (SIT). Irradiation is used to sterilize mass-reared insects so that, while they remain sexually competitive, they cannot produce offspring. As a result, it enhances the crop production and preservation of natural resources.

Food preservation and sterilization

As per WHO reports, about 25–35% of world food production is susceptible to the attack by pests, insects, bacteria, and fungi causing a great loss of the economy of the country. Food irradiation has more advantages than conventional methods. All types of radiations are not recommended for food irradiation; only three types of radiation are recommended by CODEX general standard for food irradiation which are ^{60}Co or ^{137}Cs, X-rays, or electron beams from particle accelerators. The food products are exposed to γ-radiations from the intense controlled sources to kills pests, bacteria, insects, and parasites and extends shelf-life but also reduces the food's nutritional value somewhat by destroying vitamins A, B_1 (thiamin), C, and E. No radiation remains in the food after treatment.Depending on the radiation dose and its application, radiations are classified into three categories: they are low dose (<1 kGy), medium dose (1–10 kGy), and high dose (>10 kGy) [24].

Sprout inhibition in bulbs and tubers

Irradiated potato can be stored at higher temperature of around 15°C. This not only conserves energy but also prevents sweetening of potato, commonly occurring at low temperatures. It gives advantage to the manufacturers of chips as low-sugar potato gives desired lighter color to fries and chips.

Delayed ripening of fruits

Irradiated fruits (all kinds of mangoes) of these at hard mature pre-climacteric stage at 0.25–0.75 kGy delay the ripening process by about 7 days, thus improving shelf-life. These doses are also effective in destroying quarantine pests. Irradiated fresh fruits can be stored for longer duration, sometimes up to 30 days at 12–14°C and in modified atmospheres.

Medium-dose applications

Under ice, sea food such as fish and prawns, fish-like Bombay duck, pomfret, Indian salmon, mackerel, and shrimp can be stored for about 7–10 days. Studies have demonstrated that irradiation at 1–3 kGy followed by storage at melting ice temperatures increases its shelf-life nearly threefold.

Meat and meat products including poultry have a shelf-life of about a week at 0–3°C, which could be extended up to 4 weeks by applying a dose of 2–5 kGy, which inactivates spoilage bacteria. Radiation treatment has been employed to enhance the shelf-life of intermediate moisture meat products.

High-dose applications

While transporting the spices, due to inadequate handling and processing conditions, spices get contaminated with insect eggs and microbial pathogens. When incorporated into semi-processed or processed foods, particularly, after cooking, the microbes, both spoilers and pathogens, in spices can outgrow causing spoilage and posing risk to consumers. Many of the spices develop insect infestation during storage, and unscrupulous traders convert them into spice powders. A dose of 10 kGy brings about near sterility or commercial sterility while retaining the natural characteristics of spices.

Irradiation at higher doses can also be employed for total sterilization of diets for immunocompromised patients, adventure sports, military, and astronauts.

Industry and civil engineering

Radioisotopes are commonly used in industry for checking blocked water pipes and detecting leakage in oil pipes. For example, small quantity of radioactive ^{24}Na is placed in a small enclosed ball and is allowed to move in pipe with water. The moving ball containing radioisotope is monitored with a detector. If the movement of ball stops, it indicates the blocked pipe. Similarly, radioisotope ^{24}Na is mixed with oil flowing in an underground pipe. With radiation detector, the radioactivity over the pipe is monitored. If there is a leakage place, the radiation detector will show large activity at that particular place. Radioisotopes are also used to monitor fluid flow and filtration, detect leaks, and gauge engine wear and corrosion of process in equipment.

Radioactive materials are used to inspect metal parts and the integrity of welds across a range of industries. The titanium capsule is a radioactive isotope which is placed on one side of the object being screened, and some photographic film is placed on the other side. The gamma rays pass through the object and create an image on the film. Gamma rays show flaws in metal castings or welded joints. The technique allows critical components to be inspected for internal defects without damage. Radiotracer is also used to inspect for internal defect without damage.

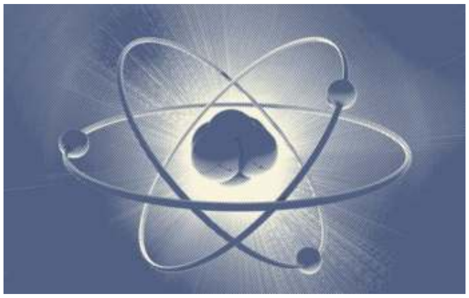
In industries, the production methods need to be constantly monitored in order to check the quality of products and to control the production process. The monitoring is carried out by quality control devices using the unique properties of radiation; such devices are called nuclear gauges. They are more useful in extreme temperature, harmful chemical process, molten glass, and metals. The gauges are also used to measure the thickness of sheet materials, including metals, textiles, paper, and plastic production.

Effects of exposure to radioisotope

Radiation passing through the material breaks the bonds by removing the electron of an atom or molecules; this induces physical, chemical, and biological changes. Ionizing radiation focuses large amount of energy into a highly localized areas of irradiated materials. Damage is caused by the interaction of this energy with nuclei or orbiting electrons. The material structure may be modified through this energy interaction; as a result the mechanical property of bulk material changes.

Nuclear Reactions

- Nuclear reactions release tremendous amount of energy (known as nuclear energy), which are being used to produce electricity in a nuclear power plant.



- The nuclear energy normally produced by **nuclear fission, nuclear fusion,** and **nuclear decay**.
- In 1938, German chemists Otto Hahn, Fritz Strassmann, and the Austrian physicist Lise Meitner conducted the experiments in which the products of neutron-bombarded uranium. As result of this experiment, the relatively tiny neutron split the nucleus of the massive uranium atoms into two roughly equal pieces and released massive energy.
- The nuclear experiments of Otto Hahn and his colleagues are popular as nuclear fission.

Nuclear Fission

- The process of nuclear fission produces free neutrons and gamma photons, while doing this also releases a very large amount of energy.
- Nuclear fission is an exothermic reaction, which can release large amounts of energy in the forms of electromagnetic radiation as well as kinetic energy.
- Nuclear fission, sometimes, can occur naturally (i.e. without neutron bombardment) as a type of radioactive decay.

Types of Nuclear Fission

- Following are the major types of Nuclear Fission −
    - **Chain Reaction and**
    - **Fission Reaction**

Chain Reaction

- When one single nuclear reaction causes one or more subsequent nuclear reactions, it is known as chain reaction.
- Such chain reaction increases the possibility of a self-propagating series of nuclear reactions.
- The nuclear chain reactions release million times more energy per reaction than any other chemical reaction; therefore, it is also known as explosive or uncontrolled chain reaction.

- When a heavy atom experiences nuclear fission, it normally breaks into two or more fission fragments. During the process, several free neutrons, gamma rays, and neutrinos are emitted, and ultimately a large amount of energy is released.
- Following are the two examples of chain reaction −
  - ^{235}U + → neutron Fission fragments + 2.4 neutrons + 192.9 MeV
  - ^{235}Pu + → neutron Fission fragments + 2.9 neutrons + 198.9 MeV
- In atom bomb, chain reaction technology is used, as it required consistent source of energy.

Fission Reactions

- The fission reaction in which neutrons (produced by fission of fuel atoms) are used to induce yet more fission for the release of sustainable energy, is known as fission reactions.
- Such reactions are slow and controllable; therefore, also known as controlled chain reaction.
- The power (electricity) producing nuclear reactor is an ideal example of controlled chain reaction.
- Based on the properties and type of usages, fission/controlled chain reaction is classified as –
  - **Power reactors**
  - **Research reactors**
  - **Breeder reactors**
- These power reactors generally convert the kinetic energy of fission products into heat; further, the heat is used to heat a working fluid that drives a heat engine, which ultimately generates mechanical or electrical power.

Nuclear Fusion

- The process by which two light nuclei are fused to form a heavy nucleus is known as nuclear fusion; during this process, a tremendous amount of energy is being released known as nuclear energy.
- The best example of nuclear fusion is – hydrogen bomb.
- A hydrogen bomb is about 1,000 times more powerful than an atom bomb.

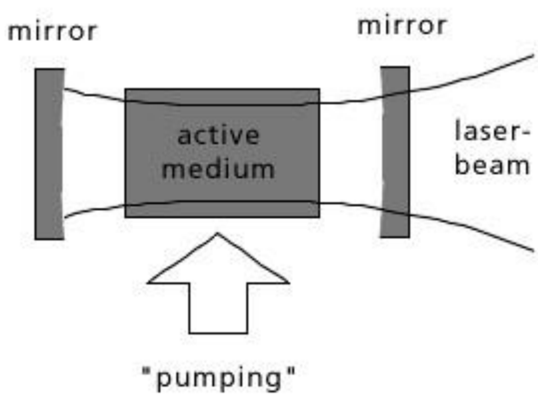
Q – Value of a Nuclear Reaction

In nuclear physics and chemistry, the Q value for a reaction is the amount of **energy** absorbed or released during the nuclear reaction. The value relates to the enthalpy of a chemical reaction or the **energy** of radioactive decay products. It can be determined from the masses of reactants and products.

Calculate Q-Value of the following nuclear reaction
$_3Li^7 + {_1H^1}$ ———> $2\,{_2He^4}$
Check whether the reaction is exoergic or endoergic
The value of Q can be calculated from the masses of the products and reactants of the equation.
The exact mass of $_3Li^7$ isotope = 7.01601 a.m.u. and that of $_1H^1$ = 1.00738 a.m.u.
The exact mass of $_2He^4$ = 4.00260 a.m.u.
Where, a.m.u. is Atomic Mass Unit.
Hence
Sum of the masses of reactants = 7.01601 + 1.00738 = 8.02384 a.m.u.
Sum of the masses of products = 2 X 4.00260 = 8.00520 a.m.u.
Therefore, ΔM = Sum of the masses of products – Sum of the masses of reactants
= 8.00520 – 8.02384 = – 0.01864 a.m.u.
As there is decrease of mass, hence energy is being released.
The value of Q will be therefore Positive i.e.
Q = + 0.01864 a.m.u. X 931.5 MeV/a.m.u = + 17.36 MeV
Hence the above reaction is exoergic.

Unit III - LASER PHYSICS

Introduction-The word LASER is an acronym which stands for Light Amplification by Stimulated Emission of Radiation. It actually represents the principle itself but is nowadays also used to describe the source of the laser beam. The main components of a laser are the laser active, light amplifying medium and an optical resonator which usually consists of two mirrors.



The first laser was constructed in 1960 by Thomas Maiman - it consisted of a ruby laser stimulated by a flash bulb. There arenow many and various ways in which the principle of laser operation can be realized.some lasers are not even a mm long while some laser systems fill entire buildings;

power outputs vary between nW and TW(10-9 - 1012 W). Maiman's ruby laser emitted light in the red spectral range at 694 nm - we now know of laser media which can emit wavelengths from several hundred m m to a few nm in the soft x-ray region. The wavelength and output power of any particular laser are defined by the application for which they are intended. Lasers are used in a wide variety of applications, such as:

- Optoelectronics
  CD players and CD-ROM drives (semiconductor lasers)
  Data transfer via fibre optic cables

- Medicine
  Ophthalmology
  Dermatology

- Measurement & instrumentation
  Mining and tunnel surveying
  Measurement of work piece surfaces
  Analysis (e.g. in mobile environmental analysis equipment)

- Manufacturing technology
  Cutting
  Welding
  Surface treatment etc.

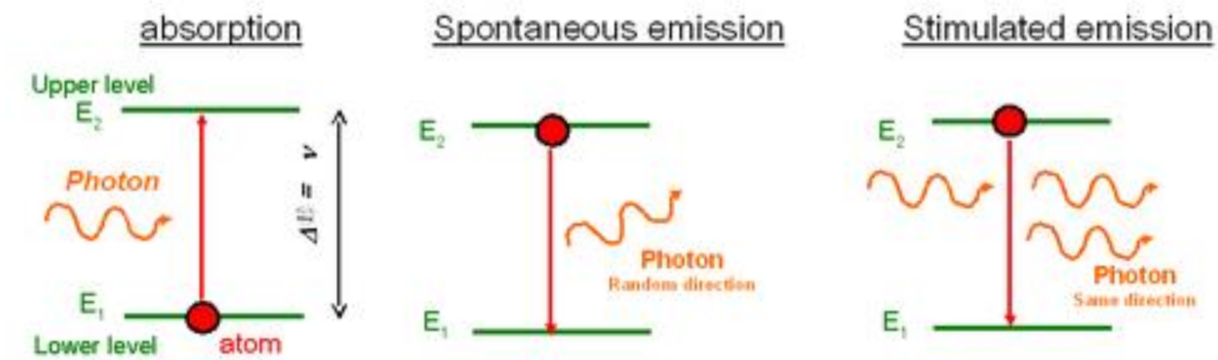
- Research
  Laser fusion
  Diagnostics
  Measurement of earth-moon distance

Principle of spontaneous emission and stimulated emission.

The three different mechanisms are shown below

1. Absorption: An atom in a lower level absorbs a photon of frequency hν and moves to an upper level.
2. Spontaneous emission: An atom in an upper level can decay spontaneously to the lower level and emit a photon of frequency hν if the transition between E2 and E1 is radiative. This photon has a random direction and phase.
3. Stimulated emission: An incident photon causes an upper level atom to decay, emitting a "stimulated" photon whose properties are identical to those of the incident photon. The term "stimulated" underlines the fact that this kind of radiation only occurs if an incident

photon is present. The amplification arises due to the similarities between the incident and emitted photons.



S.no	Stimulated Emission	Spontaneous emission
1.	An atom in the excited state is induced to return to the ground state , thereby resulting in two photons of same frequency and energy is called Stimulated emission	The atom in the excited state returns to the ground state thereby emitting a photon, without any external inducement is called Spontaneous emission.
2.	The emitted photons move in the same direction and is highly directional	The emitted photons move in all directions and are random
3.	The radiation is highly intense , monochromatic and coherent	The radiation is less intense and is incoherent.
4.	The photons are in phase, there is a constant phase difference.	The photons are not in phase (i.e.) there is no phase relationship between them.
5.	The rate of transition is given by $R_{21}(St) = B_{21}\rho_\nu N_2$	The rate of transition is given by $R_{21}(SP) = A_{21}N_2$

Population inversion and pumping

If there are more atoms in the upper level (N_2) than in the lower level (N_1), the system is not at equilibrium. In fact, at thermodynamic equilibrium, the distribution of the atoms between the levels is given by Boltzmann's Law. In this case, N_2 is always less than N_1. A situation not at equilibrium must be created by adding energy via a process known as “pumping” in order to raise enough atoms to the upper level. This is known as **population inversion** and is given by $\Delta = N_2 - N_1$. Light is amplified when the population inversion is positive. Pumping may be electrical, optical or chemical.

Relation between Einstein`s Coefficients A & B

Let us consider an atomic system in thermal equilibrium at absolute temperature T. Let N_1 and N_2 be the number of atoms per unit volume in the ground energy state E_1 and excited energy state E_2 respectively. Let J_u is the energy density of the incident radiation corresponding to frequency u.

Energy density J_u is defined as the incident energy on an atom as per unit volume in a state.

According to Einstein,

1) The rate of absorption of light (R_1) is proportional to the number of atoms N_1 per unit volume in the ground energy state E_1 and energy density J_u, of the incident radiation corresponding to frequency u.

That is $R_1 \propto N_1 J_u$

or $R_1 = B_{12}N_1J_u$ (1)

Where B_{12} is known as the Einstein's coefficient of stimulated absorption and it represents the probability of absorption of radiation.

2) The rate of spontaneous emission (R_2) is independent of energy density J_u of the incident radiation and is proportional to number of atoms N_2 in the excited state E_2 thus

$R_2 \propto N_2$ or

$R_2 = A_{21}N_2$ (2)

Where A_{21} is known as Einstein's coefficient for spontaneous emission and it represents the probability of spontaneous emission.

3) The rate of stimulated emission (R_3) is proportional to the energy density J_u, of the incident radiation corresponding to frequency u and number of atoms N_2 in the excited energy state E_2, thus

$R_3 \propto N_2 J_u$

or

$R_{1=} B_{21}N_2J_u$ (3)

Where B_{21} is known as the Einstein coefficient for stimulated emission and it represents the probability of stimulated emission.

In steady state (at thermal equilibrium), the two emission rates (spontaneous and stimulated) must balance the rate of absorption. Thus

$R_1 = R_2 + R_3$

Using equations (1, 2, and 3), we get

$B_{12}N_1J_u = A_{21}N_2 + B_{21}N_2J_u$

or $B_{12}N_1J_u – B_{21}N_2J_u = A_{21}N_2$

or $(B_{12}N_1– B_{21}N_2) J_u = A_{21}N_2$

$J_u = A_{21}N_2 / (B_{12}N_1– B_{21}N_2)$ (4)

Einstein proved thermodynamically, that the probability of stimulated absorption is equal to the probability of **stimulated emission**, thus

$B_{12} = B_{21}$

Then from equation (4),

$J_u = A_{21}N_2 / B_{12}(N_1– N_2)$

$J_u = A_{21} / \{B_{12}(N_1/N_2)-1\}$

According to Boltzman's distribution law, at absolute temperature T the probability that an atom is occur in an energy state E is proportional to $e^{-E/KT}$, where K is the Boltzman`s constant. Thus the ratio of populations of two energy levels (E_1 and E_2) at temperature T can be expressed as

$$\frac{N_1}{N_2} = \frac{e^{-E_1/KT}}{e^{-E_2/KT}} = e^{(E_2-E_1)/KT} = e^{h\upsilon/KT}$$

Substituting value of N_1/N_2 in equation (5) we get

$$J\upsilon = \frac{A_{21}}{B_{21}} \frac{1}{(e^{h\upsilon/KT} - 1)} \qquad (6)$$

Now according to Planck's radiation law, the energy density of the black body radiation of frequency υ at temperature T is given as

$$J\upsilon = \frac{8\pi h\upsilon^3}{c^3} \frac{1}{(e^{h\upsilon/KT} - 1)} \qquad (7)$$

By comparing equations (6 and 7), we get

$$\boxed{\frac{A_{21}}{B_{21}} = \frac{8\pi h\upsilon^3}{c^3}}$$

This is the relation between Einstein's coefficients in laser.

Significance of relation between Einstein`s coefficient:

It is clear from the above relation that the ratio of Einstein's coefficient of spontaneous emission to the Einstein's coefficient of stimulated absorption is proportional to cube of frequency u. It means that at thermal equilibrium, the probability of spontaneous emission increases rapidly with the energy difference between two states.

Types of lasers: On the basis of active medium used in the laser systems, lasers are classified into several types

I. Solid lasers : Ruby laser, Nd;YAG laser, Nd;Glass
II. Liquid lasers : Europium Chelate laser, SeOCl2
III. Gas lasers : CO2, He-Ne, Argon-Ion Laser
IV. Dye lasers : Rhodamine 6G
V. Semiconductor lasers :InP, GaAs.
VI. Chemical lasers : HF, DF.

Construction and components of laser: Generally, every laser system consists of three components. They are

a. Energy source
b. Active medium
c. Optical cavity or resonator

Energy source: To get laser emission, first we must have population inversion in the active medium. The energy source supplies the energy to the active medium. By absorbing that energy, the atoms or molecules or ions can be excited into higher levels. As a result we get population inversion in the active medium.

Active medium:

Definition: - In which medium we are creating population inversion to get stimulated emission of radiation is called active medium. After receiving the energy from the source, the atoms or molecules or ions get excites into higher energy levels. While de-excitation to lower energy level, the emitted photons starts stimulated emission which results laser emission. Depending upon the active medium the lasers or classified as solid state, liquid state, gaseous state and semiconductor lasers.

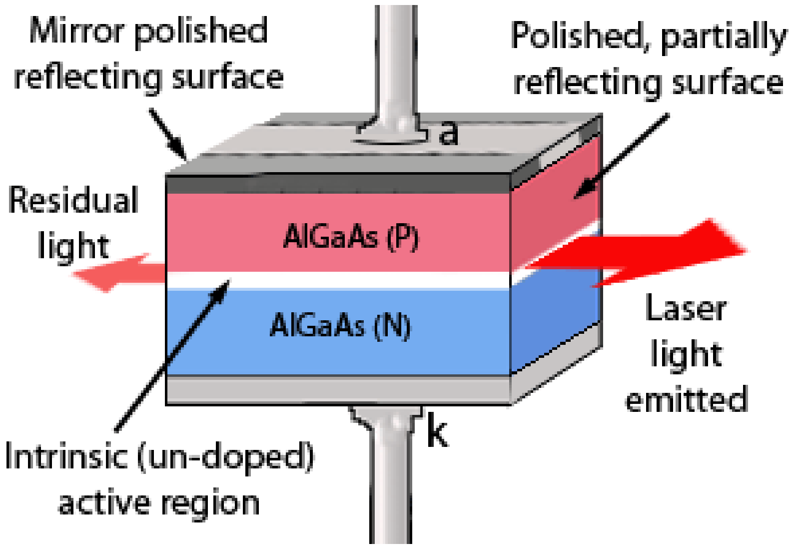
Optical cavity or resonator :

The active medium is enclosed between a fully reflective mirror and partially reflective mirror. These mirrors constitute the optical cavity or resonator. The reflectors enhance the stimulated emission process by reflecting the photons into the active medium. As a result we get high-intensity monochromatic and coherent laser light through the partially reflecting portion of the mirror.

Semiconductor diode laser: Laser diode is a specially fabricated p-n junction device that emits coherent radiation. It is operated at forward biased condition. Direct band gap semiconductors are preferred in the fabrication of semiconductor laser diodes because they emit energy in terms of light when an electron and hole recombination takes place. Compound semi-conductors like GaAs and InP are examples for direct band gap semiconductors.

Construction: In this laser system, the active medium is a p-n junction diode made from crystalline gallium arsenide. The p-region and n-region in the diode are obtained by heavily doping with germanium and tellurium respectively in GaAs. The thickness of the p-n junction is very narrow so that the emitted radiation has large divergence and poor coherence. At the junction two sides are roughed to avoid laser emission and the remaining two faces one is partially polished and the other is fully polished. The laser emission takes place from the partially polished face. To provide bias two metal contacts are provided in the top and bottom of the diode as shown in figure.

Working : The semiconductor laser device is always operated in forward bias condition. Electrons and the holes are the minority charge carriers in n-region and p-region semiconductors. When a huge current (104 Amp/mm2) is passing through the p-n junction, p-region is positively biased, holes are injected into n-region from p-region and n-region is negatively biased electrons are injected into p-region from n-region as shown in figure.



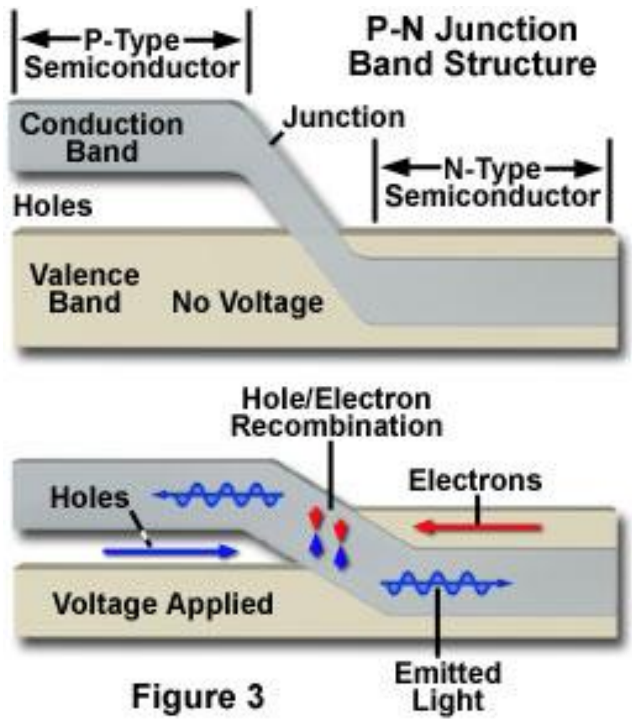


Figure 3

The continuous injection of charge carriers creates the population inversion of minority carriers in n and p sides' respectively. The electrons and holes recombine and release of light energy takes place in or near the junction as shown in figure. The emitted photons increase the rate of recombination of injected electrons from the n-region and holes in p-region by inducing more recombinations. From Planck's law $E_g = h\upsilon = h\ C/\lambda ; \lambda = hC/E_g = 6.63 \times 10^{-34} \times 3 \times 10^{8}/1.4 \times 1.6 \times 10^{-19} = 8874A^{0}$ In case of GaAs homo-junction which has an energy gap of 1.44eV gives a laser beam of wave length around 8874A^{0} . The wave length of emitted radiation depends up on the concentration of donor and acceptor atoms in GaAs. The efficiency of the laser emission is increases when we cool the GaAs diode.

Ruby LASER

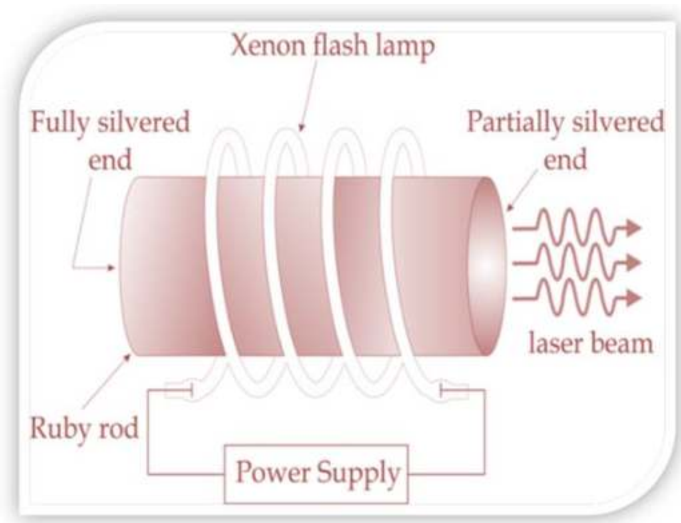
Construction:

(i) Active medium:

It is a solid-state laser, in which a rod of a synthetic ruby crystal is used as an active medium. The ruby crystal is obtained by doping a small amount (about 0.05% by weight) of chromium oxide (Cr_2O_3) in Aluminum oxide (Al_2O_3), so that some of the aluminum ions (Al^{3+}) are replaced by chromium ions (Cr^{3+}). These chromium ions give the crystal a pink or red color depending upon the doping concentration. Al_2O_3 only acts as the host while the chromium ions act as active centers in ruby crystal and responsible for the laser action. The length of the ruby rod is usually 2 cm to 30 cm and the diameter is 0.5 cm to 2 cm. *Ruby LASER*

(ii) Optical resonator:

To construct the optical resonator cavity, the ends of the rods are polished such that they become flat and parallel to each other. Now one of the ends is coated with silver completely while the other one is partially silvered. Thus, the two silver-coated ends of the rod act as an optical resonator system.

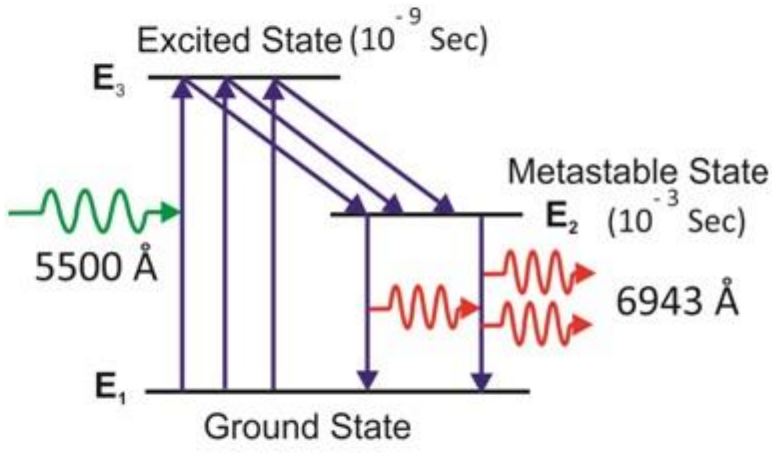


(iii) Pumping system:

The ruby rod is placed inside a helically shaped xenon flash lamp to excite the Cr^{3+} ions. Thus, in ***ruby laser population inversion*** is achieved by using optical pumping.

<u>Working of Ruby LASER</u>:

Ruby is a three energy level laser system. After absorbing light photons of wavelength 5500 Å from xenon flash lamp, some of the Cr^{3+} ions at ground energy level E_1 get excited to higher energy level E_3. At this energy level, they are unstable and by losing a part of their energy to the crystal lattice, they fall to the *metastable* energy level E_2, whose lifetime is much longer (about 10^{-3} s). Therefore, the number of Cr^{3+} ions goes on increasing in E_2 state while the number of these ions in ground state E2 goes on decreasing due to pumping by the flash lamp and soon the population inversion is achieved between states E2 and E1.



Energy Level Diagram of Ruby LASER

Now some of the Cr3+ ions will decay spontaneously to the ground state E1 by emitting photons of wavelength 6943 Å. The photons that are moving parallel to the axis of the rod will reflect back and forth by the silvered ends of the rod and stimulate other excited Cr3+ ions to radiate another photon with the same phase. Thus, due to successive reflections of these photons at the ends of the rod, the number of photons multiplies. After a few microseconds, a *monochromatic*, intense, and collimated beam of red light of wavelength 6943 Å emerges through the partially silvered end of the rod. The Ruby *laser* is a pulsed laser that emits light in the form of very short pulses.

Nd:YAG laser

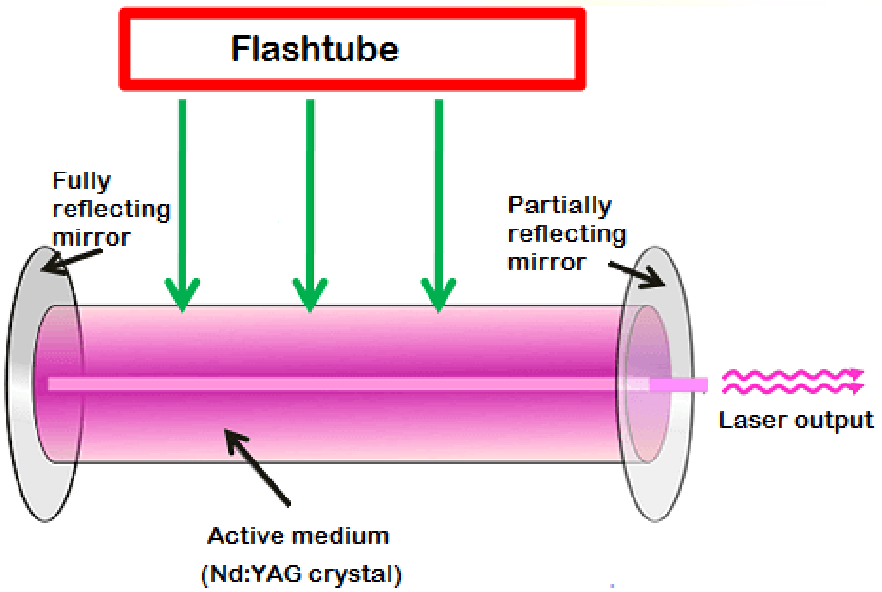
Neodymium-doped Yttrium Aluminum Garnet (Nd: YAG) laser is a solid state laser in which Nd: YAG is used as a laser medium.These lasers have many different applications in the medical and scientific field for processes such as Lasik surgery and laser spectroscopy.Nd: YAG laser is a four-level laser system, which means that the four energy levels are involved in laser action. These lasers operate in both pulsed and continuous mode. Nd: YAG laser generates laser light commonly in the near-infrared region of the spectrum at 1064 nanometers (nm). It also emits laser light at several different wavelengths including 1440 nm, 1320 nm, 1120 nm, and 940 nm.

Nd: YAG laser construction

Nd:YAG laser consists of three important elements: an energy source, active medium, and optical resonator.

Energy source

The energy source or pump source supplies energy to the active medium to achieve population inversion. In Nd: YAG laser, light energy sources such as flashtube or laser diodes are used as energy source to supply energy to the active medium. In the past, flashtubes are mostly used as pump source because of its low cost. However, nowadays, laser diodes are preferred over flashtubes because of its high efficiency and low cost.



Active medium

The active medium or laser medium of the Nd:YAG laser is made up of a synthetic crystalline material (Yttrium Aluminum Garnet (YAG)) doped with a chemical element (neodymium (Nd)). The lower energy state electrons of the neodymium ions are excited to the higher energy state to provide lasing action in the active medium.

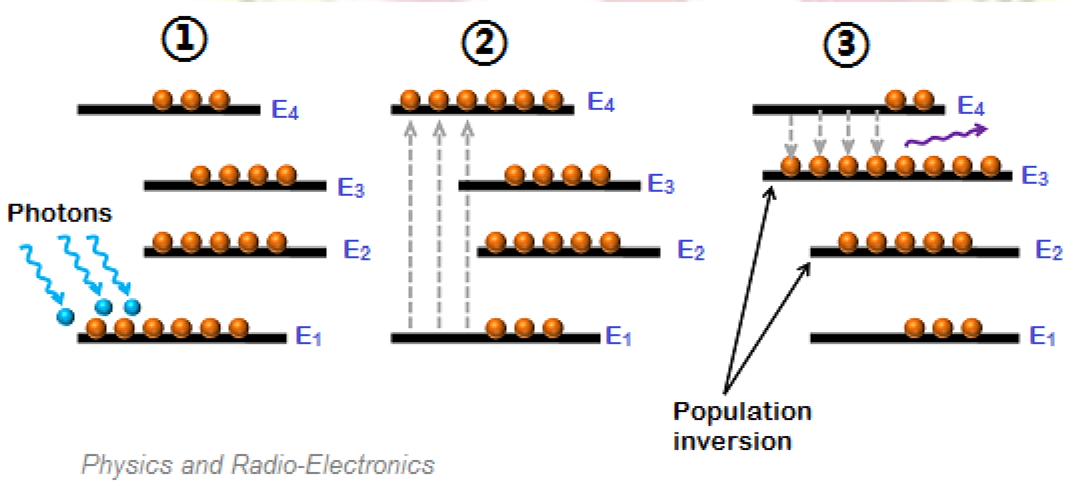
Optical resonator

The Nd:YAG crystal is placed between two mirrors. These two mirrors are optically coated or silvered.Each mirror is silvered or coated differently. One mirror is fully silvered whereas, another mirror is partially silvered. The mirror, which is fully silvered, will completely reflect the light and is known as fully reflecting mirror.On the other hand, the mirror which is partially silvered will reflect most part of the light but allows a small portion of light through it to produce the laser beam. This mirror is known as a partially reflecting mirror.

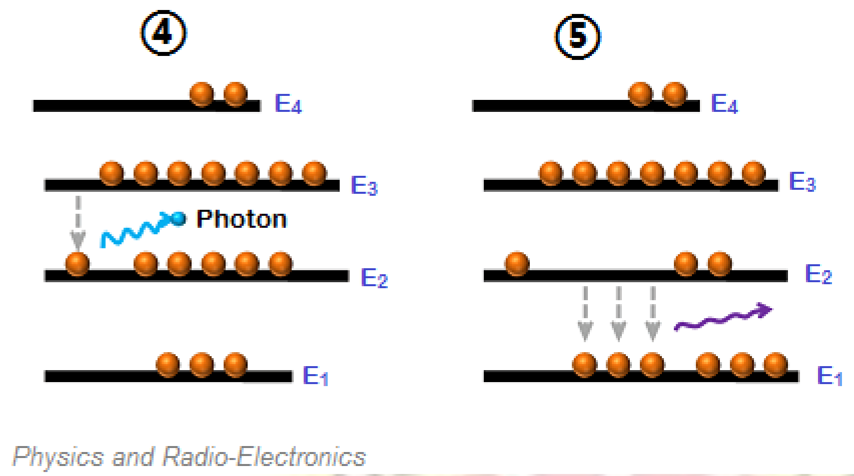
Working of Nd:YAG laser

Nd: YAG laser is a four-level laser system, which means that the four energy levels are involved in laser action. The light energy sources such as flashtubes or laser diodes are used to supply energy to the active medium.InNd:YAG laser, the lower energy state electrons in the neodymium ions are excited to the higher energy state to achieve population inversion.

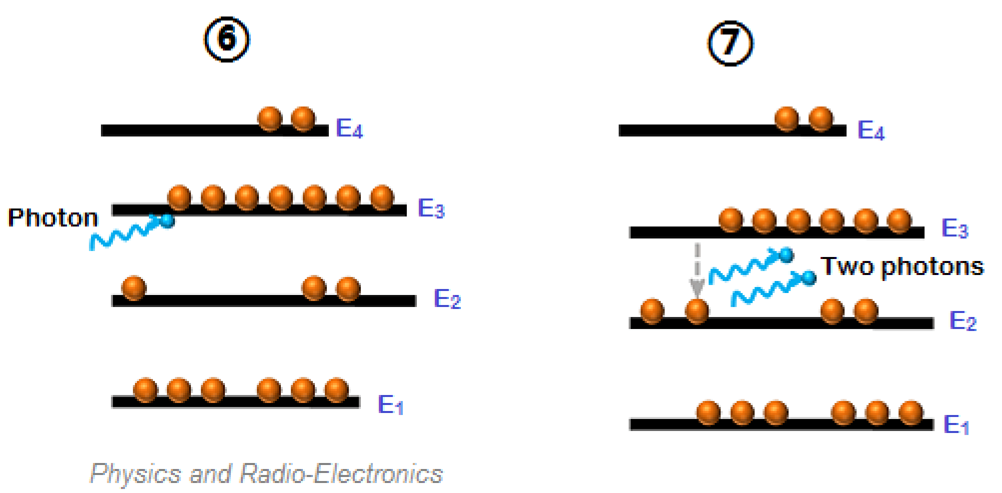
Consider a Nd:YAG crystal active medium consisting of four energy levels E_1, E_2, E_3, and E_4 with N number of electrons. The number of electrons in the energy states E1, E_2, E_3, and E_4 will be N_1, N_2, N_3, and N_4.Let us assume that the energy levels will be $E_1 < E_2 < E_3 < E_4$. The energy level E_1 is known as ground state, E_2 is the next higher energy state or excited state, E_3 is the metastable state or excited state and E_4 is the pump state or excited state. Let us assume that initially, the population will be $N_1 > N_2 > N_3 > N_4$.When flashtube or laser diode supplies light energy to the active medium (Nd:YAG crystal), the lower energy state (E_1) electrons in the neodymium ions gains enough energy and moves to the pump state or higher energy state E_4.



The lifetime of pump state or higher energy state E_4 is very small (230 microseconds (Âµs)) so the electrons in the energy state E_4 do not stay for long period. After a short period, the electrons will fall into the next lower energy state or metastable state E_3 by releasing non-radiation energy (releasing energy without emitting photons).The lifetime of metastable state E_3 is high as compared to the lifetime of pump state E_4. Therefore, the electrons reach E_3 much faster than they leave E_3. This results in an increase in the number of electrons in the metastable E_3 and hence population inversion is achieved.After some period, the electrons in the metastable state E_3 will fall into the next lower energy state E_2 by releasing photons or light. The emission of photons in this manner is called spontaneous emission.



The lifetime of energy state E_2 is very small just like the energy state E_4. Therefore, after a short period, the electrons in the energy state E_2 will fall back to the ground state E_1 by releasing radiationlessenergy.When photon emitted due to spontaneous emission is interacted with the other metastable state electron, it stimulates that electron and makes it fall into the lower energy state by releasing the photon. As a result, two photons are released. The emission of photons in this manner is called stimulated emission of radiation.



When these two photons again interacted with the metastable state electrons, four photons are released. Likewise, millions of photons are emitted. Thus, optical gain is achieved.Spontaneous emission is a natural process but stimulated emission is not a natural process. To achieve stimulated emission, we need to supply external photons or light to the active medium.

The Nd:YAG active medium generates photons or light due to spontaneous emission. The light or photons generated in the active medium will bounce back and forth between the two mirrors. This stimulates other electrons to fall into the lower energy state by releasing photons or light. Likewise, millions of electrons are stimulated to emit photons.The light generated within the active medium is reflected many times between the mirrors before it escapes through the partially reflecting mirror.

Advantages of Nd:YAG laser

- Low power consumption
- Nd:YAG laser offers high gain.
- Nd:YAG laser has good thermal properties.
- Nd:YAG laser has good mechanical properties.
- The efficiency of Nd:YAG laser is very high as compared to the ruby laser.

Applications of Nd:YAG laser

Military

Nd:YAG lasers are used in laser designators and laser rangefinders. A laser designator is a laser light source, which is used to target objects for attacking. A laser rangefinder is a rangefinder, which uses a laser light to determine the distance to an object.

Medicine

Nd: YAG lasers are used to correct posterior capsular opacification (a condition that may occur after a cataract surgery).

Nd:YAG lasers are used to remove skin cancers.

Manufacturing

Nd:YAG lasers are used for etching or marking a variety of plastics and metals.

Nd:YAG lasers are used for cutting and welding steel.

Applications of lasers.

.Due to high intensity, high monocromacity and high directionality of lasers, they are widely used in various fields like

1. communication
2. computers
3. chemistry
4. photography
5. industry
6. medicine
7. military

8. scientific research

1. **Communication** : In case of optical communication semiconductors laser diodes are used as optical sources and its band width is (1014Hz) is very high compared to the radio and microwave communications. More channels can be sent simultaneously¬ Signal cannot be tapped¬As the band width is large, more data can be sent.¬ A laser is highly directional and less divergence, hence it has greater potential use in space crafts and¬ submarines.

2. **Computers** : In LAN (local area network), data can be transferred from memory storage of one computer to other¬ computer using laser for short time. Lasers are used in CD-ROMS during recording and reading the data.

3. **Chemistry**: Lasers are used in molecular structure identification¬ Lasers are also used to accelerate some chemical reactions.¬ Using lasers, new chemical compounds can be created by breaking bonds between atoms are molecules.

4. **Photography** : Lasers are also used in the construction of holograms.¬ Lasers can be used to get 3-D lens less photography.

5. **Industry**: Lasers can be used to blast holes in diamonds and hard steel¬ Lasers are also used as a source of intense heat¬ Lasers are used to drill holes in ceramics.¬ Lasers are used to cut glass and quartz.¬ Lasers are used for heat treatment in the tooling and automotive industry.¬ Lasers are used in electronic industry in trimming the components of ICS.¬ High power lasers are used to weld or melt any material.¬ Lasers are also used to cut teeth in saws and test the quality of fabric.

6. **Medicine** ; Lasers are used for cataract removal.¬ Lasers are used for eye lens curvature corrections.¬ Lasers are used in bloodless surgery.¬ Lasers are used in cancer diagnosis and therapy.¬ Lasers are used in destroying kidney stones and gallstones.¬ Argon and carbon dioxide lasers are used in the treat men of liver and lungs.¬ Lasers used in endoscopy to scan the inner parts of the stomach.¬ Lasers used in the elimination of moles and tumours which are developing in the skin tissue.¬ Lasers are used in plastic surgery.¬ Lasers are used in the treatment of mouth diseases.

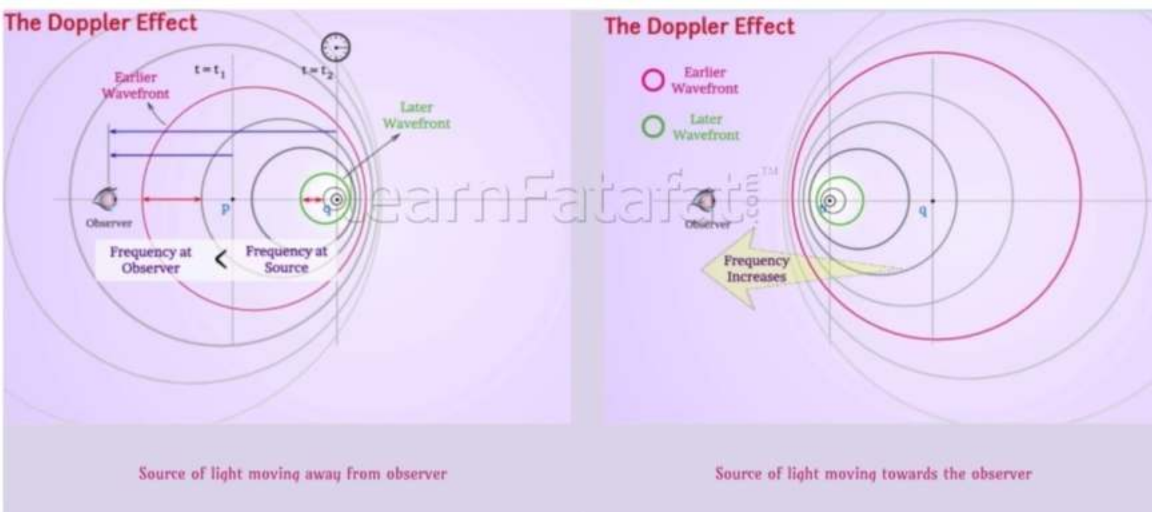
7. **Military** : Lasers can be used as a war weapon.¬ High energy lasers are used to destroy the enemy air-crofts and missiles.¬ Lasers can be used in the detection and ranging likes RADAR.

8. **Scientific field** : Lasers are used for isotope preparation.¬ Lasers are employed to create plasma.¬ Lasers are used in air pollution, to estimate the size of the dust particles.¬ Lasers are used in the field of 3D-photography¬ Lasers used in Recording and reconstruction of hologram.¬ Lasers used to produce certain chemical reactions.¬ Lasers are used in Raman spectroscopy to identify the structure of the molecule.¬ Lasers are used in the Michelson-Morley experiment.

UNIT – IV-MEDICAL PHYSICS

Doppler Effect :

Huygen's principle shows that, if the shape of wavefront is known at time t =0, then it is possible to find the shape of wavefront at later time ?. But this becomes bit difficult if there is relative motion between the source and the observer. The phenomena that arises due to such motion is called doppler effect. In this article we will talk about Doppler effect in detail.



Consider a point source of light producing spherical wavefronts, moving away from the observer. Suppose at time t1, the source is at point P. It moves away from the observer and reaches at point Q when time is t2. Thus, the wavefront produced at t = t2 will have to travel longer distance then the wavefront produced at t=t1. As the speed of wavefront is same but the distance is increased, it takes longer time for the later wavefront to reach the observer. Thus, the time difference between arrival of two successive wavefront at the observer is greater than the time difference between emission of two successive wavefronts at the source. The frequency at which the wavefronts are arrived at the observer is less than that of the frequency at which they produced at the source.

The difference in frequency observed by observer and produced by source due to relative motion of observer and source is called doppler effect.

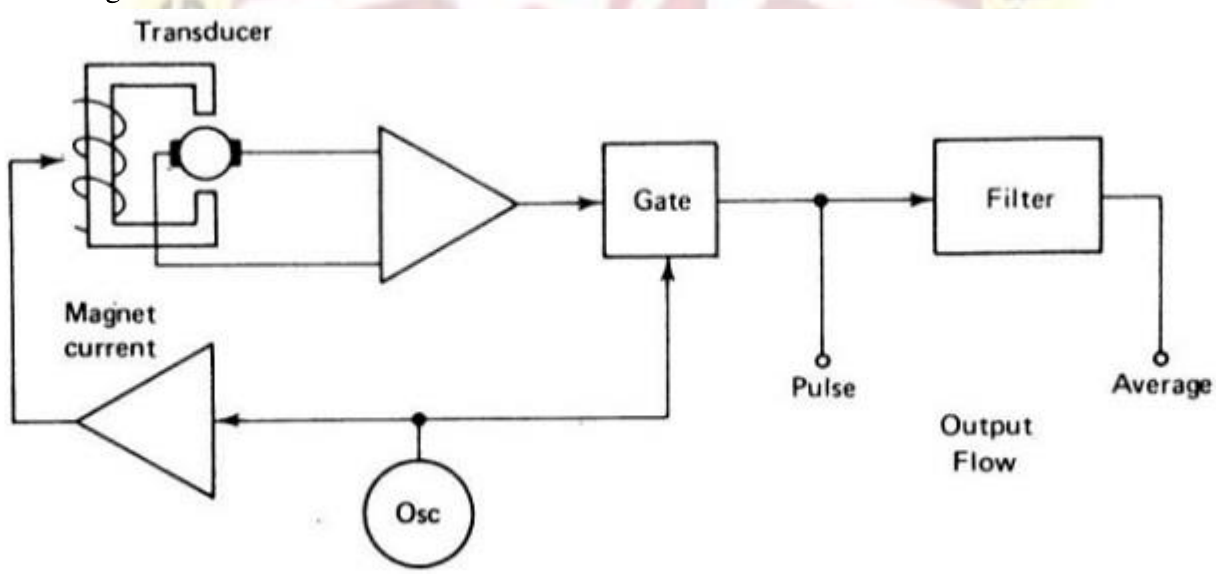
However, in opposite case, if the source is moving towards the observer then the wavefront produced in later time travel less distance than wavefront produced in earlier time. Thus, it takes less time for later wavefront to reach at the observer. Therefore, the observed frequency goes on increasing as the source progresses towards the observer.

Phenomena due to Doppler effect

- Redshift: When a source producing light moves away from the observer the wavelength in the middle of visible region of electromagnetic spectrum gets stretched. Therefore, it appears that light is shifted towards the red end of the spectrum. However, astronomers call increase in wavelength due to doppler effect as red shift. As a result white light appears red.
- Blueshift: When a source producing light moves towards observer, the wavelengths in the middle of the visible region of electromagnetic spectrum decreases. Thus, light appears to be shifted towards blue end of the spectrum. This is called blue shift. Thus white light appears blue.

Electromagnetic Blood Flow Meter and its Advantages

Electromagnetic blood flow meters are based on the principle of electromagnetic induction. According to Fleming's right hand rule, the EMF induced in the conductor under the influence of magnetic field is directly proportional to the velocity of motion of conductor. Here we consider the blood vessel carrying blood as the conductor. So here the velocity of motion is simply the blood flow through the blood vessel.



block diagram of electromagnetic blood flow meters

The block diagram of electromagnetic blood flow meter is shown. Here we simply use an oscillator of low frequency (up to 400 Hz) to drive the electromagnet which is placed in such a way that the magnetic field is perpendicular to the direction of blood flow. An EMF is induced across the blood vessel. In order to measure this, a set of electrodes are placed across the blood vessel mutually perpendicular to both magnetic field and direction of blood flow.

The EMF induced across the blood vessel will be proportional to the velocity of blood, Lumen probes with varying diameters are used for the accuracy of measurement. The output of electromagnetic blood flow meter, which is in micro volts, is enhanced by the amplifier. For the average blood flow rate we usually use LPFs after the amplifier. Amplifier drift and electrode polarization may cause some problems with electromagnetic type flow meters.

Advantages of Electromagnetic Blood Flow Meters

1.Linear dynamic range
2.Electronics required are relatively simple
3.Almost any flow sensitivity can be measured
4.It has no mechanical limitation for high and low speed flow
5. The power requirements are reasonable.

2. ULTRASONIC FLOWMETERS

The blood cells in the fluid scatter the Doppler signal diffusively.In the recent years ultrasound contrast agents have been used in order to increase the echoes. The ultrasound beam is focused by a suitable transducer geometry and a lens.

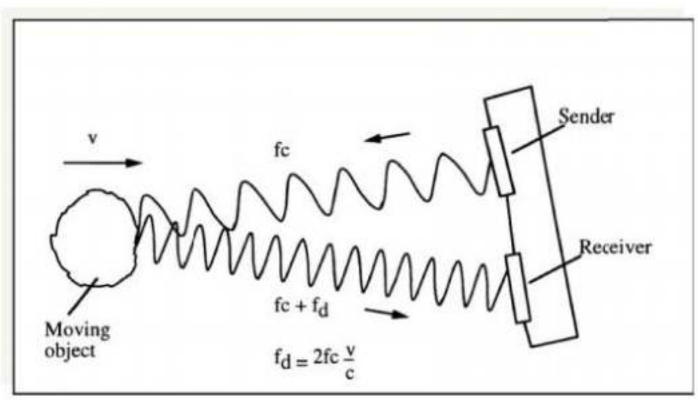


Figure 2.15 Ultrasonic flowmeters

$f_d = 2f_c v/c$

$f = 2\text{-}10\ MHz$

$c = 1500 - 1600$ m/s (1540 m/s)

$f = 1{,}3 - 13\ kHz$

In order to know where a long the beam the blood flow data is colledted, a pulsed Doppler must be used.The flow velocity is obtained from the spectral estimation of the received Doppler signalThe ultrasound Doppler device can be either *a continuous wave* or *a pulsed Doppler*

A Continuous Wave

- No minimum range
- Simpler hardware

- Range ambiguity
- Low flow cannot be detected

A Pulsed Doppler

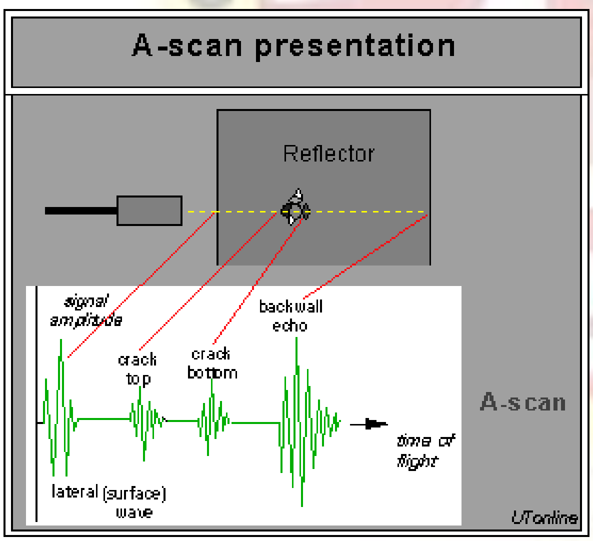
- Accuracy
- No minimum flow
- Minimum range

(Maximum flow) x (range)= limited the power decays exponentially because of the heating of the tissue. The absorption coefficient ~ proportional to frequency the far fi eld operation should be avoided due to beam divergence.

$$D_{nf} = D^2 / 4\lambda$$

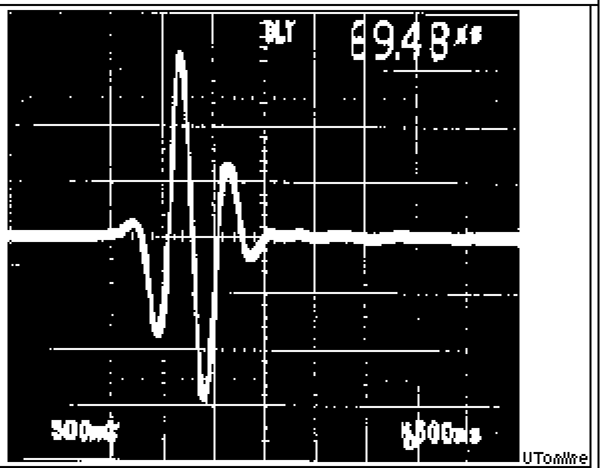
D = Transducer diameter (e.g. 1 – 5 mm) the backscattered power is proportional to f.The resolution and SNR are related to the pulse duration. Improving either one of the parameters always affects inversely to the other

A – Scan: A display in which the received pulse amplitude is represented as a displacement along one axis (usually the y-axis) and the travel time of the ultrasonic pulse is represented as a displacement along the other axis (usually the x-axis). In a linear amplification system the vertical excursion is proportional to the amplitude of the signal. With the use of logarithmic scale amplifiers the y-axis presents a logarithmic scale.



There are different kinds of single presentations possible:
1. both half waves unrectified (RF),
2. positive half wave,
3. negative half wave
4. rectified and unfiltered,
5. rectified and filtered (smoothing).

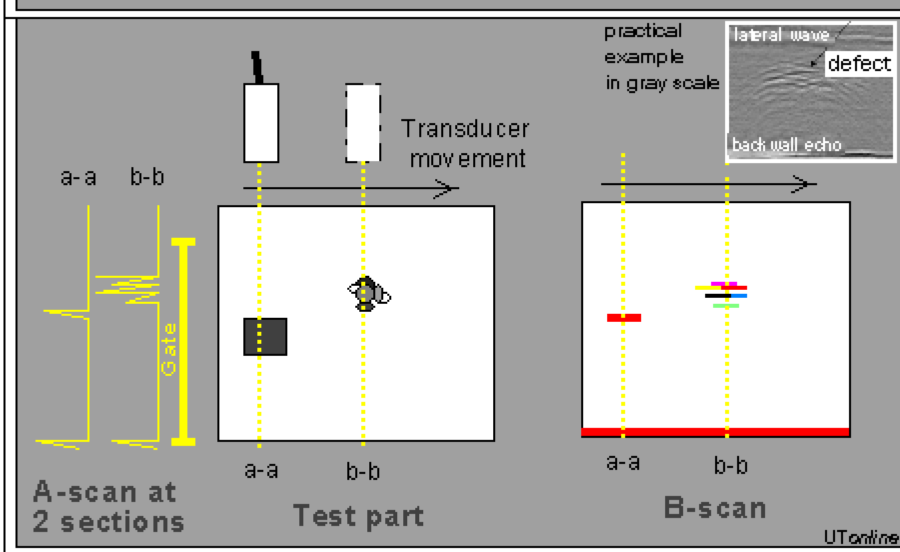
A - Screen presentation of an Echo RF Signal



An RF display is necessary for investigation of the signal phase shift (e.g., boundaries). Other presentations are useful for simplifying the result and its interpretation. A-scan displays are more complex because it is the principles that are displayed, so multiplied signals (skips of back wall, waterpath) and wave conversion need careful interpretation.
With digital instruments the A-scan evaluation is supported by functions like maximum hold, averaging, echo filtering and frozen A-scan.

B – Scan : A two dimensional graphical presentation, in rectangular coordinates, in which the travel time of an ultrasonic pulse is represented as a displacement along one axis, and transducer movement is represented as a displacement along the other axis. In the presentation, reflected pulses are shown as an event. The event marks represent the echo by different evaluations:

B-scan presentation



Ultrasonic scanning in medical diagnosis uses the same principle as sonar. Pulses of high-frequency ultrasound, generally above one megahertz, are created by a piezoelectric transducer and directed into the body. As the ultrasound traverses various internal organs, it encounters changes in acoustic impedance, which cause reflections. The amount and time delay of the various reflections can be analyzed to obtain information regarding the internal organs. In the B-scan mode, a linear array of transducers is used to scan a plane in the body, and the resultant data is displayed on a television screen as a two-dimensional plot. The A-scan technique uses a single transducer to scan along a line in the body, and the echoes are plotted as a function of time. This technique is used for measuring the distances or sizes of internal organs. The M-scan mode is used to record the motion of internal organs, as in the study of heart dysfunction. Greater resolution is obtained in ultrasonic imaging by using higher frequencies—i.e., shorter wavelengths. A limitation of this property of waves is that higher frequencies tend to be much more strongly absorbed.Because it is nonionizing, ultrasound has become one of the staples of obstetric diagnosis. During the process of drawing amniotic fluid in testing for birth defects, ultrasonic imaging is used to guide the needle and thus avoid damage to the fetus or surrounding tissue. Ultrasonic imaging of the fetus can be used to determine the date of conception, to identify multiple births, and to diagnose abnormalities in the development of the fetus.

Ultrasonic Doppler techniques have become very important in diagnosing problems in blood flow. In one technique, a three-megahertz ultrasonic beam is reflected off typical oncoming arterial blood with a Doppler shift of a few kilohertz—a frequency difference that can be heard directly by a physician. Using this technique, it is possible to monitor the heartbeat of a fetus long before a stethoscope can pick up the sound. Arterial diseases such as arteriosclerosis can also be diagnosed, and the healing of arteries can be monitored following surgery. A combination of B-scan imaging and Doppler imaging, known as duplex scanning, can identify arteries and immediately measure their blood flow; this has been extensively used to diagnose heart valve defects.

X-rays:

X-rays are types of electromagnetic radiation probably most well-known for their ability to see through a person's skin and reveal images of the bones beneath it. Advances in technology have led to more powerful and focused X-ray beams as well as ever greater applications of these light waves, from imaging teensy biological cells and structural components of materials like cement to killing cancer cells. X-rays are roughly classified into soft X-rays and hard X-rays. Soft X-rays have relatively short wavelengths of about 10 nanometers (a nanometer is one-billionth of a meter), and so they fall in the range of the electromagnetic (EM) spectrum between ultraviolet (UV) light and gamma-rays. Hard X-rays have wavelengths of about 100 picometers (a picometer is one-trillionth of a meter). These electromagnetic waves occupy the same region of the EM spectrum as gamma-rays. The only difference between them is their source: X-rays are produced by accelerating electrons, whereas gamma-rays are produced by atomic nuclei in one of four nuclear reactions.

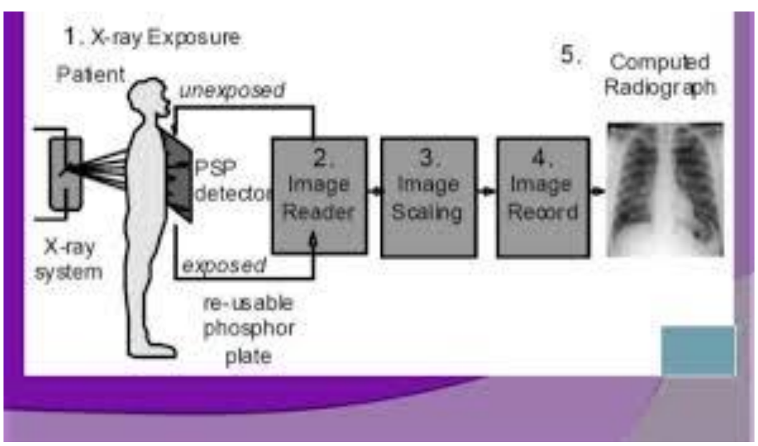
Uses of X-rays:

Due to their ability to penetrate certain materials, X-rays are used for several nondestructive evaluation and testing applications, particularly for identifying flaws or cracks in structural components. According to the NDT Resource Center, "Radiation is directed through a part and onto [a] film or other detector. The resulting shadowgraph shows the internal features" and whether the part is sound. This is the same technique used in doctors' and dentists' offices to create X-ray images of bones and teeth, respectively.X-rays are also essential for transportation security inspections of cargo, luggage and passengers. Electronic imaging detectors allow for real-time visualization of the content of packages and other passenger items. The original use of X-rays was for imaging bones, which were easily distinguishable from soft tissues on the film that was available at that time. However, more accurate focusing systems and more sensitive detection methods, such as improved photographic films and electronic imaging sensors, have made it possible to distinguish increasingly fine detail and subtle differences in tissue density, while using much lower exposure levels.

Radiography:

Medical radiography is a broad term that covers several types of studies that require the visualization of the internal parts of the body using x-ray techniques. For the purposes of this page radiography means a technique for generating and recording an x-ray pattern for the purpose of providing the user with a static image(s) after termination of the exposure. It is differentiated from *fluoroscopy*, *mammography*, and *computed tomography* which are discussed elsewhere. Radiography may also be used during the planning of radiation therapy treatment. It is used to diagnose or treat patients by recording images of the internal structure of the body to assess the presence or absence of disease, foreign objects, and structural damage or anomaly.

During a radiographic procedure, an x-ray beam is passed through the body. A portion of the x-rays are absorbed or scattered by the internal structure and the remaining x-ray pattern is transmitted to a detector so that an image may be recorded for later evaluation. The recoding of the pattern may occur on film or through electronic means.



Uses

Radiography is used in many types of examinations and procedures where a record of a static image is desired. Some examples include

- Dental examination
- Verification of correct placement of surgical markers prior to invasive procedures
- Mammography
- Orthopedic evaluations
- Spot film or static recording during fluoroscopy
- Chiropractic examinations

Risks/Benefits

Radiography is a type of x-ray procedure, and it carries the same types of risks as other x-ray procedures. The radiation dose the patient receives varies depending on the individual procedure, but is generally less than that received during fluoroscopy and computed tomography procedures.

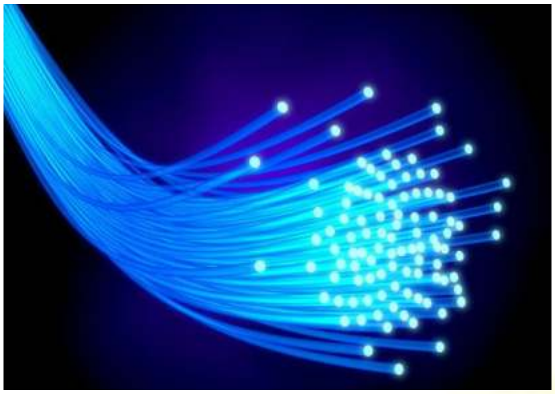
The major risks associated with radiography are the small possibilities of

- developing a radiation-induced cancer or cataracts some time later in life, and
- causing a disturbance in the growth or development of an embryo or fetus (teratogenic defect) when performed on a pregnant patient or one of childbearing age.

When an individual has a medical need, the benefit of radiography far exceeds the small cancer risk associated with the procedure. Even when radiography is medically necessary, it should use the lowest possible exposure and the minimum number of images. In most cases many of the possible risks can be reduced or eliminated with proper shielding.

UNIT – V- FIBER OPTICS

An optical fiber can be understood as a dielectric waveguide, which operates at optical frequencies. The device or a tube, if bent or if terminated to radiate energy, is called a **waveguide**, in general. Following image depicts a bunch of fiber optic cables.



The electromagnetic energy travels through it in the form of light. The light propagation, along a waveguide can be described in terms of a set of guided electromagnetic waves, called as **modes** of the waveguide.

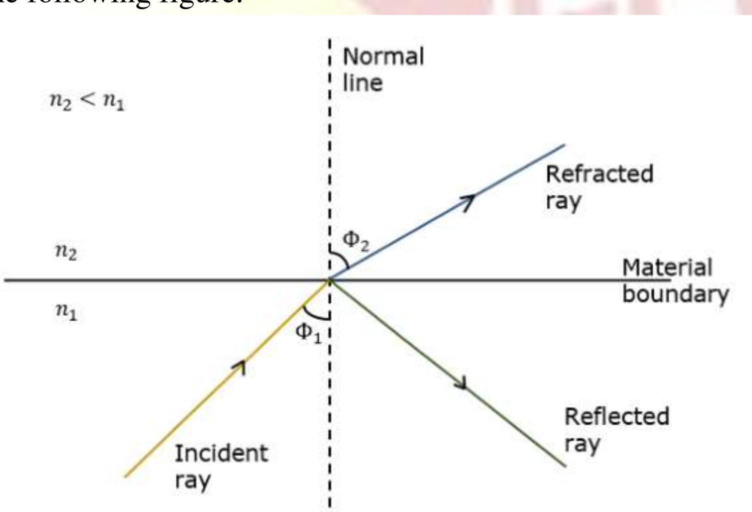
Working Principle

A fundamental optical parameter one should have an idea about, while studying fiber optics is **Refractive index**. By definition, "The ratio of the speed of light in a vacuum to that in matter is the index of refraction **n** of the material.

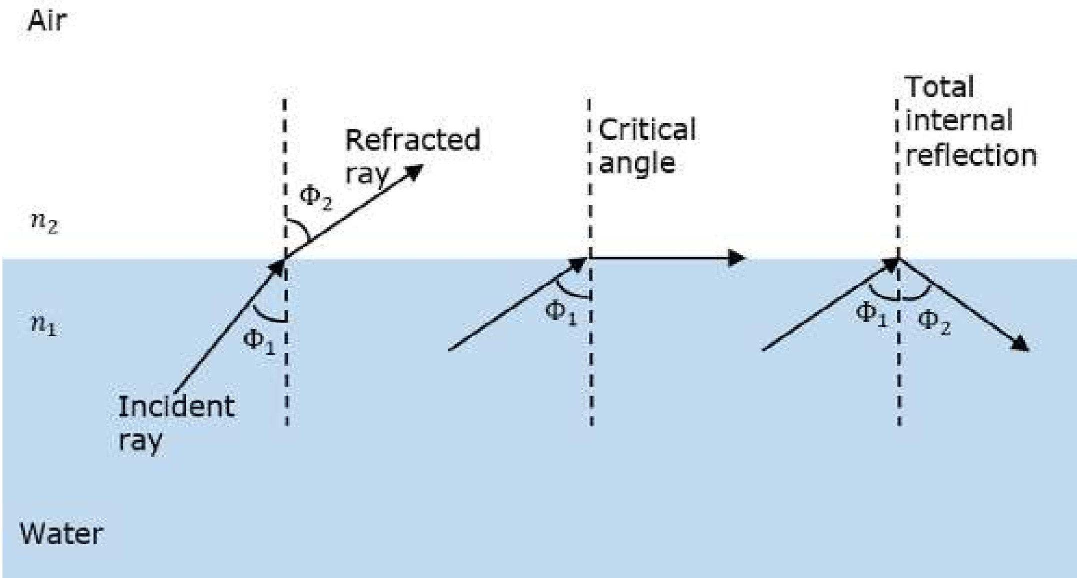
Generally, for a travelling light ray, **reflection** takes place when $n_2 < n_1$. The bent of light ray at the interface is the result of difference in the speed of light in two materials that have different refractive indices. The relationship between these angles at the interface can be termed as **Snell's law**.

n_1 and n_2 are the refractive indices of two materials

For an optically dense material, if the reflection takes place within the same material, then such a phenomenon is called as **internal reflection**. The incident angle and refracted angle are shown in the following figure.



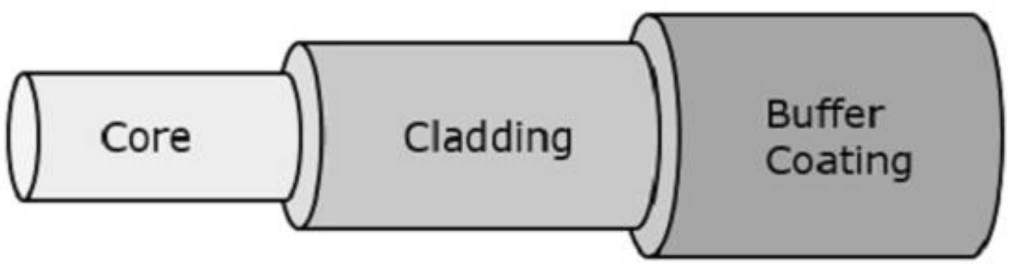
If the angle of incidence Φ_1 is much larger, then the refracted angle Φ_2 at a point becomes $\pi/2$. Further refraction is not possible beyond this point. Hence, such a point is called as **Critical angle**. When the incident angle Φ_1 is greater than the critical angle, the condition for **total internal reflection** is satisfied.The following figure shows these terms clearly.



A light ray, if passed into a glass, at such condition, it is totally reflected back into the glass with no light escaping from the surface of the glass.

Parts of a Fiber

The most commonly used optical fiber is **single solid di-electric cylinder** of radius **a** and index of refraction n_1. The following figure explains the parts of an optical fiber.



Parts of an Optical fiber

This cylinder is known as the **Core** of the fiber. A solid di-electric material surrounds the core, which is called as **Cladding**. Cladding has a refractive index n_2 which is less than n_1.

Cladding helps in −

- Reducing scattering losses.
- Adds mechanical strength to the fiber.

- Protects the core from absorbing unwanted surface contaminants.

Types of Optical Fibers

Depending upon the material composition of the core, there are two types of fibers used commonly. They are −

- **Step-index fiber** − The refractive index of the core is uniform throughout and undergoes an abrupt change (or step) at the cladding boundary.
- **Graded-index fiber** − The core refractive index is made to vary as a function of the radial distance from the center of the fiber.

Both of these are further divided into −

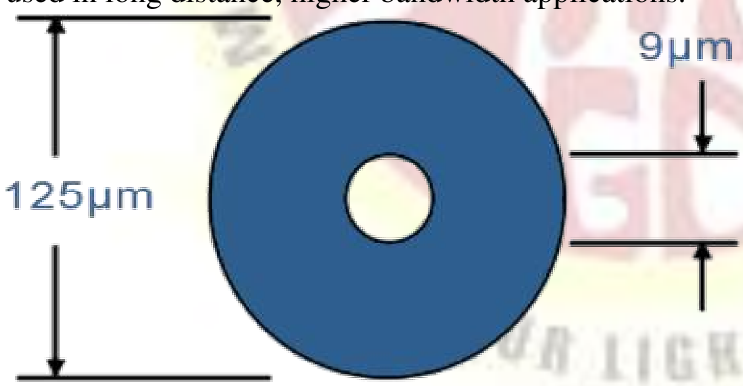
- **Single-mode fiber** − These are excited with laser.
- **Multi-mode fiber** − These are excited with LED.

Single-mode Fiber vs. Multimode Fiber

To make a better choice, we'd better have an overall understanding of single mode fiber and multimode fiber respectively.

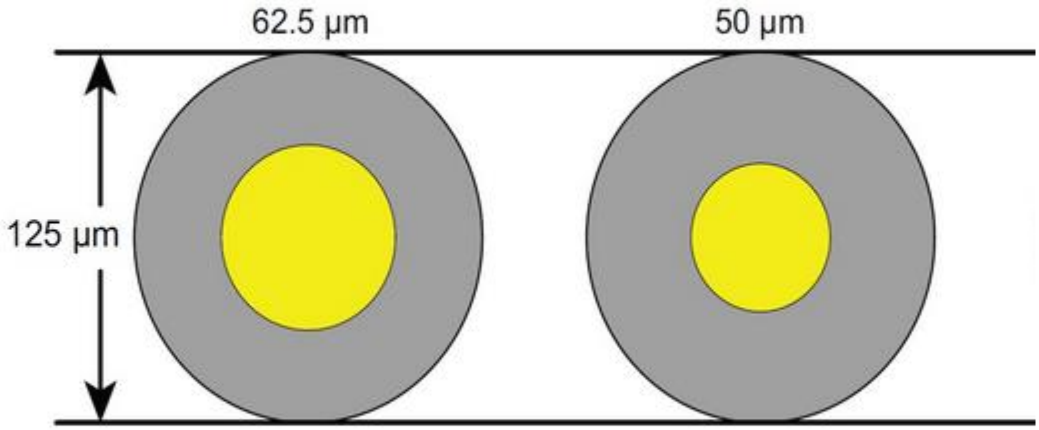
Single Mode Fiber

Generally, single mode fibers have a small core size (less than 10 µm) that permits only one mode or ray of light to be transmitted typically 1310 or 1550nm. For this reason, there is little light reflection created when light passes through the single mode fiber core. This will lower fiber attenuation and create the ability for the signal to travel further. Thus single mode fibers usually used in long distance, higher bandwidth applications.



Multimode Fiber

Multimode fibers have larger cores (62.5 µm or 50 µm) that guide many modes simultaneously, which means more data can pass through the multimode fiber core at a given time. This will create more light reflections and higher dispersion and attenuation rate, reducing quality of the signal over long distances. Generally, multimode fibers are used in short distance, data and audio/video applications in LANs.

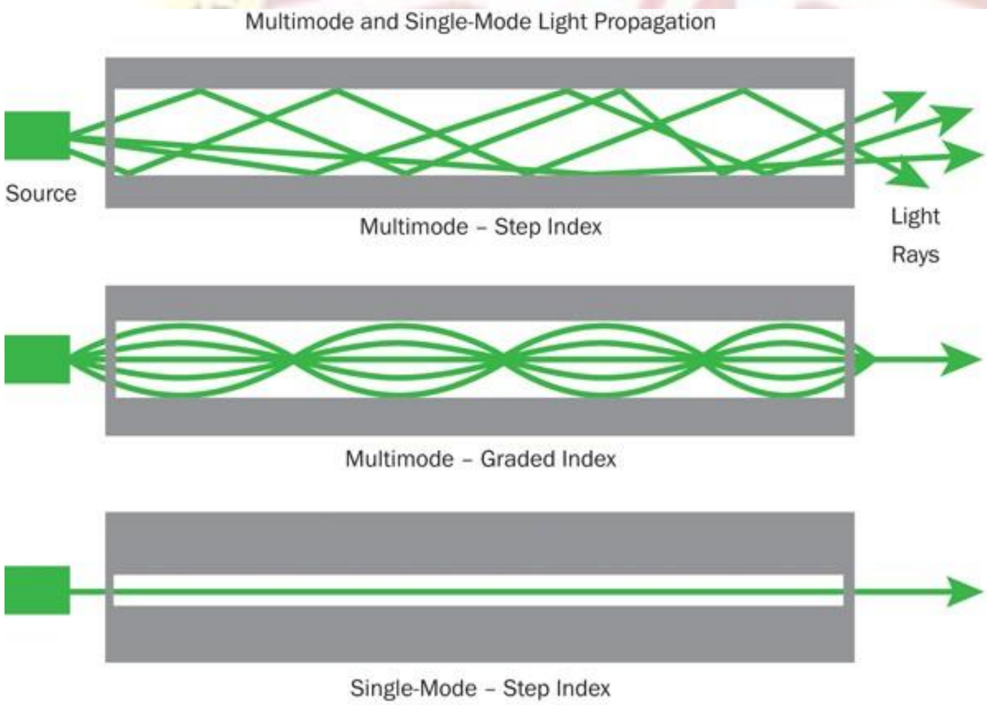


Single-mode Fiber vs. Multimode Fiber:

As mentioned above, the inner structure of single mode and multimode fibers are diverse, this naturally leads to the following differences:

Light Propagation Difference

The light propagation between single mode fiber and multimode fiber is totally different. Multimode fiber has two types of light propagation—step index and graded index, while single mode fiber has only one step index. And the light propagation reduces less in the single mode fibers transmission than that of multimode fibers.



Optics Difference

Single mode fiber needs to be used with laser diode based fiber optic transmission equipment for precise calibration required to inject light into the fiber optic cable. While Multimode fiber is usually used with LED based fiber optic equipment for short distance transmissions. In addition, single mode connectors used for single mode fiber also have higher stringent alignment requirements than that of multimode fiber connectors.

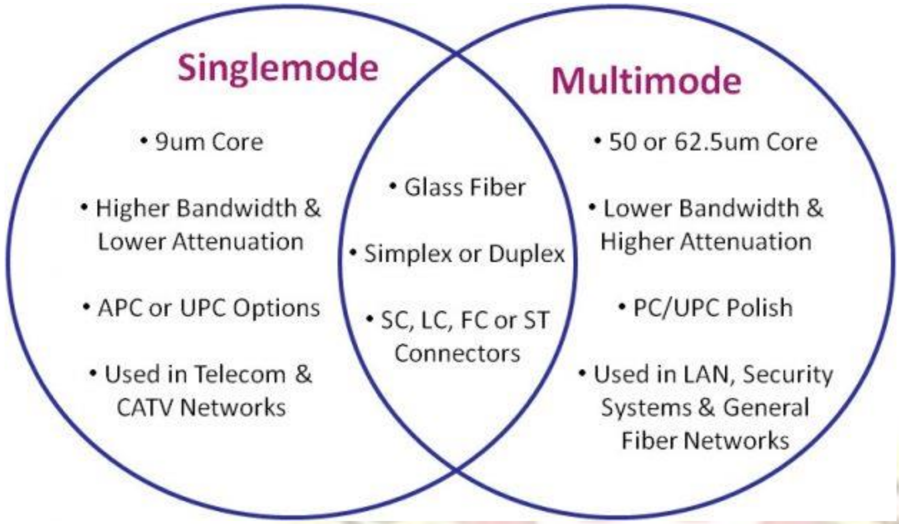
Deployment Cost Difference

Single mode fiber cable systems are usually more expensive even though the actual cost of single mode fiber cable is cheaper than that of multimode fiber cable in the market. This is because it is the optics that dominates the total cost of a network system. For example, single-mode transceivers cost 1.5 to 4 – 5 times more than multimode transceivers, depending on data rate. For more knowledge of deployment cost difference of single mode and multomode fiber, you can read this article: Single-mode Cabling Cost vs. Multimode Cabling Cost.

Further more, multimode transceivers also consume less power than single-mode transceivers. In a large data center with thousands of links, a multimode fiber cabling solution can provide substantial cost savings from both fiber transceiver and power/cooling perspective.

Single-mode Fiber vs. Multimode Fiber: Which One to Choose?

When selecting single mode fiber or multimode fiber, the most important thing to consider is the distance requirement. Within a data center, it's typical to use multimode fibers which can get you 300-400 meters. If you have very long runs or are connecting over longer distance, single mode fiber can get you 10km, 40km, 80km, and even farther. You just need to use the appropriate optics for the distance required, and again, the prices go up accordingly. It is estimated that the transmission costs of multimode fiber, including both transmitter and receiver sides, will be in the range of $ 500 to $ 800. And the transmission systems designed for use with single mode fiber will typically cost more than $ 1000.



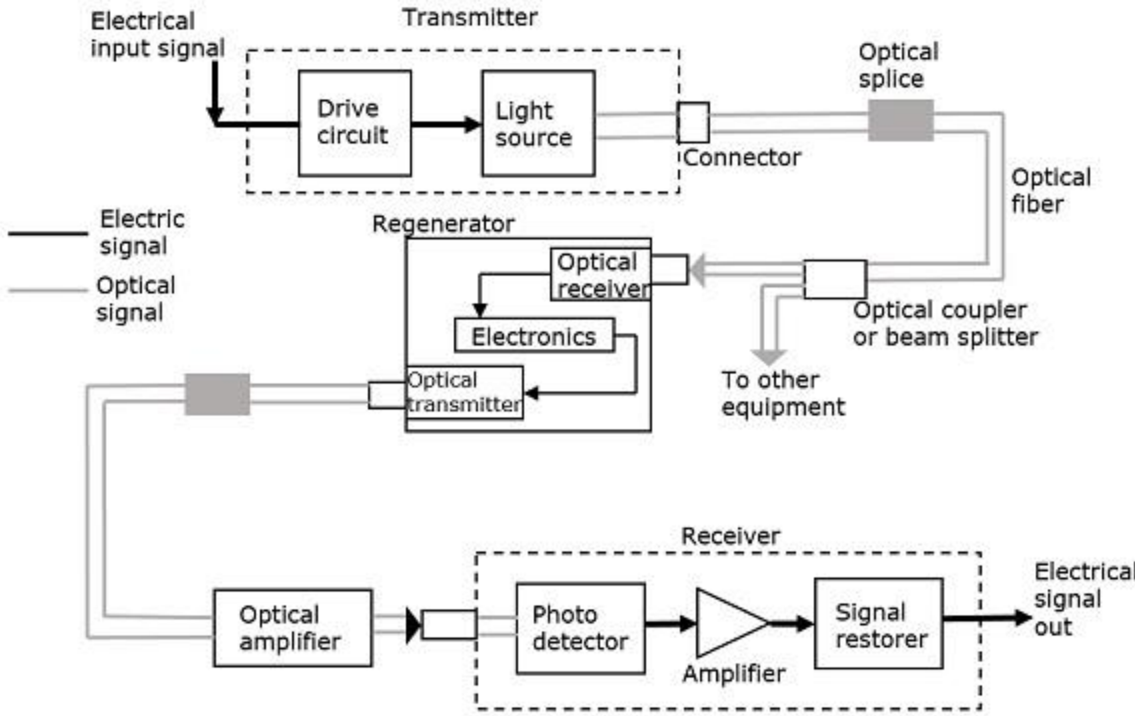
Note: single mode fiber and multimode fiber are not compatible. You cannot mix multimode and single mode fiber between two endpoints. The optics are not compatible either.

Conclusion

Generally, multimode fiber is more cost-effective choice for data center applications up to 550 meters. Single mode fiber is best used for distances exceeding 550 meters. Besides the transmission distance, the overall cost should also be taken into consideration. Whether single mode fiber or multimode fiber, choosing the one that best suits your network is the smartest choice. Nowadays, there is a trend for single mode cabling. Lots of data centers and providers will only do single mode cabling for new installs.

Optical Fiber Communications

The communication system of fiber optics is well understood by studying the parts and sections of it. The major elements of an optical fiber communication system are shown in the following figure.



The basic components are light signal transmitter, the optical fiber, and the photo detecting receiver. The additional elements such as fiber and cable splicers and connectors, regenerators, beam splitters, and optical amplifiers are employed to improve the performance of the communication system.

Transmitter section :

The main parts of the transmitter section are a source (either a **LED** or a **LASER**), efficient coupling means to couple the output power to the fiber, a modulation circuit and a level controller for LASERs. In present days, for longer repeater spacing, the use of single mode fibers and LASERs are seeming to be essential whereas the earlier transmitters operated within 0.8µm to 0.9µm wavelength range, used double hetero structure LASER or LED as optical sources. High coupling losses result from direct coupling of the source to optical fibers. For LASERs, there are two types of lenses being used for this purpose namely **discrete lenses** and **integral lenses**.

LED vs LASER as optical source :

A larger fraction of the output power can be coupled into the optical fibers in case of LASERs as they emit more directional light beam than LEDs. That is why LASERs are more suitable for high bit rate systems. LASER is more temperature dependent than LED. LASERs have narrow spectral width as well as faster response time. Consequently, LASER based systems are capable of operating at much higher modulation frequencies than LED based systems. Typical LEDs have lifetimes in excess of 10^7 hours, whereas LASERs have only 10^5 hours of lifetime. Another thing is that LEDs can start working at much lower input currents which is not possible for LASERs. So, according to the situation and requirements either LED or LASER can be utilized as an optical source.Now there are a number of factors that pose some limitations in transmitter design such as electrical power requirement, speed of response, linearity, thermal behavior, spectral width etc.

Drive circuitry :

These are the circuits used in the transmitters to switch a current in the range of ten to several hundred miliamperes required for proper functioning of optical source. For LEDs there are drive circuits like common emitter saturating switch, low impedance, emitter coupled, transconductance drive circuits etc. On the other hand for LASERs, shunt drive circuits, bias control drive circuits, ECL compatible LASER drive etc are noticeable.

Receiver section :

It includes Photodetector, low noise front end amplifier, voltage amplifier and a decision making circuit to get the exact information signal back. High impedance amplifier and Trans impedance amplifier are the two popular configurations of front end amplifier, the design of which is very critical for sensible performance of the receiver. The two most common photodetectors are **p-i-n diodes** and **avalanche photodiodes**. Quantum efficiency, responsivity and speed of response are the key parameters behind the decision of photodetectors. The most important requirements of an optical receiver are **sensitivity**, **bit rate transparency**, **bit pattern independence**, **dynamic range**, **acquisition time** etc. As the noise contributed by receiver is higher than other elements in the system so, we must put a keen check on it.

Functional Advantages

The functional advantages of optical fibers are −

- The transmission bandwidth of the fiber optic cables is higher than the metal cables.
- The amount of data transmission is higher in fiber optic cables.
- The power loss is very low and hence helpful in long-distance transmissions.
- Fiber optic cables provide high security and cannot be tapped.
- Fiber optic cables are the most secure way for data transmission.
- Fiber optic cables are immune to electromagnetic interference.
- These are not affected by electrical noise.

Physical Advantages

The physical advantages of fiber optic cables are −

- The capacity of these cables is much higher than copper wire cables.
- Though the capacity is higher, the size of the cable doesn't increase like it does in copper wire cabling system.
- The space occupied by these cables is much less.
- The weight of these FOC cables is much lighter than the copper ones.
- Since these cables are di-electric, no spark hazards are present.
- These cables are more corrosion resistant than copper cables, as they are bent easily and are flexible.
- The raw material for the manufacture of fiber optic cables is glass, which is cheaper than copper.
- Fiber optic cables last longer than copper cables.

Disadvantages

Although fiber optics offer many advantages, they have the following drawbacks −

- Though fiber optic cables last longer, the installation cost is high.
- The number of repeaters are to be increased with distance.
- They are fragile if not enclosed in a plastic sheath. Hence, more protection is needed than copper ones.

Applications of Fiber Optics

The optical fibers have many applications. Some of them are as follows −

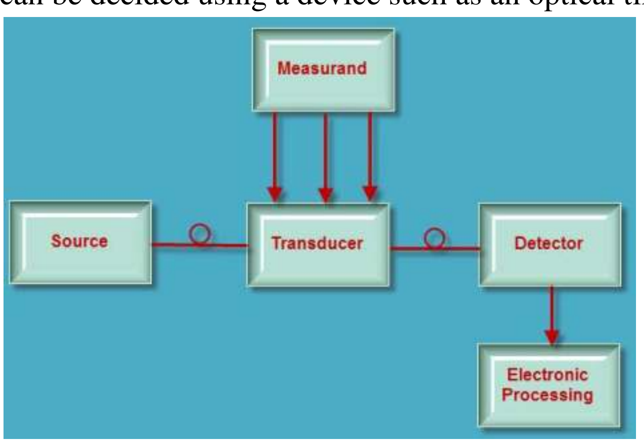
- Used in telephone systems
- Used in sub-marine cable networks
- Used in data link for computer networks, CATV Systems
- Used in CCTV surveillance cameras
- Used for connecting fire, police, and other emergency services.
- Used in hospitals, schools, and traffic management systems.
- They have many industrial uses and also used for in heavy duty constructions.

Introduction to Fiber Optic Sensors and their Types with Applications

In the year 1960, laser light was invented and after the invention of lasers, researchers had shown interest to study the applications of optical fiber communication systems for sensing, data communications, and many other applications. Subsequently the fiber optic communication system has become the ultimate choice for gigabits and beyond gigabits transmission of data. This type of fiber optic communication is used to transmit data, voice, telemetry and video over a long distance communication or computer networks or LANs. This technology uses a light wave to transmit the data over a fiber by changing electronic signals into light. Some of the excellent characteristic features of this technology include light weightness, low attenuation, smaller diameter, long distance signal transmission, transmission security, and so on.

Fiber Optic Sensors

Significantly, the telecommunication technology has changed the recent advances in fiber optic technology. The last revolution appeared as designers to combine the productive results of optoelectronic devices with fiber-optic-telecommunication devices to create fiber optic sensors. Many of the components associated with these devices are often developed for the fiber-optic-sensor applications. The ability of the fiber optic sensors has increased in the place of traditional sensor.The fiber optic sensors also called as optical fiber sensors use optical fiber or sensing element. These sensors are used to sense some quantities like temperature, pressure, vibrations, displacements, rotations or concentration of chemical species. Fibers have so many uses in the field of remote sensing because they require no electrical power at the remote location and they have tiny size.Fiber optic sensors are supreme for insensitive conditions, including noise, high vibration, extreme heat, wet and unstable environments. These sensors can easily fit in small areas and can be positioned correctly wherever flexible fibers are needed. The wavelength shift can be calculated using a device, optical frequency-domain reflectrometry. The time-delay of the fiber optic sensors can be decided using a device such as an optical time-domain Reflectometer.



Block Diagram Of Fiber Optic Sensor

The general block diagram of fiber-optic sensor is shown above. The block diagram consists of optical source (Light Emitting Diode, LASER, and Laser diode), optical fiber, sensing element, optical detector and end-processing devices (optical-spectrum analyzer, oscilloscope). These sensors are classified into three categories based on the operating principles, sensor location and application.

Types of Fiber-Optic Sensor Systems

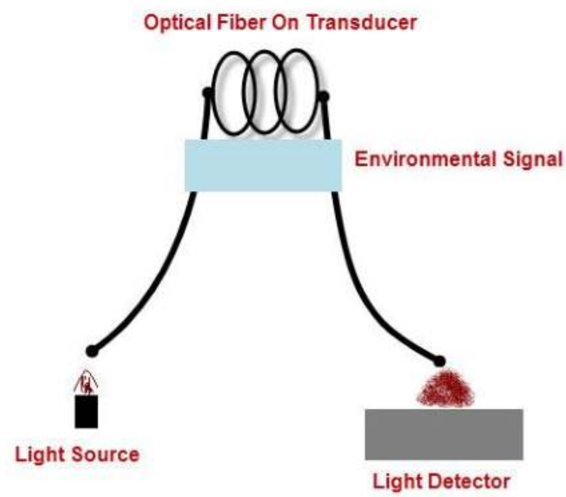
These sensors can be classified and explained in the following manner:

1. Based on the sensor location, the fiber optic sensors are classified into two types:

- Intrinsic Fiber-Optic Sensors
- Extrinsic Fiber-Optic Sensor

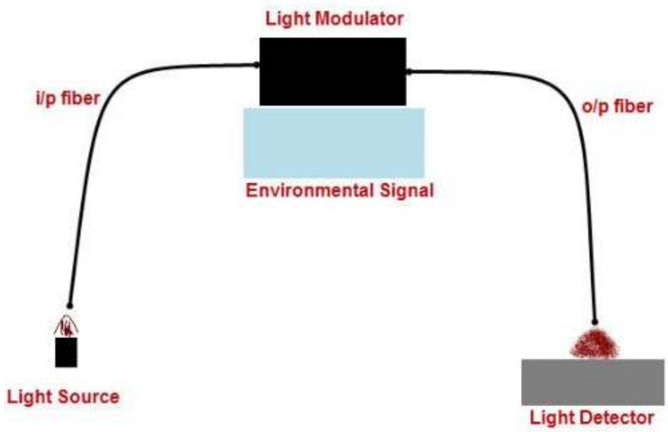
Intrinsic Type Fiber Optic Sensors

In this type of sensors, sensing takes place within the fiber itself. The sensors depend on the properties of the optical fiber itself to convert an environmental action into a modulation of the light beam passing through it. Here, one of the physical properties of light signal may be in the form of frequency, phase, polarization; intensity. The most useful feature of the intrinsic fiber optic sensor is, it provides distributed sensing over long range distances. The basic concept of the intrinsic fiber optic sensor is shown in the following figure.



Extrinsic Type Fiber optic Sensors

In extrinsic type fiber optic sensors, the fiber may be used as information carriers that show the way to a black box. It generates a light signal depending on the information arrived at the black box. The black box may be made of mirrors,gas or any other mechanisms that generates an optical signal. These sensors are used to measure rotation, vibration velocity, displacement, twisting, torque and acceleration. The major benefit of these sensors is their ability to reach places which are otherwise unreachable.



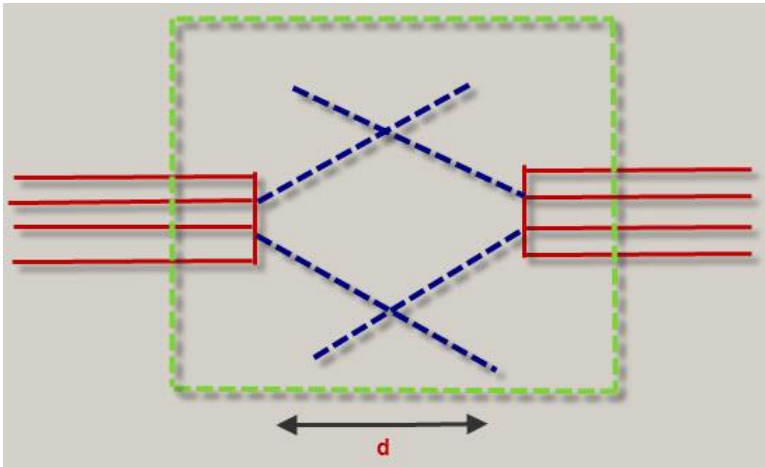
The best example of this sensor is the inside temperature measurement of the aircraft jet engine that uses a fiber to transmit a radiation into a radiation pyrometer, which is located outside of the engine. In the same way, these sensors can also be used to measure the internal temperature of the transformers. These sensors provide excellent protection of measurement signals against noise corruption. The following figure shows the basic concept of the extrinsic fiber optic sensor.

2. Based on operating principles, fiber optic sensors are classified into three types:

- Intensity based
- Phase based
- Polarization based

Intensity based Fiber Optic Sensor

Intensity based fiber optic sensors require more light and these sensors use a multi-mode-large core fibers.The shown figure gives an idea about how the light intensity work as a sensing parameter as well as how this arrangement makes the fiber to work as a vibration sensor. When there is a vibration, there will be a change in light inserted from one end to another end and this will make the intelligence for measuring the vibration amplitude.

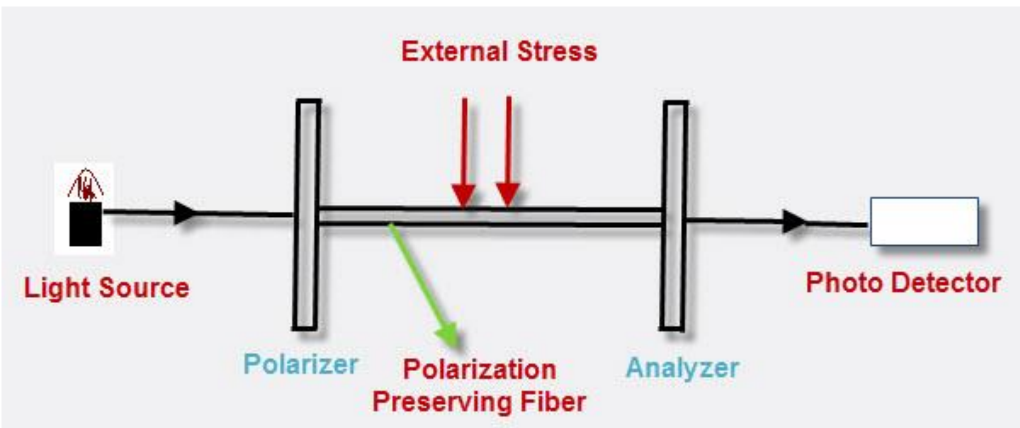


In the figure, the closer fiber optic and vibration sensor depend on the light intensity in later parts. These sensors have many limitations due to variable losses in the system that do not occur in the environment. These variable losses include loses due to splices, micro & macro bending losses, loses due to connections at joints, etc. The examples include intensity-based sensors or microbend sensor and evanescent wave sensor.

The advantages of these fiber optic sensors include low cost, ability to perform as real distributed sensors, very simple to implement, possibility of being multiplexed, etc. The disadvantages include variations in the intensity of the light and relative measurements, etc.

Polarization based Fiber Optic Sensor

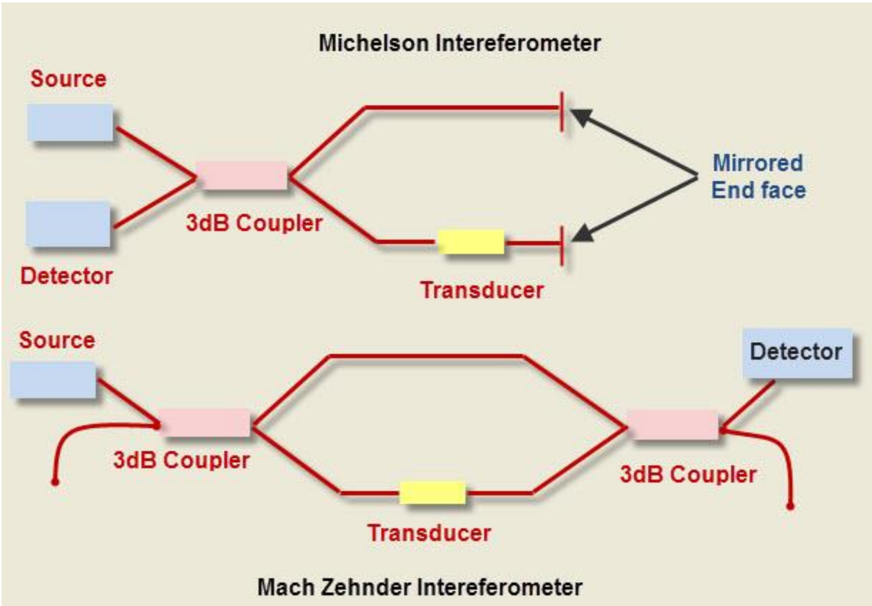
Polarization based optical fibers are important for a certain class of sensors. This property can be simply modified by various external variables and thus, these types of sensors can be used for the measurement of a range of parameters. Special fibers and other components have been developed with exact polarization features. Generally, these are used in a variety of measurements, communication and signal processing applications.



The optical setup for a polarization-based-fiber-optic sensor is shown above. It is shaped by polarizing the light from the light source through a polarizer. The polarized light is started at 45o to the selected axes of a length of birefringent polarization protecting fiber. This section of the fiber is served as sensing fiber. Then, the phase difference between the two polarization states is changed under any external disturbances such as stress or strain. Then, according to the external disturbances, the output polarization is changed.Thus, by considering the output polarization state at the next end of the fiber, the external disturbances can be detected.

Phase based Fiber Optic Sensor

These types of sensors are used to change emitter light on information signal wherein the signal is observed by the phase based fiber optic sensor. When a light beam is passed through the interferometer, then the light separates into two beams.Wherein one beam is exposed to the sensing environment and the other beam is isolated from the sensing environment, which is used as a reference. Once the two separated beams are recombined, then they get in the way with each other. The most commonly used interferometers are Michelson, Mach Zehnder, Sagnac, grating and polarimetric interferometers. Here, the Mach Zehnder and Michelson interferometers are shown below.



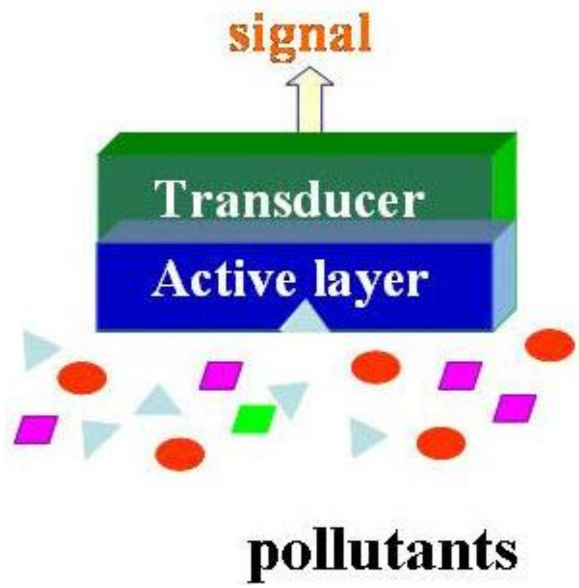
There are differences and similarities between the two interferometers. In terms of similarities, The Michelson Interferometer is frequently considered to be folded Mach Zehnder interferometer. The configuration of the Michelson interferometer requires only one optical fiber coupler. Because the light passes twice through the sensing and reference fibers, the optical phase shift per unit length of the fiber is doubled. Thus, the Michelson canessentially have better sensitivity. Another clear advantage of the Michelson is that the sensor can be interrogated with only a single fiber between the source and source detector module. But, a good-quality reflection mirror is required for the Michelson interferometer

3. Based on application, fiber optic sensors are classified into three types such as

- Chemical Sensor
- Physical Sensor
- Bio Medical Sensor

Chemical Sensor

A chemical sensor is a device which is used to transform chemical information in the form of a measurable physical signal that is associated with the concentration of a certain chemical species.The Chemical sensor is an importantcomponent of an analyzerand may include some devices that perform the following functions: signal processing, sampling, and data processing. An analyzer may be an important part of an automated system.



The working of analyzer according to a sampling plan as a function of time acts as a monitor. These sensors include two functional units: a receptor and a transducer. In the receptor part, the chemical information is transformed into an energy that may be measured by the transducer.In the transducer part, the chemical information is transformed into an analytical signal and it does not show sensitivity.

Physical Sensor

A physical sensor is a device that is made according to the physical effect and nature. These sensors are used to provide the information about a physical property of the system. This type of sensors are mostly signified by sensors such as photoelectric sensors, piezoelectric sensors, metal resistance strain sensors and semiconductor piezo-resistive sensors.

Bio Medical Sensor

Biomedical sensor is an electronic device that is used to transfer various non- electrical quantities in biomedical fields into easily detectable electrical quantities. Due to this reason, these sensors are included in health care analysis. This sensing technology is the key to collecting human pathological and physiological information.

Bio Medical Sensor

Applications of Fiber Optic Sensors

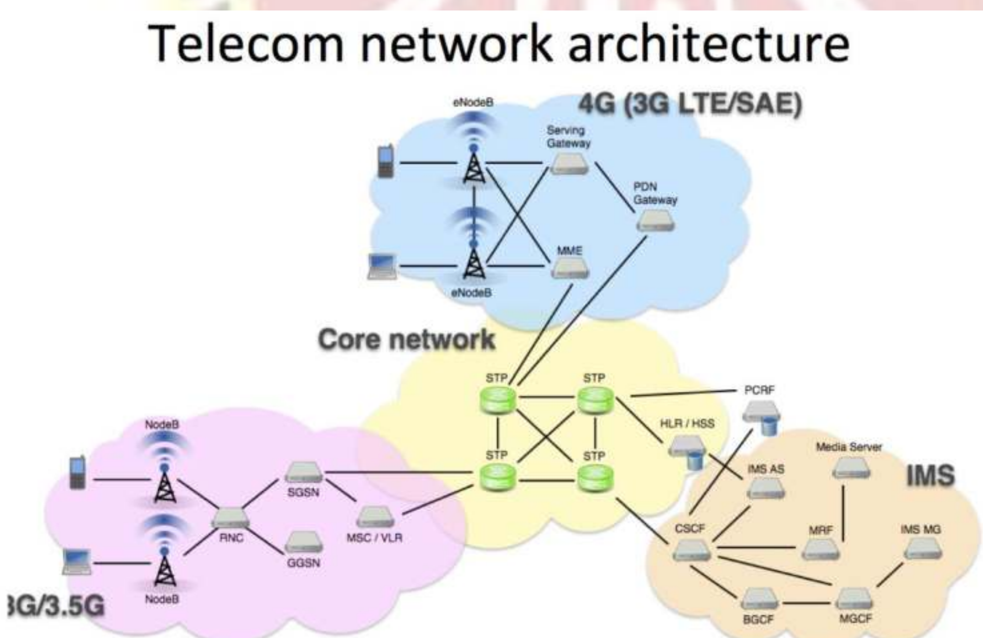
Fiber optic sensors are used in a varied range of applications such as

- Measurement of physical properties such as temperature, displacement,velocity, strain in structures of any size or any shape.
- In real time, monitoring the physical structure of health.
- Buildings and bridges, tunnels,Dams, heritage structures.
- Night vision camera, electronic security systems, Partial discharge detection and measuring wheel loads of vehicles.

Thus, an overview of fiber optic sensors and applications has been discussed. There are many advantages of using fiber optic sensors for long distance communication that include small in size, light in weight, compactness, high sensitivity, wide bandwidth, etc. All these characteristics make the best use of fiber optic as a sensor.

Telecommunications are the means of electronic transmission of information over distances. The information may be in the form of voice telephone calls, data, text, images, or video. Today, telecommunications are used to organize more or less remote computer systems into telecommunications networks. These networks themselves are run by computers.

A ***telecommunications network*** is an arrangement of computing and telecommunications resources for communication of information between distant locations.



A telecommunications network includes the following components:

1. *Terminals* for accessing the network

2. *Computers* that process information and are interconnected by the network

3. *Telecommunications links* that form a channel through which information is transmitted from a sending device to a receiving device.

4. *Telecommunications equipment* that facilitates the transmission of information.

5. *Telecommunications software* that controls message transmission over the network.

Scope of Telecommunications Networks

Two principal types of telecommunications networks can be distinguished from the point of view of their geographical scope. They are:

1. Local area networks

2. Wide area networks

Local area network (LAN): is a privately owned network that interconnects processors, usually microcomputers, within a building or on a campus site that includes several buildings.
Wide area network (WAN): is a telecommunications network that covers a large geographical area.
Metropolitan Area Networks (MAN) - are telecommunications networks that interconnect various local area networks within a metropolitan area, that is, within approximately a 50-mile range.

The signal is broadcast (radiated in many directions) over the air or space and received through an antenna. They include:

1. Terrestrial Microwave

2. Satellite Transmission

3. Radio Transmission

<u>Characteristics of Communications Media:</u>

Twisted Pair a communications medium consisting of a pair of wires.

Coaxial Cable a communications medium that consists of a relatively thick central conductor shielded by several layers of insulation and the second conductor just under the cable's shell

Fiber Optics high-capacity communications medium that consists of many strands of pure glass with a data carrying core in the middle, surrounded by a reflective coating and a protective sheath.

Terrestrial Microwave long-distance telecommunications by means of microwave signals travelling on the surface of the earth.

Satellite Transmission form of microwave transmission in which the signal is transmitted by an earth station to a satellite which rebroadcasts the signal to the receiving station.

Radio Transmission wireless communications technology that transmits voice or data over the air using a lower frequency band than microwaves.

Note: Transmission speeds keep on rising, particularly in the fiber optics area. We are now moving toward a global infrastructure of gigabit-speed fiber optic links relying on digital transmission. In this multimedia environment, data, text, voice, images, and video will travel at speeds of billions of bits per second.

Analog and Digital Communications

Most of the lines in the telephone systems of the world at present are ***analog***. Signals are transmitted as continuous waves. This is a satisfactory way to transmit voice, but digital data sent by computers (sequences of pulses representing 0s and 1s) must be converted into an analog signal for transmission over an analog line. The analog data must then be converted back into digital before entering the memory of the receiving computer. The conversion of data from digital form into analog for transmission and then back into digital at the receiving end is done by a pair of interface devices called ***modems*** (***mo***dulator-***dem***odulator).

Modem-based telecommunications have created a significant bottleneck in an environment where computer and peripheral speeds have increased dramatically. The solution is end-to-end ***digital*** communications, in which signals are sent as streams of on/off pulses. Digital lines are capable of much faster communication and digital circuitry is now cheaper than analog. All the new equipment now installed in telephone networks is indeed digital.

Trend: There is a shift toward digital telecommunications is taking place throughout the world. A digital system for telecommunications, called ***TI carrier***, is in wide use in parts of the telephone network.

Computer Networks

Computer networks differ in scope from relatively slow wide area networks, employed to transmit messages across vast geographic distances, to very fast local area networks that may connect computers located in the same building. System designers may select one of several arrangements for interconnecting network nodes, depending on an organization's requirement. There are several ways to establish a connection between the sender and the receiver of a message.

Network Topologies

Computers, switches, and terminals interconnected by network links are collectively called ***nodes***. The purpose of network control is to provide a connection between nodes that need to communicate. The arrangement of nodes and links in a network is called a ***topology***. A variety of arrangements are possible, each with its own advantages and drawbacks. Network topology has to fit the structure of the organizational unit that will use the network, and this topology should also be adapted to the unit's communication traffic patterns and to the way the databases will be stored in order to facilitate access to them.

The following topologies are the most widely used:

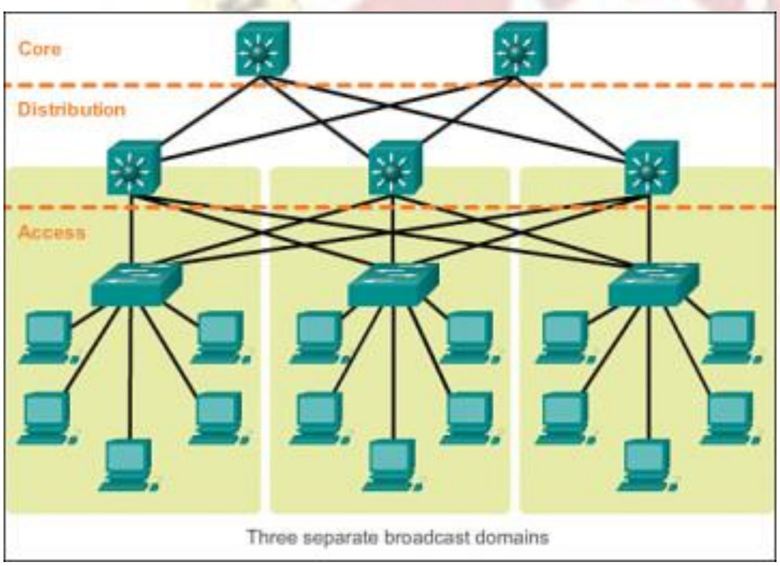
1. Hierarchical Network

2. Star Network

3. Ring Network

4. Bus Network

Hierarchical Network:



a. A corporate host computer (often a mainframe), divisional minicomputers or powerful workstations, and workgroup support via micros.

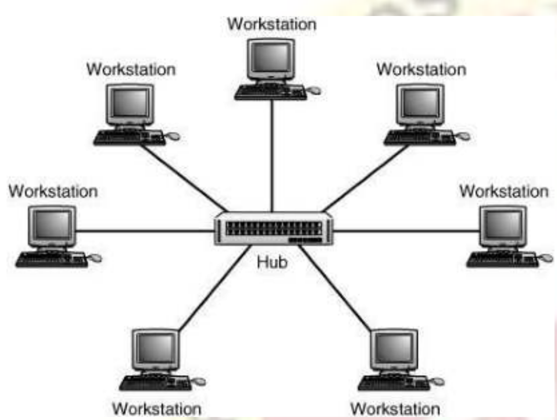
b. This topology matches the organizational structure of many firms and is still frequently used in WANs.

c. The user workstations may be, in turn, interconnected using one of the LAN topologies.

d. Failure of the host does not disable divisional processing, which is a fail-safe feature.

e. Cost-effectiveness of micros and the growing importance of groupwork leads some downsizing firms to move away from hierarchical networks to client/server computing.

Star Network:



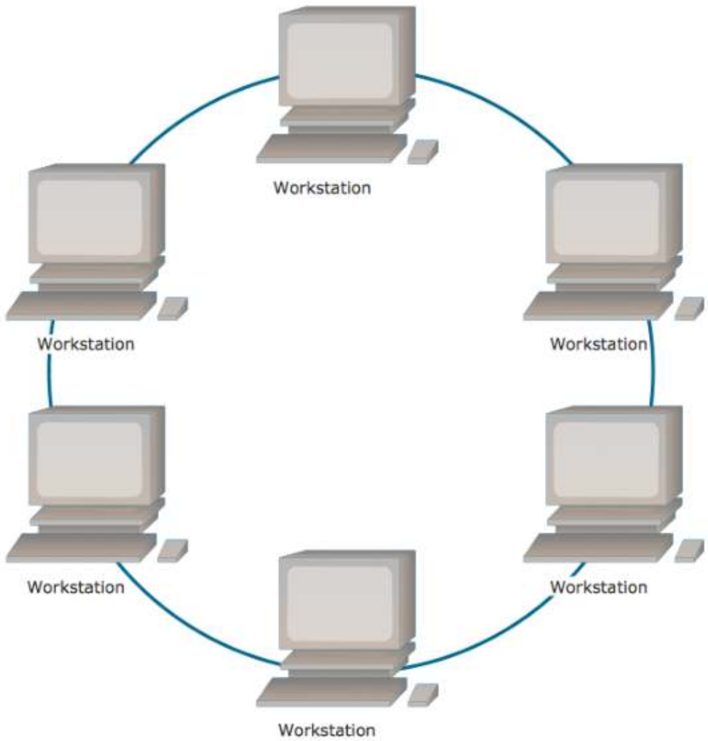
a. In a star network, a hub computer or switch (such as a PBX) interconnects a number of workstations.

b. The computer at the hub acts as the network server, providing access to the shared database and software. All communications between the workstations must go through this central mode.

c. The star network is rather easy to manage and expand, since in both cases it is largely the single central node that is affected in an expansion of a processing capacity.

d. The central node is a locus of vulnerability: it may be overloaded or it may fail, disabling the entire network.

Ring Network:



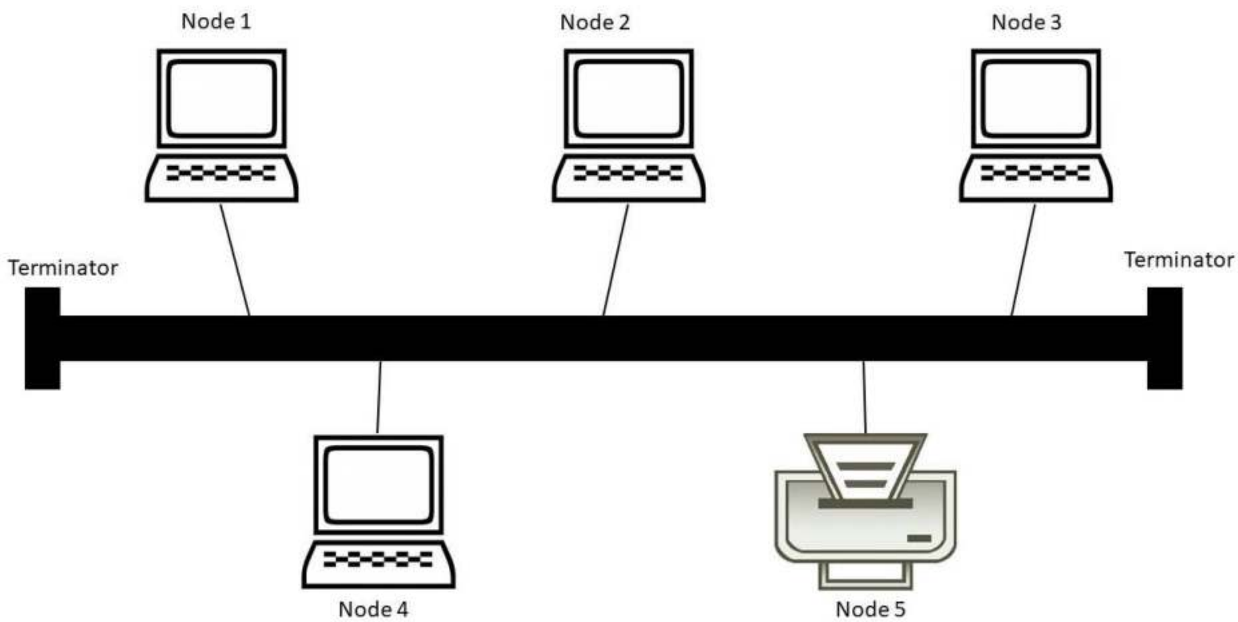
a. Each node in a ring network is connected to two of its neighbours.

b. The nodes are usually close to one another; this topology is frequently used in LANs.

c. When one node sends a message to another, the message passes through each intermediate node, which restores the signal, as signals deteriorate in transmission.

d. If a node fails, the ring is out of service, unless the ring contains two channels transmitting in opposite directions.

Bus Network:



a. The nodes on a bus network are connected to a common link such as coaxial cable. This arrangement is used in LANs.

b. A failing device does not affect the rest of the network; failure of the bus itself, of course, brings the network down.

Switching in Networks

Many users can be connected at the same time to a network of communication channels. ***Switching*** devices establish connections between nodes that need to communicate over a network. Principal techniques for switching include:

1. Circuit Switching

2. Packet Switching

3. Fast Packet Switching

Circuit Switching:

1. The circuit switching technique is employed in a telephone network.

2. Communication links are connected to switching centers, which connect to one node to another on demand.

3. The circuit is established for the entire duration of the communication

4. Circuit switching is suitable for file transfers and similar longer transmissions

Packet Switching:

1. Packet switching is of particular importance for data communication owing to its speed and its superior utilization of communication links when handling Abursty,@ intermittent, traffic. Indeed, data transmission involves short bursts of activity by a computer or a terminal when the data are sent, followed by long periods when there is no transmission.

2. Packet switching offers flexibility in connecting to a network. It is used by most of the public data networks provided by value-added carriers.

3. In packet switching, messages are divided at the source into fixed-length chunks, called ***packets***, that also include bits identifying the receiver. Typically, a packet contains 128 bytes of data.

4. Each packet, can be transmitted independently, with routing determined at each node the packet passes through (as opposed to circuit switching, where the route is predetermined).

Fast Packet Switching:

Traditional packet switching checks each packet for errors at every node the packet passes through. Modern telecommunications equipment is far more noise-free than that for which packet switching was originally designed. To take advantage of this, two fast packet-switching technologies are being introduced:

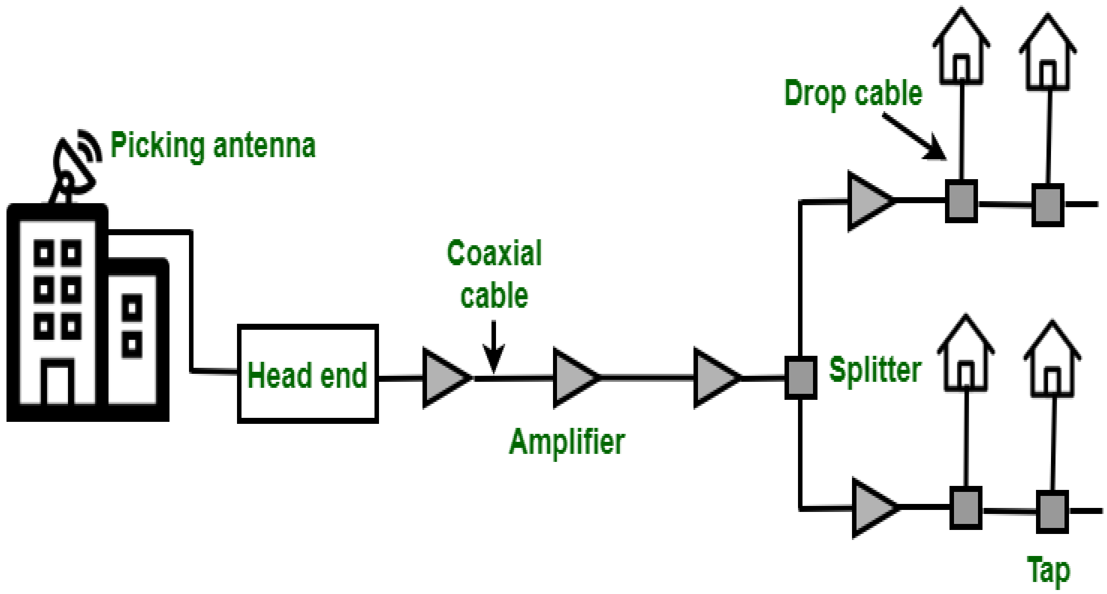
Cable TV Networks

Cable TV network started its business only as a video service provider, but with the new advancement in technology, it's moved to the business of Internet access. It also refers to the system that distributes Television signals with the utilization of transmission media. Types of Cable TV Networks are a follows –

1. Traditionally Cable Networks
2. Hybrid Fiber-Coaxial Network

Traditional Cable Network :

This network began to distribute the broadcast video signals to the locations with poor or no reception. Traditional Cable Network also called community antenna TV because this antenna is present at the highest of the building to receive signals from the TV stations then distribute these signals via coaxial cables to the community. The following is the schematic diagram of the traditional cable TV network.

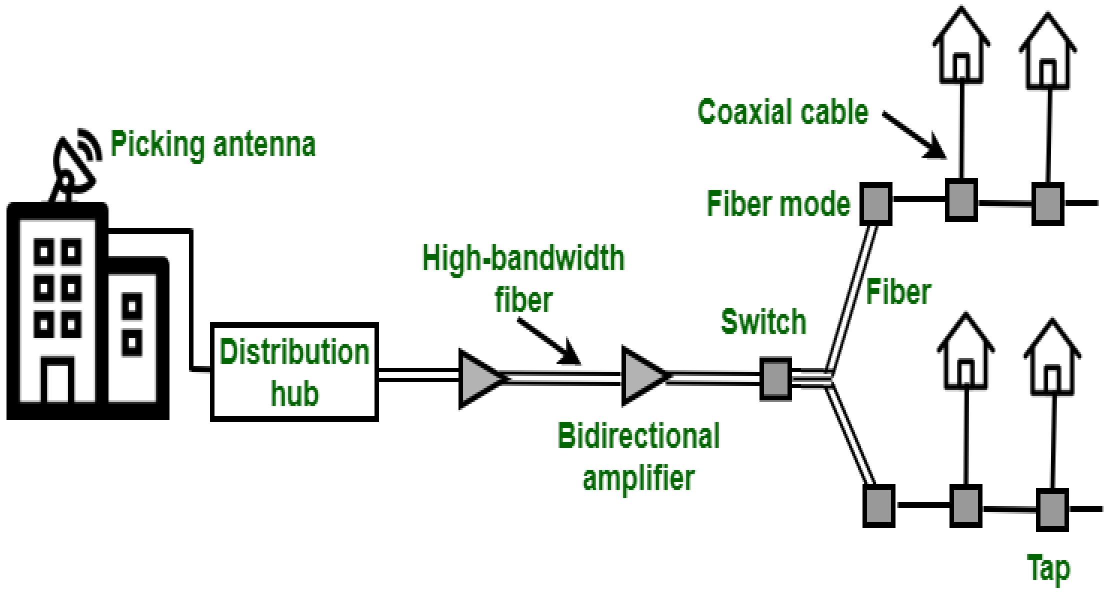


Traditional cable TV network

In this, Cable TV office is referred to as the head end which can receive the video signals from broadcasting stations and then feeds the signals into coaxial cables. Due to the distance increases, the signals are getting weaker, for this purpose amplifiers were installed through this network to regenerate the signals. During this network, we have more than 35 amplifiers between the head end and the premises of subscribers. At the other end of the Cable TV network, splitters were placed to split the signal and the tap and drop cables make the connections to the subscriber premises. Communication in this network is unidirectional. The video signals were transmitted downstream from the head end to the subscriber premises.

Hybrid Fiber-Coaxial Network :

Hybrid Fiber-Coaxial Network is that the second generation of the cable network. which is a combination of fiber-optic and coaxial cable is used in this type of network. The transmission mode is used is fiber node i.e. fiber mode. The schematic diagram of the HFC network is as follows –



Hybrid Fiber-Coaxial Network

There are nearly 400, 000 subscribers served by **Regional Cable Head (RCH)**. Modulation and demodulation of the signal are done through the **distribution hubs** after these signals are sent to the fiber nodes through fiber-optic cables. The fiber node split the analog signal so that the same signal is sent to each coaxial cable. Approx. 1000 subscribers are served by coaxial cable. Communication in this is bidirectional.

Advantages of Cable TV Network :

- Cable TV is stable in its service.
- It is fairly inexpensive.

Disadvantages of Cable TV Network :

- Due to the supply of single provider, it creates monopoly.
- It will cause to less privacy, when out TV cable it connected to the internet or world wide web.

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