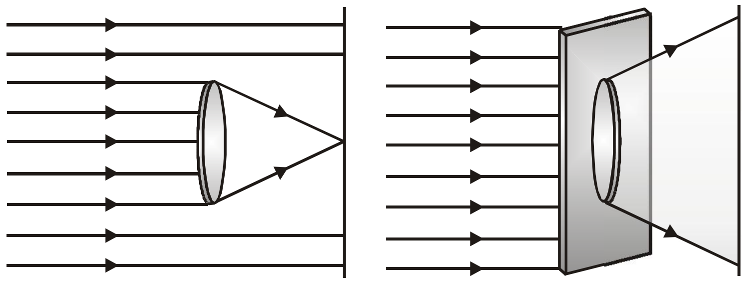
DIFFRACTION OF LIGHT

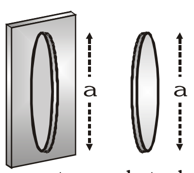
Bending of light rays from sharp edges of an opaque obstacle or aperture and its spreading in the eometricle shaddow region is defined as diffraction of light or deviation of light from its rectilinear propogation tendency is defined as diffraction of light.

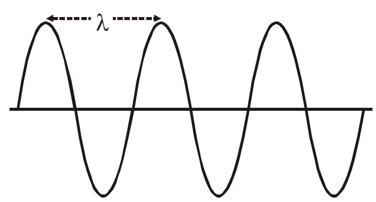


- Diffraction was discovered by Grimaldi
- Theoritically explained by Fresnel
- Diffraction is possible in all type of waves means in mechanical or electromagnetic waves shows diffraction.

Diffraction depends on two factors :

(i) Size of obstacles or aperture (ii) Wave length of the wave



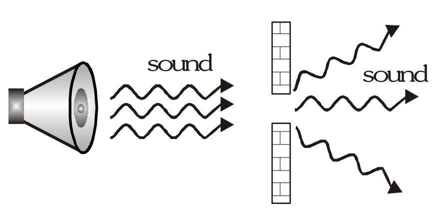


Condition of diffraction Size of obstacle or aperture should be nearly equal to the wave length of light

$\lambda \simeq a \qquad \frac{a}{\lambda} \simeq 1$

If size of obstacle is much greater than wave length of light, then rectilinear motion of light is observed.

- It is practically observed when size of aperture or obstacle is greater than 50 λ then obstacle or aperature does not shows diffraction.
- Wave length of light is in the order 10^{-7} m. In general obstacle of this wave length is not present so light rays does not show diffraction and it appears to travel in straight line Sound wave shows more diffraction as compare to light rays because wavelength of sound is high (16 mm to 16m). So it is generally diffracted by the objects in our daily life.
- Diffraction of ultrasonic wave is also not observed as easily as sound wave because their wavelength is of the order of about 1 cm. Diffraction of radio waves is very conveniently observed because of its very large wavelength (2.5 m to 250 m). X-ray can be diffracted easily by crystel. It was discovered by Lave.



diffraction of sound from a window

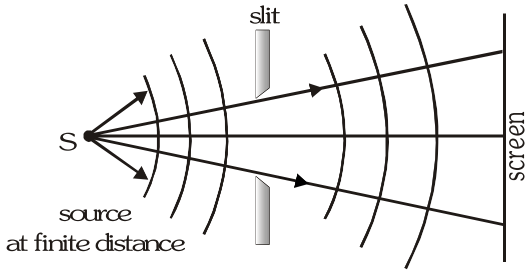
TYPES OF DIFFRACTION

(i) There are two type of diffraction of light : (a) Fresnel's diffraction. (b) Fraunhofer's diffraction.

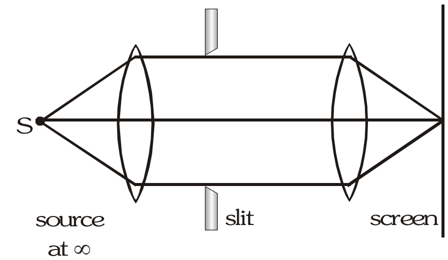
(a) Fresnel diffraction

If either source or screen or both are at finite distance from the diffracting device (obstacle or aperture), the diffraction is called fresnel diffraction and the pattern is the shadow of the diffracting device modified by diffraction effect.

Example :- Diffraction at a straight edge, small opaque disc, narrow wire are examples of fresnel diffraction.



Fresnel's diffraction



Fraunhofer's diffraction

(b) Fraunhofer diffraction

Fraunhofer diffraction is a particular limiting case of fresnel diffraction.In this case, both source and screen are effectively at infinite distance from the diffracting device and pattern is the image of source modified by diffraction effects.

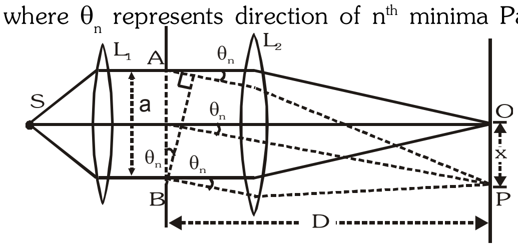
Example :- Diffraction at single slit, double slit and diffraction grating are the examples of fraunhofer diffraction.

Comparison between fresnel and fraunhofer diffraction

	Fresnel Diffraction	Fraunhofer Diffraction
(a)	Source and screen both are at finite distance from the diffractor.	Source and screen both are at infinite distance from the diffractor.
(b)	Incident and diffracted wave fronts are spherical or cylinderical.	Incident and diffracted wavefronts are plane due to infinite distance from source.
(c)	Mirror or lenses are not used for obtaining the diffraction pattern.	Lens are used in this diffraction pattern.
(d)	Centre of diffraction pattern is sometime bright and sometime dark depending on size of diffractor and distance of observation point.	Centre of diffraction is always bright.
(e)	Amplitude of wave coming from different half period zones are different due to difference of obliquity.	Amplitude of waves coming from different half period zones are same due to same obliquity.

FRAUNHOFER DIFFRACTION DUE TO SINGLE SLIT

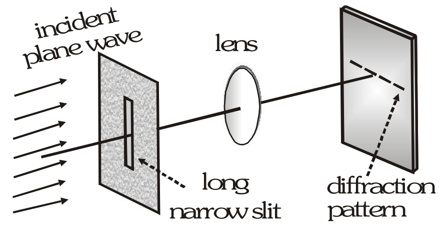
AB is single slit of width a, Plane wavefront is incident on a slit AB. Secondary wavelets coming from every part of AB reach the axial point P in same phase forming the central maxima. The intensity of central maxima is maximum in this diffrection. where θ_n represents direction of n^{th} minima Path difference BB' = a sin θ_n



for n^{th} minima $a \sin \theta_n = n\lambda$ $\therefore$ $\sin\theta_n \approx \theta_n = \dfrac{n\lambda}{a}$ (if θ_n is small)

- When path difference between the secondary wavelets coming from A and B is $n\lambda$ or $2n\left[\frac{\lambda}{2}\right]$ or even multiple of $\frac{\lambda}{2}$ then minima occurs

  For minima $a\sin\theta_n = 2n\left[\frac{\lambda}{2}\right]$ where n = 1, 2, 3 ...



- When path difference between the secondary wavelets coming from A and B is $(2n+1)\frac{\lambda}{2}$ or odd multiple of $\frac{\lambda}{2}$ then maxima occurs

  For maxima $a\sin\theta_n = (2n+1)\frac{\lambda}{2}$ where n = 1, 2, 3 ...

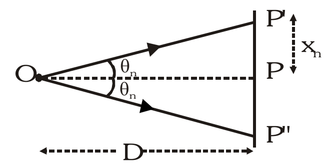
  n = 1 $\rightarrow$ first maxima and n = 2 $\rightarrow$ second maxima

- In alternate order minima and maxima occurs on both sides of central maxima.

  For n^{th} minima

  If distance of n^{th} minima from central maxima = x_n

  distance of slit from screen = D , width of slit = a



  Path difference $\delta = a\sin\theta_n = \frac{2n\lambda}{2} \Rightarrow \sin\theta_n = \frac{n\lambda}{a}$

  In Δ POP' $\tan\theta_n = \frac{x_n}{D}$ If θ_n is small $\Rightarrow \sin\theta_n \approx \tan\theta_n \approx \theta_n$

  $x_n = \frac{n\lambda D}{a} \Rightarrow \theta_n = \frac{x_n}{D} = \frac{n\lambda}{a}$ First minima occurs both sides on central maxima.

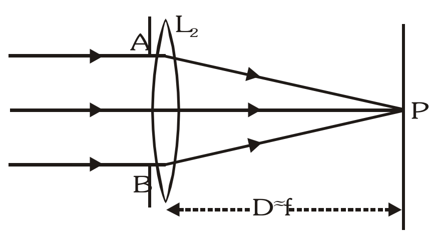
  For first minima $x = \frac{D\lambda}{a}$ and $\theta = \frac{x}{D} = \frac{\lambda}{a}$

- Linear width of central maxima $w_x = 2x \Rightarrow w_x = \frac{2D\lambda}{a}$

- Angular width of central maxima $w_\theta = 2\theta = \frac{2\lambda}{a}$

SPECIAL CASE

Lens L_2 is shifted very near to slit AB. In this case distance between slit and screen will be nearly equal to the focal length of lense L_2 (i.e. D $\approx$ f) $\theta_n = \frac{x_n}{f} = \frac{n\lambda}{a} \Rightarrow x_n = \frac{n\lambda f}{a}$



$w_x = \frac{2\lambda f}{a}$ and angular width of central maxima $w_B = \frac{2x}{f} = \frac{2\lambda}{a}$

Fringe width : Distance between two consecutive maxima (bright fringe) or minima (dark fringe) is known as fringe width. Fringe width of central maxima is doubled then the width of other maximas i.e.,

$$\beta = x_{n+1} - x_n = (n+1)\frac{\lambda D}{a} - \frac{n\lambda D}{a} = \frac{\lambda D}{a}$$

Intensity curve of Fraunhofer's diffraction

Intensity of maxima in Fraunhofer's diffrection is determined by

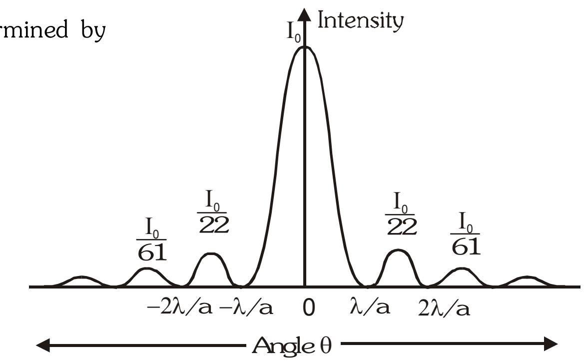
$$I = \left[\frac{2}{(2n+1)\pi}\right]^2 I_0$$

I_0 =intensity of central maxima

n = order of maxima

intensity of first maxima $I_1 = \frac{4}{9\pi^2}I_0 \approx \frac{I_0}{22}$

intensity of second maxima $I_2 = \frac{4}{25\pi^2}I_0 \approx \frac{I_0}{61}$



☯ *Diffraction occurs in slit is always fraunhofer diffraction as diffraction pattern obtained from the cracks between the fingers, when viewed a distant tubelight and in YDSE experiment are fraunhofer diffraction.*

GOLDEN KEY POINTS

- The width of central maxima $\propto \lambda$, that is, more for red colour and less for blue.

  i.e., $w_x \propto \lambda$ as $\lambda_{blue} < \lambda_{red} \Rightarrow w_{blue} < w_{red}$
- For obtaining the fraunhofer diffraction, focal length of second lens (L_2) is used.

  $w_x \propto \lambda \propto f \propto 1/a$ width will be more for narrow slit
- By decreasing linear width of slit, the width of central maxima increase.

RESOLVING POWER (R.P.)

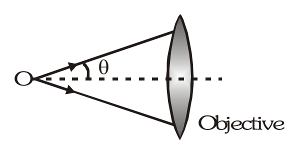
A large number of images are formed as a consequence of light diffraction from a source. If two sources are separated such that their central maxima do not overlap, their images can be distinguished and are said to be resolved R.P. of an optical instrument is its ability to distinguish two neighbouring points.

Linear R.P. = $d/\lambda D$ here D = Observed distance

Angular R.P. = d/λ d = Distance between two points

(1) **Microscope** : In reference to a microscope, the minimum distance between two lines at which they are just distinct is called Resolving limit (RL) and it's reciprocal is called Resolving power (RP)

$$\text{R.L.} = \frac{\lambda}{2\mu\sin\theta} \text{ and } \text{R.P.} = \frac{2\mu\sin\theta}{\lambda} \Rightarrow \text{R.P.} \propto \frac{1}{\lambda}$$



λ = Wavelength of light used to illuminate the object

μ = Refractive index of the medium between object and objective,

θ = Half angle of the cone of light from the point object, $\mu\sin\theta$ = Numerical aperture.

(2) **Telescope** : Smallest angular separations ($d\theta$) between two distant object, whose images are separated in the telescope is called resolving limit. So resolving limit $d\theta = \frac{1.22\lambda}{a}$ and resolving power

$$(\text{RP}) = \frac{1}{d\theta} = \frac{a}{1.22\lambda} \Rightarrow \text{R.P.} \propto \frac{1}{\lambda}$$ where a = aperture of objective.

Example

Light of wavelength 6000Å is incident normally on a slit of width 24 10^{-5} cm. Find out the angular position of second minimum from central maximum ?

Sol. a $\sin\theta = 2\lambda$ given $\lambda = 6$ 10^{-7} m, a = 24 10^{-5} 10^{-2} m

$$\sin\theta = \frac{2\lambda}{a} = \frac{2\times 6\times 10^{-7}}{24\times 10^{-7}} = \frac{1}{2} \qquad \therefore \qquad \theta = 30$$

Example

Light of wavelength 6328Å is incident normally on a slit of width 0.2 mm. Calculate the angular width of central maximum on a screen distance 9 m ?

Sol. given $\lambda = 6.328$ 10^{-7} m, a = 0.2 10^{-3} m

$$w_\theta = \frac{2\lambda}{a} = \frac{2\times 6.328\times 10^{-7}}{2\times 10^{-4}}\text{ radian} = \frac{6.328\times 10^{-3}\times 180}{3.14} = 0.36$$

Example

Light of wavelength 5000Å is incident on a slit of width 0.1 mm. Find out the width of the central bright line on a screen distance 2m from the slit ?

Sol. $$w_x = \frac{2f\lambda}{a} = \frac{2\times 2\times 5\times 10^{-7}}{10^{-4}} = 20 \text{ mm}$$

Example

The fraunhofer diffraction pattern of a single slit is formed at the focal plane of a lens of focal length 1m. The width of the slit is 0.3 mm. If the third minimum is formed at a distance of 5 mm from the central maximum then calculate the wavelength of light.

Sol. $$x_n = \frac{nf\lambda}{a} \Rightarrow \qquad \lambda = \frac{ax_n}{fn} = \frac{3\times 10^{-4}\times 5\times 10^{-3}}{3\times 1} = 5000\text{Å} \qquad [\because \ n = 3]$$

Example

Find the half angular width of the central bright maximum in the Fraunhofer diffraction pattern of a slit of width 12 10^{-5} cm when the slit is illuminated by monochromatic light of wavelength 6000 Å.

Sol. $\because$ $\sin\theta = \dfrac{\lambda}{a}$ θ = half angular width of the central maximum.

a = 12 10^{-5} cm, λ = 6000 Å = 6 10^{-5} cm $\therefore$ $\sin\theta = \dfrac{\lambda}{a} = \dfrac{6\times 10^{-5}}{12\times 10^{-5}} = 0.50$ $\Rightarrow \theta = 30$

Example

Light of wavelength 6000 Å is incident on a slit of width 0.30 mm. The screen is placed 2 m from the slit. Find (a) the position of the first dark fringe and (b) the width of the central bright fringe.

Sol. The first fringe is on either side of the central bright fringe.

here   n = ±1, D = 2 m, λ = 6000 Å = 6 10^{-7} m

$\therefore$ $\sin\theta = \dfrac{x}{D}$ $\Rightarrow$ a = 0.30 mm = 3 10^{-4} m $\Rightarrow$ a $\sin\theta = n\lambda \Rightarrow \dfrac{ax}{D} = n\lambda$

(a) $x = \dfrac{n\lambda D}{a}$ $\Rightarrow$ $x = \pm\left[\dfrac{1\times 6\times 10^{-7}\times 2}{3\times 10^{-4}}\right] = \pm 4\times 10^{-3}\text{m}$

The positive and negative signs corresponds to the dark fringes on either side of the central bright fringe.

(b)   The width of the central bright fringe y = 2x = 2   4 10^{-3} = 8 10^{-3} m = 8 mm

DIFFERENCE BETWEEN INTERFERENCE AND DIFFRACTION :

	Interference	Diffraction
(1)	It is the phenomenon of superposition of two waves coming from two different coherent sources.	(1) It is the phenomenon of superposition of two waves coming from two different parts of the same wave front.
(2)	In interference pattern, all bright lines are equally bright and equally spaced.	(2) All bright lines are not equally bright and equally wide. Brightness and width goes on decreasing with the angle of diffraction.
(3)	All dark lines are totally dark	(3) Dark lines are not perfectly dark. Their contrast with bright lines and width goes on decreasing with angle of diffraction.
(4)	In interference bands are large in number	(4) In diffraction bands are a few in number

Example

A Slit of width a is illuminated by monochromatic light of wavelength 650nm at normal incidence. Calculate the value of a when -

(a) the first minimum falls at an angle of diffraction of 30

(b) the first maximum falls at an angle of diffraction of 30 .

Sol. (a) for first minimum $\sin\theta_1 = \frac{\lambda}{a}$ $\quad \therefore a = \frac{\lambda}{\sin\theta_1} = \frac{650\times10^{-9}}{\sin 30°} = \frac{650\times10^{-9}}{0.5} = 1.3 \quad 10^{-6}$m

(b) For first maximum $\sin\theta_1 = \frac{3\lambda}{2a}$ $\quad \therefore \quad a = \frac{3\lambda}{2\sin\theta} = \frac{3\times650\times10^{-9}}{2\times0.5} = 1.95 \quad 10^{-6}$m

Example

Red light of wavelength 6500Å from a distant source falls on a slit 0.50 mm wide. What is the distance between the first two dark bands on each side of the central bright of the diffraction pattern observed on a screen placed 1.8 m. from the slit.

Sol. Given λ = 6500Å = 65 $\quad 10^{-8}$ m, a = 0.5 mm = 0.5 $\quad 10^{-3}$ m., D = 1.8 m.

Required distance between first two dark bands will be equal to width of central maxima.

$$W_x = \frac{2\lambda D}{a} = \frac{2\times6500\times10^{-10}\times1.8}{0.5\times10^{-3}} = 468 \quad 10^{-5}\text{ m} = 4.68\text{ mm}$$

Example

In a single slit diffraction experiment first minimum for λ_1 = 660 nm coincides with first maxima for wavelength λ_2. Calculate λ_2.

Sol. For minima in diffraction pattern $\quad d\sin\theta = n\lambda$

For first minima $\quad d\sin\theta_1 = (1)\lambda_1 \Rightarrow \sin\theta_1 = \frac{\lambda_1}{d}$

For first maxima $\quad d\sin\theta_2 = \frac{3}{2}\lambda_2 \Rightarrow \sin\theta_2 = \frac{3\lambda_2}{2d}$

The two will coincide if, $\theta_1 = \theta_2$ or $\sin\theta_1 = \sin\theta_2$

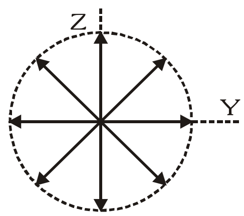
$$\therefore \quad \frac{\lambda_1}{d} = \frac{3\lambda_2}{2d} \Rightarrow \lambda_2 = \frac{2}{3}\lambda_1 = \frac{2}{3} \quad 660\text{ nm} = 440\text{ nm.}$$

POLARISATION

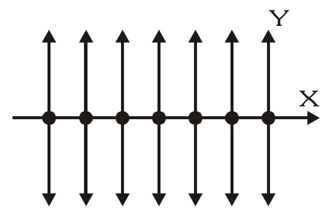
Experiments on interference and diffraction have shown that light is a form of wave motion. These effects do not tell us about the type of wave motion i.e., whether the light waves are longitudinal or transverese.
The phenomenon of polarization has helped to establish beyond doubt that light waves are transverse waves.

UNPOLARISED LIGHT

An ordinary beam of light consists of a large number of waves emitted by the atoms of the light source. Each atom produces a wave with its own orientation of electric vector $\vec{E}$ so all direction of vibration of $\vec{E}$ are equally probable.



unpolarised light propagating along . X-axis



unpolarised light

The resultant electromagnetic wave is a super position of waves produced by the individual atomic sources and it is called unpolarised light. In ordinary or unpolarised light, the vibrations of the electric vector occur symmetrically in all possible directions in a plane perpendicular to the direction of propagation of light.

POLARISATION

The phenomenon of restricting the vibration of light (electric vector) in a particular direction perpendicular to the direction of propagation of wave is called polarisation of light. In polarised light, the vibration of the electric vector occur in a plane perpendicular to the direction of propagation of light and are confined to a single direction in the plane (do not occur symmetrically in all possible directions). After polarisation the vibrations become asymmetrical about the direction of propagation of light.

POLARISER

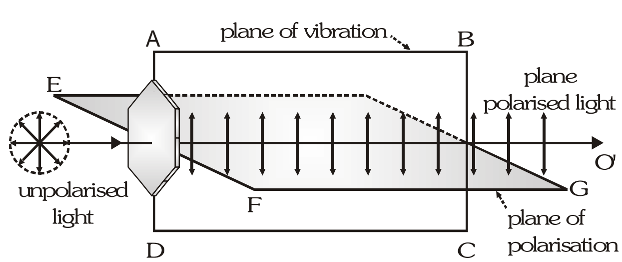
Tourmaline crystal : When light is passed through a tomaline crystal cut parallel to its optic axis, the vibrations of the light carrying out of the tourmaline crystal are confined only to one direction in a plane perpendicular to the direction of propagation of light. The emergent light from the crystal is said to be plane polarised light.

Nicol Prism : A nicol prism is an optical device which can be used for the production and detection of plane polarised light. It was invented by William Nicol in 1828.

Polaroid : A polaroid is a thin commercial sheet in the form of circular disc which makes use of the property of selective absorption to produce an intense beam of plane polarised light.

PLANE OF POLARISATION AND PLANE OF VIBRATION :

The plane in which vibrations of light vector and the direction of propogation lie is known as plane of vibration A plane normal to the plane of vibration and in which no vibration takes place is known as plane of polarisation



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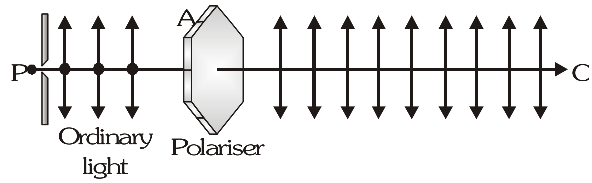
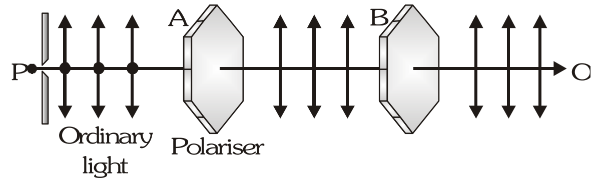
EXPERIMENTAL DEMONSTRATION OF POLARISATION OF LIGHT

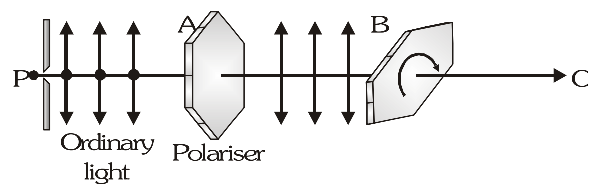
Take two tourmaline crystals cut parallel to their crystallographic axis (optic axis).



First hold the crystal A normally to the path of a beam of colour light. The emergent beam will be slightly coloured. Rotate the crystal A about PO. No change in the intensity or the colour of the emergent beam of light. Take another crystal B and hold it in the path of the emergent beam of so that its axis is parallel to the axis of the crystal A. The beam of light passes through both the crystals and outcoming light appears coloured.



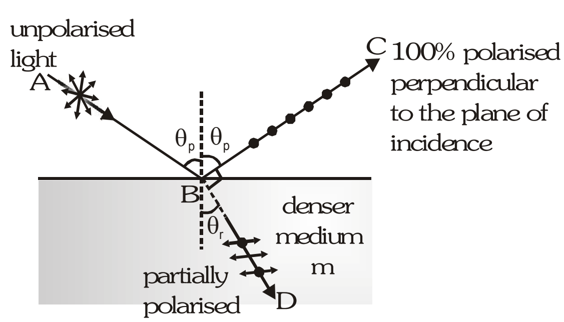
Now, rotate the crystal B about the axis PO. It will be seen that the intensity of the emergent beam decreases and when the axes of both the crystals are at right angles to each other no light comes out of the crystal B.



If the crystal B is further rotated light reappears and intensity becomes maximum again when their axes are parallel. This occurs after a further rotation of B through 90 . This experiment confirms that the light waves are transverse in nature. The vibrations in light waves are perpendicular to the direction of propogation of the the wave. First crystal A polarises the light so it is called polariser. Second crystal B, analyses the light whether it is polarised or not, so it is called analyser.

METHODS OF OBTAINING PLANE POLARISED LIGHT

- **Polarisation by reflection :** The simplest method to produce plane polarised light is by reflection. This method was discovered by Malus in 1808. When a beam of ordinary light is reflected from a surface, the reflected light is partially polarised. The degree of polarisation of the polarised light in the reflected beam is greatest when it is incident at an angle called polarising angle or Brewster's angle.



- **Polarising angle** : Polarising angle is that angle of incidence at which the reflected light is completely plane polarisation.
- **Brewster's Law** : When unpolarised light strikes at polarising angle θ_P on an interface separating a rare medium from a denser medium of refractive index μ , such that $\mu = \tan\theta_P$ then the reflected light (light in rare medium) is completely polarised. Also reflected and refracted rays are normal to each other. This relation is known as Brewster's law. The law state that the tangent of the polarising angle of incidence of a transparent medium is equal to its refractive index $\mu = \tan\theta_P$

In case of polarisation by reflection :

(i) For $i = \theta_P$ refracted light is partially polarised.

(ii) For $i = \theta_P$ reflected and refracted rays are perpendicular to each other.

(iii) For $i < \theta_P$ or $i > \theta_P$ both reflected and refracted light become partially polarised.

According to snell's law $\mu = \dfrac{\sin\theta_p}{\sin\theta_r}$ ....(i)

But according to Brewster's law $\mu = \tan\theta_p = \dfrac{\sin\theta_p}{\cos\theta_p}$ ....(ii)

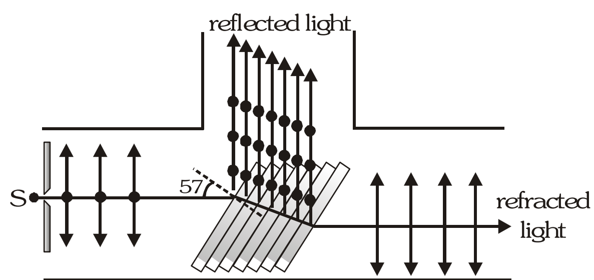
From equation (i) and (ii) $\dfrac{\sin\theta_p}{\sin\theta_r} = \dfrac{\sin\theta_p}{\cos\theta_p} \Rightarrow \sin\theta_r = \cos\theta_p$

$\therefore \sin\theta_r = \sin(90 - \theta_p) \Rightarrow \theta_r = 90 - \theta_p$ or $\theta_p + \theta_r = 90$

Thus reflected and refracted rays are mutually perpendicular

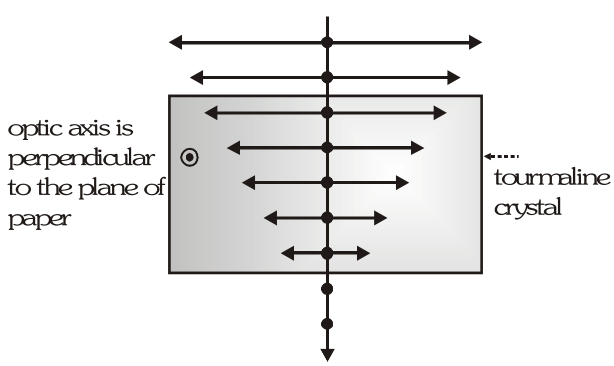
By Refraction

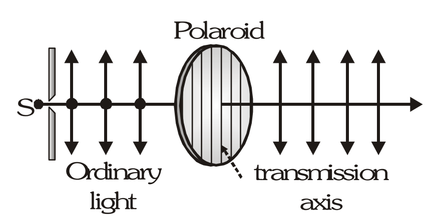
In this method, a pile of glass plates is formed by taking 20 to 30 microscope slides and light is made to be incident at polarising angle 57 . According Brewster law, the reflected light will be plane polarised with vibrations perpendicular to the plane of incidence and the transmitted light will be partially polarised. Since in one reflection about 15% of the light with vibration perpendicular to plane of paper is reflected therefore after passing through a number of plates emerging light will become plane polarised with vibrations in the plane of paper.



By Dichroism

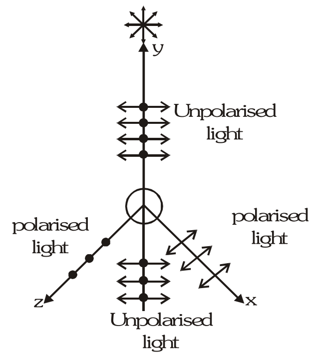
Some crystals such as tourmaline and sheets of iodosulphate of quinone have the property of strongly absorbing the light with vibrations perpendicular of a specific direction (called transmision axis) and transmitting the light with vibration parallel to it. This selective absorption of light is called dichroism. So if unpolarised light passes through proper thickness of these, the transmitted light will plane polarised with vibrations parallel to transmission axis. Polaroids work on this principle.





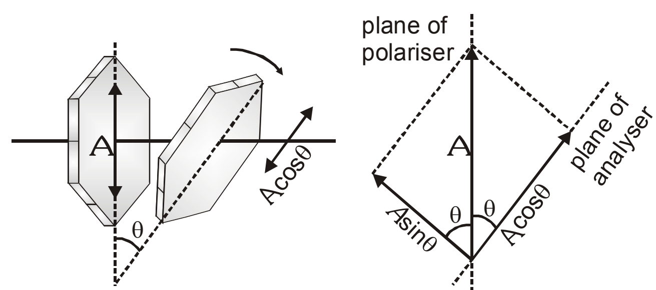
By scattering :

When light is incident on small particles of dust, air molecule etc. (having smaller size as compared to the wavelength of light), it is absorbed by the electrons and is re-radiated in all directions. The phenomenon is called as scattering. Light scattered in a direction at right angles to the incident light is always plane-polarised.



Law of Malus

When a completely plane polarised light beam light beamis incident analyser, then intensity intensity of emergent light varies as the square of cosine of the angle between the planes of transmission of the analyser and the polarizer. $I \propto \cos^2\theta \Rightarrow I = I_0 \cos^2\theta$



(i) If $\theta = 0$ then $I = I_0$ maximum value (Parallel arrangement)

(ii) If $\theta = 90$ then $I = 0$ minimum value (Crossed arrangement)

If plane polarised light of intensity $I_0(= KA^2)$ is incident on a polaroid and its vibrations of amplitude A make angle θ with transmission axis, then the component of vibrations parallel to transmission axis will be $A\cos\theta$ while perpendicular to it will be $A\sin\theta$.

Polaroid will pass only those vibrations which are parallel to transmission axis i.e. $A\cos\theta$, $\because I_0 \propto A^2$

So the intensity of emergent light $I = K(A\cos\theta)^2 = KA^2\cos^2\theta$

If an unpolarised light is converted into plane polarised light its intensity becomes half.

If light of intensity I_1, emerging from one polaroid called polariser is incident on a second polaroid (called analyser) the intensity of light emerging from the second polaroid is

$I_2 = I_1 \cos^2\theta$ θ = angle between the transmission axis of the two polaroids.

Optical Activity

When plane polarised light passes through certain substances, the plane of polarisation of the emergent light is rotated about the direction of propagation of light through a certain angle. This phenomenon is optical rotation.

The substance which rotate the plane of polarision rotates the plane of polarisation is known as optical active substance. Ex. Sugar solution, sugar crystal, soldium chlorate etc.

Optical activity of a substance is measured with the help of polarimeter in terms of specific rotation which is defined as the rotation produced by a solution of length 10 cm (1dm) and of unit concentration (1g/cc) for a given wave length of light at a given temp.

specific rotation $[\alpha]_{t^\circ C}^{\lambda} = \dfrac{\theta}{L \times C}$ θ = rotation in length L at concentration

Types of optically active substances

(a) **Dextro rotatory substances**

Those substances which rotate the plane of polarisation in clockwise direction are called dextro rotatory of right handed substances.

(b) **Laveo rotatory substances**

These substances which rotate the plane of polarisation in the anticlockwise direction are called laveo rotatory or left handed subsances.

The amount of optical rotation depends upon the thickness and density of the crystal or concentration in case of solutions, the temperature and the wavelength of light used.

Rotation varies inversely as the square of the wavelenth of light.

APPLICATIONS AND USES OF POLARISATION

- By determining the polarising angle and using Brewster's Law $\mu = \tan\theta_p$ refractive index of dark transparent substance can be determined.
- In calculators and watches, numbers and letters are formed by liquid crystals through polarisation of light called liquid crystal display (L.C.D.)
- In CD player polarised laser beam acts as needle for producing sound from compact disc.
- It has also been used in recording and reproducing three dimensional pictures.
- Polarised light is used in optical stress analysis known as photoelasticity.
- Polarisation is also used to study asymmetries in molecules and crystals through the phenomenon of optical activity.

Example

Two polaroids are crossed to each other. When one of them is rotated through 60 , then what percentage of the incident unpolarised light will be transmitted by the polaroids ?

Sol. Initially the polaroids are crossed to each other, that is the angle between their polarising directions is 90 . When one is rotated through 60 , then the angle between their polarising directions will become 30 .

Let the intensity of the incident unpolarised light = I_0

Then the intensity of light emerging from the first polaroid is $I_1 = \frac{1}{2} I_0$

This light is plane polarised and passes through the second polaroid.

The intensity of light emerging from the second polaroid is $I_2 = I_1 \cos^2\theta$

θ = the angle between the polarising directions of the two polaroids.

$I_1 = \frac{1}{2} I_0$ and $\theta = 30$ so $I_2 = I_1 \cos^2 30° = \frac{1}{2} I_0 \cos^2 30°$ $\Rightarrow$ $\frac{I_2}{I_0} = \frac{3}{8}$

$\therefore$ transmission percentage = $\frac{I_2}{I_0} \times 100 = \frac{3}{8} \times 100 = 37.5\%$

Example

At what angle of incidence will the light reflected from water (μ = 1.3) be completely polarised ?

Sol. μ = 1.3,

From Brewster's law $\tan \theta_p = \mu = 1.3$ $\Rightarrow \theta = \tan^{-1} 1.3 = 53$

Example

If light beam is incident at polarising angle (56.3) on air-glass interface, then what is the angle of refraction in glass ?

Sol. $\because i_p + r_p = 90$ $\therefore r_p = 90 - i_p = 90 - 56.3 = 33.7$

Example

A polariser and an analyser are oriented so that maximum light is transmitted, what will be the intensity of outcoming light when analyer is rotated through 60 .

Sol. According to Malus Law $I = I_0 \cos^2 \theta = I_0 \cos^2 60 = I_0 \left[\frac{1}{2}\right]^2 = \frac{I_0}{4}$

Example

A 300 mm long tube containing 60 cm^3 of sugar solution produces an optical rotations of 10 when placed in a saccharimeter. If specific rotation of sugar is 60 , calculate the quantity of sugar contained in the tube solution.

Sol. ℓ = 300 mm = 30 cm = 3 decimetre, θ = 10 , $[\alpha]_\lambda^T = 60°$, volume of solution = 60 cm^3

$\theta = [\alpha]_\lambda^T \ell C \Rightarrow C = \frac{\theta}{[\alpha]_\lambda^T \ell} = \frac{10°}{60° \times 3} = \frac{1}{18}$ g cm^{-3}

Quantity of sugar contained = $\frac{1}{18}$ 60 = 3.33 g

CHECK YOUR GRASP | EXERCISE-I

1. Diffraction and interference of light refers to :–
(A) quantum nature of light (B) wave nature of light
(C) transverse nature of light (D) electromagnetic nature of light

2. The phenomenon of diffraction of light was discovered by :–
(A) Huygens (B) Newton (C) Fresnel (D) Grimaldi

3. Sound waves shows more diffraction as compare to light rays :–
(A) wavelength of sound waves is more as compare to light rays
(B) wavelength of light rays is more as compare to sound waves
(C) wavelength of sound waves and light ray is same
(D) none of these

4. The conversation going on, in some room, can be heared by the person outside the room. The reason for it is :–
(A) interference of sound (B) reflection of sound (C) diffraction of sound (D) refraction of sound

5. Diffraction initiated from obstacle, depends upon the
(A) size of obstacle (B) wave length, size of obstacle
(C) wave length and distance of obstacle from screen (D) size of obstacle and its distance from screen

6. Phenomenon of diffraction occurs :–
(A) only in case of light and sound waves (B) for all kinds of waves
(C) for electro-magnetic waves and not for matter waves (D) for light waves only

7. Diffraction of light is observed only, when the obstacle size is :–
(A) very large (B) very small
(C) of the same order that of wavelength of light (D) any size

8. Which of the following ray gives more distinct diffraction :–
(A) X-ray (B) light ray (C) γ –ray (D) Radio wave

9. All fringes of diffraction are of :–
(A) the same intensity (B) unequal width (C) the same width (D) full darkness

10. A single slit of width d is placed in the path of beam of wavelength λ. The angular width of the principal maximum obtained is :–
(A) $\frac{d}{\lambda}$ (B) $\frac{\lambda}{d}$ (C) $\frac{2\lambda}{d}$ (D) $\frac{2d}{\lambda}$

11. Direction of the second maximum in the Fraunhofer diffraction pattern at a single slit is given by (a is the width of the slit) :–
(A) $a\sin\theta = \frac{\lambda}{2}$ (B) $a\cos\theta = \frac{3\lambda}{2}$ (C) $a \sin \theta = \lambda$ (D) $a\sin\theta = \frac{3\lambda}{2}$

12. Angular width (θ) of central maximum of a diffraction pattern of a single slit does not depend upon :–
(A) distance between slit and source (B) wavelength of light used
(C) width of the slit (D) frequency of light used

13. Red light is generally used to observe diffraction pattern from single slit. If green light is used instead of red light, then diffraction pattern :–
(A) will be more clear (B) will be contract (C) will be expanded (D) will not visualize

14. Calculate angular width of central maxima if λ = 6000 Å, a = 18 10^{-5} cm :–
(A) 20 (B) 40 (C) 30 (D) 260

15. In single slit Fraunhoffer diffraction which type of wavefront is required :–
(A) cylindrical (B) spherical (C) elliptical (D) plane

16. In the diffraction pattern of a single slit aperture, the width of the central fringe compared to widths of the other fringes, is :–
(A) equal (B) less (C) little more (D) double

17. Central fringe obtained in diffraction pattern due to a single slit :–
(A) is of minimum intensity (B) is of maximum intensity
(C) intensity does not depend upon slit width (D) none of the above

18. In a single slit diffraction pattern, if the light source is used of less wave length then previous one. Then width of the central fringe will be :–

(A) less (B) increase (C) unchanged (D) none of the above

19. In the laboratory, diffraction of light by a single slit is being observed. If slit is made slightly narrow, then diffraction pattern will :–

(A) be more spreaded than before (B) be less spreaded than before
(C) be spreaded as before (D) be disappeared

20. Find the half angular width of the central bright maximum in the Fraunhofer diffraction pattern of a slit of width 12 10^{-5} cm when the slit is illuminated by monochromatic light of wavelength 6000 Å.

(A) 40 (B) 45 (C) 30° (D) 60

21. In a Fraunhofer's diffraction by a slit, if slit width is a, wave length λ, focal length of lens is f, linear width of central maxima is :–

(A) $\frac{f\lambda}{a}$ (B) $\frac{fa}{\lambda}$ (C) $\frac{2f\lambda}{a}$ (D) $\frac{f\lambda}{2a}$

22. In a Fraunhofer's diffraction obtained by a single slit aperture, the value of path difference for n^{th} order of minima is :–

(A) $n\lambda$ (B) $2n\lambda$ (C) $\frac{(2n-1)\lambda}{2}$ (D) $(2n-1)\lambda$

23. A polariser is used to :

(A) Reduce intensity of light (B) Produce polarised light
(C) Increase intensity of light (D) Produce unpolarised light

24. Light waves can be polarised as they are :

(A) Transverse (B) Of high frequency (C) Longitudinal (D) Reflected

25. Through which character we can distinguish the light waves from sound waves :

(A) Interference (B) Refraction (C) Polarisation (D) Reflection

26. The angle of polarisation for any medium is 60 , what will be critical angle for this :

(A) $\sin^{-1}\sqrt{3}$ (B) $\tan^{-1}\sqrt{3}$ (C) $\cos^{-1}\sqrt{3}$ (D) $\sin^{-1}\frac{1}{\sqrt{3}}$

27. The angle of incidence at which reflected light is totally polarized for reflection from air to glass (refractive index n)

(A) $\sin^{-1}(n)$ (B) $\sin^{-1}\left(\frac{1}{n}\right)$ (C) $\tan^{-1}\left(\frac{1}{n}\right)$ (D) $\tan^{-1}(n)$

28. A polaroid is placed at 45 to an incoming light of intensity I_0. Now the intensity of light passing through polaroid after polarisation would be :

(A) I_0 (B) $I_0/2$ (C) $I_0/4$ (D) Zero

29. Plane polarised light is passed through a polaroid. On viewing through the polariod we find that when the polariod is given one complete rotation about the direction of the light, one of the following is observed.

(A) The intensity of light gradually decreases to zero and remains at zero
(B) The intensity of light gradually increases to a maximum and remains at maximum
(C) There is no change in intensity
(D) The intensity of light is twice maximum and twice zero

30. A ray of light is incident on the surface of a glass plate at an angle of incidence equal to Brewster's angle ϕ. If μ represents the refractive index of glass with respect to air, then the angle between reflected and refracted rays is :

(A) $90 + \phi$ (B) $\sin^{-1}(\mu\cos\phi)$ (C) 90 (D) $90 - \sin^{-1}(\sin\phi/\mu)$

31. A beam of light strikes a glass plate at an angle of incident 60 and reflected light is completely polarised than the refractive index of the plate is:-

(A) 1.5 (B) $\sqrt{3}$ (C) $\sqrt{2}$ (D) $\frac{3}{2}$

32. Polarised glass is used in sun glasses because :
(A) It reduces the light intensity to half an account of polarisation
(B) It is fashionable
(C) It has good colour
(D) It is cheaper

33. When unpolarized light beam is incident from air onto glass (n=1.5) at the polarizing angle :
(A) Reflected beam is polarized 100 percent
(B) Reflected and refracted beams are partially polarized
(C) The reason for (A) is that almost all the light is reflected
(D) All of the above

34. When the angle of incidence on a material is 60 , the reflected light is completely polarized. The velocity of the refracted ray inside the material is (in ms^{-1}) :

(A) $3 \quad 10^8$ (B) $\left(\frac{3}{\sqrt{2}}\right) \quad 10^8$ (C) $\sqrt{3} \quad 10^8$ (D) $0.5 \quad 10^8$

CHECK YOUR GRASP **ANSWER-KEY** **EXERCISE-I**

Que.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Ans.	B	D	A	C	B	B	C	D	B	C	D	A	B	B	D	D	B	A	A	C
Que.	21	22	23	24	25	26	27	28	29	30	31	32	33	34						
Ans.	C	A	B	A	C	D	D	B	D	C	B	A	A	C						

PREVIOUS YEARS QUESTIONS EXERCISE-II

1. Electromagnetic waves are transverse in nature is evident by- [AIEEE - 2002]
(1) polarization (2) interference (3) reflection (4) diffraction

2. When an unpolarized light of intensity I_0 is incident on a polarizing sheet, the intensity of the light which does not get transmitted is- [AIEEE - 2005]

(1) $\frac{1}{2} I_0$ (2) $\frac{1}{4} I_0$ (3) zero (4) I_0

3. If I_0 is the intensity of the principle maximum in the single slit diffraction pattern, then what will be its intensity when the slit width is doubled- [AIEEE - 2005]

(1) $2I_0$ (2) $4I_0$ (3) I_0 (4) $\frac{I_0}{2}$

4. **Statement-1:** On viewing the clear blue portion of the sky through a Calcite Crystal, the intensity of transmitted light varies as the crystal is rotated. [AIEEE - 2011]
Statement-1: The light coming from the sky is polarized due to scattering of sun light by particles in the atmosphere. The scattering is largest for blue light.
(1) Statement-1 is false, statement-2 is true
(2) Statement-1 is true, statement-2 is false
(3) Statement-1 is true, statement-2 true; statement-2 is the correct explanation of statement-1
(4) Statement-1 is true, statement-2 is true; statement -2 is not correct explanation of statement-1.

5. A beam of unpolarised light of intensity I_0 is passed through a polaroid A and then through another polaroid B which is oriented so that its principal plane makes an angle of 45 relative to that of A. The intensity of the emergent light is :-
(1) I_0 (2) $I_0/2$ (3) $I_0/4$ (4) $I_0/8$

PREVIOUS YEARS QUESTIONS **ANSWER-KEY** **EXERCISE-II**

Que.	1	2	3	4	5
Ans.	1	1	3	3	3