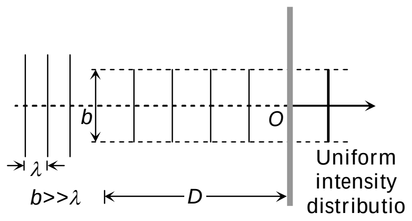
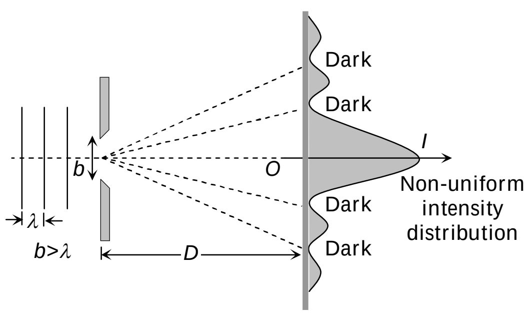
Diffraction of Light

(1) The phenomenon of bending of light around the corners of an obstacle/aperture of the size comparable to the wave length of light is called diffraction.



(A) Size of the slit is very large compared to wavelength



(B) Size of the slit is comparable to wavelength

(2) The phenomenon resulting from the superposition of secondary wavelets originating from different parts of the same wave front is define as diffraction of light.

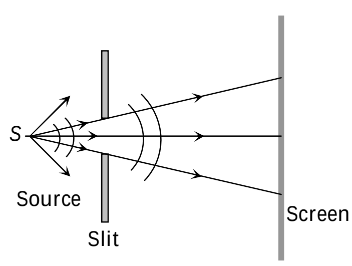
(3) Diffraction is the characteristic of all types of waves.

(4) Greater the wave length of wave higher will be it's degree of diffraction.

Types of Diffraction

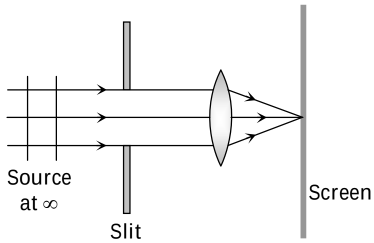
(1) **Fresnel diffraction :** If either source or screen or both are at finite distance from the diffracting device (obstacle or aperture), the diffraction is called Fresnel type.

Common examples : Diffraction at a straight edge, narrow wire or small opaque disc *etc*.



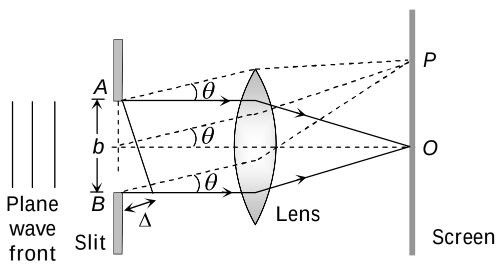
(2) **Fraunhofer diffraction :** In this case both source and screen are effectively at infinite distance from the diffracting device.

Common examples : Diffraction at single slit, double slit and diffraction grating.



Diffraction at Single Slit (Fraunhoffer Diffraction)

Suppose a plane wave front is incident on a slit *AB* (of width b). Each and every part of the expose part of the plane wave front (i.e. every part of the slit) acts as a source of secondary wavelets spreading in all directions. The diffraction is obtained on a screen placed at a large distance. (In practice, this condition is achieved by placing the screen at the focal plane of a converging lens placed just after the slit).



(1) The diffraction pattern consists of a central bright fringe (central maxima) surrounded by dark and bright lines (called secondary minima and maxima).

(2) At point *O* on the screen, the central maxima is obtained. The wavelets originating from points A and B meets in the same phase at this point, hence at *O*, intensity is maximum.

(3) **Secondary minima :** For obtaining n^{th} secondary minima at P on the screen, path difference between the diffracted waves $\Delta = b\sin\theta = n\lambda$

(i) Angular position of n^{th} secondary minima $\sin\theta \approx \theta = \frac{n\lambda}{b}$

(ii) Distance of n^{th} secondary minima from central maxima

$x_n = D.\theta = \frac{n\lambda D}{b} = \frac{n\lambda f}{b}$; where D = Distance between slit and screen. $f \approx D$ = Focal length of converging lens.

(4) **Secondary maxima :** For n^{th} secondary maxima at P on the screen.

Path difference $\Delta = b\sin\theta = (2n+1)\frac{\lambda}{2}$; where n = 1, 2, 3 .....

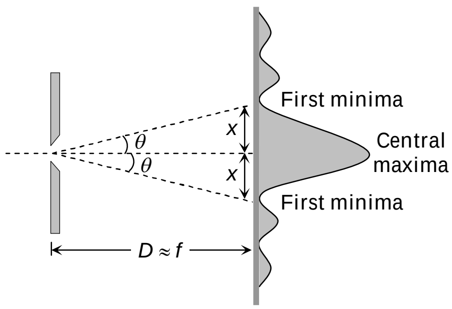
(i) Angular position of n^{th} secondary maxima

$$\sin \approx \theta \approx \frac{(2n+1)\lambda}{2b}$$

(ii) Distance of n^{th} secondary maxima from central maxima

$$x_n = D.\theta = \frac{(2n+1)\lambda D}{2b} = \frac{(2n+1)\lambda f}{2b}$$

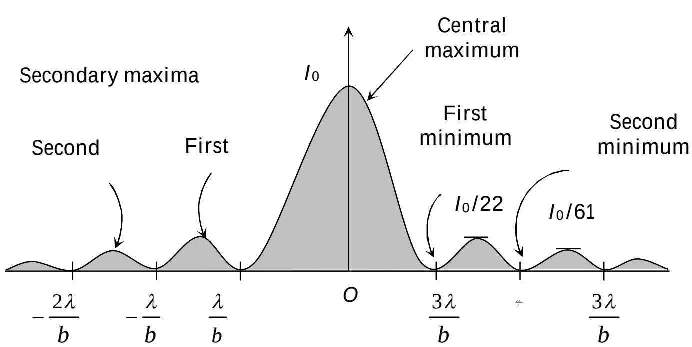
(5) **Central maxima :** The central maxima lies between the first minima on both sides.

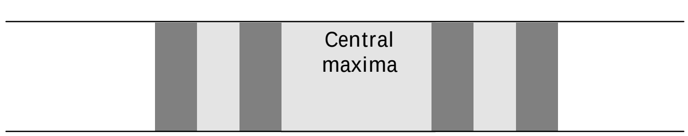


(i) The Angular width d central maxima = $2\theta = \frac{2\lambda}{b}$

(ii) Linear width of central maxima $= 2x = 2D\theta = 2f\theta = \frac{2\lambda f}{b}$

(6) **Intensity distribution :** If the intensity of the central maxima is I_0 then the intensity of the first and second secondary maxima are found to be $\frac{I_0}{22}$ and $\frac{I_0}{61}$. Thus diffraction fringes are of unequal width and unequal intensities.





(i) The mathematical expression for in intensity distribution on the screen is given by

$I = I_o\left(\frac{\sin\alpha}{\alpha}\right)^2$ where α is just a convenient connection between the angle θ that locates a point on the viewing screening and light intensity *I*.

ϕ = Phase difference between the top and bottom ray from the slit width *b*.

Also $\alpha = \frac{1}{2}\phi = \frac{\pi b}{\lambda}\sin\theta$

(ii) As the slit width increases (relative to wavelength) the width of the control diffraction maxima decreases; that is, the light undergoes less flaring by the slit. The secondary maxima also decreases in width (and becomes weaker).

(iii) If $b >> \lambda$, the secondary maxima due to the slit disappear; we then no longer have single slit diffraction.

(iv) When the slit width is reduced by a factor of 2, the amplitude of the wave at the centre of the screen is reduced by a factor of 2, so the intensity at the centre is reduced by a factor of 4.

Diffraction Gratings

One of the most useful tools in the study of light and of objects that emit and absorbs light is the diffraction grating.

(1) this device consists parallel slits of equal width and equal spacing called rulings, perhaps as many as several thousand per *mm*.

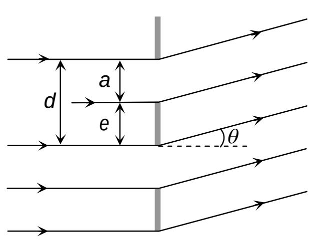
(2) The separation (*d*) between rulings is called grating spacing. (If *N*-rulings occupy a total width ω, then $d = \frac{\omega}{N}$)

(3) For light ray emerging from each slit at an angle θ, there is a path difference *d* sinθ, between each ray the one directly above. The *d* is called the grating element

d = *a* + *e*

where *a* = width of the slit

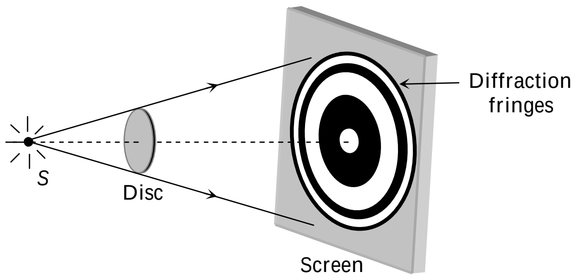
e = opaque part



(4) The condition for formation of bright fringe is $d\sin\theta = n\lambda$, where *n* = 0, 1, 2, ... is called the order of diffraction.

Diffraction Due to a Circular Disc

When a disc is placed in the path of a light beam, then diffraction pattern is formed on the screen.



(1) At the centre of the circular shadow of disc, there occurs a bright spot. This spot is called Fresnel's spot or Poisson's spot.

(2) The intensity of bright spot decreases, when the size of the disc is increased or when the screen is moved towards the disc.

(3) Circular alternate bright and dark fringes are formed around the bright spot with fringe width in decreasing order.

(4) Let *r* be the radius of the disc, *d* is the distance between screen and the disc and λ is the wavelength of light used.

If *n* HPZ are covered by disc then $nd\lambda = \pi r^2 \Rightarrow n = \frac{r^2}{d\lambda}$

(5) If the disc obstruct only first HPZ, the resultant amplitude at the central point $R = -R_2 + R_3 + ... \approx -\frac{R_2}{2}$.

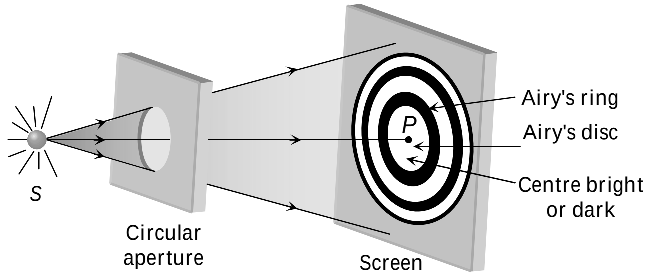
So intensity is $\frac{kR_2^2}{4}$ which is slightly less than the intensity $\frac{k\,R_1^2}{4}$ due to whole wave front, when no obstacle is placed.

(6) The intensity at bright spot is given by $I = k\left[\frac{R_{n+1}}{2}\right]^2$

where *n* = Number of obstructed HPZ's

Diffraction Due to a Circular Aperture

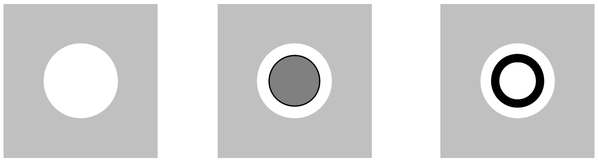
When a circular aperture is placed in the path of a light beam, then following diffraction pattern is formed on the screen.



(1) If only one HPZ is allowed by the aperture then the resultant amplitude at *P* would be R_1 which is twice the value of amplitude for the unobstructed wave front. The intensity would there fore be $4I_0$, where I_0 represents the intensity at point *P*, due to unobstructed wave front.

(2) If the first two HPZ's are permitted by aperture than the resultant intensity at the centre point *P* will be very small (as $R_1 - R_2 \approx 0$). In this case the diffraction pattern consist of a bright circle of light with a dark spot.

(3) In general if number of HPZ's (n) passing through aperture is odd, then the central point will be bright and if n is even, central point will be dark.



(A) n=1, r^2=$b\lambda$ bright centre　(B) n=2, r^2=2$b\lambda$ dark centre　(C) n=3, r^2=3$b\lambda$ bright centre

(4) The central bright disc is known as Airy's disc.

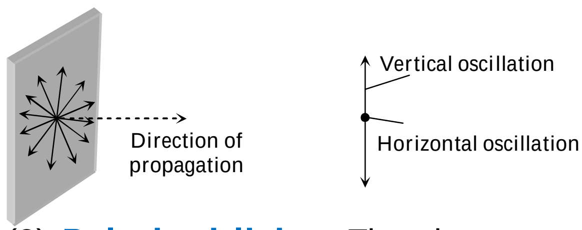
(5) In the non axial region bright and dark diffraction rings are obtained. The intensity of bright diffraction rings gradually goes on decreasing whereas that of dark diffraction goes on increasing.

(6) The first dark ring obtained around the central bright disc is known as Airy's ring.

Polarisation of Light

Light propagates as transverse EM waves. The magnitude of electric field is much larger as compared to magnitude of magnetic field. We generally prefer to describe light as electric field oscillations.

(1) **Unpolarised light :** In ordinary light (light from sun, bulb *etc*.) the electric field vectors are distributed in all directions in a light is called unpolarised light. The oscillation of propagation of light wave. This resolved into horizontal and vertical component.



(2) **Polarised light :** The phenomenon of limiting the vibrating of electric field vector in one direction in a plane perpendicular to the direction of propagation of light wave is called polarization of light.

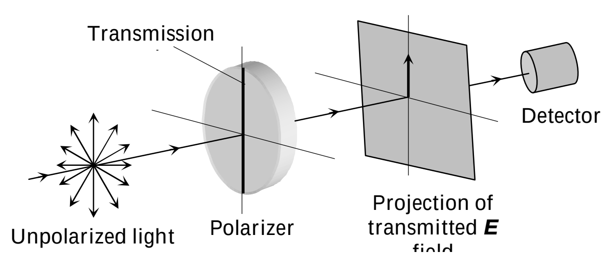
(i) The plane in which oscillation occurs in the polarised light is called plane of oscillation.

(ii) The plane perpendicular to the plane of oscillation is called plane of polarisation.

(iii) Light can be polarised by transmitting through certain crystals such as tourmaline or polaroids.

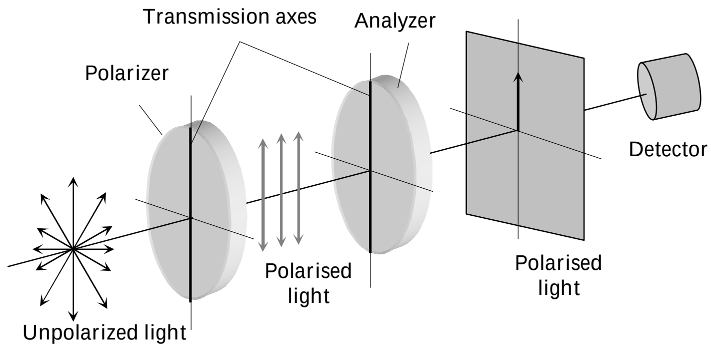
(3) **Polaroids :** It is a device used to produce the plane polarised light. It is based on the principle of selective absorption and is more effective than the tourmaline crystal. or

It is a thin film of ultramicroscopic crystals of quinine idosulphate with their optic axis parallel to each other.



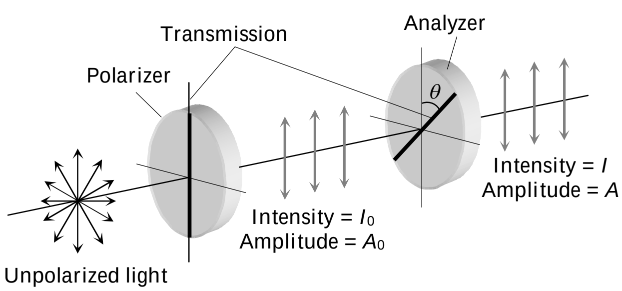
(i) Polaroids allow the light oscillations parallel to the transmission axis pass through them.

(ii) The crystal or polaroid on which unpolarised light is incident is called polariser. Crystal or polaroid on which polarised light is incident is called analyser.



(A) Transmission axes of the polariser and analyser are parallel to each other, so whole of the polarised light passes through analyser

(4) **Malus law :** This law states that the intensity of the polarised light transmitted through the analyser varies as the square of the cosine of the angle between the plane of transmission of the analyser and the plane of the polariser.



(i) $I = I_0 \cos^2\theta$ and $A^2 = A_0^2 \cos^2\theta \Rightarrow A = A_0 \cos\theta$

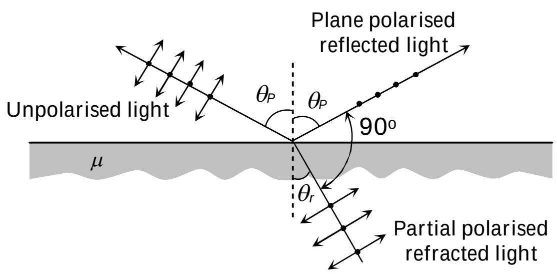
If $\theta = 0^o$, $I = I_0$, $A = A_0$, If $\theta = 90^o$, $I = 0$, $A = 0$

(ii) If $I_i =$ Intensity of unpolarised light.

So $I_0 = \frac{I_i}{2}$ *i.e.* if an unpolarised light is converted into plane polarised light (say by passing it through a Polaroid or a Nicol-prism), its intensity becomes half. and $I = \frac{I_i}{2}\cos^2\theta$

Methods of Producing Polarised Light

(1) **Polarisation by reflection :** Brewster discovered that when a beam of unpolarised light is reflected from a transparent medium (refractive index =μ), the reflected light is completely plane polarised at a certain angle of incidence (called the angle of polarisation θ_p).



From fig. it is clear that $\theta_P + \theta_r = 90^o$

Also $\mu = \tan\theta_p$ Brewster's law

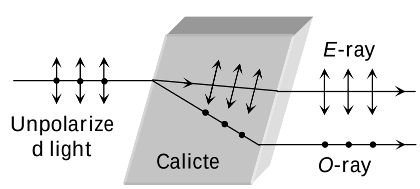
(i) For $i < \theta_P$ or $i > \theta_P$

Both reflected and refracted rays becomes partially polarised

(ii) For glass $\theta_P \approx 57^o$, for water $\theta_P \approx 53^o$

(2) **By Dichroism :** Some crystals such as tourmaline and sheets of iodosulphate of quinine have the property of strongly absorbing the light with vibrations perpendicular to a specific direction (called transmission axis) transmitting the light with vibrations parallel to it. This selective absorption of light is called dichroism.

(3) **By double refraction :** In certain crystals, like calcite, quartz and tourmaline *etc*, incident unpolarized light splits up into two light beams of equal intensities with perpendicular polarization.



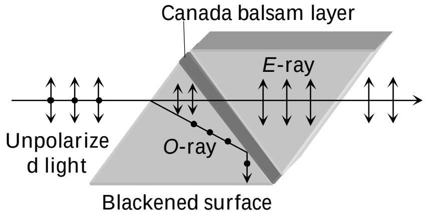
(i) One of the ray is ordinary ray (*O*-ray) it obey's the Snell's law. Another ray's extra ordinary ray (*E*-ray) it doesn't obey's the Snell's law.

(ii) Along a particular direction (fixed in the crystal, the two velocities (velocity of *O*-ray v_o and velocity of *E*-ray v_e) are equal; this direction is known as the optic axis of the crystal (crystal's known as uniaxial crystal). Optic axis is a direction and not any line in crystal.

(iii) In the direction, perpendicular to the optic axis for negative crystal (calcite) $v_e > v_o$ and $\mu_e < \mu_o$.

For positive crystal $v_e < v_o$, $\mu_e > \mu_o$.

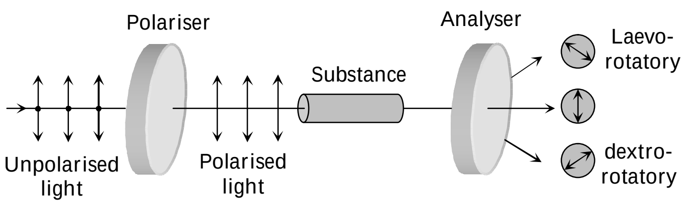
(4) **Nicol prism :** Nicol prism is made up of calcite crystal and in it *E*-ray is isolated from *O*-ray through total internal reflection of *O*-ray at canada balsam layer and then absorbing it at the blackened surface as shown in fig.



The refractive index for the *O*-ray is more that for the *E*-ray. The refractive index of Canada balsam lies between the refractive indices of calcite for the *O*-ray and *E*-ray

(5) **By Scattering :** It is found that scattered light in directions perpendicular to the direction of incident light is completely plane polarised while transmitted light is unpolarised. Light in all other directions is partially polarised.

(6) **Optical activity and specific rotation :** When plane polarised light passes through certain substances, the plane of polarisation of the light is rotated about the direction of propagation of light through a certain angle. This phenomenon is called optical activity or optical rotation and the substances optically active.



Polarimeter

If the optically active substance rotates the plane of polarisation clockwise (looking against the direction of light), it is said to be *dextro-rotatory* or *right-handed.* However, if the substance rotates the plane of polarisation anti-clockwise, it is called *laevo-rotatory* or *left-handed.*

The optical activity of a substance is related to the asymmetry of the molecule or crystal as a whole, *e.g.*, a solution of cane-sugar is dextro-rotatory due to asymmetrical molecular structure while crystals of quartz are dextro or laevo-rotatory due to structural asymmetry which vanishes when quartz is fused.

Optical activity of a substance is measured with help of polarimeter in terms of 'specific rotation' which is defined as the rotation produced by a solution of length 10 *cm* (1 *dm*) and of unit concentration (*i.e.* 1 *g*/cc) for a given wavelength of light at a given temperature. *i.e.* $[\alpha]^{\lambda}_{t^oC} = \dfrac{\theta}{L \times C}$ where θ is the rotation in length *L* at concentration *C*.

(7) **Applications and uses of polarisation**

(i) By determining the polarising angle and using Brewster's law, *i.e.* $\mu = \tan\theta_P$, refractive index of dark transparent substance can be determined.

(ii) It is used to reduce glare.

(iii) In calculators and watches, numbers and letters are formed by liquid crystals through polarisation of light called liquid crystal display **(LCD)**.

(iv) In CD player polarised laser beam acts as needle for producing sound from compact disc which is an encoded digital format.

(v) It has also been used in recording and reproducing three-dimensional pictures.

(vi) Polarisation of scattered sunlight is used for navigation in solar-compass in polar regions.

(vii) Polarised light is used in optical stress analysis known as 'photoelasticity'.

(viii) Polarisation is also used to study asymmetries in molecules and crystals through the phenomenon of 'optical activity'.

(ix) A polarised light is used to study surface of nucleic acids (DNA, RNA)