NILASAILA INSTITUTE OF SCIENCE AND TECHNOLOGY

LECTURE NOTE ON

APPLIED PHYSICS – II

(For all the branches of diploma engineering)

SEMESTER : 2ND

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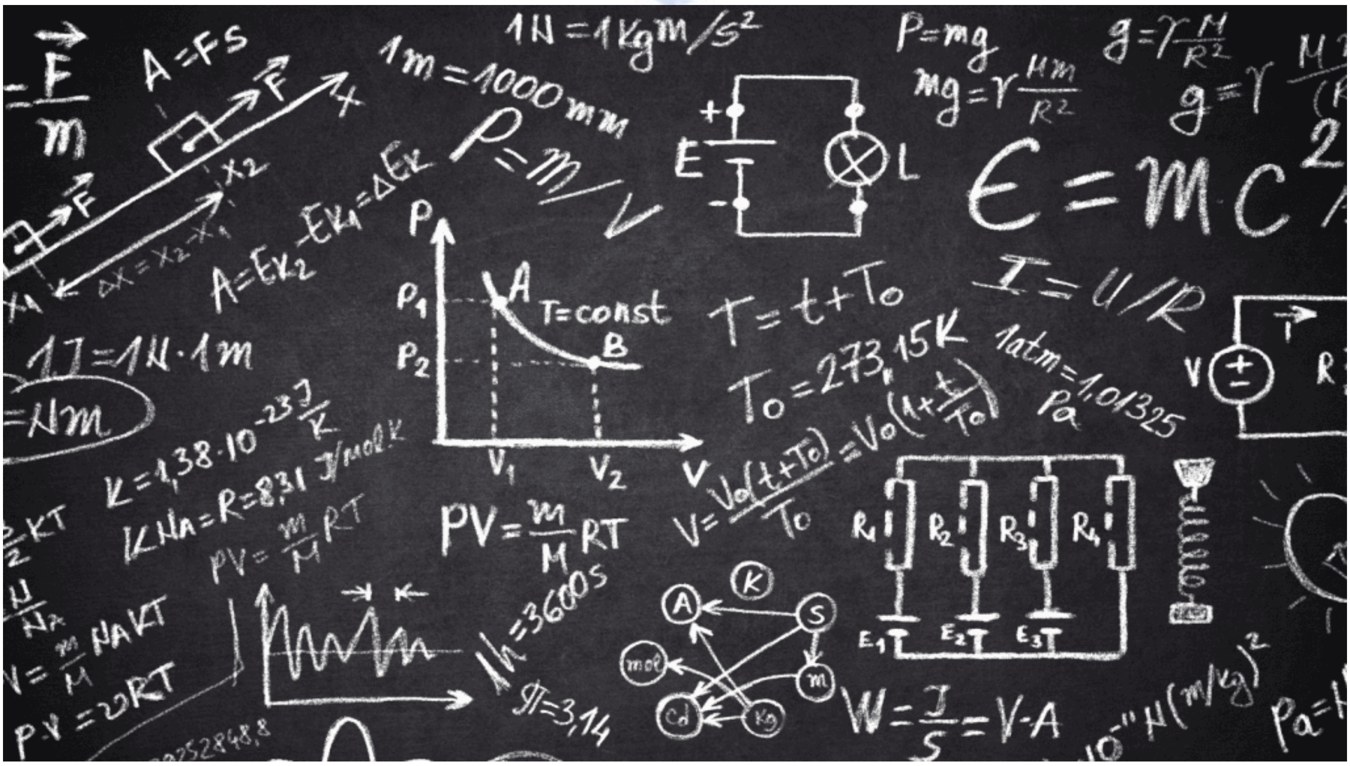


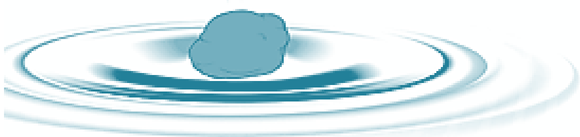
CONTENTS

	Chapters	Page no.
1.	***Wave Motion and its Applications***	***2 - 11***
2.	***Optics***	***12 - 23***
3.	***Electrostatics***	***24 - 33***
4.	***Current Electricity***	***34 - 41***
5.	***Electromagnetism***	***42 - 49***
6.	***Semiconductor Physics***	***50 - 58***
7.	***Modern Physics***	***59 - 68***

CHAPTER 1 : WAVE MOTION AND ITS APPLICATIONS

Wave motion:

When a stone is dropped on water surface there is sound of dropping stone and ripples in the water surface. The sound travels through air and we hear that sound through our ears and at the same time circular ripples propagates on water surface from the point of origin to the region all around . A part of kinetic energy of stone is transferred to water molecules and we say that a wave has propagated through water. Similarly, a part of kinetic energy of stone is converted into sound energy and it reaches to ear through air and a sound wave propagates through air. When energy is transferred from one point of medium to another, there is a propagation of wave, without changing the average position of particles of the medium. The wave motion describes how a wave propagates though a medium without changing the overall position of the particles in the medium.



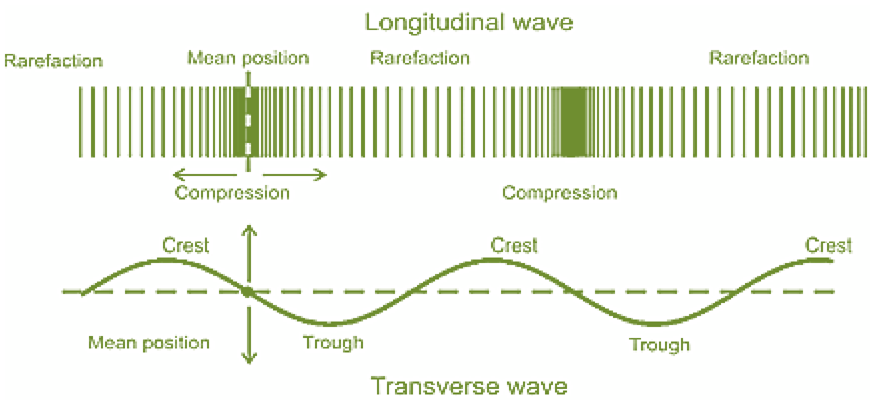
I Ripple in water due to energy transfer from stone

Transverse and Longitudinal waves:

If the direction of vibration is perpendicular to the travel of the wave than the waves are called **Transverse waves** and if the direction of vibration is along the direction of wave propagation than the waves are called **Longitudinal waves.**

Examples of transverse wave: light, all electromagnetic wave

Examples of longitudinal wave: sound



Wave Velocity:

The disturbance given in string moves along the string with certain velocity which depends upon the elastic properties and density of string. If the disturbance is given continuously 'to and fro' than we say that wave propagates with a velocity known as wave velocity and the magnitude of wave velocity depend upon the elastic properties and density of medium. It is represented by 'v' and given by formula,

$v = x/t$ (m/s) ,where 'x' is the distance in meters travelled in time 't' sec.

Frequency:

The reciprocal of Time period is known as frequency of oscillation. It is also defined as the number oscillations in one second. Its unit is Hertz (Hz)

Example: If the Time period of one oscillation is 0.5 second, then the frequency is 2 Hz i.e. two oscillations will be completed in one second. $f = 1/T$.

Wave length:

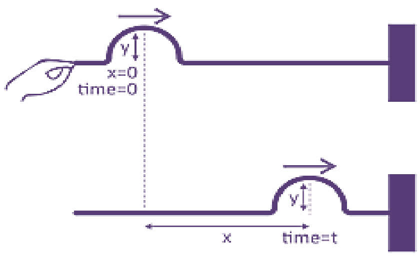
It is the distance between two consecutive crests or between two consecutive troughs .
And it is also the distance between two consecutive compressions or between two rarefractions .
Wave length and frequency are related as follows: $v = f\lambda$

Sound and light waves and their properties:

Waves can be mechanical or electromagnetic wave. The mechanical waves require medium to travel, whereas the electromagnetic waves can travel without medium in vacuum also. Sound waves as they require medium to travel cannot travel in vacuum. It can travel in air, solids and liquid. The velocity in different medium is different. The sound wave can be longitudinal and transverse both. In air the sound waves are longitudinal.

As the sound wave moves in air there will be air density distribution due to longitudinal nature. Hence there will be difference in the air pressure due to compression and rarefaction. The velocity of sound waves in air varies with density of air. The velocity of sound wave is 340 m / s at 20°C in air. Light wave can propagate in vacuum and in medium also. The light waves are transverse in nature. As the light waves move there is variation of electric and magnetic field vectors. The velocity of light wave is 3 × 10^8 m / s in air or vacuum.

Wave Equation:



Propagation of disturbance

The disturbance moves in positive x direction, It moves with velocity 'v'. The disturbance at x = 0 reaches to x after time 't' with velocity, v.

The displacement 'y', at x = 0 is,

$$Y = f(t) \quad ....(1)$$

The displacement at distance x at time t, will be same as, at x=0 and at time = t - x / v .

At point 'x' displacement will be, $y = f(t-x/v)$ ....(2)

If we introduce a continuous disturbance at x=0, then this continuous disturbance will propagate along 'x' with velocity 'v'. For an oscillatory displacement 'y' , which is defined by following equation,

$$y = a \sin(\omega t) = a \sin\{(2\pi/T)t\}$$

Where, a is the amplitude of oscillatory displacement, T is periodic time or Time period and Hence, at distance x

$$w = 2\pi/T$$

$$y = a \sin\{\omega(t-x/v)\} \quad (\therefore \omega=2\pi f] \quad ...(3)$$

$$\Rightarrow y = a \sin\{2\pi f\,(t-x/v)\} \quad ....(4)$$

$$\Rightarrow y = a \sin\{2\pi\,(t/T-x/\lambda)\} \quad ....(5)$$

$$\Rightarrow y = a \sin(\omega t - kx) \quad ....(6)$$

Eq. 5 and Eq. 6 are known as general wave equation representing wave motion in medium, where $k = 2\pi / \lambda$ is wavenumber, $w = 2\pi f$ is angular frequency. Eq. 5 and 6 represents wave travelling in positive 'x' direction and having displacement in 'y' direction, the displacement can also be represented as displacement vector.

As, waves moves in medium both x and t changes, if 't' increases 'x' also increases such that the argument of sin function in Eq. 6 remains constant.

Hence, $\omega t - kx = \text{constant}$

Differentiating w.r.t time $\omega - k(dx/dt) = 0$ ......(7)

$$\omega = k\,(dx/dt) \quad ....(8)$$

$$\omega/k = (dx/dt) \quad ....(9)$$

$$v = \omega/k = f\lambda \quad .....(10)$$

Eq. 10 gives velocity of wave in terms of frequency and wavelength.

Amplitude:

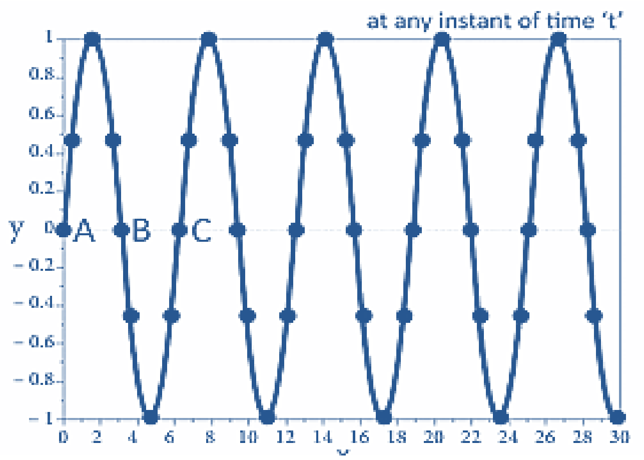
Amplitude of a wave is the maximum displacement travelled by a wave. Intensity of wave is proportional to the square of amplitude of the wave.

Phase:

Phase is a dynamical state depends on position and direction of displacement. The wave velocity may also be termed as phase velocity.

Phase difference:

In the figure the point A, B and C are at mean position, but the point A and C are at same phase. For these two points the position and direction of displacement are same. The point B is at same position, but direction of displacement is opposite. Hence it will have some phase difference with point A. The Point B will change its position and it will take T / 2 times to reach the same phase as A, Hence the time taken for point B to reach the phase which the point A, initially has is known as phase difference between points A and B. The phase difference between two points is the time difference to acquire the same dynamical state. As the wave motion resembles with trigonometric function, it is simpler to express phase difference in terms of angle. In period 'T', the wave completes one oscillation. Similarly, it takes '2π' angle to complete one cycle in trigonometric functions. Therefore 'T' can be expressed as 2π and T / 2 as π and so on. If two waves have phase difference of T / 4 we can say that they have phase difference of π / 2.



Principle of superposition of waves:

If a wave passes through medium then the particle performs oscillatory motion. If two waves meet at any point, then the resultant motion of the particle is a resultant of the vector addition of the displacement of two waves at that point and this is known as superposition of waves.

Resultant displacement, $y = y_1 + y_2$

Let first wave and second wave have same frequency and are represented as,

$$y_1 = a_1 \sin(\omega t)$$

$$y_2 = a_2 \sin(\omega t + \emptyset)$$

where ϕ is phase difference between two waves and resultant displacement will be,

$$y = y_1 + y_2$$

$$y = a_1 \sin \omega t + a_2 \sin(\omega t + \emptyset)$$

$$y = a_1 \sin \omega t + a_2 \sin(\omega t) \cos \emptyset + a_2 \cos(\omega t) \sin \emptyset$$

$$y = \sin(\omega t)\,[a_1 + a_2 \cos(\emptyset)] + a_2 \cos(\omega t) \sin \emptyset$$

Let ,

$$a_1 + a_2 \cos(\emptyset) = a' \cos(\alpha)$$

$$a_2 \sin(\emptyset) = a' \sin(\alpha)$$

$$Y = \sin(\omega t)\, a' \cos(\alpha) + \cos(\omega t)\, a' \sin(\alpha)$$

$$Y = a' \sin(\omega t + \emptyset)$$

This is the resultant amplitude due to superposition of waves at any point. The amplitude of resultant wave is a' and frequency is same as the combining waves.

Simple Harmonic Motion (SHM):

Simple Harmonic motion (SHM) is a simplest and special case of oscillatory motion. In SHM the particle oscillates from its mean position in straight line. The restoring force is linear and directed towards centre and it tries to bring back the particle in mean position. Restoring force is directly proportional to displacement and opposite from the direction of displacement.

$$F \propto -y$$

$$F = -k\,y$$

where k is proportionality constant and from Newton's second law of motion ,

$$F = ma$$

$$a = F/m$$

$$a = -(k/m)\,y$$

Expression for displacement, velocity, acceleration, time period and frequency :

Displacement: The displacement is defined as shift in distance from mean position and as it is a vector quantity, the direction of displacement is measured with respect to mean position in half oscillation it is positive and in other half oscillation it is negative. The maximum displacement is called as Amplitude of SHM. It is denoted as 'A'. the expression for displacement is,

$$y = A \sin(\omega t)$$

Velocity: Rate of change of displacement is velocity and is given by differentiating the displacement with time.

$$V = dy/dt$$

$$V = A\,\omega \cos(\omega t)$$

Acceleration: Rate of change of velocity is acceleration and is given by differentiating the velocity with time.

$$a = \frac{dv}{dt}$$

$$a = \frac{d}{dt}(A\omega \cos \omega t)$$

$$a = -A\,\omega^2 \sin \omega t$$

$$a = -\omega^2 y$$

$$\omega^2 = k/m$$

Frequency: The frequency of oscillation will be calculated from angular frequency given in equation,

$$\omega^2 = k/m$$

$$\omega = \sqrt{\frac{k}{m}}$$

$$\omega = 2\pi f$$

$$\Rightarrow f = \frac{\omega}{2\pi} \qquad \Rightarrow f = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$$

Time period: The time period of oscillator is reciprocal of frequency. It is also defined as time taken to complete one oscillation. $T = 2\pi\sqrt{\frac{m}{k}}$

Simple harmonic progressive wave:

The particle of medium undergoes SHM and the wave travel continuously in the medium are called as progressive waves or Simple harmonic progressive waves.

$$y = a \sin\{\omega(t-x/v)\} \qquad (\because \omega=2\pi f)$$

$$\Rightarrow y = a \sin\{\tfrac{2\pi}{T}(t-x/v)\}$$

$$\Rightarrow y = a \sin\{\tfrac{2\pi}{vT}(vt-x)\}$$

$$\Rightarrow y = a \sin\{2\tfrac{\pi}{\lambda}(vt-x)\}$$

- All the particles of medium perform SHM, when simple harmonic progressive wave passes through medium.
- All the particles vibrates with same amplitude and same frequency.
- Energy is transmitted through the medium.

Energy transfer:

As the energy from one particle is transferred to another particle, when simple harmonic waves passes through medium, the particle doing SHM have kinetic energy (KE) and potential energy (PE) and the sum of the KE and PE i.e. total energy is the energy transferred to the other particle. PE is due to the displacement from mean position. The KE is due to the velocity of particle. The restoring force is written as,

$$F = -k\,y$$

If dW is work done against the restoring force for displacing the particle through dy, then

$$dW = -kydy$$

$$dW = Fdy$$

Total work done in displacing particle from 0 to y is, $W = ½ky^2$

Where negative sign has been removed as it is only resemblance of direction. Hence $PE = ½ky^2$

From above equations, $PE = ½\, m\omega^2 A^2 \sin^2(\omega t)$

The KE is due to the velocity of particle. The KE of particle doing SHM can be given by,

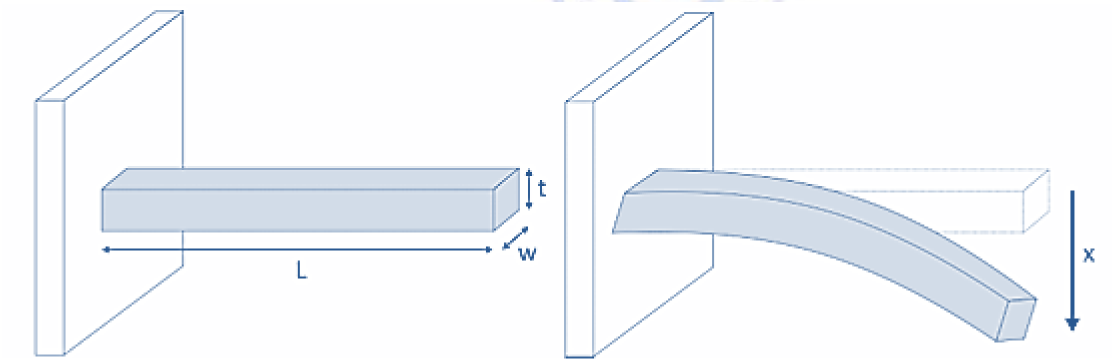
$$KE = ½\, mv^2 = ½\, mA^2\omega^2 \cos^2\,(\omega t)$$

Now the total energy $= KE + PE = ½\, mA^2 w^2$

The energy given by is transferred from one particle to another as the simple harmonic waves travels through medium. The total energy of particle will remain same at each instant of time.

Vibration of cantilever:

A cantilever is a system, in which one end of beam which is made up of elastic material such as steel is fixed with rigid support and another end is kept free. The length of cantilever is very large as compared to its width. A separate body having certain mass is hanged at free end for applying force for deflection. If the free end is given a little deflection and released, the beam starts vibrating along the fixed end, this vibration is known as cantilever vibration. The Time period of the vibration depends upon the elastic properties of beam material and dimensions of the beam. In the Figure a cantilever has been shown with Length L, width w and thickness t. The Time period of SHM is given $by,\ T = 2\pi(\sqrt{(m/k)}$



In case of cantilever, k is the stiffness of the system and m is the mass hanged on free end. k depends on the length (L), area, moment of inertia (I) and Young's Modulus (Y) of the material of the beam and for a cantilever beam is given by: $I = \frac{wt^3}{12}$

In case of rectangular beam, $k = 3Y\frac{wt^3}{12L^3} = Yw\frac{t^3}{4L^3}$

$$Therefore \quad T = 2\pi\sqrt{\frac{m4L^3}{Y\,wt^3}}$$

Hence the T of cantilever oscillations is given $by\ k = 3YI/L^3$

As from above equation Time period of cantilever oscillations depends on its dimensions and elasticity of material of cantilever.

Free, forced and resonant vibrations with examples :

Free vibration: When a simple pendulum or cantilever are given an initial amplitude or deflection and the external force is removed. Then the system oscillates with a frequency known as its natural frequency and such vibration are known as free vibrations. The vibration frequency or natural frequency totally depends upon the system parameters.

Examples: Hitting a tuning fork and let it sound.

Give displacement to a simple pendulum and let it oscillate.

Forced vibration: When an oscillatory system is vibrating in its natural frequency. The overall energy of system given at the time of deflection decreases due the external damping forces, say due to air friction in case of simple pendulum. The amplitude of the vibration decreases continuously due to damping and the vibration stops, and the system again comes to rest. If an oscillator has given continuous external energy, so that it will over comes damping and vibrate continuously. In such systems an external signal (may be electrical), through proper arrangements continuously provides energy to the oscillator. The frequency of the external oscillator may not be equal to natural frequency of oscillator. Such vibrations are known as forced vibrations. The frequency of forced harmonic oscillator vibration is the frequency of external source.

Examples :
- A swing is provided energy, when it goes down swing.
- Vibration in suspension bridge, due to vehicle movement.

Resonant vibration: In forced vibrations the transfer of energy from the external source to the oscillator is less if the frequency of external source differs with the natural frequency of oscillator. The amount of energy transfer increase if the frequency of external source approaches towards their natural frequency of oscillator. When the frequency of external source is equal to natural frequency of oscillator than such vibrations are known as resonant vibrations.

Examples :
- Tuning of radio station.
- Vibration produced in a tuning fork placed near a vibrating tuning fork of same frequency.
- Cooking in microwave oven.

ACOUSTICS OF BUILDINGS :

Echo and Reverberation:

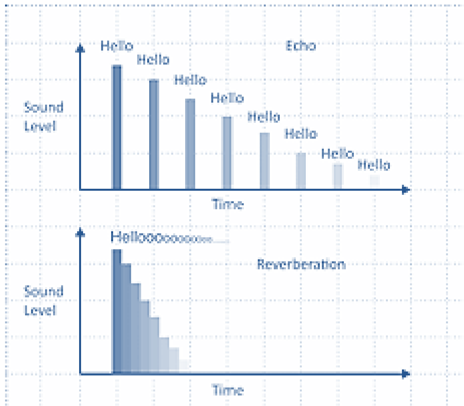
Direct sound and reflection of direct sound produced from the source that arrives at the listener with an time interval is known as Echo.

The direct sound and its multiple reflections with decreasing intensity reaches to listener in very less time interval such that a continuous sound of decreasing intensity arrives at listener. This phenomenon is known as reverberation.

Reverberation time:

As Reverberation is due to multiple reflection of sound in closed room or space and as the time passes the sound decays. Although the time for which the sound persists in class room or space is small and can be

measured and is called as reverberation time.



Coefficient of absorption of sound:

Reverberation reduces, when the reflections form surfaces such as ceiling, curtains, chairs and wall absorbs sound and hence reverberation time decreases. Absorption of sound is measure of decrease in energy of sound when it hits the sound absorbing material and it is measured in terms of sound absorbing coefficient (α) which can be mathematically defined as : $\alpha = (Ea / Ei)$

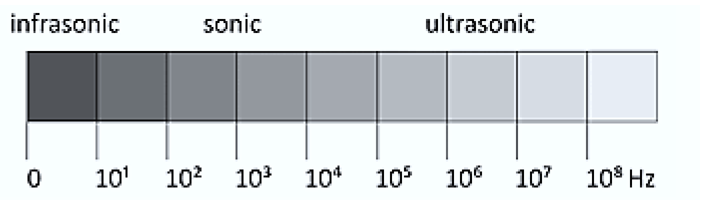
Where Ei : incident sound energy on the surface and Ea : absorbed sound energy by the surface

Methods to control reverberation time:

- Soft furnishing
- Installation of acoustic panels
- Use of sound absorbing material in ceiling and wall
- Proper installation of sound devices.
- Overall architecture of room as per requirements
- Audience in room
- Decorations on wall such as paintings etc.

Ultrasonic waves:

The frequency of sound wave below 20 Hz is known as Infrasonic and the sound wave having frequency above 20,000Hz is Ultrasonic waves .



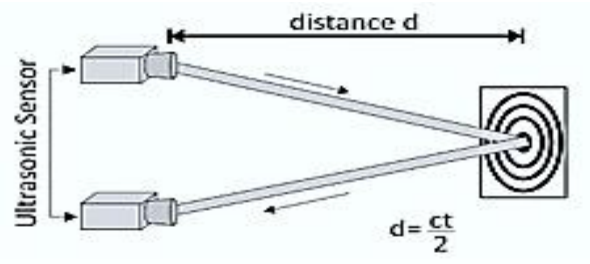
Engineering and medical applications of ultrasonic waves:

(a) Ultrasound scanning: This application is generally known as sonography in medical test. It is majorly used for diagnosis of organs and scan of foetuses (unborn babies). It is mainly based on reflection of ultrasonic waves from the hard boundaries of organs or foetuses and reconstruction of images of the reflected ultrasonic waves. The diagnostic sonography machine operates in the frequency range of 2 to 18 megahertz.

(b) Non - Destructive testing : The cracks in metal effects the overall mechanical strength of metal and working of the machine made up of these metals such as engine of plane. The ultrasound scanner is moved around the surface of metal and detects the cracks inside the metal. The ultrasound waves are reflected from the cracks, due to change in the medium at the cracks. This method of detecting cracks is also known as non-destructive testing (NDT).

(c) Sound navigation and ranging (SONAR): SONAR is an application used by submarines to detect the nearby ships, submarines and other obstacles. As sound is mechanical wave and the sound travels faster in water as compared to air. An ultrasonic signal is sent by submarine when it is beneath the surface and it receives echo of the same signal. The time of flight is the time between sending signal and receiving echo.

(d) Position sensor: Such sensors are now easily available in market based on the same principle as SONAR. It consists of one sender and one receiver antenna of ultrasonic wave. The distance is measured by measuring the time of flight of ultrasonic wave. The velocity of sound wave is changed with temperature hence care has to be taken while making calculations for the distance.



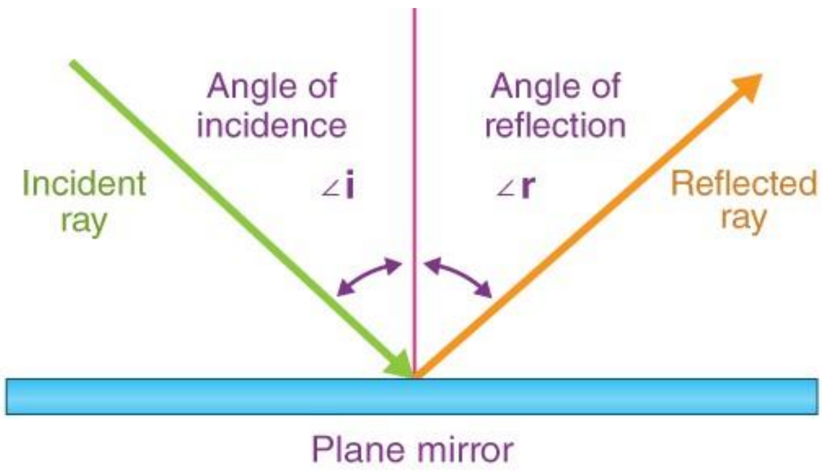
(e)Ultra sonication: Ultra sonication helps in processing of chemical reactions and cleaning of chemical equipment in industries and laboratories. Ultra sonication generates alternating low-pressure and high-pressure waves in liquids, leading to the formation and violent collapse of small vacuum bubbles. This helps in removing air bubbles inside the chemical reaction chamber and makes reaction faster.

CHAPTER :2

OPTICS

BASIC OPTICAL LAWS:

- **Reflection:** When a light ray moving in a medium and incident to the interface with other medium, where it makes some angle with the normal, it gets back in the same medium in the other side of normal with the same angle with which it has been incident. This phenomenon is known as reflection of light.

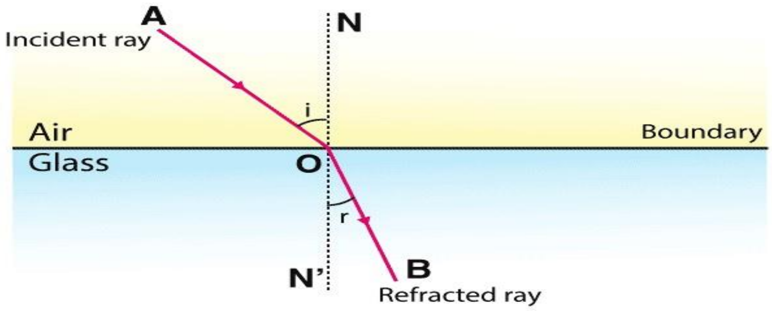


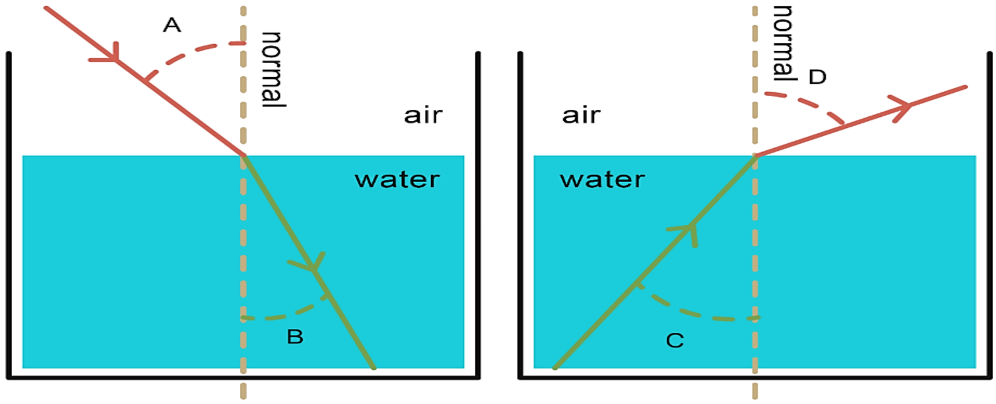
Let the incident ray makes 'i' angle (called as angle of incidence) with normal and the ray is reflected with 'r' (called as angle of reflection) angle.

➢ The angle of reflection is always equal to the angle of incidence and this law is known as Law of reflection. $\angle i = \angle r$

➢ Also, the incident ray, reflected ray and normal lies in same plane as given in figure.

- **Refraction:** When a light ray moving in a rarer medium and incident on the interface of a rarer and a denser medium making some angle with the normal, when the light ray enters the denser medium it bends towards the normal. This phenomenon is known as refraction of light and vice versa will happen when light ray moves from a denser to a rarer medium .The light ray moves away from normal when it enters from denser to rarer medium.





In the first figure , Let the incident ray makes 'i' angle (called as angle of incidence) with normal and the refracted ray makes r' (called as angle of refraction) angle with normal. The ratio of sin of angle of incidence to sin of angle of refraction is equal to the ratio velocity of light in both mediums and this law is known as Snell's Law of refraction. $\frac{\sin(i)}{\sin(r')} = \frac{v1}{v2} = \mu_2^1$

where v1 is the velocity of light in rarer medium and v2 is the velocity in denser medium. μ_1 is refractive index of first medium and μ_2 *is* refractive index of second medium . Where, μ_2^1 is defined as the refractive index of medium 2 with respect to 1 (vacuum or air). When a light ray travelling in air is incident on a surface it gets partially reflected and refracted from the surface. The surface which reflects more are shiny or opaque surfaces such as mirror, metal surface etc. and the surfaces which refracts more are transparent surfaces such as glass, water surface etc. No surface is 100 % reflective or 100 % refractive.

Refractive index:

The refractive index of any medium is defined as ratio of the velocity of light in vacuum or air to the velocity of light in that medium. It is represented by 'μ' . It is a dimensionless physical quantity. The refractive index of any medium with respect to air cannot be less than '1' . it is a measure of a physical property that determines what should be the direction and velocity of the light.

Refractive index of (μ) = (velocity of light in air or vacuum) / (velocity of light in medium)

Image and image formation by mirrors, lens and thin lenses:

Real Image and virtual Image: Real image is formed when the light rays meets after refraction or reflection from lens or mirror respectively. It is Inverted and can be taken on screen. Virtual image is formed when the light rays appears to meet after refraction or reflection from lens or mirror respectively. It is erect and cannot be taken on screen.

Image formation by mirrors, lens and thin lens:

To explain image formation from Lens or mirror following points can be comprehended:

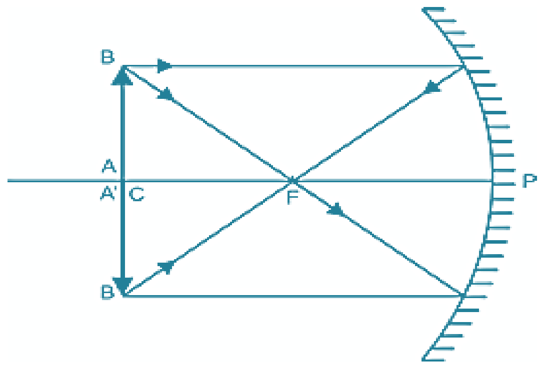
- The light ray passing through parallel to axis after reflection or refraction passes through focus of mirror or lens respectively and vice versa.
- The light ray passing though optical centre moves without deviation after reflection or refraction from mirror or lens respectively.

There are two types of curved mirrors i,e concave and convex mirror.

Image formation by concave mirror:

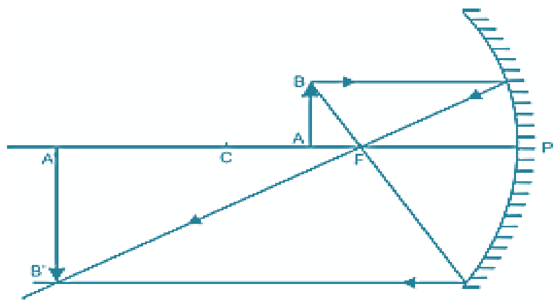
When object is placed at C

Image is
- Formed at C
- Real
- Inverted
- Same size



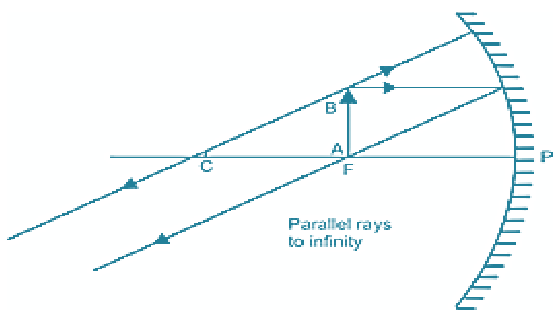
When object is placed between C and F

Image is
- Formed beyond C
- Real
- Inverted
- Magnified



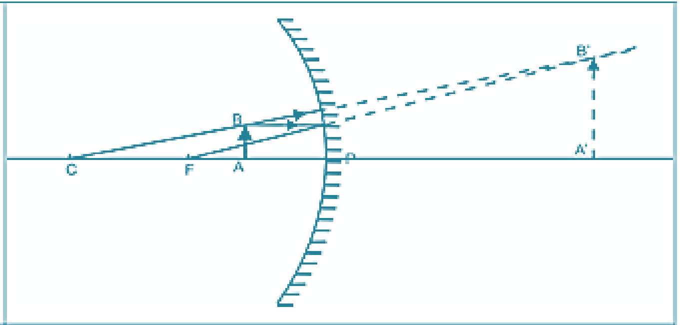
When object is placed at F

Image is
- Formed at infinity
- Real
- Inverted
- Magnified



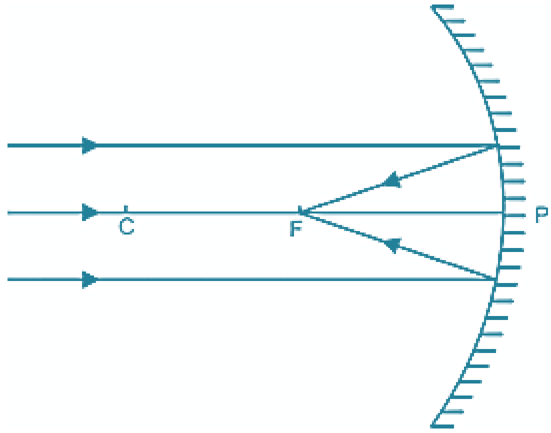
When object is placed between F and P

Image is
- Formed behind the mirror
- Virtual
- Erect
- Magnified



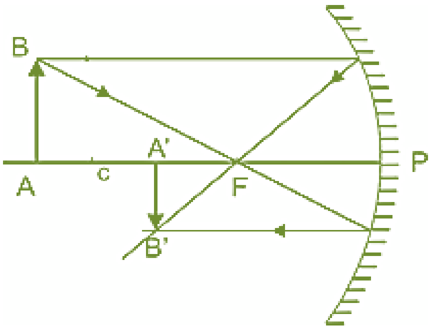
When object is placed at infinity

Image is
- Formed at F
- Real
- Inverted
- Highly diminished (point size)



When object is placed beyond C

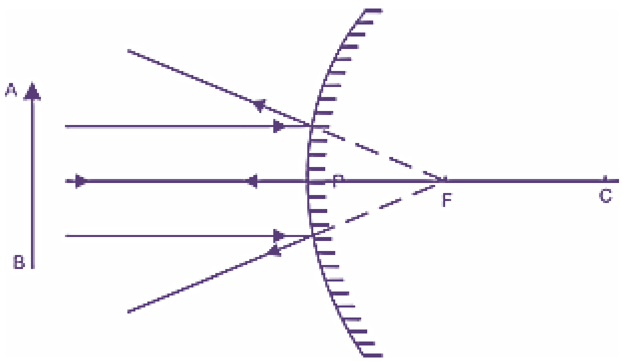
Image is
- Formed between F and C
- Real
- Inverted
- Diminished

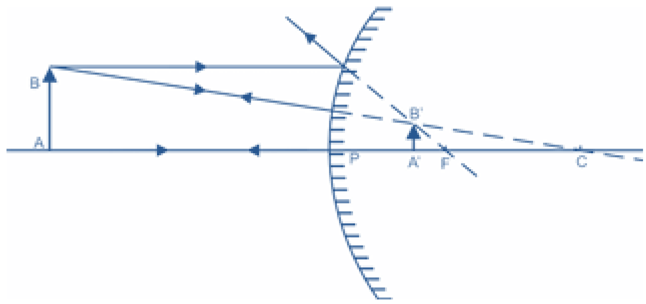


<u>Image formation by convex mirror:</u>

When object is placed at infinity

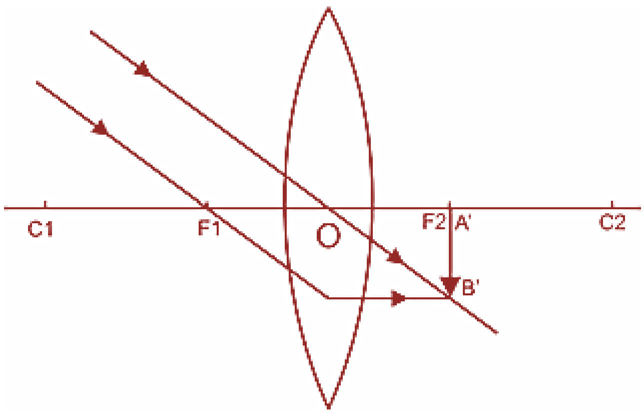
Image is
- Formed behind the mirror
- Virtual
- Erect
- Highly diminished (point size)



When object is placed between Infinity and P Image is • Formed between P and F behind the mirror • Virtual • Erect • Diminished (point size)	

There are two types of lenses . (i) concave or diverging lens, (ii) convex or diverging lens .

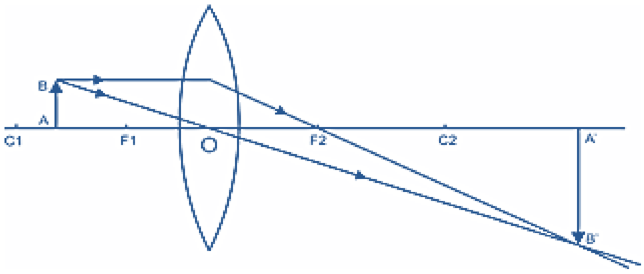
<u>Image formation by convex lens:</u>

When object is placed at infinity Image is • Formed at F2 • Real • Inverted • Highly diminished	

When object is placed between C1 and F1

Image is

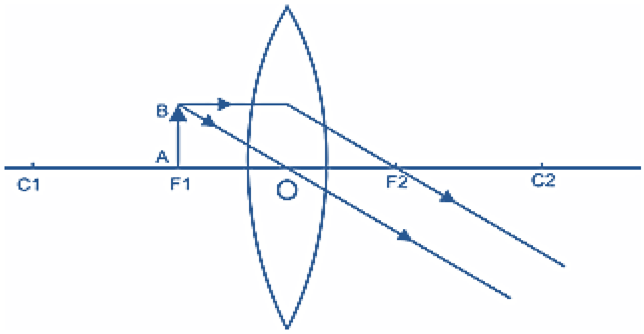
- Formed beyond C2
- Real
- Inverted
- Magnified



When object is placed at F1

Image is

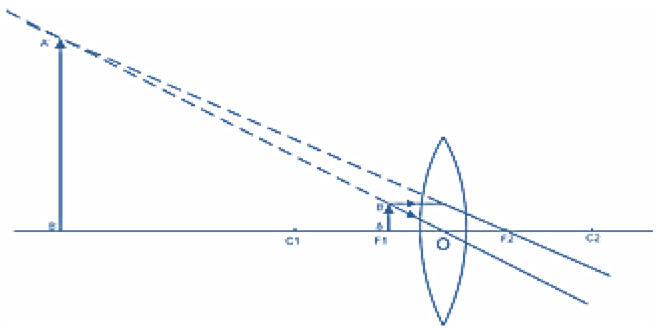
- Formed at infinity
- Real
- Inverted
- Magnified



When object is placed between F1 and O

Image is

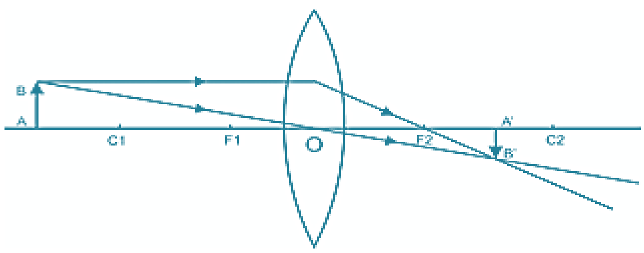
- Formed on same side of objects
- Virtual
- Erect
- Magnified



When object is placed beyond C1

Image is

- Formed between F2 and C2
- Real
- Inverted
- Diminished



When object is placed at C1

Image is

- Formed at C2
- Real
- Inverted
- Same size

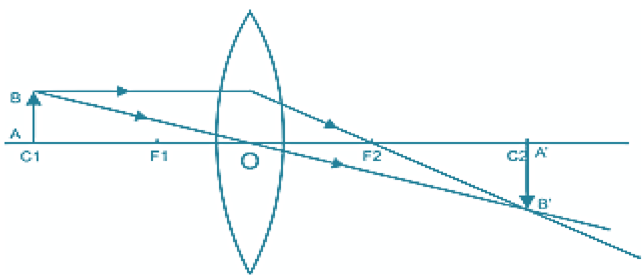
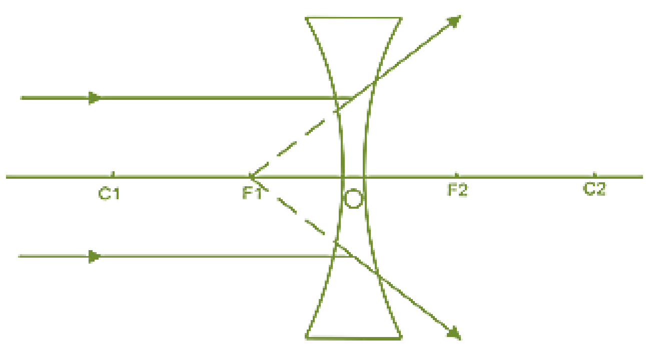


Image formation by concave lens:

When object is placed at infinity

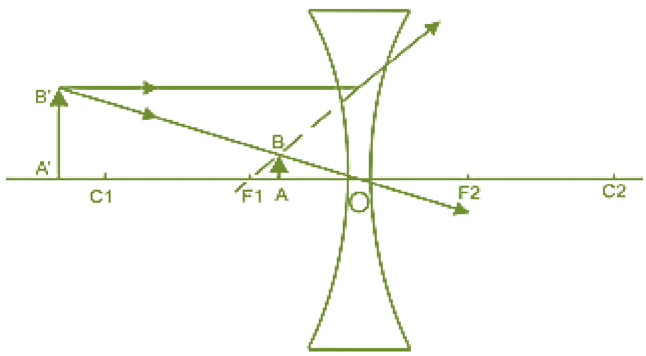
- Image is
- Formed on same side
- Virtual
- Erect
- Highly diminished (point size)



When object is placed between infinity and O

Image is

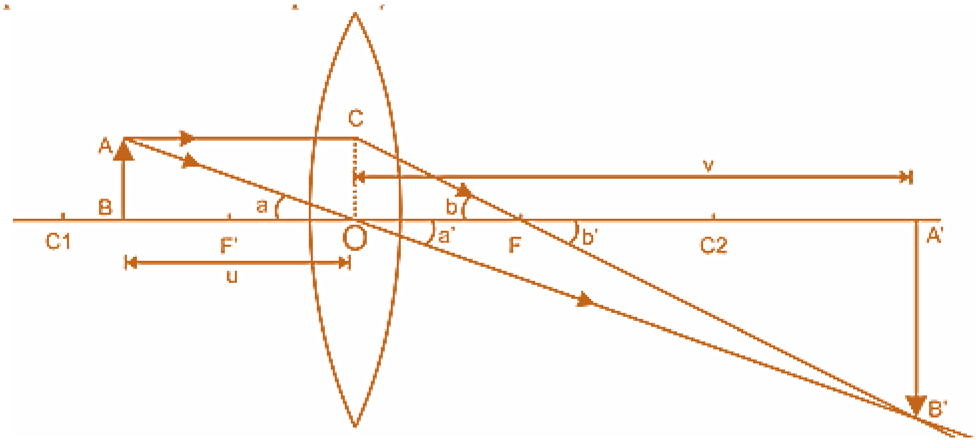
- Formed between O and F1
- Virtual
- Erect
- Diminished



Thin lens : A thin lens is a lens which has small thickness, in other words the distance from image or object from lens surface and optical centre is almost equal.

Lens formula :

For a lens 'L' with focal length 'f', let AB is an object and Its image is A'B'. The distance of object and image from optical centre is u and v respectively.



Let us find the general relation between f, u and v. The distance is taken from surface of lens. The distance which is in direction of light ray is taken positive and the distance opposite to direction of light ray is negative. In present case v is taken positive and u is taken negative.

In Δ AOB and Δ A'OB' , $\angle a = \angle a'$ [vertically opposite angle]

tan (a) = tan(a')

$$\frac{AB}{OA} = \frac{A'B'}{OA'}$$

$$AB \,/\, A'B' = -u \,/\, v \qquad \text{...........(1)}$$

Similarly, in Δ COF and Δ A'FB'

$$\angle b = \angle b' \qquad \text{[vertically opposite angle]}$$

$$OC \,/\, OF = A'B' \,/\, FA'$$

$$AB \,/\, A'B' = f \,/\, (v - f) \qquad \text{............(2)}$$

As from figure AB = OC

Equating equation (1) and (2)..

$$- u / v = f / (v - f)$$

$$- u(v - f) = v f$$

$$- uv + uf = vf$$

Dividing both sides of the above equation with uvf we get,

$$-\frac{1}{f} + \frac{1}{v} = \frac{1}{u}$$

$$\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$$

This equation is known as lens formula, it will also be valid for concave lens.

Power of Lens:

The power of any lens is the ability to bend the light ray. The converging of light ray means meeting of all ray to one point and diverging of light rays means coming out of light ray from one point. The power of lens can also be defined as the converging or diverging ability of lens. Mathematically, it is defined as the reciprocal of focal length of lens. The lens which has less focal length has more power and vice versa.

$$Power\ of\ lens = \frac{1}{f(meters)}$$

The unit of power is dioptre . The focal length of lens is to be taken in meter to calculate the power of lens. Convex lens has positive power value, whereas concave lens has negative power values.

Magnification:

The ratio of the size of image to the size of object is known as the image magnification.

Magnification (m) = size of image / size of object

$$= A'B' / AB$$

From equation (2), $m = \frac{v-f}{f}$ ....(3)

From lens maker formula, $\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$

$$\frac{1}{v} - \frac{1}{f} = \frac{1}{u}$$

$$\frac{f - v}{vf} = \frac{1}{u}$$

$$\frac{v-f}{f} = -\frac{v}{u} \qquad \text{.........} (4)$$

Comparing equation (3) and (4) , $m = -\frac{v}{u}$

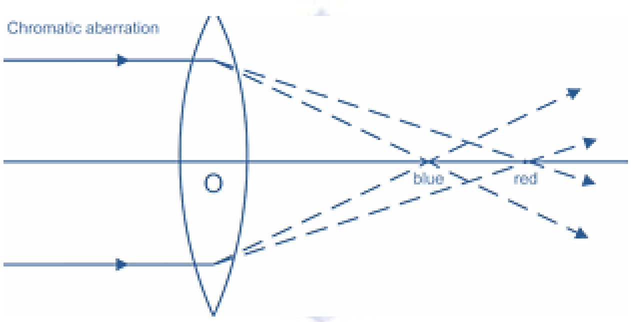
Here –ve sign indicates inverse image and magnitude of magnification is given by v/u.

Defects:

It is also known as aberrations of lens. The image formation of an object from convex lens, kept at different distance from surface of convex lens is given in Table . In actual situations there is deviation in the formation of images, which is explained in Table, this is due to defects or aberration of lens. It is of two type:

Chromatic aberration and Spherical aberration .

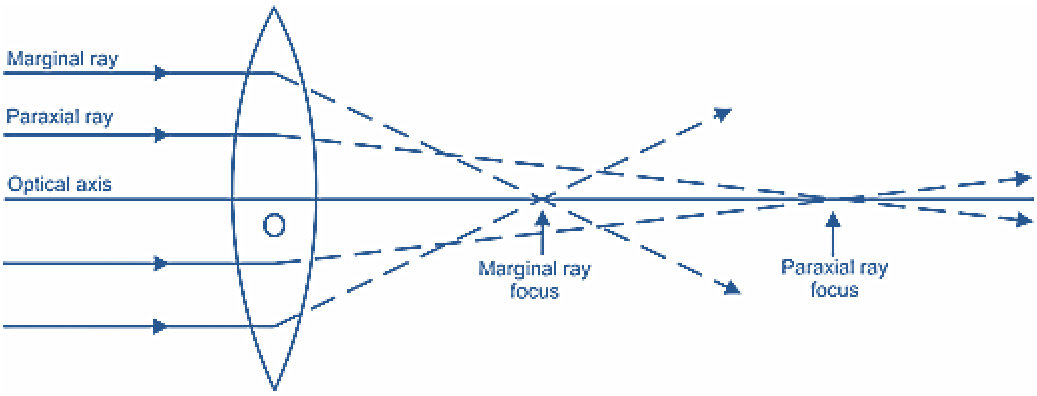
Chromatic aberration:



In image formation, we have considered a light having single wave length. White light consists of several colour wavelength. If we take white light as a source, then different colour light forms images at different point. This defect due to colour of light is known as chromatic aberration. As per Snell's law, different colour light will have different angle of refraction and focused at different point.

Effect: series of colour images formed when white light is incident on spherical lens.

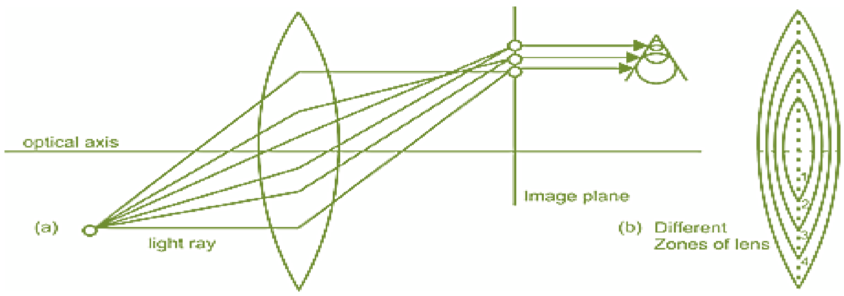
Spherical aberration:



In convex or concave lens, when objects are placed at infinity, their point images are formed at focus. All the parallel rays of light are supposed to pass through the focus, but in actual case the lines near to principal axis bent little and lines away from principal axis bent more and hence they do not focus on single point. This defect is due to spherical surface of lens and known as spherical aberration.

Effect: out of focus image, or focus is not sharp point.

Coma:

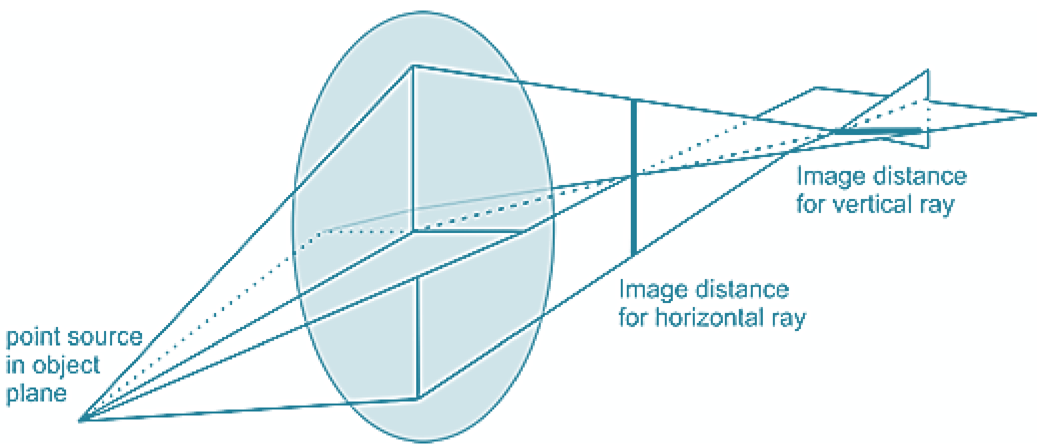


In spherical aberration the light rays coming from the object are parallel to principal axis. If the point object is away from principal axis, the light rays coming from the point not parallel to principal axis and spherical aberration applied to such rays results in defects known as Coma. Unequal magnification of the image formed due to different zones of lens. The circular image of point will be formed perpendicular to principal axis .

Effect: Image is sharped in centre but blurred towards the edges .

Astigmatism:

If the light from a point object is passed through lens then for a perfect lens it should form a focused bright spot on the opposite side of the lens. In case the focal length of the lens is different for different planes, there will be no such sharp focus point, where all the light rays incident from the object meet.

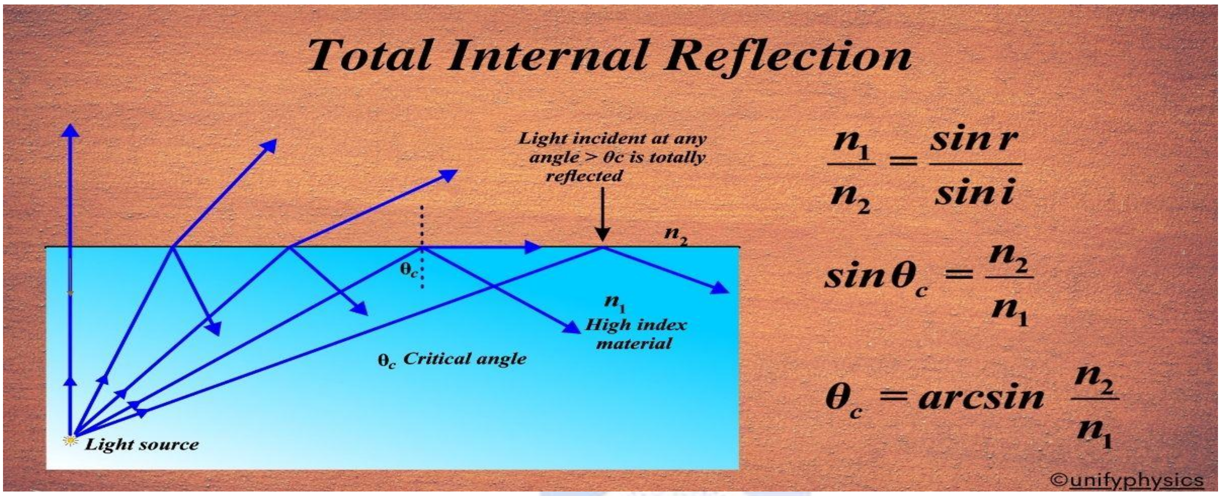


Effect: The light coming from horizontal and vertical plane will meet at vertical line and horizontal line respectively as a result a blurred image will form. The size of image changes along the principal axis.

Total Internal reflection :

As from Snell's law of refraction, when a light ray passes from denser to rarer medium, it bends away from the normal. If we increase the angle of incidence the angle of refraction also increases. At an angle of incidence, the angle of refraction is 90^0. This angle of incidence is known as **critical angle**. If we increase the angle of incidence above the critical angle, the angle of refraction is greater than 90^0 and the light ray renters the denser medium or we can say that reflected in the same medium. This phenomenon of reflection is known as total internal reflection.

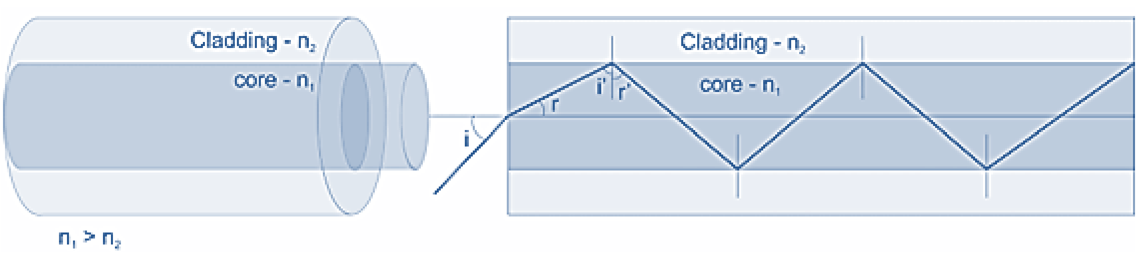
Example of total internal reflection : Shining of diamond, Formation of mirage, Periscope



Applications of Total internal reflection in Optical fibre:

When a light ray enters the optical fibre, making angle i with the core axis, it is refracted, and angle r is smaller than angle i. The refracted ray reaches the core cladding interface and if the angle I' is greater than critical angle the light ray will be totally internally reflected. This light ray will further have successive TIR at each core cladding and until it reaches the end of the fibre. The process of TIR to take place in optical fibre depends upon following factors

- Angle of incidence (i) with optical axis.
- Refractive index of core and cladding.



Optical instruments:

Optical Instruments are the instruments based on the principle of optics and uses optical devices such as lens or mirror to measure the physical quantities or to observe objects.

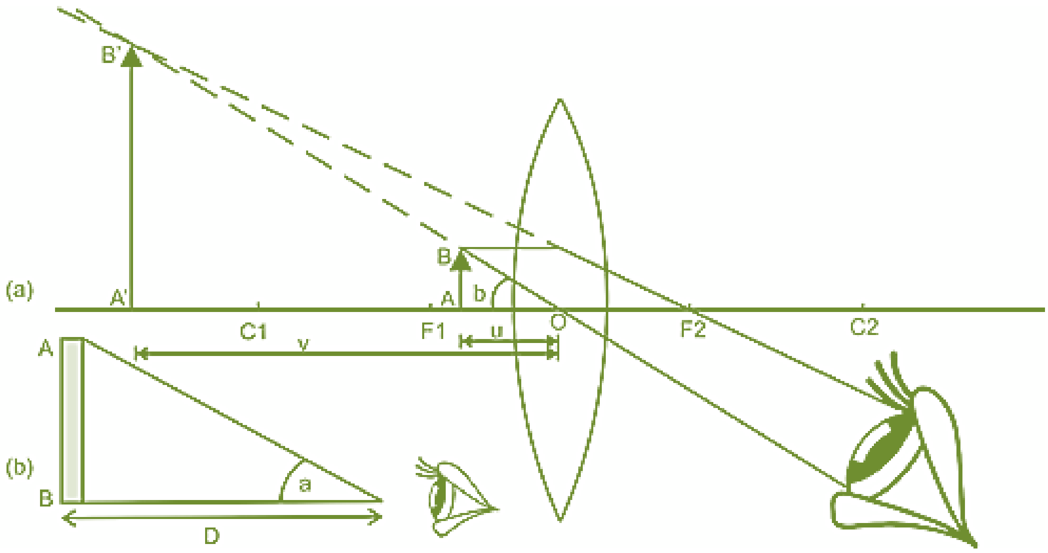
Example: Human eye, spectrometer, periscope, microscope, telescope, projector .

Simple and compound microscope:

A microscope is an optical instrument used to magnify small objects. It is made up of lens or combination of lenses. The magnifying power of microscope depends upon the parameters of lens used for making microscope and the wavelength of source of light used. The meaning of micro is small, and scope is to see, hence the name suggest that microscope is used to observe small objects. The two basic types of microscope are • Simple microscope

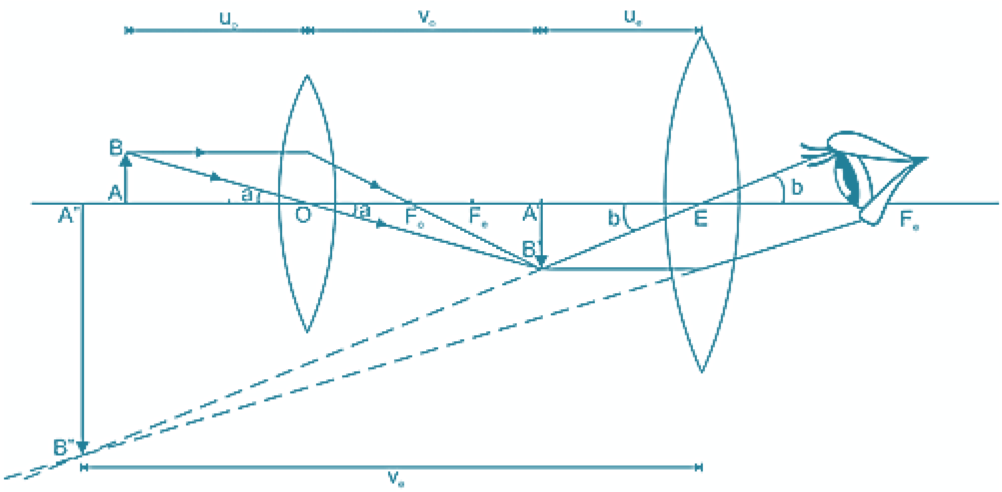
• Compound microscope

Simple microscope: When an object kept between focus and optical centre of convex lens its virtual and enlarged image is formed. This property of convex lens is used in designing simple microscope.



Compound microscope:

For larger magnification a combination of two lens microscope or compound microscope shows the ray. The lens which is near to object is objective lens and the lens from which, the image is observed is eye piece. The focal length of objective and eyepiece is fo and fe respectively.



Here, u_o is the actual object distance from the objective lens. And v_e is the image distance from objective.

f_o is the focal length of objective lens and f_e is the focal length of eyepiece.

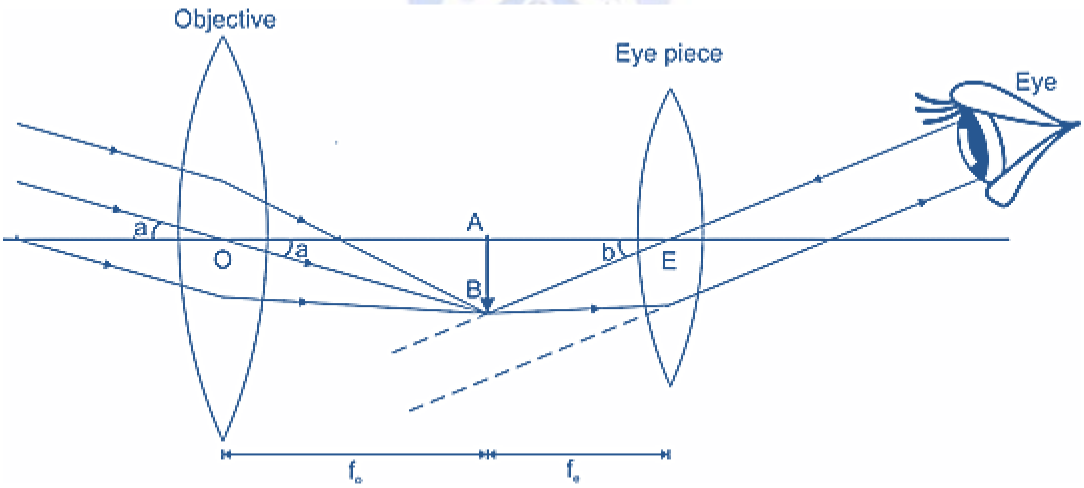
The magnifying power of the compound microscope is given by ; = $m_e \times m_e$

$$= (-v_o / u_o)[1 + D / fe]$$

Astronomical telescope in normal Adjustment :

The meaning of ' tele ' is 'distant' or 'far', hence as the name suggest that telescope is used to observe distant objects such as astronomical objects or terrestrial objects. The simple astronomical telescope consists of two lenses. The objective is a convex lens of long focal length and with large aperture. The real image of the distant object forms at the focus of objective lens. The eyepiece is convex lens of small focal length. The optical system of telescope is like microscope. The objective lens forms real and diminished image AB of the object. The eyepiece enlarges the image AB (which is object for eyepiece) and forms magnified virtual image. In normal adjustment the image AB is formed at the focus of eyepiece and its magnified and en large virtual image is formed at infinity. If the final image formed by the by the eyepiece lies at infinity. The distance between the objective and eyepiece is the sum of their focal length,

fo + fe



Magnifying power:

The distance between the objective and eyepiece is very small as compared to the distance of the objective from the object. The angle 'a' subtended at the unaided eye by the object can be taken as the angle subtended by the object at the objective.

Magnifying power = |m| = b / a

|m| = fo / fe

Resolving power:

The resolving power of any optical instrument is the ability of instrument to resolve any two near objects and form separate image of those nearby objects. In case of telescope the resolving power is the ability to form separable images of two distant objects or astronomical object. In case of microscope the two smaller nearby objects are resolved. Our eye is also an optical instrument.

Uses of microscope and telescope Microscope:

Microscope:

• Analysis of soil particles

• Find out various skin diseases.

• In microbiology to study samples of algae, fungi.

• To magnify the fine parts of the jewellery.

Telescope:

• View astronomical objects such as planets, galaxy, natural satellite of planet.

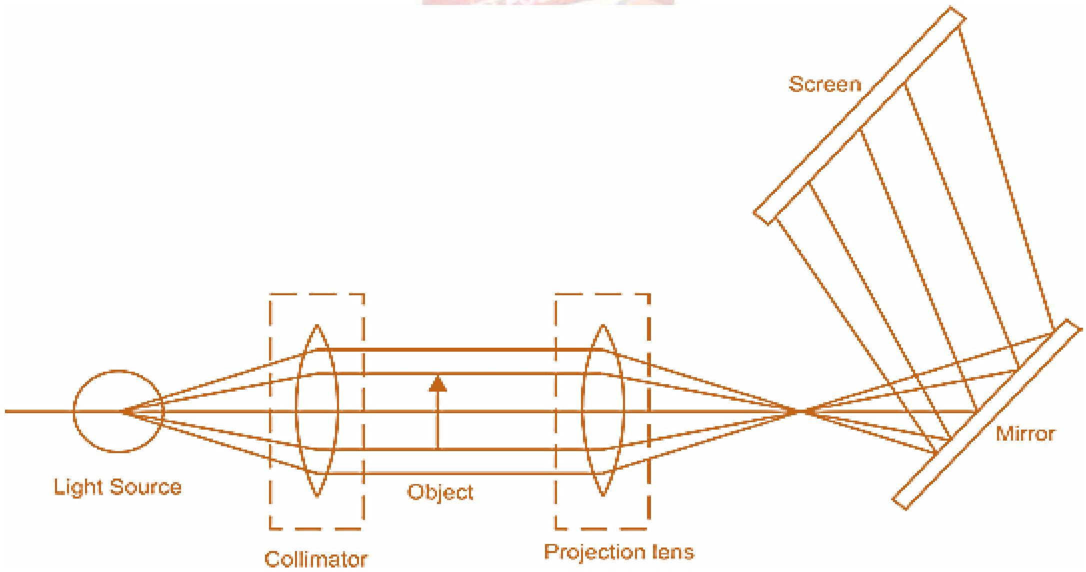
• Solar and lunar eclipse.

• Observe Moon surface

Optical Projection system

Optical Projection system:

Optical projection systems are optical devices used to form magnified projected image of an object. Overhead projector (OHP), slide projector and LCD projector are the examples of optical projector systems, generally used in class room and seminars to project the teaching learning material, power point presentations etc .



CHAPTER : 3

Electrostatics

COULOMB'S LAW :

According to Coulomb's law, the force of attraction or repulsion between two stationary point charges is directly proportional to the product of the magnitude of their charges and inversely proportional to the square of the distance between them. This force acts on the line that connects the two charges. Consider two charges q_1 and q_2 , separated by distance r then according to Coulomb's law,

$$F \propto q_1 q_2$$

$$F \propto \frac{1}{r^2}$$

Combining these equations,

$$F \propto \frac{q_1 q_2}{r^2}$$

$$F = K \frac{q_1 q_2}{r^2}$$

Where K is constant of proportionality and called as electrostatic constant. When two charges are placed in free space then K in S.I. unit is given by,

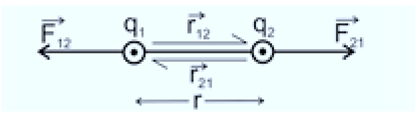
$$K = \frac{1}{4\pi\epsilon_o} = 9\times 10^9 \, N \frac{m^2}{C^2}$$

Where ϵ_o is called permitting of free space. The equation can be rewritten as,

$$F = \frac{1}{4\pi\epsilon_o} \frac{q_1 q_2}{r^2}$$

In vector Form:

Consider two charges q1 and q2 placed r distance apart, then



By Coulomb's law Force on charge q2 due to q1 is, $\vec{F}_{21} = \frac{1}{4\pi\epsilon_o} \frac{q_1 q_2}{r^2} \hat{r}_{12}$

Force on charge q1 due to q2 is, $\vec{F}_{12} = \frac{1}{4\pi\epsilon_o} \frac{q_1 q_2}{r^2} \hat{r}_{21}$

Since, $\hat{r}_{21} = -\hat{r}_{12}$

So, $\vec{F}_{12} = -\vec{F}_{21}$

And $|\vec{F}_{12}| = |\vec{F}_{21}|$

As a result, Coulomb's law of force is in accord with Newton's third law of motion.

Unit of charge:

SI unit of charge is Coulomb.

Electric field :

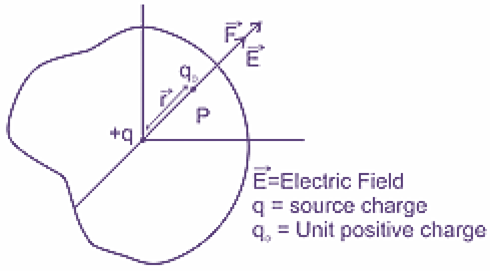
Let us consider a source charge and in its vicinity, we have kept a unit positive charge, then the force experienced by a unit positive test charge at that point, without altering the position of the source charge, is characterized as the electric field or electric field strength 'E' at that point or in other words force per unit charge is the electric field at the point.

According to above statement, Electric field strength (E),

$$\vec{E} = \lim_{q \to 0} \frac{\vec{F}}{q_0}$$

Dimension of E is, E = $[MLT^{-3}A^{-1}]$

As unit of E is, $\frac{N}{C}$



$$\vec{E} = \frac{\vec{F}}{q_0}\hat{r}$$

But by Coulomb's law,

$$\vec{F} = \frac{1}{4\pi\varepsilon_o}\frac{qq_o}{r^2}\hat{r}$$

So

$$\vec{E} = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2}\hat{r}$$

The direction of electric field is same as the direction of Coulomb force.

Electric lines of force and their properties:

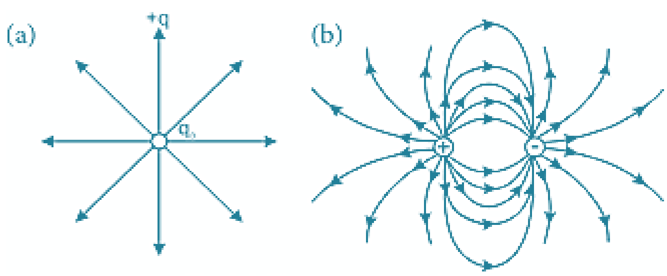
An electric line of force is a curve along which the unit positive charge moves away from the specified positive charge.

• The field lines never intersect each other because if they intersect at a point then at that point there will be two directions of electric field.

• The field lines run perpendicular to the charge's surface.

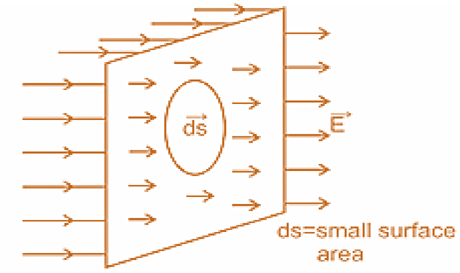
• Both the magnitude of the charge and the number of field lines are proportional.

• The field lines begin (diverge) from the positive charge and conclude (converge) to the negative charge.



Electric flux (φ):

The total number of electric lines of force passing through a specific area inside an electric field is a measure of the electric flux through that area.



$$\vec{ds} = small\ surface\ area$$

$$d\phi = \vec{E}.\vec{ds}$$

If ds make an angle θ with electric field (E)

Then electric flux through ds is

$$d\phi = E\,ds\cos\theta$$

For whole surface

$$\int d\phi = \int Eds\cos\theta$$

$$\phi = \int Eds\cos\theta$$

Electric flux is a scalar quantity

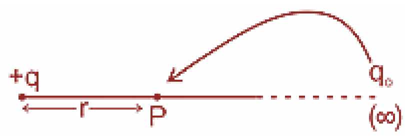
Unit of ϕ = unit of E × unit of S

$$= N/C \times m^2$$

$$= Nm^2/C$$

Electric Potential (V):

Let q is a positive charge and q0 is unit positive charge at infinite distance from q. The amount of work done in moving a unit positive test charge from infinity to a point P against the electric field is electric potential at point P.



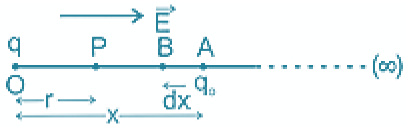
Electric potential = work done / charge

$$V = \frac{W}{q_0}$$

Electric Potential due to a point charge :

Consider a positive charge q placed at the origin O. Now we will find the electric potential at point P at distance r from charge q. According to definition of electric potential, the amount of work done to bring q_0 from infinity to that point P is equal to electric potential. Consider q_0 at a point 'A' ,then

$$F = \frac{1}{4\pi\epsilon_o}\frac{qq_o}{x^2}$$



$$dw = \vec{F}.\vec{dx}$$
$$dw = Fdx\cos(180)$$
$$dw = -Fdx$$
$$dw = -\frac{1}{4\pi\varepsilon_0}\frac{qq_0}{x^2}dx$$
$$\int dw = -\frac{1}{4\pi\varepsilon_0}qq_0\int_\infty^r \frac{1}{x^2}dx$$
$$W = \frac{-qq_0}{4\pi\varepsilon_0}\int_\infty^r x^{-2}dx$$

Then,
$$W = \frac{-qq_0}{4\pi\varepsilon_0}\left[\frac{-1}{x}\right]_\infty^r$$

Total work done to move q_0 from ∞ to P

$$W = \frac{1}{4\pi\varepsilon_0}\frac{qq_0}{r}$$

and
$$\frac{W}{q_0} = \frac{1}{4\pi\varepsilon_0}\frac{q}{r}$$
$$\left[\frac{W}{q_0} = V \ \ \textit{Electric potential}\right]$$
$$V = \frac{1}{4\pi\varepsilon_0}\frac{q}{r}$$

Electric Potential difference:

The amount of work done to move a unit positive charge q0 from one point to another point inside the electric field is known as electric potential difference". So $V = V_B - V_A = \frac{W_{AB}}{q}$

Gauss' Law :

Gauss' law states that "the total electric flux (φ) passing through any "closed surface" is $\frac{1}{\epsilon_o}$ times of charge enclosed by the surface". $\varphi = \frac{q}{\epsilon_o}$

Consider +q charge at the centre of sphere of radius r then electric flux by small surface of sphere is given by

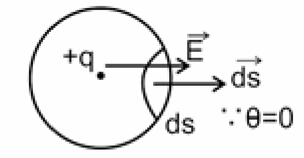


Fig 3.9 Depiction of Gauss' law

Then

$$d\phi = \vec{E}.\vec{ds}$$
$$d\phi = Eds\cos\theta$$
$$d\phi = Eds \quad (as\, \theta = 0)$$

Electric flux through whole surface is

$$\int d\phi = \int Eds$$
$$\phi = E\int ds$$
$$\left[\because E = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2}\right]$$
$$\phi = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2}\int ds$$
$$\phi = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2}\times 4\pi r^2$$

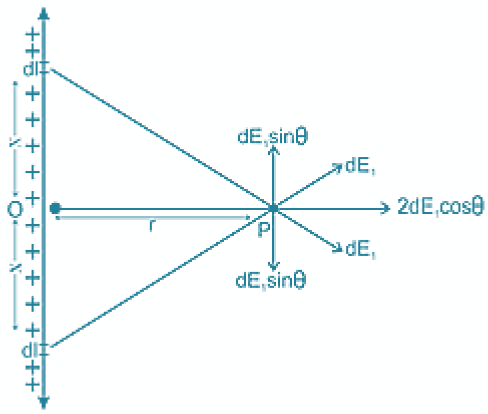
So,

$$\phi = \frac{1}{\varepsilon_0}\times q$$

Applications of Gauss' law :

(a) Electric field due to an infinitely long straight charged wire.:

Consider a thin infinitely long straight wire having a uniform linear charge density 'λ' (quantity of charge per unit length. First, we find the direction of electric field by line charge distribution. Let us consider a point P at r distance from point O in linear charge distribution. We can also assume two small charge element dl at x distance above and below point O. The resultant electric field at point P due to both charge element is perpendicular to the line charge.



Hence by symmetry, the field "E" of the line charge is directed normally outwards and its magnitude is determined with help of Gauss' law. To determine the field at a distance r from the line charge we choose a cylindrical Gaussian surface of radius r and length l. It consists of three surface S1 , S2 and S3 First, we calculate for S3 surface, let us consider a small surface ds in S3 and electric flux through surface ds

For whole cylindrical surface

$$d\phi = \vec{E}.\vec{ds}$$

$$\int d\phi = \oint \vec{E}.\vec{ds}$$

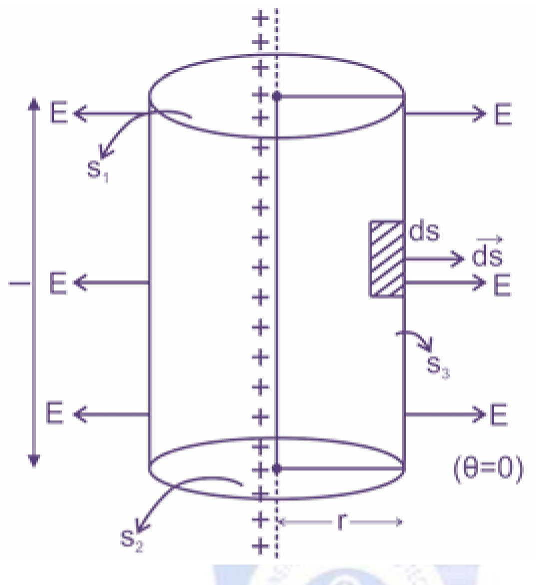
$$\phi = \int Eds\cos\theta \quad \because \theta = 0$$

$$\phi = E\int ds$$

$$\phi = E\times 2\pi rl$$

Also, by Gaussian Theorem

$$\phi = \frac{q}{\varepsilon_o}$$



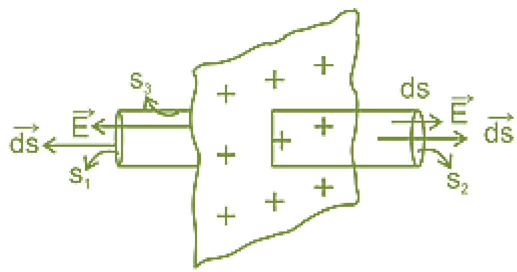
$$E\times 2\pi rl = \frac{q}{\varepsilon_o}$$

$$E = \frac{1}{2\pi\varepsilon_o}\frac{q}{rl} \qquad \left[\because \frac{q}{l} = \lambda, linear\ charge\ density\right]$$

$$E = \frac{1}{2\pi\varepsilon_o}\frac{\lambda}{r}$$

The Magnitude of electric field at Surface S1 and S2 will be zero as the angle between the electric field vector and the area vector of each surface is 90^0

(b) Electric field due to uniformly charged plane sheet:



Consider +q charge is given to an infinite sheet so that charge will uniformly distributed over the surface having surface charge density 'σ' (quantity of charge per unit area). Due to uniform distribution of charge, electric field can be calculated by drawing a Gaussian surface in the form of cylinder. The cylinder consists of surface S1 , S2 and S3 . First, we calculate for Surface S1 and S2 So electric flux through ds on both surface (S1 and S2)

For whole sheet,

$$d\phi = 2\vec{E}.\vec{ds}$$

$$\int d\phi = 2\int Eds\cos(0)$$

$$\phi = 2E\int ds$$

$$\left[\int ds = Stotal\ surface\ Area\right]$$

then

$$\phi = 2ES$$

Also, by Gauss' Law

$$\phi = \frac{q}{\varepsilon_o}$$

$$2ES = \frac{q}{\varepsilon_o}$$

$$E = \frac{q}{2\varepsilon_o S}$$

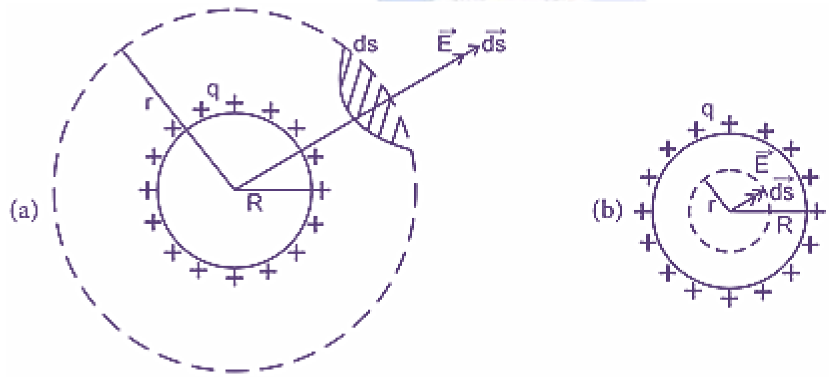
$$\left[Surface\ charge\ density\ \sigma = \frac{q}{S}\right]$$

$$E = \frac{\sigma}{2\varepsilon_o}$$

The Magnitude of electric field at Surface S3 is zero as the angle between the electric field vector and the area vector of surface S3 is 90^0.

(c) <u>Electric field due to a uniformly charged sphere :</u>

Consider a sphere of metal of radius R when charge q is given to it, then charge will uniformly distribute over the surface, so it surfaces charge density is, $\sigma = \frac{q}{4\pi R^2} \Rightarrow q = 4\pi R^2\sigma$



(i) <u>Electric field outside of sphere:</u>

Draw a Gaussian spherical surface of radius r (r > R), and calculate electric flux by small area ds,

$$d\phi = \vec{E}.\vec{ds}$$

For whole surface
$$\int d\phi = \int \vec{E}.\vec{ds}$$
$$\phi = \int E_1 ds \cos(0)$$
$$\phi = E_1 \int ds$$
$$\phi = E_1 \times 4\pi r^2$$

Also, by Gauss' law
$$\phi = \frac{q}{\varepsilon_o}$$

So by Eq 3.24
$$E_1 \times 4\pi r^2 = \frac{q}{\varepsilon_o}$$
$$E_1 = \frac{1}{4\pi\varepsilon_o}\frac{q}{r^2}$$
$$\because q = 4\pi R^2\sigma$$

So,
$$E_1 = \frac{1}{4\pi\varepsilon_o}\frac{4\pi R^2\sigma}{r^2}$$
$$E_1 = \frac{R^2\sigma}{\varepsilon_o r^2}$$

(ii) Electric field on the surface of sphere :

Put r = R, $E = \frac{\sigma}{\epsilon_0}$

(iii) Inside the sphere, consider a surface inside sphere of radius r :

As the charge is uniformly distributed on surface of sphere of Radius R

Hence $\because q = o$

Then by Gauss' law $E_3 = o$

There is no charge inside the sphere of radius r

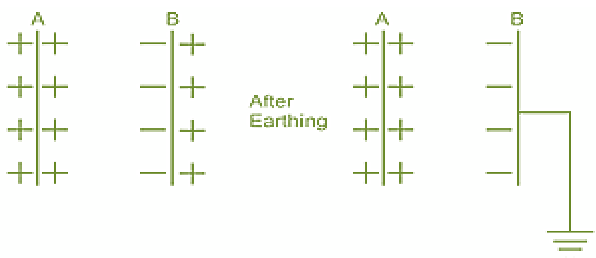
Therefore, the electric field at any point inside the metallic sphere is zero.

CAPACITORS AND ITS WORKING:

A capacitor is an arrangement consisting of two conductors separated by a distance. It is used to store the charges.

Principle of a Capacitor:

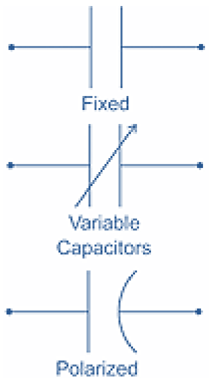
Consider a positively charged plate A of a metal placed near an uncharged plate B, due to induction, negative charge develops on plate B on the face near to the plate A and positive charge on another face of B. If we connect plate B to ground then, the positive charge on plate B will flow to the ground. There will be only negative charge on plate B, due to this potential of plate A decreases. To raise the potential of plate A, it can acquire more charges. Such a system of storing charges made up of two conductors is called a capacitor.



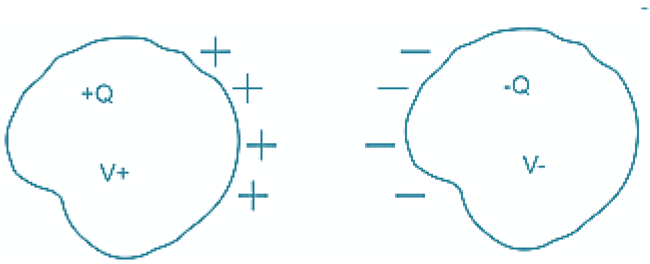
Types of capacitors:

Capacitors are distinguished based on following:

- **Shape of electrodes**: Parallel plate, spherical and cylindrical
- **Materials between electrodes** : Dielectric (nonpolar) and Electrolytic (polar capacitor)
- **Capacitance** : Fixed and variable capacitor



Capacitance and its units:



Usually, a capacitor consists of two conductor having charges +Q and -Q. For a given capacitor the charge (Q) on the capacitor is proportional to the potential difference (V)

So, $Q \alpha V$

$Q = CV$

$C = \text{Capacitance of the capacitor}$

also $C = \frac{Q}{V}$

When V = 1 volt $C = Q$

So, the capacitance of capacitor may be defined as the charge required to increase the potential of conductor by unit.

$$\because Q = CV$$

$$C = \frac{Q}{V}$$

When $Q = 1C, \quad V = 1volt$

Then, $C = \frac{1C}{1volt} = 1F$ (Farad F)

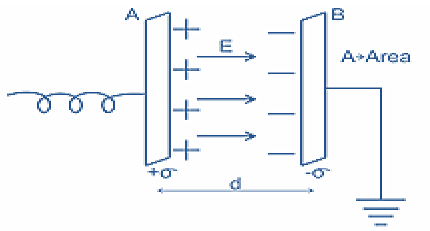
one microfarad : $1\mu F = 10^{-6} F$

One Picofarad $1pF = 10^{-12} F$

Parallel plate capacitor :

It consists of two large plane parallel conducting plates, separated by a small distance d Electric field between the plates,

$$E = \frac{\sigma}{\varepsilon_o} \qquad \sigma = \text{surface charge density}$$



For a uniform electric field

$$E = \frac{V}{d} \Rightarrow V = Ed$$

So

$$V = \frac{\sigma}{\varepsilon_o} \times d \quad \left\{\sigma = \frac{Q}{A}\right\}$$

$$V = \frac{Qd}{\varepsilon_o A} = \frac{Qd}{\varepsilon_o A}$$

$$\because Q = VC$$

$$C = \frac{Q}{V} = \frac{Q}{\frac{Qd}{\varepsilon_0 A}} \Rightarrow C = \frac{\varepsilon_o A}{d}$$

Thus, for a parallel plate capacitor,

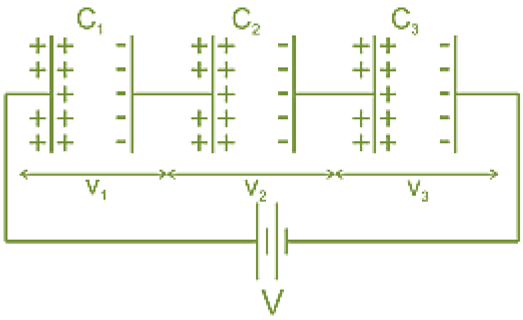
$$C \ \alpha \ A \ area$$

$$C \ \alpha \ \frac{1}{d} \ distance$$

$$C \ \alpha \ \varepsilon_0 \ permittivity \ of \ medium \ between \ plates.$$

Series and parallel Combination of capacitors :

Capacitance in series : When the negative plate of one capacitor is connected to positive plate of second and negative of second to the positive of third and so on, the capacitor is said to be connected in series.



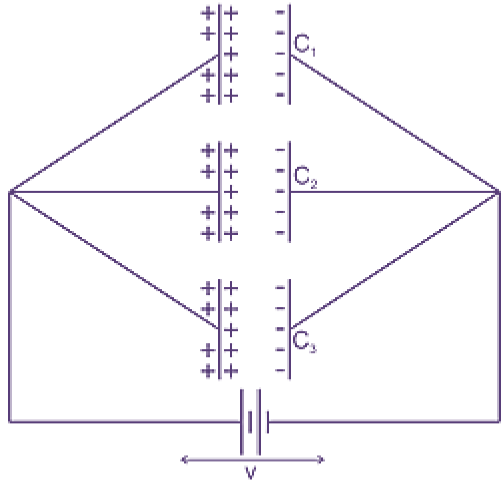
The potential across the capacitors is, $V_1 = \frac{Q}{C_1}$, $V_2 = \frac{Q}{C_2}$,$V_3 = Q/C_3$

Since Total potential V is, V = $V_1 + V_2 + V_3$

$$\frac{Q}{C} = \frac{Q}{C_1} + \frac{Q}{C_2} + \frac{Q}{C_3}$$

$$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$$,Where C is the total capacitance.

Capacitance in parallel:



When the positive plate of all capacitors is connected to one common point and the negative plate to another common point. The capacitors are said to be in parallel

All the capacitors have a common potential difference V but different charges given by

$$
\begin{aligned}
Q_1 &= C_1V,\ Q_2 = C_2V,\ Q_3 = C_3V \\
\because Q &= Q_1 + Q_2 + Q_3 \\
CV &= C_1V + C_2V + C_3V \\
C &= C_1 + C_2 + C_3 \\
C &= \text{Total Capacitance}
\end{aligned}
$$

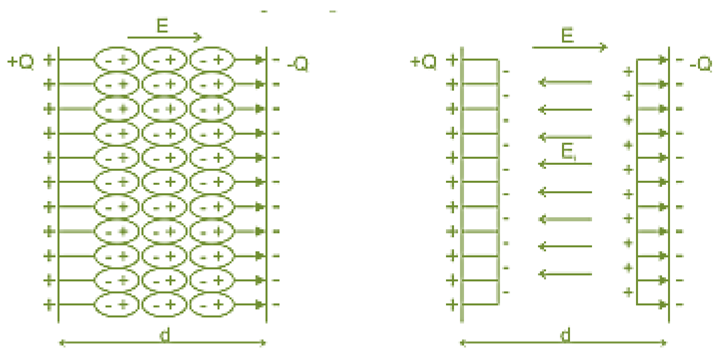
Dielectric and its effect on Capacitance:

Dielectric are insulating materials such as ceramic, mica, glass, plastics, and the oxides of various metals. When dielectrics are placed in an electric field E (say inside a parallel plate capacitor) electric polarization occurs i.e. the positive charges within the dielectric are displaced minutely in the direction of the electric field, and the negative charges are displaced minutely in the direction opposite to the electric field. Due to the separation of charge, or polarization, the net electric field inside the dielectric reduces because the electric field developed inside the dielectric is opposite to electric field E. As, net electric field decreases the V between plates decreases and the capacitance is increased. Each dielectric material is characterized by dielectric constant 'K'. It is the ratio of electrical permitting of material with that of air. The dielectric constant of air is 1 and for other insulators greater than 1.

Capacitance of capacitor is given by, $C_0 = \varepsilon_0 \frac{A}{d}$

If we insert a dielectric medium (with dielectric constant K) between the plates then capacitance increases by K times,

$$
\begin{aligned}
C &= \frac{K\varepsilon_o A}{d} \\
C &= KC_0
\end{aligned}
$$



Dielectric breakdown:

Dielectric materials are electrical insulators that is, they prevent the flow of current. Dielectric breakdown is the phenomenon of failure of an insulating material to prevent the flow of current. When applied electrical field increases to a certain value ionization takes place inside the material which creates large number of electrons and ions. Electrical discharge taking place in air is an example of dielectric break down which takes place at electric $field\ 3 \times 10^6\ V$/m. In a parallel plate capacitor, if we increase the voltage across the plates, the electric field also increases. The breakdown voltage is the voltage at which the dielectric failure occurs. Every capacitor which we buy from market or available in laboratory has some maximum voltage value, we cannot use the capacitors beyond that voltage, otherwise the dielectric breakdown occurs in capacitors and the dielectric material is no longer electrically insulating.

CHAPTER 5

CURRENT ELECTRICITY

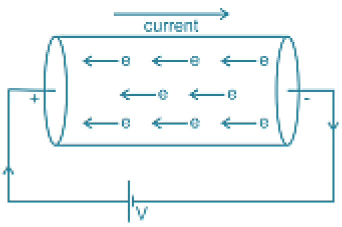
ELECTRIC CURRENT AND ITS UNITS :

Electric current is defined as the rate of flow of electric charge (say electrons) through a crosssection of a conductor. $Electric\ current\ (I) = \frac{charge}{time} = \frac{q}{t}$

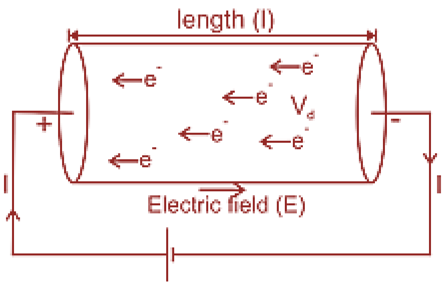
Ampere is SI unit of current. CGS unit of current is stat ampere, 1 A = 3×10^9 stat ampere

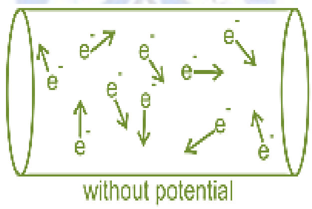
Direction of current:

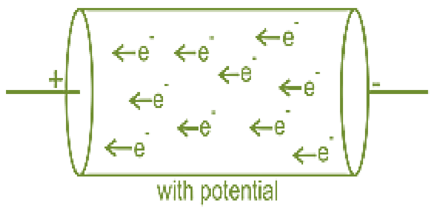
The convention of flow of current is from positive terminal (higher potential) to negative terminal (lower potential).



Relation between Current and Drift velocity:







A metallic conductor contains large number free electrons (nearly 1023). Due to thermal energy these free electrons flow randomly in every direction. Therefore, the average thermal velocity of electron is zero. When we apply an external electric field, the free electron moves towards positive terminal of supply following zig zag path (due to initial thermal velocity and collision with ion and electrons). The average velocity with which the free electrons get drifted towards the positive end of the conductor under the influence of an external electric field applied is called as Drift velocity (vd)

Let us consider a conductor of length l and area of cross-section A,

hence volume of conductor is Al

If n is density of electron, then Total no. of free electrons are Aln

e is charge of one electron, total charge of free electron ,q= Aeln

Due to this electric field, free electrons move with drift velocity (vd) towards positive end. Time taken by free electron to travel from one end of conductor to other will be, $t = l\ /\ v_d$

I = Aeln/t

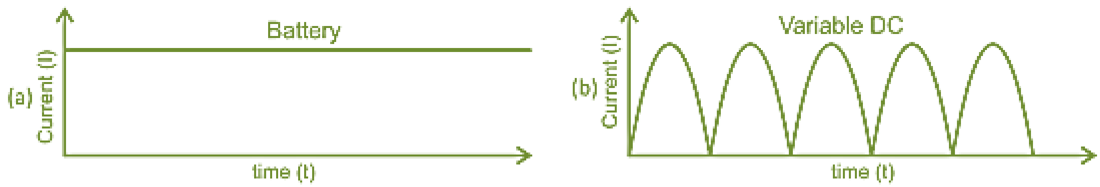
I = nAv_de

Hence current in a conductor depends upon the area of cross section, charge per unit volume and drift velocity.

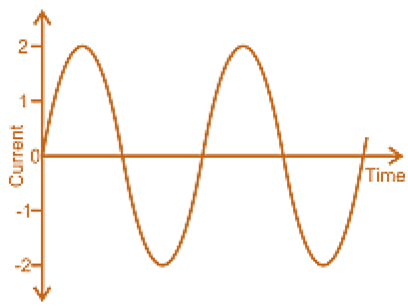
DIRECT AND ALTERNATING CURRENT:

The flow of current in a conductor depends upon the nature of electric field present at the ends of the conductor. The magnitude and direction of current varies as per the electric field at the end of conductor. On the basis of this concept the current can be divided in two types:

Direct current (DC): If current is flowing in a wire AB such that the flow of current is unidirectional, that is the current always flows from point A to B, even if the magnitude of current changes the, direction of current does not change. Such type of current is known as DC current. Direct current is of two type: variable and fixed DC. In variable the magnitude of current changes with time, whereas in fixed DC the magnitude of current does not changes with time.



Alternating current (AC)- When both the magnitude and direction of current changes, such type of current is known as alternating current. In an alternating current the magnitude changes continuously and the direction changes periodically.



RESISTANCE (R) AND ITS UNITS:

This obstruction in the flow of charge can be measured as a property of material and is known as electrical resistance. Resistance is measured in ohms (Ω).

SPECIFIC RESISTANCE (ρ):

Hence the resistance of any metallic wire is directly proportional to the length (l) of wire and inversely proportional to the area of cross section (A) of wire,

$$R \ \alpha \ l$$

$$R \ \alpha \ \frac{1}{A}$$

$$R \ \alpha \ \frac{l}{A}, \qquad R = \frac{\rho l}{A}$$

ρ is specific resistance and it depends upon the property of material of wire and temperature. The unit of specific resistance can be calculated as follows

$$\rho = \frac{RA}{l}$$

$$\text{Unit of } \rho = \frac{ohm - m^2}{m} = ohm - m$$

$$\text{Dimensional formula of } \rho = \frac{RA}{l} = \frac{[M^1L^2T^{-3}A^{-2}]L^2}{L} = [M^1L^3T^{-3}A^{-2}]$$

CONDUCTANCE (G):

As resistance is measure obstruction of flow of charge, conductance is measure of ease with which charge flows through a substance. The conductance is reciprocal of resistance. It is denoted by G and Its unit is mho (inverse of ohm) or siemens (S). G= 1/R

SPECIFIC CONDUCTANCE (κ):

As conductance is the reciprocal of resistance, similarly the specific conductance of given material is reciprocal of specific resistance or resistivity of that material. It is denoted by κ (kappa) It unit is Siemens/meter (S/m).

K = G (l/A)

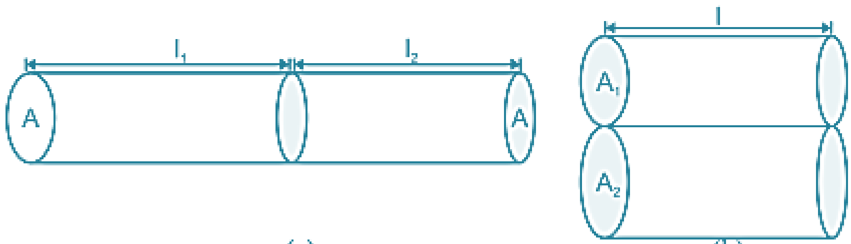
SERIES AND PARALLEL COMBINATIONS OF RESISTANCE:

As we know that, $R = \frac{\rho l}{A}$

If we take two wire of same material and same area of cross section and length l_1 and l_2

Then resistance of first wire is given by, $R_1 = \frac{\rho l_1}{A}$

And resistance of second wire is given by, $R_2 = \frac{\rho l_2}{A}$



(a) (b)

If we connect the two wires in series that is , through same area of cross section, than total resistance (R) of combined wires will be,

$$R = \frac{\rho l}{A}$$

$$R = \frac{\rho(l_1 + l_2)}{A} = \frac{\rho l_1}{A} + \frac{\rho l_2}{A}$$

$$R = R_1 + R_2$$

If we take two wire of same material and same length l but different area of cross section A_1 and A_2

Then resistance of first wire is given by, $R_1 = \frac{\rho l}{A_1}$

And resistance of second wire is given by, $R_2 = \frac{\rho l}{A_2}$

If we connect the two wires in parallel that is, along the length, than total resistance (R) of combined

$$R = \frac{\rho l}{A} = \frac{\rho l}{(A_1 + A_2)}$$

$$R = \frac{1}{(A_1 / \rho l + A_2 / \rho l)}$$

$$R = \frac{1}{(1/R_1 + 1/R_2)}$$

$$\frac{1}{R} = \left(\frac{1}{R_1} + \frac{1}{R_2}\right)$$

FACTORS AFFECTING THE RESISTANCE OF WIRE:

- **Length**: if the length increases the resistance increases

  R α L

- Area of cross-section $R \ \alpha \ \frac{l}{A}$

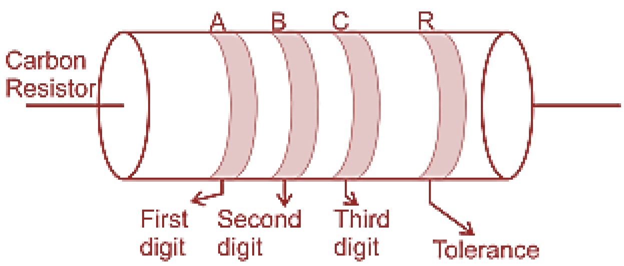
  if the area of cross section increases the resistance decreases
- **Nature of material**

  Resistance depends upon the resistivity of material of given wire, two wire made of different material but of same length and same area of cross section, have different resistance.
- **Temperature of conductor**

  The resistance also depends upon the temperature of the conductor. Conductors have positive temperature coefficient of resistance (α). i.e. their resistance increases as the temperature increases.

CARBON RESISTANCES AND COLOR CODING:

Many materials are used to make resistance, metals and alloys such as Nichrome , brass, platinum, and tungsten alloys are also used for this purpose. These materials have low electrical resistivity. With the help of these metals low resistance having more current capacity can be made but It is very difficult to make high resistance resistor with this metal alloy because it will be very bulky. Hence to make resistors of high resistance material, carbon is a good alternate. Such type of resistances, made of carbon are known as carbon resistances. They are small and can provide high resistance. The value of carbon resistor can be determined by decoding the colour code. In the system of colour coding, strips of different colours are given on the body of the resistor, The colours on strips are noted from left to right.



We have to identify the colours of the strips (A, B and C) on carbon resistor and each colour correspond to certain digit (from 0-9). After identifying the colour the resistance value can be determined as follows:

1. A - First digit of resistance in Ohm
2. B - Second digit of resistance in Ohm

3. C - No. of zero which follow A & B

4. R - % accuracy of resistance

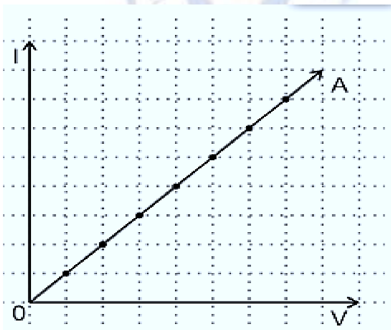
COLOUR (A, B)	INITIAL LETTER	Corresponding Digit or number	MULTIPLIER (C)	COLOUR (R)	Tolerance
Black	B	0	10^0	Gold	±5%
Brown	B	1	10^1	Silver	±10 %
Red	R	2	10^2	No colour	±20%
Orange	O	3	10^3		
Yellow	Y	4	10^4		
Green	G	5	10^5		
Blue	B	6	10^6		
Violet	V	7	10^7		
Grey	G	8	10^8		
White	W	9	10^9		
Gold			10^{-1}		
Silver			10^{-2}		

To remember the value of colour coding used for carbon resistor, the following can be remembered B B ROY of Great Britain has Very Good Wife wearing Gold Silver necklace.

OHM'S LAW AND ITS VERIFICATION:

Statement: The current (I) flowing through a conductor is directly proportional to the potential difference (V) applied across the end of the conductor provided that all the physical conditions and temperature remains constant.

$$I \propto V \quad or \quad V \propto I$$
$$V = RI$$
$$R = \frac{V}{L}$$



Applications of Ohm's Law

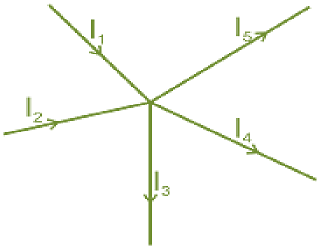
1. With the help of Ohm's law the current in a given circuit can be calculated.

2. If a circuit consists of number of elements, then voltage across each element can be measured using Ohm's law

3. Equivalent resistance in series and parallel combination of resistance can also calculated by applying Ohms law.

KIRCHHOFF'S LAWS:

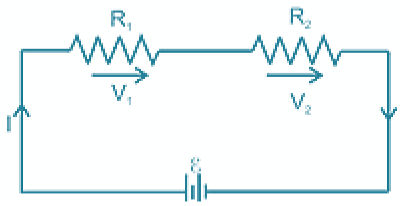
Kirchhoff 's current law (KCL) : The algebraic sum of all currents meeting at a junction or node is equal to zero. Physically, this law states that charge cannot collect at a node; whatever enters must go out.



I1 + I2 –I3 –I4 –I4 =0

KIRCHHOFF'S VOLTAGE LAW (KVL): According to the voltage law, the sum of voltages around each closed loop in a circuit is equal to zero or the summation of all the voltage source in a given loop is equal to summation of the product of current and resistance in a given loop. The closed loop may be define as: start at a node and trace a path across the circuit that leads back to the original node. The sign of voltage of any element is taken according to the direction of current in that element. The sign is taken positive, if the direction of traversal is in the direction of current and vice versa. The sign of voltage source is taken negative if the direction of traversal is from negative to positive and vice versa

$$-\varepsilon + V_1 + V_2 = 0$$
$$\varepsilon = V_1 + V_2 = I(R_1 + R_2)$$
$$I = \varepsilon / (R_1 + R_2)$$
$$\sum V = \sum IR \quad \text{for the loop}$$



<u>**WHEATSTONE BRIDGE AND ITS APPLICATIONS:**</u>

Statement: It is an arrangement of four resistance used to determine one of these resistances quickly and accurately, in terms of remaining three resistance. When bridge is balanced then point B and Point D both are at the same potential and no current flows through galvanometer. It means deflection in galvanometer is zero

For the loop abda: $I_1P + GI_g - I_2R = 0$

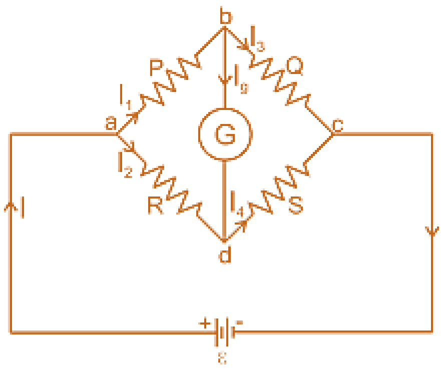
$I_3Q - I_4S - GI_g = 0$

For the loop bcdb: $I_g = 0$

$I_1P = I_2R$

In balance conditions then: $I_3Q = I_4S$

$$P/Q = R/S$$

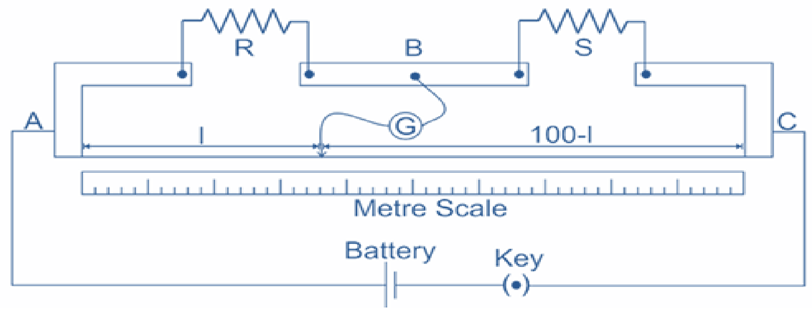


<u>**Application of Wheatstone bridge: Slide wire bridge:**</u>

Meter bridge or slide wire bridge is the simplest application of the Wheatstone bridge, used to measure an unknown resistance. It consists of a 1m long manganese or constant an wire of uniform cross-sectional area stretched and clamped with metallic strips bent at right angles. The metallic strips has two gaps where two resistors (one known (R) and one unknown (S))can be connected. The endpoints where the wire is clamped are connected to a cell or a battery or voltage source through a key. One end of a galvanometer is connected to the metallic strip midway between the two gaps. The other end of the galvanometer is connected to a 'jockey'. The jockey is moved along the wire and balancing point is determined. At a particular position of jockey, current in galvanometer becomes zero. Let the balancing length is l. Then

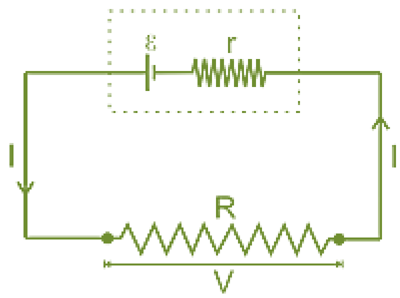
$$\frac{R}{S} = \frac{R_{cm} l}{R_{cm}(100-l)} = \frac{l}{100-l}$$

$$S = (100-l)\,R/l$$



CONCEPT OF TERMINAL POTENTIAL DIFFERENCE AND ELECTRO MOTIVE FORCE:

Cell is a device which converts chemical energy into electrical energy. It consists of two electrodes and electrolytes. Learners must have understood the concept of cell in electrochemistry. Cell acts as a voltage source to provide current in external load. Electromotive force or emf (ε) of a cell is the maximum potential difference between two electrode of the cell when no current is drawn from the cell. Each voltage source say DC voltage source, battery or a cell has some internal resistance (r) which is resistance offered by the electrolyte and electrodes of a cell to the passage of electric current through the cell. The internal resistance (r) of cell depends upon number of factors such as area of electrode, distance between electrode, concentration of electrolyte and temperature. Whenever a load is connected to cell than the voltage on load is always less than the emf, hence terminal Potential difference of a cell is defined as the potential difference between the two electrodes of a cell in a closed circuit. It is denoted by V and measured in volt. $V < \varepsilon$



By Ohm's Law, Magnitude of current, $I = \frac{\varepsilon}{r+R}$

Potential difference across r, $V_r = Ir$

Voltage across load (V) is,

$$V = \varepsilon - V_r = \varepsilon - Ir$$

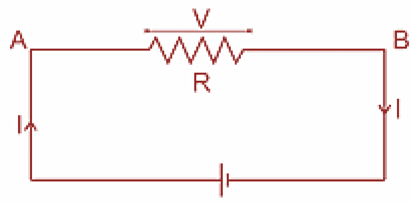
$$r = \frac{\varepsilon - V}{I}$$

Also, potential difference across R,

$$V = IR, \; I = \frac{V}{R}$$

Hence $$r = \frac{(\varepsilon - V)}{V} \times R$$

HEATING EFFECT OF CURRENT:



Whenever electric current passes through a conductor, the temperature of the conductor increases due to heat produced the by electric current. If the potential difference across conductor is V and I current flows through conductor AB of resistance R for time t then, The work done by electric field to move charge from A to B in the conductor is, $W = q \times V$ we know ,(V = IR)

$$W = IR \times It \quad where\ (q = It)$$

$$W = I^2 Rt$$

The above work done changes into heat energy to overcome the resistance offered by the conductor,

$$H = W = I^2 Rt$$

i) H is proportional to I^2, for given resistance R

ii) H is proportional to R, for given I

iii) H is proportional to t, for a given resistance R and current I

The law stated above is known as Joule's law of Heating.

ELECTRIC POWER:

The rate at which an appliance converts electrical energy into other forms of energy is known as electric power. The power of electric bulb is the rate at which it converts electrical energy into light. A bulb of high power consumes more electrical energy and gives more light energy as compared to the bulb of low power. The appliances in our house hold consumes electrical power as per their functioning.

$$P = \frac{W}{t} = \frac{VIt}{t} = VI \; J/s$$

$$Power\ (in\ watt) = Volt \times Ampere$$

$$1\ watt = 1\ Ampere - Volt$$

Bigger units of power are kW and MW

$$1\ kW = 10^3\ W, \quad 1 MW = 10^6\ W$$

and $$1\ horse\ power\ (hp) = 746\ watt$$

$$P = VI \quad and \quad V = IR, \quad I = V/R$$

Therefore $$P = I^2 R$$

or $$P = V^2/R$$

ELECTRIC ENERGY AND ITS UNITS:

The total work done by the source of emf in maintaining an electric current in the circuit for a given time is called as electric energy consumed in the circuit.

$$\begin{aligned} \text{Electric Energy } W &= VIt = P.t \\ \text{Electric Energy} &= \text{Electric power} \times \text{time} \\ \text{Electric Energy in Joule} &= 1 \text{ volt} \times 1 \text{ amp} \times 1 \text{ sec} \\ &= 1 \text{watt} \times 1 \text{ sec} \end{aligned}$$

Commercial unit of electric energy is kilowatt – hour (kWh)

$$\begin{aligned} 1 \text{ kWh} &= (1000W)(60 \times 60s) \\ &= 3.6 \times 10^6 J \end{aligned}$$

ADVANTAGES OF ELECTRIC ENERGY OVER OTHER FORMS OF ENERGY:

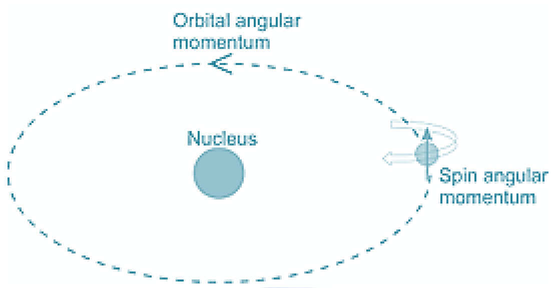
- Electrical energy can be easily transformed into other forms of energy- like
  - heat in heaters and oven,
  - light in electrical bulb and Tube-lights,
  - mechanical energy in electric motors grinder,
  - chemical energy in cell or battery charging.
- Ease of control: Through electrical switches and circuits
- Flexible : Easily Transported through wires
- Efficient and Reliable

CHAPTER 5 :

ELECTROMAGNETISM

TYPES OF MAGNETIC MATERIALS:

Materials are made up of atoms and in atoms there are electrons. Electrons can be considered as tiny magnets with magnetic moment. There are two kind of electron motion: orbital and spin. Atoms contains many electrons spinning about its own axis and rotating around nucleus. The magnetic moment of electrons associated with each kind of motion is a vector quantity, perpendicular to the orbit and parallel to the axis of spin of electrons. The magnetic moment of atom is calculated as the vector sum of moment of all electrons.



Dia, para and ferromagnetic materials with their properties:

(a) Diamagnetic materials:

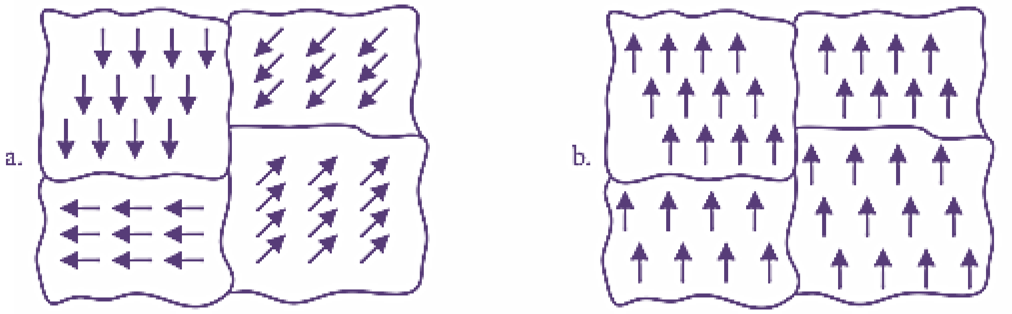
In diamagnetic materials, the atom has no net magnetic moment, because the magnetic moment of each electron is arranged in such a way that they cancel out each other. Such materials are known as diamagnetic materials. These materials are repelled by magnetic field. These materials are also known as negative magnetic materials. The monoatomic (He, Ne, A, etc.) and polyatomic gases ($H2$, $N2$, etc.) and NaCl, diamond, Si, Ge are examples of diamagnetic materials.

(b) Paramagnetic materials:

In Paramagnetic materials, the atom has net magnetic moment because of partial cancellation of magnetic moment of individual electrons. Such materials have magnetic moment due to the presence of unpaired electrons. When an external magnetic field is applied, magnetic moment of unpaired electrons align parallel to applied magnetic field, causing a net magnetic moment. The materials with unpaired electrons such as Al, FeO, Oxygen, Titanium, are the examples of paramagnetic materials.

(c) Ferromagnetic materials:

In ferromagnetic materials, there is a net magnetic moment due to the presence of unpaired electrons. When an external magnetic field is applied, these magnetic moments are aligned parallel to the applied filed. It results in the increase in magnetization of the materials. In the non-magnetized state, atomic dipoles in small regions of the ferromagnetic materials called domains are aligned in the same direction. The domain exhibits a net magnetic moment even in the absence of external magnetic field. On applying external magnetic field these domains all align themselves in the direction of the applied field. In this way, the material is strongly magnetized in a direction parallel to the magnetizing field.



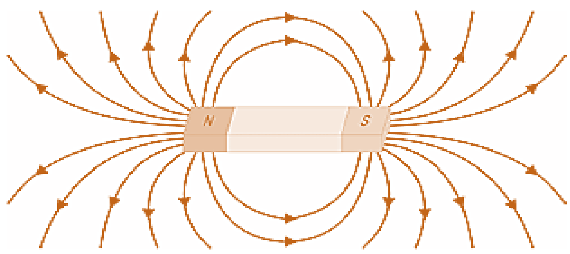
Magnetic field and units:

The force of attraction or repulsion is directly proportional to the product of the pole strengths of corresponding poles and inversely proportional to the square of the distance between the two poles. This force is also known as Coulomb magnetic force.

$$F \ \alpha \ m_1 \times m_2$$
$$F \ \alpha \ 1/r^2$$
$$F = k m_1 m_2 / r^2$$

$k = \frac{\mu 0}{4\pi} = 10^{-7}$ Henry/meter, and m1 and m2 in SI unit that is Amp × m, r in meter and μ0 is magnetic permeability of free space An isolated unit positive charges exists, whereas an isolated magnetic pole doesn't exists, but still if we consider an isolated north pole of unit pole strength(m) and kept it at a point 'P' near to the bar magnet or a current carrying conductor (acting as magnet) then the force on north pole of unit pole strength is the magnetic field due to bar magnet or a current carrying conductor at that point.

$$B = F/m$$
$$\text{Dimensional formula of } B = MLT^{-2}/AL = MA^{-1}T^{-2}$$



The CGS unit of magnetic field is Gauss. The SI unit of magnetic field is Tesla. The magnetic field strength of earth $is\ 3.05 \times 10^{-5} Tesla$, $1\ Tesla = 10^4 Gauss$

Magnetic intensity:

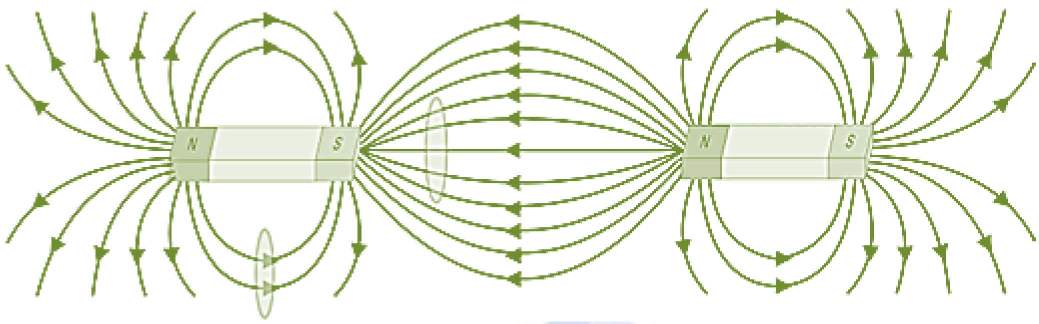
It is represented by H. The magnetic field intensity is the ratio of magnetic field with the permeability.

For free space, $H = B / \mu_o$

$B = \mu_o / H$, The SI unit of magnetic intensity is Amp / meter

Magnetic lines of force:

The magnetic force existing around the magnet can be explained in terms of the magnetic lines of force. Magnetic field lines originate from the north pole and merge to the south pole of a bar magnet. They do not intersect each other and the strength of the magnetic field is defined as the number of lines of force passing through a unit area perpendicular to the field.



Magnetic flux and units:

The magnetic force existing around the magnet can be explained in terms of the magnetic lines of force. Magnetic field lines originate from the north pole and merge to the south pole of a bar magnet. They do not intersect each other and the strength of the magnetic field is defined as the number of lines of force passing through a unit area perpendicular to the field.

Magnetization:

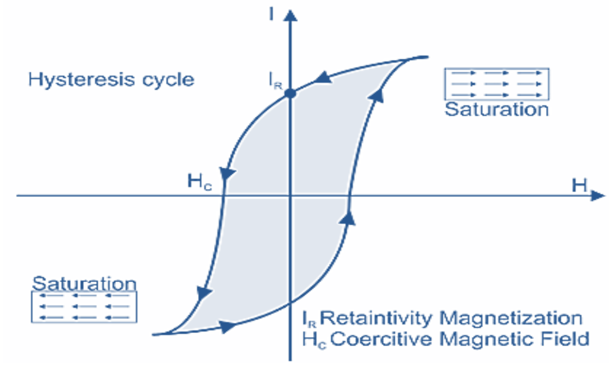
When a magnetic material is placed in a magnetizing field, it gets magnetized. The magnetic moment developed per unit volume in magnetizing material is known as intensity of magnetization of magnetization or Magnetization (I), $I = M / V$

where, V is the volume of the material, with length 2l and area of cross section A

As Magnetic moment m × 2l { m is pole strength and 21 is length of magnet}

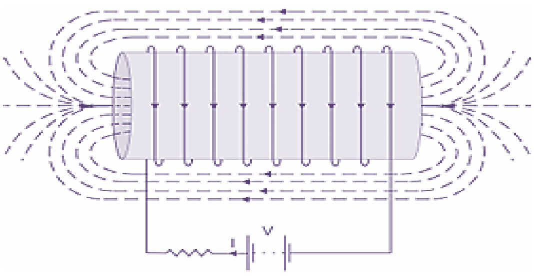
We can as, $I = m \times 2l / V = m / (V / 2l) = m / A$

Thus, magnetization (I) can also be defined as the pole strength per unit area of cross section. The unit of I is Ampere / meter.



The variation of I with H is known as magnetization curve. The diamagnetic, and paramagnetic materials have a linear relation between I and H curve and retain no magnetization when the field is removed. The ferromagnetic materials show nonlinear relationship curve between I and H. At large magnetic field when magnetization becomes Fig. 5.5 Magnetization curve constant is known as saturation (IS). In ferromagnetic materials, I do not reduce to zero when applied field is removed and it is known as retentivity of material (IR). The field has to be applied in opposite direction to remove the magnetization and this applied field is called coercive magnetic field (HC).

CONCEPT OF ELECTROMAGNETIC INDUCTION:



It is given that there is a heating effect when a current pass through a wire. Similarly, a current-carrying wire produces a magnetic field around the wire. When current flows through a wire wounded in the form of coil i.e. solenoid then magnetic field is developed around the solenoid and solenoid behaves like a bar magnet. On the other hand, if we bring a permanent magnet near a closed coil connected with galvanometer and move the magnet towards one of the ends of coil then electric current passes through the coil and deflection is observed in galvanometer. It demonstrates the presence of electric current due to movement of magnet. Hence electric current produces magnetic field and a moving magnet produces electric current. This phenomenon is known as Electromagnetic induction.

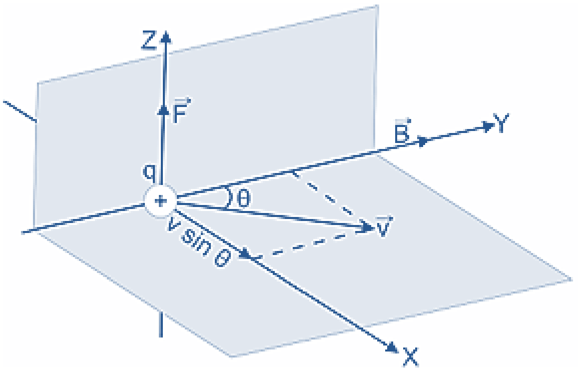
Faraday's laws:

Michel Faraday has given two laws of electromagnetic induction. They are stated as follows:

1^{st} Law: "Whenever the magnetic flux linked with closed circuit changes, an emf is induced in the circuit, the induced emf persists only, as long as there is change in magnetic flux".

2nd Law:" The magnitude of the induced emf is proportional to rate of change of magnetic flux, linked with the closed circuit". $emf(e) \; = \; -k d\phi / dt$

Lorentz force (force on moving charge in magnetic field):



Let us consider a magnetic field (B) along y direction and a charge (q) moving in xy plane with velocity (v) making an angle θ with the direction of magnetic field. The moving charge will experience a force in the direction perpendicular to motion of charge and magnetic field. This force is known as Lorentz force. The Lorentz force depends upon following factors,

$$F \; \alpha \; B$$

$$F \; \alpha \; q$$

Hence, $F \; \alpha \; v \sin\theta$

$$F = qvB \sin\theta$$

In case if θ is 90 degree. $F = q\,V\,B$

can be rewritten as, $\vec{F} = q\,(\vec{V} \times \vec{B})$

Force on current carrying conductor :

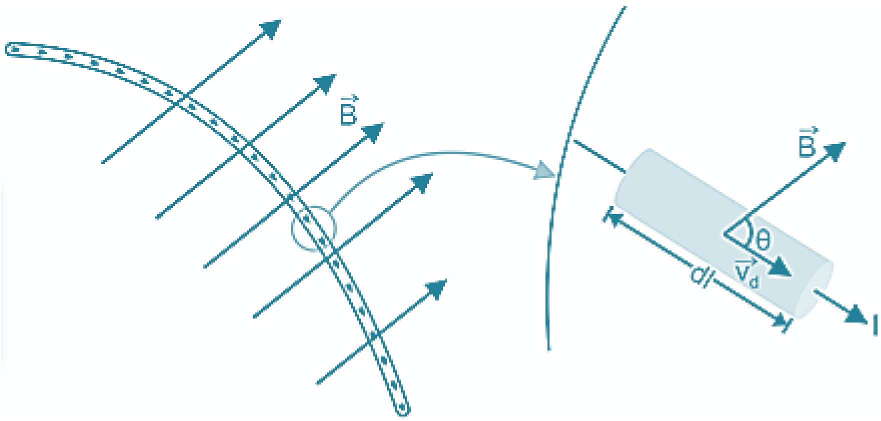
Let us consider a current (I) is flowing is conductor of length (L) and area of cross section (A) with (n) no of charge per unit volume and placed in magnetic field (B). The force due to magnetic field in small length element dl will be given by Lorentz force,

$$dF = qvB \sin(\theta)$$

q is the charge in element $= (nAdl)e$

v is the velocity of electron in element $= v_d$

θ is the angle between magnetic field and v_d



$$\begin{aligned} \text{Hence} \quad dF &= (nAdl)e \times v_d \times B\sin(\theta) \\ dF &= (nAe \times v_d)\, dl \times B\sin(\theta) \\ dF &= I \times dl \times B\sin(\theta) \qquad [I = nAevd] \end{aligned}$$

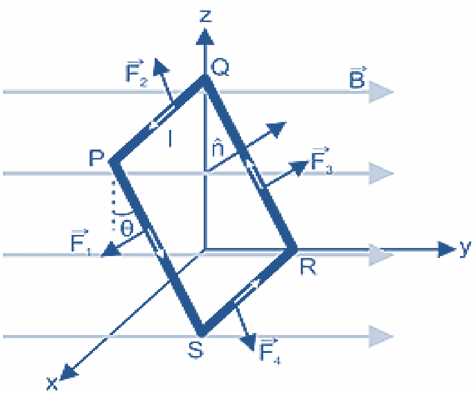
on integrating over complete length $\vec{F} = I(\vec{l} \times \vec{B})$

Force on rectangular coil placed in magnetic field :

Let us consider a current carrying rectangular loop PQRS, placed in magnetic field. The direction of magnetic field and a current loop is such that the normal (ˆ n) to the plane of loop making an angle θ with B. As described in previous section there will be force in each side of current loop i.e., PQ, QR, RS and SP . Namely F1 , F2 , F3 and F4 respectively. For simplicity let us consider that the angle between ˆ n and B is zero then,

$$\begin{aligned} \vec{F_1} &= I\left(l\left(-\hat{k}\right)\times B\hat{j}\right) = IlB(\hat{i}) \\ \vec{F_1} &= I\left(l\left(-\hat{k}\right)\times B\hat{j}\right) = IlB(\hat{i}) \\ \vec{F_3} &= I\left(l\left(\hat{k}\right)\times B\hat{j}\right) = IlB(-\hat{i}) \\ \vec{F_4} &= I\left(l\left(-\hat{i}\right)\times B\hat{j}\right) = IlB(-\hat{k}) \end{aligned}$$

Than resultant force on coil is zero and if the angle between $\hat{n}$ and B is 90° then,



$$\begin{aligned} \vec{F_1} &= I\left(l\left(\hat{j}\right)\times B\hat{j}\right) = 0 \\ \vec{F_2} &= I\left(l\left(\hat{i}\right)\times B\hat{j}\right) = IlB(\hat{k}) \\ \vec{F_3} &= I\left(l\left(\hat{j}\right)\times B\hat{j}\right) = 0 \\ \vec{F_4} &= I\left(l\left(-\hat{i}\right)\times B\hat{j}\right) = IlB(-\hat{k}) \end{aligned}$$

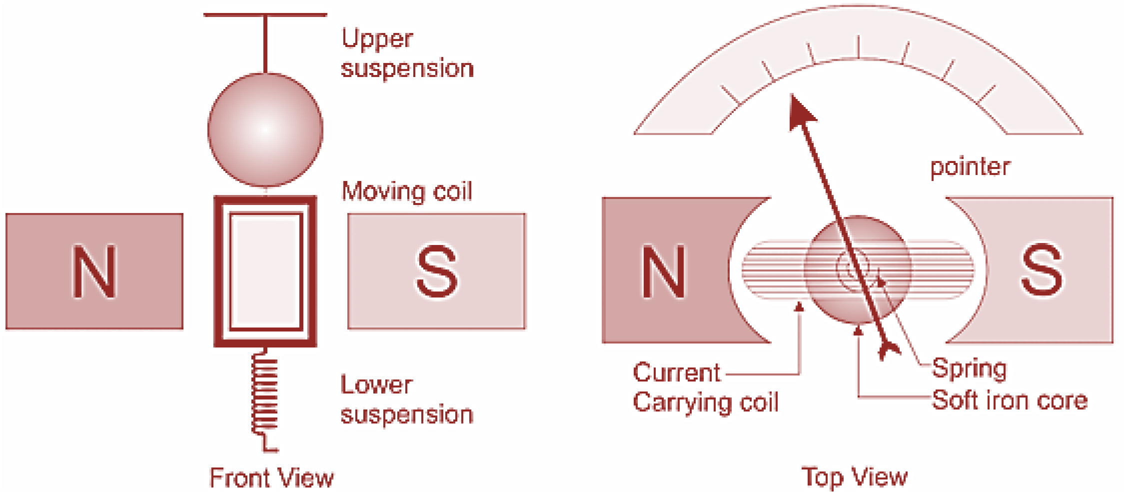
Hence due to presence of two equal and opposite forces F2 and F4 acting in opposite direction a couple acts on the coil and produces torque (τ), causes the coil to deflect and is given by,

$$\begin{aligned} \tau &= \text{Force} \times \text{perpendicular distance between the Forces} \\ \tau &= IlB \times b \\ \tau &= I(lb)B = IAB \\ \tau &= I(\vec{A} \times \vec{B}) \end{aligned}$$

The force is maximum when area vector $\vec{A}$ (normal to the plane of coil) and $\vec{B}$ are perpendicular, and it decreases as the angle between Area vector and $\vec{B}$ decreases.

Moving coil galvanometer: Principle, construction and working :

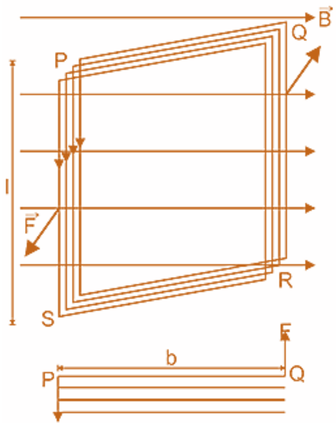
A galvanometer is a device for measuring small electrical currents. It is a device that gives a deflection in the magnetic needle whenever the current passes through it. Moving coil galvanometers are the most often used galvanometers for current measurement. It's an electromagnetic device that can detect electric currents as low as a few microamperes. If a current carrying coil is placed in a magnetic field it experiences magnetic torque. The current through the coil is directly proportional to the angle through which coil is deflected due to magnetic torque.



Construction: The moving coil galvanometer consists of a rectangular coil made of thin insulated copper wire, wounded on a metallic frame. The rectangular coil is free to rotate about a fixed axis. The coil is suspended freely in a uniform radial magnetic field through a phosphor-bronze strip, connected to a movable torsion head. To make the field radial cylindrical soft iron core is symmetrically positioned inside the coil to improve the strength of the magnetic field. The lower part of the coil is attached to a phosphor-bronze spring having a small number of turns. The other end of the spring is connected to binding screws. When we pass current in coil there will be oscillation and as per arrangement in this case the oscillation is damped oscillation as discussed in unit 1. The spring is used to produce a counter torque which balances the magnetic torque and hence helps in producing a steady angular deflection. A plane mirror which is attached to the suspension wire, along with a lamp and scale arrangement, is used to measure the deflection of the coil. Zero-point of the scale is at the centre.

If a current I flows through a rectangular coil (Fig. 5.11) with a cross-sectional area of A and N turns. The coil receives a torque when it is put in a unit form radial magnetic field B. Consider a single turn 'PQRS' of a rectangular coil with a length of l and width of b. This coil is suspended in a magnetic field with a strength of B, with the coil's plane parallel to the magnetic field. Because the sides PQ and SR are parallel to the magnetic field's direction, as they do not experience any magnetic field's effective force. The sides PS and QR are perpendicular to the direction of field and experience an effective force F given by,

$$F = BIl$$



Due to presence of two equal and opposite forces F couple, a couple acts on the coil and produces torque (τ), causes the coil to deflect and the torque acting on 'N' turns of the coil is given by, $\tau = NIAB$

The coil rotates because of torque and the phosphor bronze strip twists. In turn, the spring S attached to the coil produces a counter torque or restoring torque kθ which results in a steady angular deflection. At equilibrium condition: kθ = NIAB

Here k is called as the torsional constant of the spring . The deflection or twist θ is measured as the value indicated on a scale by a pointer which is connected to the suspension wire. θ = (NAB / k)I

θ α I

The quantity NAB/k is a constant for a given galvanometer. Hence the deflection in galvanometer is directly proportional to the current that flows through it. The moving coil galvanometer is a highly sensitive instrument and is used to detect the presence of current in any given circuit. The galvanometer can be used to measure:

a) the value of current in the circuit by connecting a low resistance in parallel.

b) the voltage by connecting high resistance in series.

CONVERSION OF A GALVANOMETER INTO AMMETER AND VOLTMETER :

(i) Conversion of galvanometer into ammeter:

A galvanometer is converted into an ammeter by connecting a low resistance called as shunt parallel to galvanometer coil. Shunt resistance is selected as per requirement of the desired range of the ammeter and by connecting shunt the total resistance becomes very low, due to parallel combination of resistances. Ammeter is always connected in series to measure the electric current flowing in the circuit. The current passing though ammeter is divided into two parts: Ig passes through galvanometer coil and remaining current (I-Ig) passes through shunt. The voltage across the galvanometer and shunt resistance is equal, due to the parallel connection. Therefore,

$$G I_g = (I - I_g) S$$
$$S / G = I_g / (I - I_g)$$

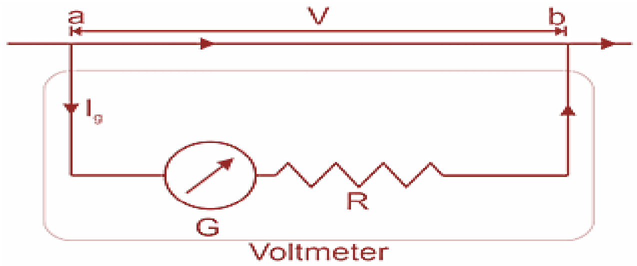
Where, G – Resistance of the galvanometer coil, I – Total current passing through the circuit, Ig – Total current passing through the galvanometer which corresponds to full-scale reading or full-scale deflection, S – Value of shunt resistance.

(ii) <u>Conversion of galvanometer into voltmeter:</u>

A galvanometer is converted into a voltmeter by connecting high resistance in series. As voltage across two parallel point is same, hence voltmeter is always connected in parallel to the component in a given circuit, whose voltage we have to measure. A suitable high resistance is selected, depending on the range of the voltmeter. In the given circuit, G = Resistance of the galvanometer, R = Value of high resistance,

I = Total current passing through the circuit, IG = Total current passing through the galvanometer which cor responds to a full-scale deflection, V = Voltage drops across the series connection of galvanometer and high resistance. When current Ig passes through the series combination of the galvanometer and the high resistance R; the volt age drop across the branch ab is given by:

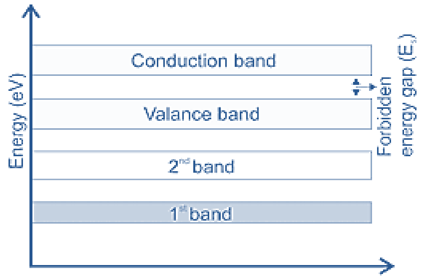
$$V = G.I_g + R.I_g$$
$$V / I_g = G + R$$
$$R = (V / I_g) - G$$



The value of R can be obtained using the above equation.

Semiconductor Physics

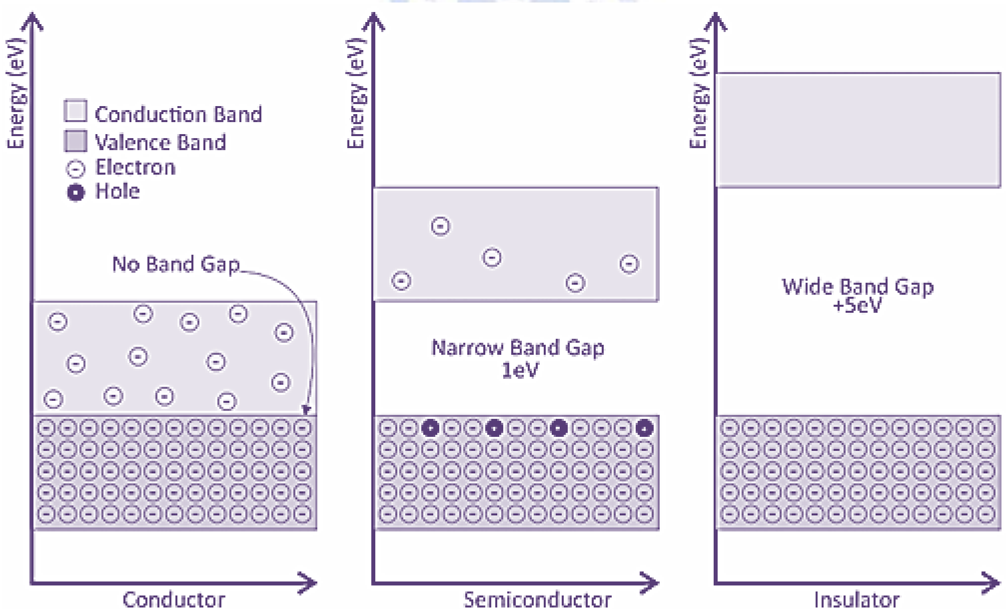
ENERGY BANDS IN SOLIDS:



The top most filled band is known as the valence band and the energy band available after the valence band is the conduction band. The electrons bound to the atoms will remain in the valence band and in all the other bands having energy less than the valence band. The electrons detached from atoms and moving freely in the solids are free electrons. The conduction band contains such free electrons, also known as conduction electrons.

TYPES OF MATERIALS (INSULATOR, SEMICONDUCTOR, CONDUCTOR) :

Based on conductivity solids can be classified in three categories namely conductor semiconductor and insulator. Based on theory of energy bands, they can also be classified as follows:



• The energy difference between the top energy level of the valence band and lowest energy level of conduction band is the energy gap.

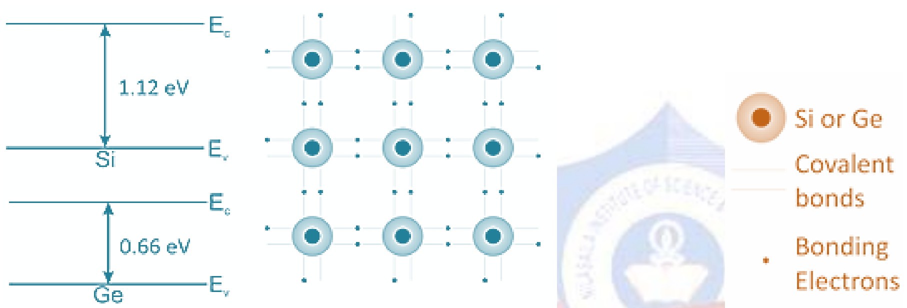
• The number of electrons available in the conduction band of material decides the conductivity of that material.

• In metals the valence band and the conduction band overlaps. The electron available in the valence band requires very less energy to transit from valence band to conduction band. In conductors large number of electrons are available in conduction band. The conductivity in conductors decreases with increase in temperature as it increases the electron collisions. In semiconductors there is a small energy gap between the valence band and the conduction band and it is of the order of 1eV. The electron available in the valence band transits to the conduction band through thermal agitations. The number of electrons in the conduction band in

semiconductors are less, hence the conductivity of semiconductors is less. The conductivity in semiconductors increases with increase in temperature as it increases the number of electrons in the conduction band.

• In insulators there is a large energy gap between the valence band and the conduction band of the order of 6eV. No electrons are available in the conduction band and it requires a large amount of energy for the valence band electrons to transit in the conduction band. Hence the conductivity of the insulator is almost zero.

INTRINSIC AND EXTRINSIC SEMICONDUCTORS:



Si and Ge are semiconducting materials in elemental state. Si and Ge are tetravalent, having four electrons in the valence shell. Each atom forms a covalent bond with other four neighbouring atoms and there is no free electron at 0 K. At 0 K intrinsic semiconductor are insulators and as we increase temperature, due to thermal excitation the valence bond breaks and as per energy band diagram the electron from valence band transit to conduction band. Leaving a vacancy of electrons known as 'holes' in the valence band. In Intrinsic semiconductor there are two types of mobile charge carriers that are electrons and holes. Both are equal in number. The number of electrons in the conduction band depends upon the temperature. If temperature increases the number of electrons and holes increases. The atomic arrangement and energy band diagram for Si and Ge,

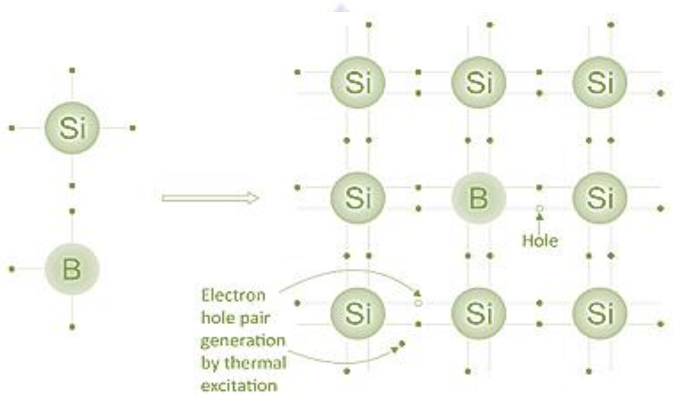
At normal temperature that is 27^0 C or 300 K, the thermal energy of maximum number of electrons is ½ kT, where k is Boltzmann constant and T is temperature in absolute scale is 0.0026 eV, hence very few electrons have energy equal to or more than band gap energy , which will jump to conduction band. Therefore, the conductivity of semiconducting material is very low at room temperature.

n = p = n_i & $n_p = n^2{}_i$, where, n= concentration of conducting electron and p = concentration of holes

As, pure semiconductor has very low conductivity at room temperature and If we want to increase conductivity the temperature has to be increased, which is not a feasible solution. To increase conductivity of semiconductor material at room temperature, other elements are added as impurity. Such semi conductors are known as extrinsic semiconductors.

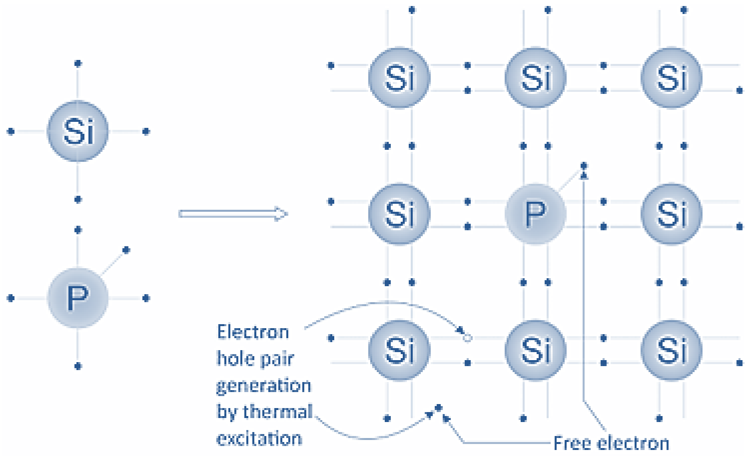
There are two types of extrinsic semiconductors:

P type semiconductors: When trivalent element is added as impurity in pure semiconductors, then the semiconductor is known as p type semiconductor. The elements of group III such as Aluminium , boron and indium are added as impurity for p type semiconductors. In p type semiconductors, the impurity atom is surrounded by four silicon atoms. The trivalent impurity atom has three valence electrons and forms covalent bonds with three Si atoms and one valence electron of fourth silicon atom remains unpaired. This unpaired electron of Si is attracted by trivalent impurity atoms and creates vacancy of electron in silicon atom i.e. hole. The trivalent impurity atoms act as immobile negative ions as they accept one electron and are known as acceptors. There are few additional holes and electrons due to thermal excitation also. Hence in p type semiconductors we have three types of charge carriers, majority of holes, minority electrons and immobile negative ions.



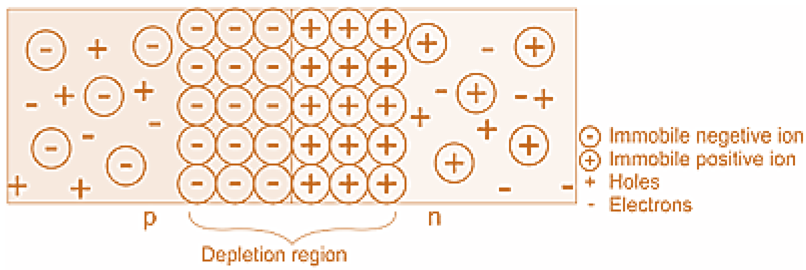
N type semiconductors: When a pentavalent element is added as impurity in pure semiconductors, then the semiconductor is known as n type semiconductor. The elements of group V such as phosphorous, Arsenic and Antimony are added as impurity for n type semiconductors. In n type semiconductors, the impurity atom is surrounded by four silicon atoms. The pentavalent impurity atom has five valence electrons and forms covalent bonds with four Si atoms and the fifth valence electron remains unpaired. This unpaired electron of impurity is detached from the impurity atom and creates free electrons. The pentavalent impurity atoms act as immobile positive ions as they have donated one electron and are known as donors. There are few additional holes and electrons due to thermal excitations also. Hence in n type semiconductors we have three types of charge carriers, majority of electrons, minority holes and immobile positive ions.

In extrinsic semiconductors $n_o \times p_o = n^2{}_i$ where, n_o = concentration of conducting electron and p_o = concentration of holes In p type semiconductors $p_o >> n_o$ and in n type semiconductor $n_o >> p_o$



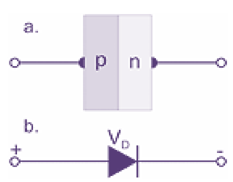
p-n JUNCTION :

When there is a junction of p and n type of materials by means of a special fabrication method, then this junction is known as p-n junction. The junction is made such that there is no physical gap between two materials and mobile charge carriers can diffuse from one region to another. In p-n junction the majority and minority charge carriers diffuse from n region to p region and vice versa.



The electron diffuses form n to region p and holes from region p diffuses to region n. Due to this diffusion, holes and electrons neutralize each other near the junction. There is depletion (shortage) of mobile charge carriers in the junction. A layer is formed at a junction and is known as depletion layer. In the depletion layer due to loss of majority charge carriers in n and p there will be immobile negative ions in p and immobile positive ions in n. This layer of ions creates an electric field directed from n to p. As the field in the region starts developing, the diffusion rate decreases, as the force due to electric field on holes is in the direction of electric field and on electrons in the direction opposite to electric field. The diffusion will cease when the field sufficiently develops to stop the motion of holes and electrons. A potential is developed and is known as potential barrier or depletion potential. Charges can travel from one region to another only if they have sufficient energy to overcome the potential barrier. The p region is at higher potential than the n region in the depletion layer.

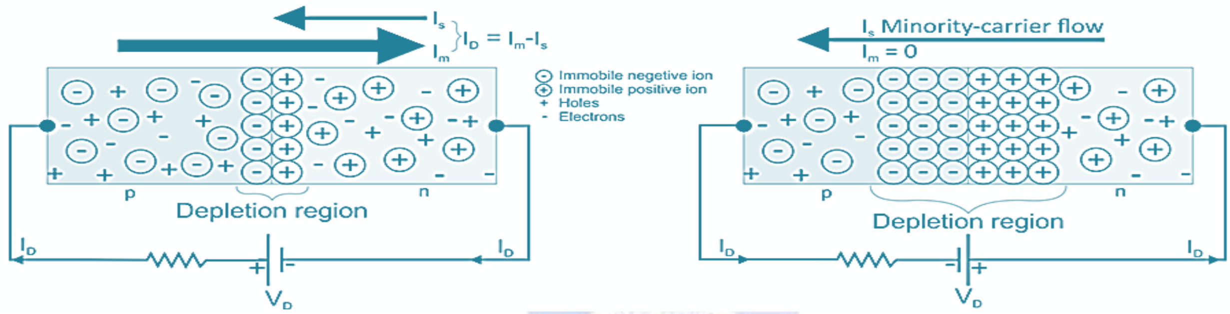
JUNCTION DIODE AND V-I CHARACTERISTICS :



If we add two metallic terminals at two open ends of p-n junction through ohmic contact (no resistance between metallic wire and semiconductor), than this two terminal device, used in circuits is known as p-n junction diode. When supply is not connected across the diode, no current flows through it. External biasing or supply is required to flow the current through the diode. There are two ways in which external DC supply can be connected to diode.

Forward biasing: When positive terminal of the battery or DC power supply is connected to p and negative terminal of battery or DC power supply is connected to n, then this biasing is known as forward biasing.

Reverse biasing: When positive terminal of the battery or DC power supply is connected to n and negative terminal of battery or DC power supply is connected to p. then this biasing is known as reverse biasing.



TYPES OF JUNCTION DIODE :

The junction diode can be classified by the V-I characteristics and working, which depends on following factors: a. Doping concentration

b. Semiconductor material used

c. Construction

d. Type of junction material

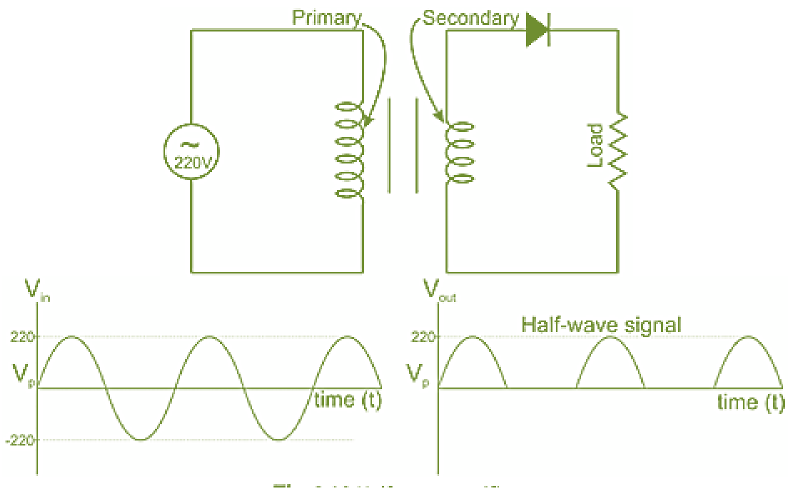
Doping Concentration: If the doping concentration more than 1ppm then the diode is known as a highly doped diode. one example of a highly doped diode is the Zener diode. Due to increase in doping the depletion layer of such diodes is very thin as compared to normal junction diodes. Zener diodes can be used as voltage regulator. **Semiconductor material used** : In place of silicon or Germanium, if we use compound semiconductors such as GaAs, then the working of junction diodes depends upon the material used. The diodes made up of GaAs are used as Light emitting diode (LED) and photodiode. The LED in forward bias is used as an indicator and conversion of electrical signal into optical signal. Photodiodes are used in reverse bias to convert optical signals into electrical signals.

Construction: Working of junction diodes depends on its construction also. If the thickness of p and n side of junction is different say the p side is very thin as compared to n side or vice versa. Such types of junction are used to construct solar cells, which convert optical energy into electrical energy.

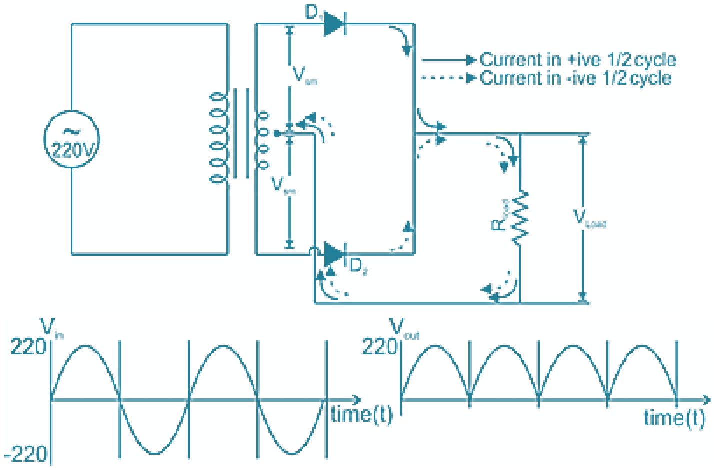
Type of junction material: In place of semiconductor - semiconductor junction, metal – semiconductor junction is used to form a junction diode. Schottky diode is an example of metal semiconductor junction., which is used in power electronic circuits.

DIODE AS RECTIFIER :

Half wave rectifier : In a Half wave rectifier, a step down transformer is used to scale down the AC voltage (say from 220 V to 12V), this AC signal is given to a circuit where a diode is connected in series with resistance (R). The diode will be in forward bias for one half cycle and in reverse bias in another half cycle. The voltage across the diode in forward bias is low (equal to knee voltage), then the total voltage will appear on Resistance R as per Kirchhoff's law. In reverse bias no current or very less current will flow, hence the voltage across resistance R is very low and all the voltage will appear on diode. Figure Shows the circuit of the Half wave rectifier. The input and output waveform is there. The voltage appearing on the R is variable DC voltage and further given to filter circuits to convert variable DC into constant DC.



Full wave rectifier: (centre taped) In a Half wave rectifier, only one-half cycle is used to convert AC signal to DC signal. If we use a centre tapped step down transformer and two diodes then a full wave of AC can be rectified. In a full wave rectifier, the AC signal is given to a circuit with two diodes and one load resistance (R). In the first Half cycle, the first diode is in forward bias and the second diode is in reverse bias. The situation will be reversed In next half cycle. The voltage will appear across resistance R in both half cycles. Figure Shows the circuit of full wave rectifiers. The input and out waveform is also displayed in Figure .The voltage appearing on the R is variable DC voltage and further given to filter circuits to convert variable DC into constant DC.



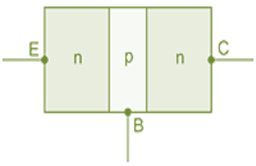
TRANSISTOR :

A transistor is a three-terminal device, it consists of two p-n junctions, which is created by either keeping n type material in between two p type material regions or p type material in between two n type regions. Unlike diodes the thickness of n and p regions is different. The three terminals of transistors are known as base, emitter and collector. The doping of the base region is low as compared to the emitter and collector region. The thickness of the base region is also less as compared to emitter and collector. There are two p-n junctions formed in transistors namely emitter- base junction and collector- base junction. For normal working of transistors the emitter- base junction is kept in forward bias and collector-base junction in reverse bias. As we know, for a junction the resistance is low in forward bias and high in reverse bias. The current passing through the emitter and collector is the same and it sees different resistance in the emitter base region and collector base region, hence there is transfer of resistance, therefore this device is known as a transistor.

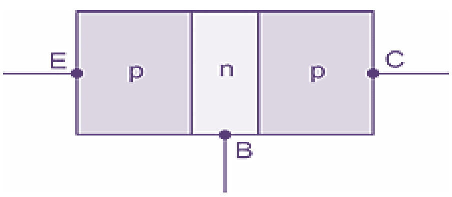
TYPES OF TRANSISTORS:

There are two types of transistor

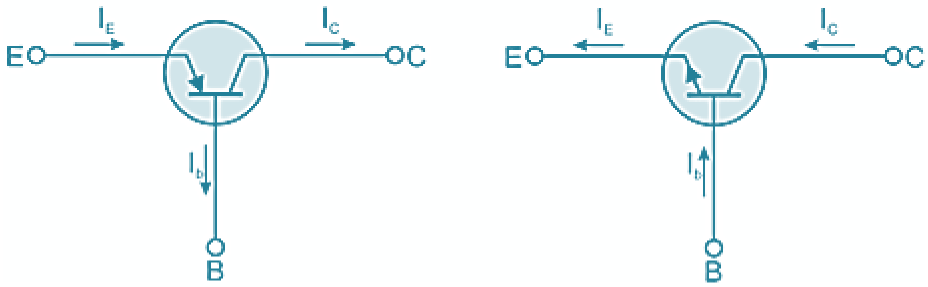
- npn: emitter and collector is n type and base is p type



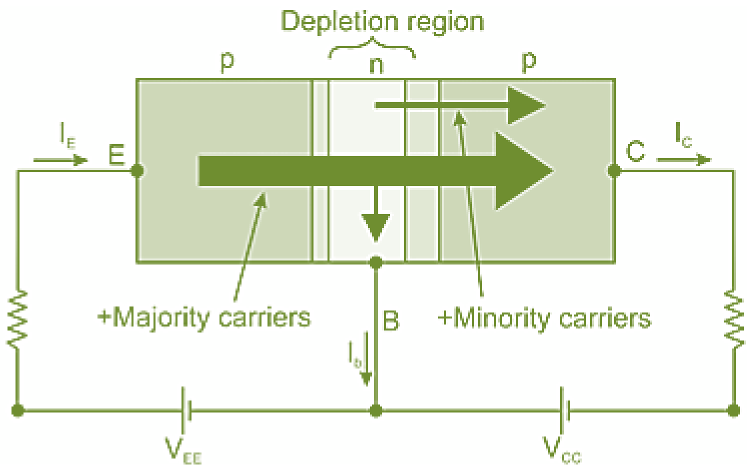
- pnp: emitter and collector is p type and base is n type



Symbols of pnp and npn transistors



Operation of transistors:



For a transistor biasing the emitter- base junction is kept in forward bias and Collector base junction is kept in reverse bias. As from junction characteristics, when a junction is in forward bias the voltage across the diode is of the order of 0.7 volt (if Si is used) and current is in milliampere and in reverse bias the current is in micro ampere and the junction voltage is equal to the applied voltage. In transistor, emitter current flows from emitter to base and as the base junction is very thin, very small base current flows from base and maximum part of emitter current flows through the collector. Large current flows across the collector - base junction, which is having more voltage (V_{CC}), hence power is amplified in transistors.

$$I_e = I_c + I_b$$

$$I_e \sim I_c$$

SOME ELECTRONIC APPLICATIONS OF TRANSISTOR :

• Voltage amplifier

•Current amplifier

•As a switch

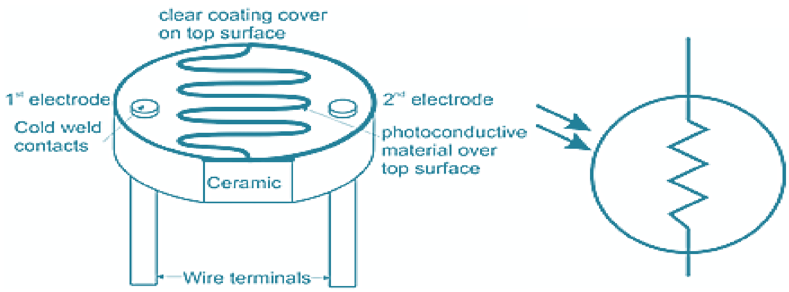
•For designing different types of logic gates circuits

•As basic building block of operational amplifier

PHOTOCELLS :

A photoconductive cell is a two terminal semiconductor device, the resistance between terminals varies with the intensity of light. The fig 6.14 shows the construction of a photocell.

Photoconductive materials used in photocell are CdS and CdSe. The photocell does not have a junction like other junction devices such as photodiodes. A thin layer of the photoconductive material is deposited on a ceramic substrate. Two metal terminal are connected at the ends of thin layer to connect photoconductive cell in circuit. The resistance of a thin layer of material, typically is of the order of 100 k Ohm and reduced to 100 Ohms when illuminated with light.

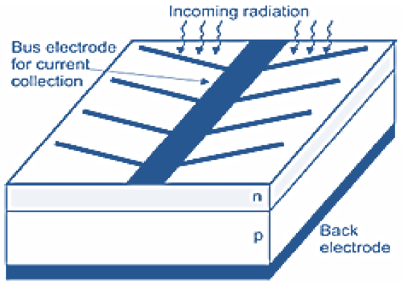


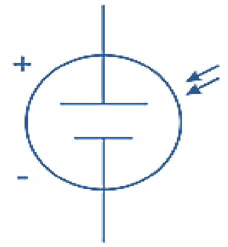
It can be used for number of applications as follows:

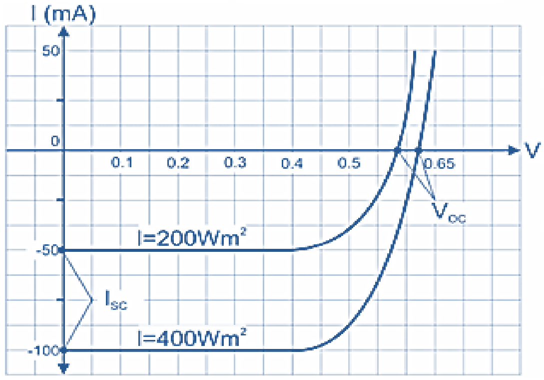
- Automatic Headlight
- Dimmer Night Light
- Street Light Control

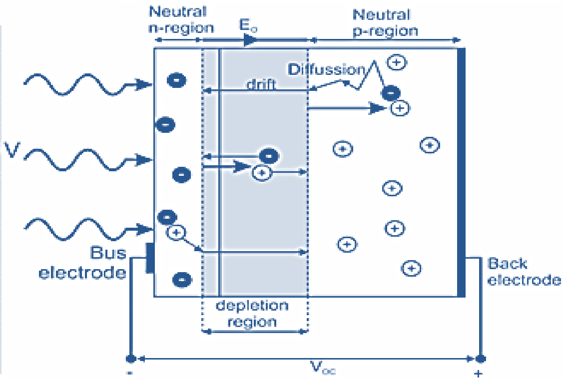
SOLAR CELLS:

A solar cell is also a junction device, which is used to convert light energy into electrical energy. The n region of the solar cell is thin as compared to the p region unlike normal p-n junction diodes. This junction is kept in light in a way that the n region is exposed to light. The valence band electron absorbs photons and moves into the conduction band. Due to this a large number of free electrons and holes are available in n region. As the n layer is very thin, the depletion layer electric field separates the holes and electrons and forces electrons to remain in the n region and diffuse the holes in the p region . A positive potential is developed at p and negative potential is developed at n terminal and current will flow when an external resistance is added between p and n terminal. The voltage developed across terminals without load is known as open circuit voltage (VOC) is of the order of 0.5 V and the maximum load current also known as short circuit current (ISC) is of the order of few mA, which increases as the intensity of light increases and absorption of photons in solar cell increases. The direction of current inside solar cell is from n to p, hence the V-I characteristics is drawn in IV quadrant.









Application of solar cell :

The voltage developed across solar cells and the maximum load current which can be drawn from solar cells is not enough to run any device, therefore series and parallel combinations of solar cells are used for practical purposes and are known as solar panels.

Solar panels has number of engineering applications:

- Power generation
- Water filtration
- plant Solar chargers

CHAPTER 7 :

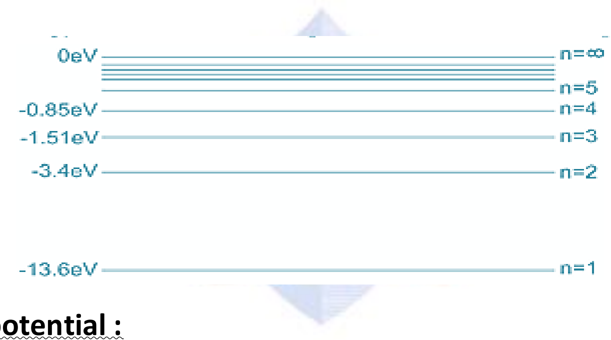
MODERN PHYSICS

LASERS :

LASER is acronym of "Light amplification by stimulated emission of radiation" and it is like other light sources such as electric bulb, CFL, tube light and lamp with some unique properties which make it different and special source of light.

Energy Level :

There is availability of energy bands for electrons present in solids and sharp energy levels for electrons in an isolated atom. Electrons in an atom transits between these levels by absorbing and releasing energy in the form of photons or of when an energetic electron collides with atom. As per Bohr theory of atoms the energy levels available for electron in an atom are discrete .The atoms of different elements will have different energy levels and the picture will be quite different . There is change in number of electrons in each type of atoms. In solids instead of sharp energy levels energy bands are available.



Ionization and Excitation potential :

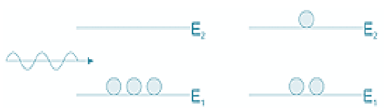
The lowest energy state available in atom for an electron is known as ground state. All the energy states above the ground level are known as excited energy states. The energy required to excite an electron from ground state to any of the excited state is known as excitation energy. The energy required to excite the electron to n = ∞ , or to knock out the electron from atom is known as ionization energy.

Spontaneous and Stimulated emission:

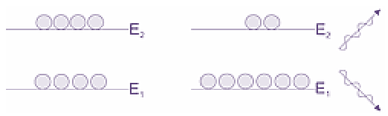
The phenomena which takes place when light interacts with matter. A photon having energy equal to the difference of energy between the excited state and the ground state can also excite the electron from ground to excited state. This phenomenon is known as optical absorption. $E = h\nu = E_2 - E_1$

The electron excited to higher energy level, has a definite lifetime in excited state and is of the order of 10^{-7} seconds. The atoms from excited state transits from excited energy level to ground level and in this process, it releases a photon of energy E2 – E1 , this phenomenon is known as spontaneous emission.

If an electron is in excited state and before transition to ground state, it interacts with photon of en ergy E2 – E1 , than it is forced to come to ground state or the photon stimulates the excited electron transit to ground state. In this process two photons identical in all respect are emitted and the phenomenon is known as stimulated emission.



optical absorption

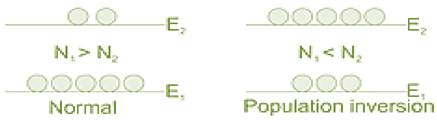


Spontaneous Emission

Stimulated Emission

Population inversion :

Laser is highly monochromatic and the there should be more and more stimulated emission to produce laser. The probability of stimulated emission is more if the electrons stay in the excited state for more time. The excited energy levels has a width , $h\Delta\nu = E_2 - E_1$

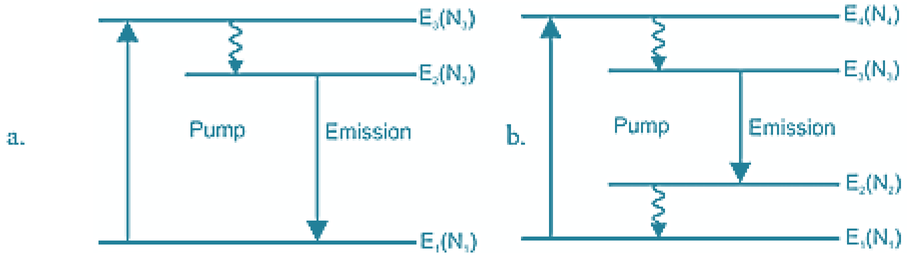


The light radiation coming out due to transition from E2 to E1 will have spectral width i.e. it consists of range of frequencies. Hence it will affect the monochromaticity. Secondly due to width of energy level the time for which the electron stays in excited state is also less. For more stimulated emission we require large number of atoms in the excited state. The excited energy level for which the width is very less are known as metastable states. The lifetime of atoms in metastable state is of the order of 10-3 sec. Hence when atoms are excited to such excited level they stay there for more time and in between, through proper mechanism, large number of atoms can be excited to this state. Such that the number of atoms in excited state is more than the number of atoms in ground state. This condition is known as population inversion (inverse to the normal condition). The presence of metastable state in energy levels of any material, make that material suitable for producing laser.

Pumping method :

Pumping method is also known as pumping scheme. To produce laser we should have stimulated emission and for stimulated emission we should have population inversion and the method with which we create population inversion is known as pumping method. Two types of pumping methods or pumping mechanism is used in lasers.

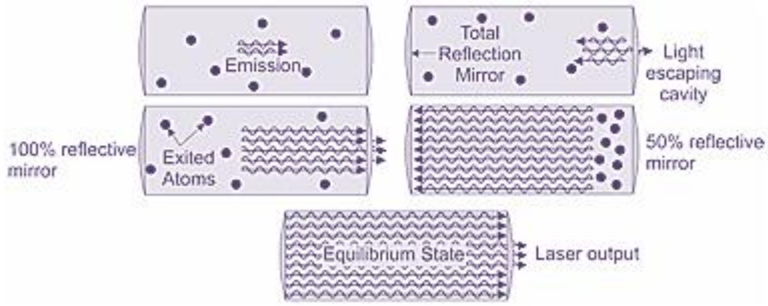
a. Three level b. Four level.



In three level pumping mechanism the atoms are excited to higher energy level above metastable state, through optical absorption or electrical excitation. The optical absorption is achieved providing external source of light radiation. The photons from external source excite the ground level atoms to exited level. Whereas in electrical excitation, energetic electrons collides with ground state atoms and excite them to excited level.

In four level pumping mechanism the atoms are excited to higher energy level above metastable state, through optical absorption or electrical excitation. The atoms from the higher energy levels transit to metastable state, where population inversion is created. From metastable state the large number of atoms transits to a unstable excited level above the ground level and this transition is amplified to produce laser. The laser light is produced due to transition between metastable state and unstable excited state. As the excited state above, ground level is unstable hence remain empty.

Optical feedback :



In lasers, the mechanism used to amplify light radiation is known as optical feedback. The material which is having metastable state or the materials whose atoms transitions create lasers is known as active medium. The active medium is kept in an optical cavity known as optical resonator. The optical resonator is a cylindrical shape glass enclosure having plane mirrors at both the ends. One mirror is 100 % reflective and another is 50% reflective. The pumping source in case of optical method is kept outsides the optical resonator.

Types of Lasers :

To create laser light source following is essentially required and are known as component of lasers:

a. Active medium: solid and gas

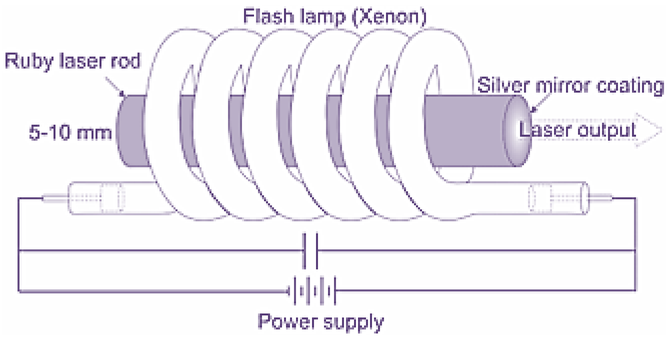
b. Pumping method: three level and four level

c. Optical resonator: As per active medium

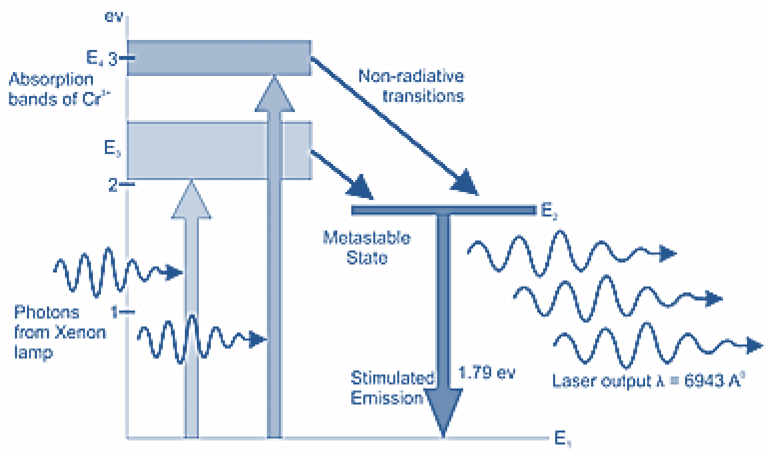
Ruby laser:

Quality	Description
Active medium	Solid: Ruby rod(Al_2O_3) doped with 0.5% Chromium atoms, Cr^{3+} (active material) Solid state laser
Pumping method	Xenon Flash lamp 80 W
Pumping scheme used	Three level
Optical resonator	The end of rod are polished act as mirror
Wavelength	6943 A°

Construction



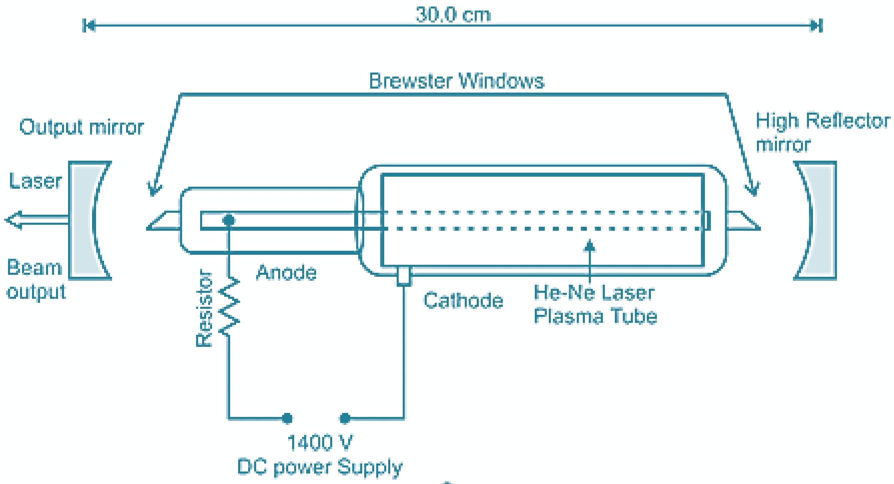
Energy level diagram



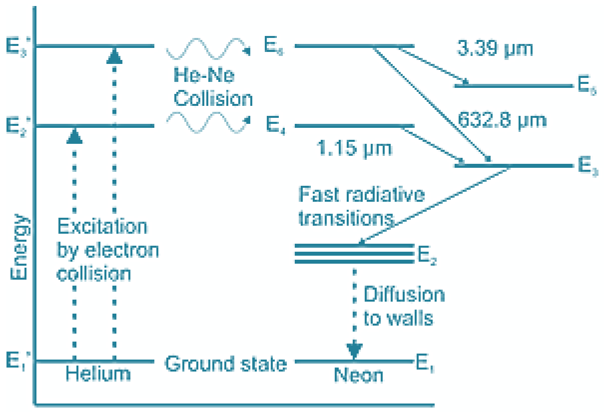
He- Ne Laser :

Quality	Description
Active medium	Gas: He: Ne (10:1) Gas Laser
Pumping method	Electrical High frequency signal
Pumping scheme used	Four level
Optical resonator	Quartz tube
Wavelength	6328A°

Working :



a.

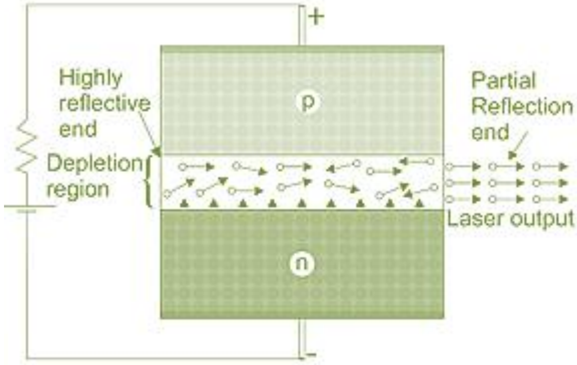


b.

By electronic discharge methods, the helium atoms are excited to E2 ′ and E3 ′ level (metastable states) through collision with electrons. These excited atoms of He collides elastically to Ne ground atoms and excite then directly to E4 and E6 levels. Ne atoms from E6 and E4 level make transitions to E3 with emission of photons and these photons travels in gas mixture. The photons traveling parallel to the axis of tube are reflected back and forth by mirror connected at the end of tube and start simulated emission of excited neon atom. This process continues and coherent radiation is built up in the tube. When the beam become sufficiently intense a portion of it come out in the form of laser.

Semiconductor laser:

Quality	**Description**
Active medium	Solid :p-n junction diode (semiconducting material- GaAs)
Pumping method	Band to band transitions
Pumping scheme used	Band to band transitions
Optical resonator	The end of depletion region is cleaved, form an optical resonator
Wavelength	6328A°



Working : The laser diode is also p-n junction diode as explained in unit 6. One of the p-n junction which is used to convert electrical energy into light energy is LED. When light emitting diode (LED) is in forward bias majority charge carriers in p-n junction combines and gives light radiation. The light which we get from LED is not coherent. The diode laser is modified version of LED. It is very much cost effective and miniature version of laser.

Laser characteristics:

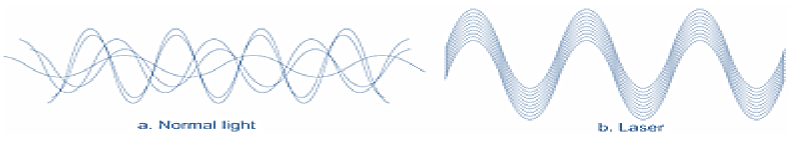
• ***Highly directional:*** Laser source emits light radiations only in one direction. It is highly directional. The ordinary source emits light radiation in all direction.

• ***Monochromatic***: Laser light is highly monochromatic, the wavelength spread of laser light is of the order of 0.01 A°, whereas ordinary light white light source has wavelength spread of 3000 A°

• ***Coherent:*** Laser light is highly coherent. We can observe interference phenomena bylaser beam. All the waves composing laser beam have same phase.

• ***Divergence:*** The divergence or angular spread of laser beam is very small as compare to conventional light sources. The laser beam travel large distance with almost same beam size.

• ***High intensity:*** In laser beam the energy is concentrated in a very small region. The keychain laser or the laser used in laboratory, having milli watt power, but still damage our eye on direct exposure.



Engineering and medical applications of lasers :

• **Bar code readers:** To read data using barcode technology, it must first be scanned with a laser and then ana lysed. Scanners, often known as lasers, are used to read barcodes. They measure the light reflected by linear barcode technology and can tell the difference between white and black lines.

• CD/DVD Player: CD/ DVD player, consists of miniature laser beam (a semiconductor diode laser) and a small photo cell. A CD/DVD player reads digital information stored on a CD/DVD in the form “bumps” and “pits” near its surface to encode digital or binary data. Laser that falls on a bump is reflected but light that strikes on “pit” not reflected, hence the digital signal is encoded with corresponding reflection in photocell.

• **Computer printers:** In laser printer, laser beam is used to transfer the pattern of image or text on a negatively charged drum. The areas where, laser is not passed is positively charged and attracts the negatively charged toner to create the replica of image on paper.

• Laser shows: High power different coloured laser beam is used in laser shows.

• **Holography:** Hologram is a 3 D image of object uses coherent property of laser used. Now a days, 3D image of person can be created at distant place by using digital holography.

• **Position and motion control:** Laser light reflection is used for precise motion control.

•**Fibre optic communications:** As optical fibre uses light signal for transmission, diode lasers are used to convert digital signal into optical signal.

• **Material processing:** As the size of laser beam is very small and having high power, precise metal cutting can be done with the help of lasers. Lasers is also used to make pattern on metal surface.

• **Medical:** Infrared lasers are used to remove a very thin layer of skin (0.1 mm). They take advantage of the presence of water in the skin to provide a capacity to remove skin and body tissue in the absence of pigment in general. Laser hair removal is one of the most common application in cosmetic procedures. Laser beams fall on hair follicles. Pigment in the follicles absorb the light. This absorption destroys the hair. For retina operation, visible laser is used. Visible light is transparent to the cornea and crystalline lens can be focused with eye's lens on the retina. The most popular visible laser is the green argon laser. Blood less surgery can be done by using Laser. Lasers are useful in cancer diagnosis.

FIBER OPTICS :

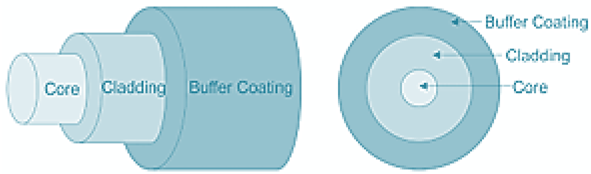
The optical fibre has brought revolution in communication systems and have number of other engineering applications. The branch of physics related with the science and technology used in optical fibre is known as Fibre optics.

Introduction to optical Fibres :

Optical fibres are fibres or wire type cylindrical structures made up of glass or silica. It is also known as fibre of glasses. As glass is transparent material and allow light wave to pass through it and act as insula tor, similarly optical fibres allows light signals to pass through it and as insulator it does not catches any electromagnetic wave as noise.

Optical fibres consists of

- Solid cylindrical glass rod called the core, through which light in the form of light or optical signal propagates. Diameter of core is 5 micrometres to 100 micrometres.
- Surrounded by another coaxial cylindrical structure made of glass of lower refractive index called the cladding. The diameter of cladding is usually 125 micrometres.
- Protective covering : To provide mechanical strength to this core-cladding arrangement, other coaxial surrounding called the buffer coating and jacketing. Buffer jacket diameter is around 250 micrometres.

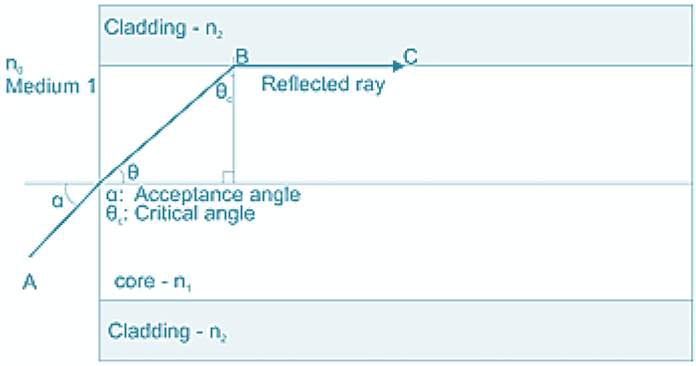


Light propagation, acceptance angle and numerical aperture :

The light wave propagates in optical fibre with total internal reflection (TIR) phenomenon.

Applying Snell's law at the medium1-core interface, $n_0 \sin\alpha = n_1 \sin\theta$

after substitution for θ, $\theta = \frac{\pi}{2} - \theta_c$



$$\sin\alpha = \frac{n_1}{n}\cos\theta_c$$

$$\cos\theta_c = \sqrt{1-\sin^2\theta_c}$$

$$\sin\theta_c = \frac{n_2}{n_1}$$

$$\cos\theta_c = \sqrt{1-\frac{n_2^2}{n_1^2}}$$

$$\sin\alpha = \frac{\sqrt{n_1^2 - n_2^2}}{n_0}$$

Fibre types :

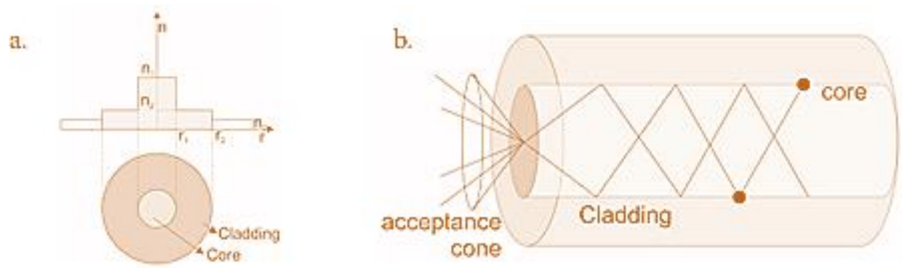
Optical fibre can be broadly classified, based on two factors and they are:

- Refractive index profile
- Number of modes

Refractive index profile :

Based on refractive index profile the fibre can be divided in two categories:

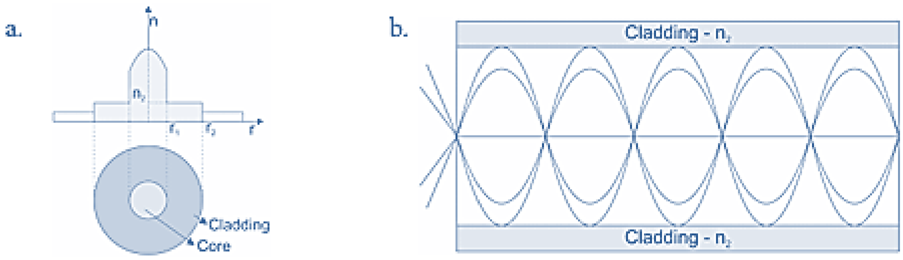
(a) Step index fibre:



In step index fibre, the light rays propagate in straight lines through TIR. The light ray entering at same time in step index fibre at different angles of incidence travel different path in fibre and emerges out in different times in and this phenomenon known as pulse dispersion. The rays which enters with more angle of incidence travel more distance as compared to the rays entering with less angle of incidence.

(b) Graded index fibre:

When a light ray enters in graded index fibre, due to gradual variation in refractive index from core axis to core cladding interface the light rays move in curved path instead of straight path. The rays which enters fibre with more angle of incidence travel more distance in the region where refractive index is less, hence more velocity and less time as compare to the rays entering with less angle of incidence. The path of travelling for the two rays having different angle of incidence is different but the time taken for both rays to emerge out from fibre is same. The pulse dispersion is low in Graded index fibre.



<u>**Number of modes :**</u>

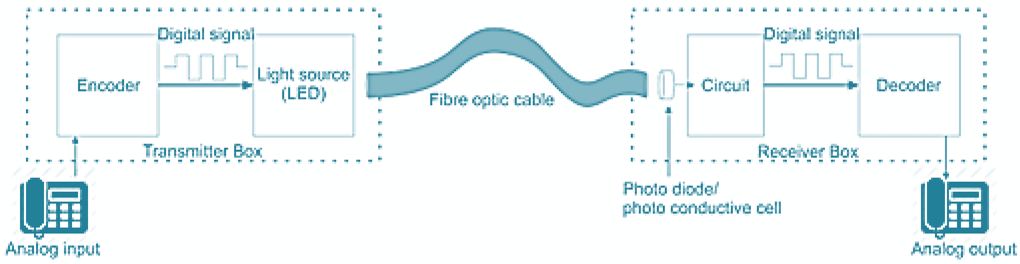
Based on mode of propagation of light the optical fibres can be divided in two categories:

- Single mode fibres
- Multimode fibres

(a) ***Single mode fibre:*** In single mode fibre only one mode of light propagation is allowed for light propagation in fibre. The diameter of core is 5 micrometre and cladding diameter is around 50 micrometres. It is step index fibre. Fabrication of such fibre is very difficult. As there is only single mode there is no pulse dispersion. It is suitable for long distance communication.

(b) ***Multi-mode fibre :*** Number of modes is allowed for light propagation in multimode fibre. The diameter of core is 50 micrometre and cladding diameter is around 100 micrometres. Multi-mode fibre can be a step index fibre or graded index. As there are number of modes allowed in this fibre, there is pulse dispersion in fibre (which can be minimized in case of graded index fibres). The fabrication of multimode fibre is less difficult as compare to Single mode fibre.

<u>**Applications in telecommunication, medical and sensors :**</u>



schematic of optical fibre communication systems and it has following advantages over other communication systems:

- More information carrying capacity
- Smaller size and weight
- Availability of raw material for fibre.
- Faster signal propagation
- External light could not enter fibre as it is well protected.
- No external electromagnetic signal pickup as fibre is non-metallic.
- Corrosion is less severe than copper wire

Medical applications:

- **Endoscope:** Internal organs and tissues can be seen through bodily orifices by using endoscope made up of multifibre . Endoscopes are used by doctors to explore symptoms including nausea and gastrointestinal pain, confirm diagnosis using biopsies, and give medical treatment.

Sensors:

Fibre optic sensors are used as transducers for various physical phenomena such as strain and temperature measurements. Fibre sensors are specially designed sensors in which there is shift in the frequency of the incident and reflected wave on applying pressure and temperature. Theses sensors work in extreme conditions where normal sensors cannot be used. Fibre based High voltage and high current sensors can be used in extreme harsh conditions. As fibre is insulator there is immunity to electromagnetic interference.

NANOSCIENCE AND NANOTECHNOLOGY: INTRODUCTION

The concept of nanotechnology was first introduced by famous physicist and Noble laureates Richard Feynman's. As per his quotes "The principle of physics as far as I can see do not speak against the possibility of manoeuvring things atom by atom. In principle it can be done but in practice it has not been done" and "There is plenty of room at the bottom". Eric Drexler has introduced the term nanotechnology in his book "engine of creation". Drexler make direct comparison between macroscopic machine part and component of biological cell.

Nanoparticles and nanomaterial:

Nano word taken form the Greek word "dwarf" and means 10-9, or one billionth. In present context Nano refers to 10-9 meters, or 1 nanometre (nm) and also

1nm = 1/1,00,00,00,000 meter or one billionth of a meter

1millimeter = (1/1000) meter

1micrometer = (1/1000) millimetre

1nanometer = (1/1000) micrometre

Nano materials are materials having dimensions in Nano Scale (10-9 m) or at least one dimension in Nano scale.

Properties at Nano scale :

• Melting point depression

Reduction of melting point of a material with size

• Lattice Constant

Lattice constant of nanoparticle depends on size and shape.

• Mechanical properties

High stiffness and high strength Density of defects in nanotubes is less Deformation

•Electrical Properties

Metals become insulator CNT shows semiconducting and metallic property

•Optical Properties

Gold nanoparticles are green ,Semiconducting nanoparticle absorption (Tuneable)

• Inactive to more chemically active ,Metallic to non metallic and Ferro magnetic to paramagnetic.

Nanotechnology:

Top down: Approach to the Nano scale dimension starting with the bulk scale materials by physical breaking of the source material through high energy processes. Example : Ball milling, Mechanical attrition.

Bottom up: Approach to the Nano scale dimension starting with the atomic scale materials by chemical method and other synthesis processes. Example: chemical precipitation, Chemical vapour deposition.

Nanotechnology based devices and applications:

Sensors: Sensors based on nanotechnology can detect very minute amounts of chemical vapours. In nanotechnology -based sensors, several types of detecting elements, such as carbon nanotubes, zinc oxide nanowires, can be used. Nanotubes, nanowires, and nanoparticles are so small, only a few gas molecules are needed to affect the electrical characteristics of the sensing element.

Solar Cell : Silver nanowires, titanium dioxide nanoparticles, and an infrared-absorbing polymer are combined to create a solar cell that is roughly 70% transparent to visible light. low-cost and high-efficiency flexible solar cells can be produced by using nanowires covered with zinc oxide. Combination of carbon nanotubes and buck balls is used to produce solar cells.

Batteries: Increasing the battery's available power and reducing the charging time are the two requirements for good batteries. Nanoparticles are coated on the surface of an electrode to provide these benefits. This increases the electrode's surface area, allowing more current to pass between the electrode and the battery's chemicals. ***Fuel cell*** : Nanotechnology is being utilized in fuel cells to lower the cost of catalysts that make hydrogen ions from fuels like methanol and to enhance the efficiency of membranes that separate hydrogen ions from other gases like oxygen.

Nanometre size devices:

SET The single electron transistor (SET) is a new type of switching device that uses controlled electron tunnelling to amplify current. The dimensions of SET are in nanometre range.

Quantum well and quantum dot laser: Quantum well and quantum dot lasers are semiconductor lasers that uses quantum dots and quantum well as the active laser medium in the light emitting region.