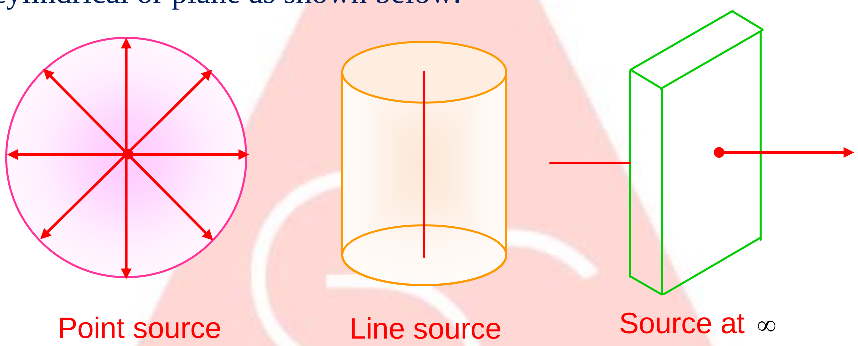
WAVE OPTICS

11 WAVE OPTICS

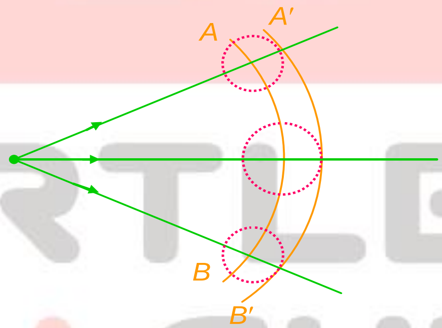
Wave optics concerns with the explanation of the observed phenomena such as interference. In wave optics, light is treated as a wave. Huygen was the first scientist who assumed that a body emits light in the form of waves. In his wave theory, Huygen used a term– the wave front. First of all, we will understand what he meant by the term, the wave front.

(i) **Wave front:** The locus of all the particles of the medium vibrating in the same phase at a given instant is called wavefront. The shape of the wavefront depends on the source producing the waves and is usually spherical, cylindrical or plane as shown below.



(ii) **Ray:** In a homogeneous medium, the wavefront is always perpendicular to the direction of wave propagation. Hence, a line drawn normal to the wavefront gives the directions of propagation of a wave and is called a ray.

11.1 HUYGEN'S WAVE THEORY



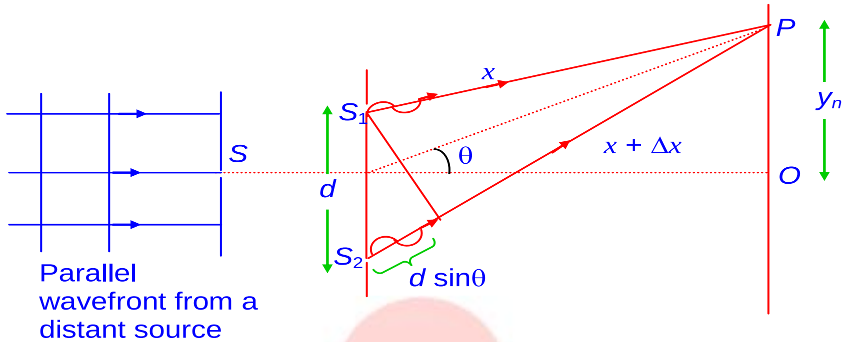
Each point of a source of light is a centre of disturbance from where waves spread in all directions. Each point on a wavefront is a source of new disturbance, called secondary wavelets. These wavelets are spherical and travel with speed of light in that medium. The forward envelope of the secondary wavelets at any instant gives the new wavefront.

12 INTERFERENCE

The terms interference in general, refers to any situation where two or more waves overlap each-other in the same region of space. But usually, interference refers to the superposition of two coherent waves of same frequency moving in the same direction.

12.1 YOUNG'S DOUBLE SLIT EXPERIMENT

It was carried out in 1802 by Thomos Young to prove the wave nature of light.



Two slits S_1 and S_2 are made in an opaque screen, parallel and very close to each-other. These two are illuminated by another narrow slit S which in turn is lit by a bright source. Light wave spread out from S and fall on both S_1 and S_2. Any phase difference between S_1 and S_2 is unaffected and remain constant. The light waves going from S_1 and S_2 to any point P on the screen interfere with each other. At some point the waves superpose in such a way that the resultant intensity is greater than the sum of the intensities due to separate waves (CONSTRUCTIVE INTERFERENCE) while at some other point, it is lesser than the sum of the separate intensities (DESTRUCTIVE INTERFERENCE). Thus the overall picture is a pattern of dark and bright bands known as fringe pattern. The dark bands are known as dark fringes and the bright bands are known as bright fringes.

12.2 THEORY OF INTERFERENCE

Let the two waves each of angular frequency ω from sources S_1 and S_2 reach the point P. If the waves have amplitudes A_1 and A_2 respectively. then

$$y_1 = A_1 \sin(\omega t - kx) \qquad \ldots \text{(i)}$$

and, $y_2 = A_2 \sin(\omega t - k(x + \Delta x))$

or, $y_2 = A_2 \sin[\omega t - kx - \phi] \qquad \ldots \text{(ii)}$

where $\phi = k\,\Delta x = \dfrac{2\pi}{\lambda}(\Delta x) \qquad \ldots \text{(iii)}$

So, by the principle of superposition, the resultant wave at P will be

$$y = y_1 + y_2 = A_1 \sin(\omega t - kx) + A_2 \sin(\omega t - kx - \phi)$$

or, $y = [A_1 + A_2 \cos\phi) \sin[\omega t - kx] - [A_2 \sin\phi] \cos(\omega t - kx) \qquad \ldots \text{(iv)}$

Let $A_1 + A_2 \cos\phi = A \cos\alpha$

$A_2 \sin\phi = A \sin\alpha$

So, $A^2[\cos^2\alpha + \sin^2\alpha] = (A_1 + A_2 \cos\phi)^2 + (A_2 \sin\phi)^2$

or, $A^2 = A_1^2 + A_2^2 + 2A_1A_2 \cos\phi$

and $\alpha = \tan^{-1}\left[\dfrac{A_2 \sin\phi}{A_1 + A_2 \cos\phi}\right]$

Hence, equation (iv) becomes

$$y = A \sin(\omega t - kx) \cos\alpha - A\cos(\omega t - kx) \sin\alpha$$

or, $y = A \sin(\omega t - kx - \alpha) \qquad \ldots \text{(v)}$

From above equation, it is clear that in case of superposition of two waves of equal frequencies propagating almost in the same direction, resultant is harmonic wave of same frequency ω and wavelength ($\lambda = \dfrac{2\pi}{k}$) but amplitude

$A^2 = A_1^2 + A_2^2 + 2A_1A_2 \cos\phi$

Now as intensity of wave is given by

$$I = \frac{1}{2}\rho v\omega^2 A^2 = KA^2 \quad [K = \frac{1}{2}\rho v\omega^2]$$

So the intensity of the resultant wave

$$I = K[A_1^2 + A_2^2 + 2A_1A_2\cos\phi]$$

or, $I = I_1 + I_2 + 2\sqrt{I_1 I_2}\cos\phi$ **… (43)**

$[\text{As } I_1 = KA_1^2;\ I_2 = KA_2^2]$

12.3 CONDITION FOR CONSTRUCTIVE INTERFERENCE

Intensity will be maximum when

$\cos\phi = \text{maximum} = 1$

$\Rightarrow$ $\phi = 0, \pm 2\pi, \pm 4\pi \ldots$ **… (44)**

or, $\phi = \pm 2\pi n$

Where $n = 0, 1, 2, \ldots$

Now, $\frac{2\pi}{\lambda}(\Delta x) = \Delta\phi = \pm 2\pi n$

or, $\Delta x = \pm n\lambda$, **where n = 0, 1, 2,** **… (45)**

and, $I_{max.} = I_1 + I_2 + 2\sqrt{I_1 I_2}$

or, $I_{max.} = \left(\sqrt{I_1} + \sqrt{I_2}\right)^2$

$\propto (A_1 + A_2)^2$

12.4 CONDITION FOR DESTRUCTIVE INTERFERENCE

Intensity will be minimum when

$\cos\phi = \text{minimum} = -1$

i.e., $\phi = \pm\pi, \pm 3\pi, \pm 5\pi$

or, $\phi = \pm(2n-1)\pi$, **with** $n = 1, 2, 3 \ldots$ **… (46)**

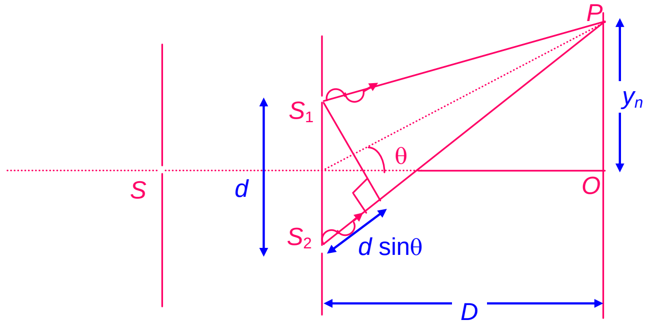
or, $\frac{2\pi}{\lambda}(\Delta x) = \pm(2n-1)\pi \quad [\because \Delta\phi = \frac{2\pi}{\lambda}(\Delta x)]$

or, $\Delta x = \pm(2n-1)\frac{\lambda}{2}$ **with** $n = 1, 2, \ldots$ **… (47)**

also, $I_{min} = \left(\sqrt{I_1} \sim \sqrt{I_2}\right)^2$

$\propto (A_1 \sim A_2)^2$

12.5 LOCATION OF BRIGHT FRINGES



Let P be the position of n^{th} maxima on the screen. The two waves arriving at P follow the path S_1P and S_2P, thus the path difference between the two waves is

$$p = S_2P - S_1P = d\sin\theta$$

From experimental conditions, we know that $D >> d$, therefore, the angle θ is small.

Thus

$$\sin\theta \approx \tan\theta = \frac{y_n}{D}$$

or, $p = d\sin\theta = d\left(\frac{y_n}{D}\right)$ for n^{th} maxima,

or, $p = n\lambda$

or, $d\left(\frac{y_n}{D}\right) = n\lambda$

or, $y_n = n\lambda\frac{D}{d}$ where $n = 0, 1, 2, \ldots$ … (48)

12.6 LOCATION OF DARK FRINGES

For n^{th} minima, we have

$$p = (2n-1)\frac{\lambda}{2} \quad \text{or,} \quad d\left(\frac{y_n}{D}\right) = (2n\text{-}1)\frac{\lambda}{2}$$

∴ $y_n = (2n-1)\frac{\lambda D}{2d}$ where $n = 1, 2, 3 \ldots$ … (49)

12.7 FRINGE WIDTH (ω)

The separation between two consecutive dark (or bright) fringes is known as fringe width (ω).

$$\therefore \quad \omega = y_{n+1} - y_n = (n+1)\frac{\lambda D}{d} - \frac{n\lambda D}{d}$$

⇒ $\omega = \frac{\lambda D}{d}$ … (50)

Angular fringe width or angular separation between fringes is

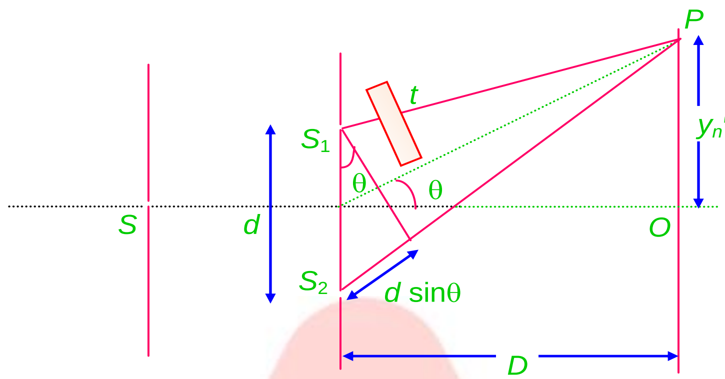
$$\theta = \frac{\omega}{D}$$

⇒ $\theta = \frac{\lambda}{d}$ … (51)

12.8 DISPLACEMENT OF FRINGE PATTERN

Let us analyse what happens if a thin transparent plate of thickness t and refractive index μ is placed in front of one of sources, for example, in front of S_1. This changes the path difference because light from S_1 now takes longer time to reach the screen.

$$\text{Time taken} = \frac{d_{air}}{V_{air}} + \frac{d_{plate}}{V_{plate}} = \frac{S_1P - t}{C} + \frac{t}{C/\mu}\left[\mu = \frac{C_{air}}{C_{medium}}\right] = \frac{S_1P + t(\mu - 1)}{C}$$



Hence the effective path that is equivalently covered in air O is $S_1P + (\mu\text{-}1)\,t$

$\therefore$ path difference $p = S_2P - [S_1P + t\,(\mu\text{-}1)]$

$= S_2P - S_1\,P - (\mu\text{-}1)\,t$

$\because$ $S_2P - S_1P = d\sin\theta$

$\therefore$ $p = d\sin\theta + (\mu - 1)\,t$

As $\sin\theta \approx \tan\theta = \dfrac{y'_n}{D}$

$\therefore$ $p = \dfrac{dy'_n}{D} + (\mu - 1)t$ or, $y'_n = \dfrac{n\lambda D}{d} - (\mu - 1)\dfrac{tD}{d}$

In the absence of film, the position of the nth maxima is given by

$y_n = \dfrac{n\lambda D}{d}$

Therefore, the fringe shift is given by , $y_0 = y_n - y'_n = (\mu - 1)\dfrac{tD}{d}$ **… (52)**

When a transparent sheet is introduced, the fringe pattern shifts in the direction where the film is placed.

12.9 COHERENT WAVES

Two waves of same frequency are said to be ‘coherent’ if their phase difference does not change with time, i.e., their phase difference is independent of time.

For observing interference effects, waves (or sources) must be coherent.

In case of two coherent sources, the resultant intensity at any point is given by

$I_R = I_1 + I_2 + 2\sqrt{I_1 I_2}\cos\phi$, where ϕ is the phase difference between the two coherent waves reaching the point.

In case of incoherent sources, the resultant intensity at any point is given by

$I_R = I_1 + I_2 + \ldots$

13 DIFFRACTION OF LIGHT

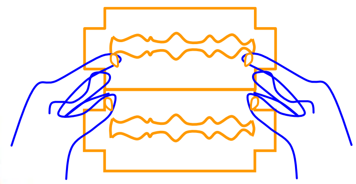
The phenomenon of bending of light around the corners of an obstacle or aperture is called the **diffraction of light**. On account of diffraction, light deviates from is linear path and enters into the regions of geometrical shadow of the obstacle.

In fact, diffraction is a characteristic of wave motion and all types of wave motions exhibit this effect.

A person sitting in a room can hear the sound of another person sitting outside the room, even though the speaker may not be visible. This is due to the bending of sound waves around the corners of the open door or window i.e. diffraction of sound. Similarly, radio waves too exhibit diffraction easily.

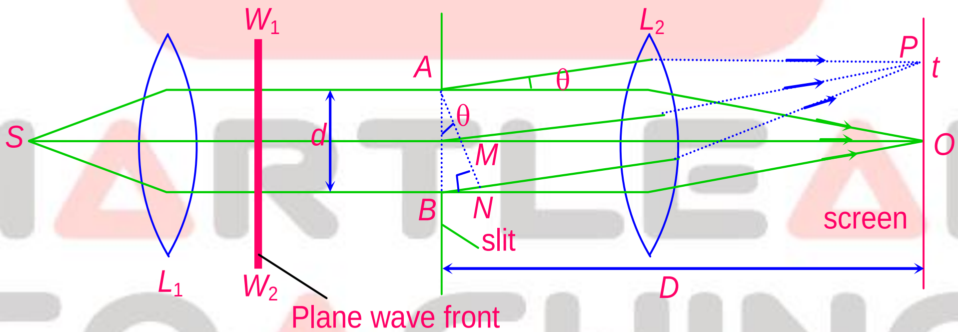
Experimental studies have revealed that diffraction occurs more prominently when the wavelength of the waves is comparable with the size of the obstacle or aperture. Since the wavelength of visible light is very small ($\lambda = 10^{-6}$m) and the size of the common obstacles or aperture is very large, the diffraction of visible light is not very common. However, when the size of the obstacle or aperture (slit) is made very small (comparable with the wavelength) even visible light shows this phenomenon. Diffraction is common in case of sound wave and radio waves because their wavelength is large and comparable to the size of common obstacle.

According to **Fresnel**, **diffraction** occurs on account of mutual interference of secondary wavelets starting from portions of the wavefront which are not blocked by the obstacle or from portions of the wavefront which are allowed to pass through the aperture.



13.1 DIFFRACTION AT A SINGLE SLIT

Consider a narrow slit *AB* of width *d* kept perpendicular to the plane of the paper. Let a plane wavefront of monochromatic light be incident normally on this slit. As the width *d* of the slit is comparable to the wavelength λ of the light, the light gets diffracted on passing through the slit. The converging lens L_2 helps in focusing the diffraction pattern on the screen. The diffraction pattern consists of a bright band at its centre (O) with alternate dark and bright bands on both sides. The intensity of the bright bands decreases very sharply as one move away from *O* on both sides.



Explanation: As the plane wavefront W_1 W_2 is incident normally on the slit, the entire slit *AB* gets, illuminated. According to Huygen's principle, each point on the portion *AB* of the wavefront becomes the source of secondary disturbance. The secondary wavelets start spreading from *AB* in all directions.

13.2 POSITION OF CENTRAL MAXIMA

The secondary wavelets travelling parallel to *MO* are focussed at *O* by the converging lens I_2. Actually, the secondary wavelets originating from any two points equidistant from the centre of the slit *M* (one each in *MA* and *MB*) cover equal distances before converging at *O*. Hence, the path difference between them is zero. As a result, they produce the brightest band at *O* on the screen. This is called the central maximum.

13.3 POSITION OF SECONDARY MAXIMA AND MINIMA

Consider the secondary wave travelling in a direction making an angle θ with *MO*. All these waves are focussed by lens L_1 at point *P*. Such waves start from all the points of slit *AB* in the same phase but travel different distances in reaching the point P. The intensity at point P will, therefore, depend on the path difference between the secondary waves emitted from the corresponding points (equidistant from M) of the wavefront AB.

Let us calculate the path difference between two secondary waves emitting from points A and B of the wavefront. Draw AN perpendicular to the wave coming from B.

$\therefore$ Path difference between the secondary wavelets which originate from A and B and reach point P on the screen, $BN = AB \sin\theta = d \sin\theta$.

Secondary minima: Let this path difference be equal to 1 λ i.e.

$\therefore \quad d\sin\theta = \lambda$

Hence the path difference between the wavelets originating from points A and M and reaching point P will be $\lambda/2$. Similarly, the path difference between the wavelets originating from M and B and reaching P will also be $\lambda/2$. Thus for each point in the upper half of the slit AM, there exists a corresponding point in its lower half MB such that the wavelets originating from such points reach point P out of phase i.e. having a phase difference of π. Therefore, destructive interference takes place at point P and it represents the first secondary minima.

Similarly, if $d \sin\theta = 2\lambda$.

The slit AB can be imagined to be divided into four equal parts. The path difference between the wavelets originating from corresponding points in two adjacent parts will be $2\lambda/4 = \lambda/2$. Hence, the wavelets cause destructive interference and point P again represents the second minima.

In general, for n^{th} minima, we have $d\sin\theta = n\lambda$

Where $n = 1, 2, 3,\ldots\ldots$

Hence, the direction of n^{th} secondary minima

$$\sin\theta = n\frac{\lambda}{d}$$

$\therefore$ For small values θ, $\sin\theta_n = \theta_n = n\dfrac{\lambda}{d}$

Secondary maxima: Let the path difference between the wavelets originating from A and B and reaching an off –point P_1 (not shown in the figure) be $3\lambda/2$.

$\therefore \quad d\sin\theta = 3\lambda/2$

We assume that the slit AB is divided into three equal parts so that the difference between the wavelets originating from the corresponding points in the first two parts is $\lambda/2$. Such wavelets cause destructive interference at P_1. However, the wavelets originating from different point of the third part reinforce each other (not completely as for them, $0 > d \sin\theta < \lambda/2$) and give rise to the first secondary maxima at P_1. The intensity at the first secondary maxima is much smaller than that of the central maxima.

Similarly, $d \sin\theta = 5\lambda/2$ give the second secondary maxima with much lower intensity than the first maxima.

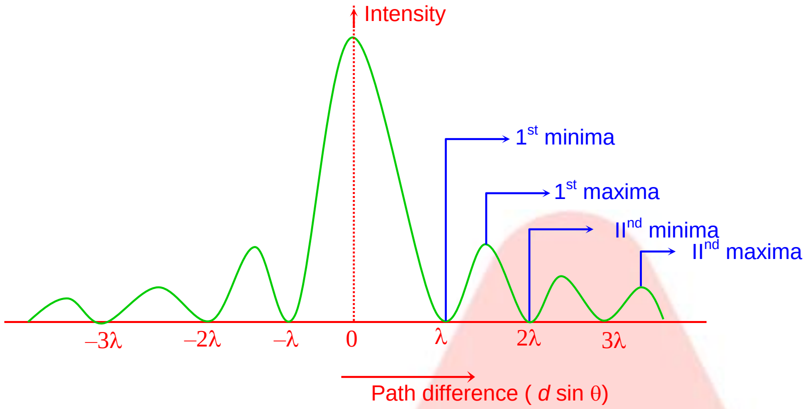
In general, for n^{th} secondary maxima the have $d\sin\theta = (2n+1)\lambda/2$

Where n = 1, 2, 3 ….

The direction of n^{th} secondary maxima is

$$\sin\theta = \theta_n = \frac{(2n+1)\lambda}{2d}$$

Thus, the diffraction pattern due to a single slit consists of central maxima flanked by alternate minima and secondary maxima. The intensity distribution in the pattern on the screen in shown in figure.



The graph shows that as we go away from the central maxima O on both sides, the intensity of secondary maxima decreases very rapidly.

13.4 WIDTH OF CENTRAL MAXIMA

It is the distance between the first secondary minimum an either side of the central maxima

Let y be the distance of a first minimum from the centre (O) of the central maxima.

$$\therefore \quad d\sin\theta = \lambda \text{ and } \sin\theta = \theta = \frac{\lambda}{d} D$$

Let f be the focal length of the converging lens L_2 (placed very close to slit AB) and D is the distance of the screen from AB.

$$\therefore \quad D = f$$

Hence , $\theta = \frac{y}{f} = \frac{y}{D}$

Comparing equation, we get $\frac{y}{D} = \frac{\lambda}{d}$, $y = \frac{\lambda}{d}$

$\therefore$ width of central maxima = $2y = \frac{2\lambda D}{d} = \frac{2\lambda f}{d}$

Figure shows the widths of the central maxima (CD) and the first secondary maximum (DE or CF)

Let y_1 and y_2 respectively be the distance of the first minima and the second minima from O. Then width of the first secondary maximum = $y_2 - y_1 = \frac{2\lambda D}{d} - \frac{\lambda D}{d} = \frac{\lambda D}{d}$.

The width of the central maxima is twice the width of the first secondary maximum.

13.5 DIFFRACTION PATTERN AT SINGLE SLIT DUE TO MONOCHROMATIC LIGHT AND WHITE LIGHT

When a parallel beam of monochromatic light is incident normally on the slit, the diffraction pattern obtained on the screen consists of alternate bright and dark bands of equal width. The intensity is maximum at the central bright band and it decreases very rapidly for successive secondary bright bands i.e. maximum.

When the beam of white light is incident on the slit, the diffraction pattern is coloured. The central maxima is white but the other bands are coloured. As the band width $\propto \lambda$ the red band will be wider than the violet band (as $\lambda_R > \lambda_V$).

FRESNEL DISTANCE (Z_F)

It is defined as the distance of the screen from the slit at which the spreading of light due to diffraction at single slit becomes equal to the width of the slit.

From the figure $\theta = \frac{y}{D} = \frac{d}{D}$ and for 1st minima $\theta = \frac{\lambda}{d}$

$$\therefore \quad \frac{\lambda}{d} = \frac{d}{D}$$

$$\therefore \quad D = Z_F = \frac{d^2}{\lambda}$$

13.6 DIFFRACTION BETWEEN INTERFERENCE AND DIFFRACTION OF LIGHT

Inspite of the fact that interference and diffraction both are the consequence of the superposition of wave and also that mostly both occur simultaneously, they are different. Following are the main points of the difference between them.

INTERFERENCE	DIFFRACTION
1. It occurs due to the superposition of the secondary wavelets originating from two coherent sources.	*1. It occurs due to the superposition of the secondary wavelets originating from different points of the same wavefront.*
2. The width of all fringes is equal.	*2. The width of all fringes is not equal.*
3. All maxima are of the same intensity.	*3. Intensity of secondary maxima fall off rapidly as we go away from the central maxima.*
4. Interference pattern consists of a large number of bands.	*4. In diffraction pattern there are only a few bands.*

13.7 RESOLVING POWER OF MICROSCOPE OR TELESCOPE

Due to diffraction of light a point source can never give a point image. It gives an image in the from of a circular disc. This fact puts a limit on resolving two neighbouring points imaged by a lens, when two point objects are close to each other, their images i,e, diffraction patterns as seen through optical instruments, will also be close and overlap each other. If the overlapping is small both the point objects are seen separate in the optical instrument. However if the overlapping is large, the two points objects will not be seen as separate i.e. optical instrument is not able to resolve them.

Hence resolving power of an optical instrument is the power or ability of the instrument to produce distinct separate image of two close objects.

The minimum distance between the two objects which can just be seen as separate by the optical instrument is called the limit of resolution of the instrument. Smaller the limit of resolution of the optical instrument, greater is its resolving power and vice-versa.

Resolving power of a microscope: The resolving power of microscope is its ability to form separate images of two point objects lying close together. It is determined by the least distance between the two points which can be distinguished. This distance is given by $d = \frac{\lambda}{2\mu \sin\theta}$, where λ is the wavelength of light used to illuminate the object and μ is the refractive index of the medium between the object and the objective. The angle θ is the half angle of the cone of light from the point object.

Resolving power $= \frac{1}{d} = \frac{2\mu \sin\theta}{\lambda}$

13.8 RESOLVING POWER OF A TELESCOPE

The resolving power of a telescope is the reciprocal of the smallest angular separation between two distant objects whose images are separated in the telescope. This is given by $\theta = \frac{1.22\lambda}{a}$,

where θ is the angle subtended by the point object at the objective, λ is the wavelength of light used and *a* is the diameter of the telescope objective. A telescope with a larger aperture objective gives a high resolving power.

13.9 POLARISATION AND PLANE POLARISED LIGHT

In writing equation for light wave, we assumed that the direction of electric field is fixed and the magnitude varies sinusoidally with space and time. The electric field in a light wave propagating in free space is perpendicular to the direction of propagation. However, there are infinite numbers of directions perpendicular to the direction of propagation and the electric field may be along any of these directions. For example, if the light propagates along the X-axis, the electric field may be along the *Y*-axis, or along the *Z*-axis or along any direction in the Y-Z plane. If the electric field at a point always remains parallel to a fixed direction as the time passes, the light is called linearly polarized along the direction. For example, if the electric field at a point is always parallel to the *Y*-axis, we say that the light is linearly polarized along the Y-axis. The same is also called plane polarized light. The plane containing the electric field and the direction of propagation is called the plane of polarization.

The phenomenon of restricting the vibrations of light in a particular direction perpendicular to direction of wave motion is called polarisation of light.

13.10 POLARISATION OF LIGHT BY REFLECTION:

When unpolarised light is reflected from a surface, the reflected light may be completely polarised, partially polarised or non-polarised. This would depend on the angle of incidence.

If angle of incidences is 0^0 or 90^0, the reflected beam remains unpolarised. For angles of incidence between 0^0 and 90^0, the reflected beam is polarized to varying degree.

The angle of incidence at which the reflected light is completely plane polarized is called polarising angle or Brewster's angle. It is represented by i_p. The value of i_p depends on the wavelength of light used. Therefore, complete polarisation is possible only for monochromatic light. If non-polarised light is incident along *AO* at angle i_p on the interface *XY* separating air from a medium of refractive index μ, the light reflected along *OB* is completely plane polarised. The light refracted along *OC* continues to be unpolarised.

Infact, the non-polarised light has two electric field components, one perpendicular to the plane of incidence (represented by dots) and the other in the plane of incidence (represented by arrows).

The vibrations of electric vector perpendicular to the plane of incidence remain always parallel to the reflecting surface, whatever be the angle of incidence. Therefore, condition of their reflection is not changed with the change in the angle of incidence. However, the other set of oscillations of electric vector in the plane of incidence make different angles with the reflecting surface, as angle of incidence of unpolarised light is changed. At the polarising angle (i_p), most of these vibration of electric vector get transmitted and are not reflected.

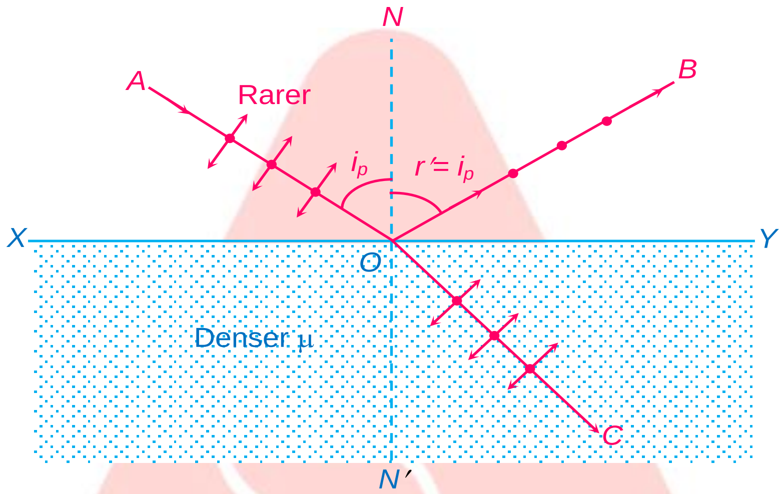
The reflected light therefore, contains vibrations of electric vector perpendicular to the plane of incidence. Hence the reflected light is completely plane polarised in a direction perpendicular to the plane of incidence.

13.11 BREWSTER'S LAW

According to this law, when unpolarised light is incident at polarising angle i_p on an interface separating air from a medium of refractive index μ, then the reflected light is fully polarized (perpendicular to the plane of incidence), provided.

$$\mu = \tan i_p$$

This relation represents Brewster's Law



$$\angle BOY + \angle YOC = 90^0$$

$$(90^0 - i_p) + (90^0 - r) = 90^0$$

where r is the angle of refraction

or $\quad 90^0 - i_p = r$ … (i)

According to Snell's law,

$$\mu = \frac{\sin i}{\sin r}$$

When $i = i_p$, $i = (90^0 - i_p)$

$$\therefore \quad \mu = \frac{\sin i_p}{\sin(90^0 - i_p)} = \frac{\sin i_p}{\cos i_p} = \tan i_p$$

This proves Brewster's law.

14 SCATTERING OF LIGHT

When light passes though a medium, a part of it appears in directions other than the incident direction. The phenomenon is called **scattering of light**. The basic process in scattering is absorption of light by the molecules of gas and other particles of the medium followed by re-radiation in different directions. The strength of scattering can be measured by the loss of energy in the light beam as it passes through the medium. In absorption, the light energy is converted into internal energy of the medium whereas in scattering, the light energy is radiated in other directions.

There are two types of scattering. If these particles are smaller than the wavelength of incident light, then scattering is proportional to $\frac{1}{\lambda^4}$. This is known as Rayleigh's law of scattering

Thus, red light is scattered the least and violet is scattered the most law of scattering. This is the reason why danger signals are made of red colour so that they can be seen from far away. The blue appearance of sky is due to scattering of sunlight from the atmosphere. When we look at the sky, it is the scattered light that enters the eyes. Among the shorter wavelengths, the colour blue is present in larger proportion in sunlight. Light of shorter wavelengths are scattered by air molecules which because of there smaller size follow Rayleigh's scattering. Blue light is strongly scattered by the air molecules and reach the observer. This explains the blue colour of sky.

The appearance of red colour of sun at the sunset and at the sunrise is also because of scattering of sunlight due to air molecules. The blue and neighbouring colours are scattered away in the path and light reaching the observer is predominantly red.

The sky would appear black and stars could be seen during day hours, if the earth had no atmosphere and hence no scattering.

Clouds contain a high concentration of water droplets or ice crystals which due to their comparatively larger size scatter light uniformly of all wavelengths. Since light of all wavelength is eventually scattered out of the cloud, so the cloud looks white.

MIND MAP

OPTICS

1. Reflection of light:

- In case of reflection at a plane or curved mirror, $\angle i = \angle r$.
- The image formed by a plane mirror is at the same distance behind the mirror as the object is in front of it. It is virtual, erect and of the same size as the object. The image formed by a plane mirror is laterally inverted.
- Derivation produced by a plane mirror $= 180° - 2i = 2g$, where g is the glancing angle.
- Keeping the direction of the incident ray fixed, if the plane mirror is rotated through angle θ, then reflected ray gets rotated through 2θ in the same sense.
- If two plane mirrors are inclined at angle θ, then number of images formed

  $= \dfrac{360°}{\theta} - 1$, if $\left(\dfrac{360°}{\theta}\right)$ is an even integer.

  $= \dfrac{360°}{\theta}$, if $\left(\dfrac{360°}{\theta}\right)$ is an odd integer, and object is placed unsymmetrical to the mirrors.

  $= \dfrac{360°}{\theta} - 1$, if $\left(\dfrac{360°}{\theta}\right)$ is an odd integer, and object is placed symmetrical to the mirrors.
- In case of a spherical mirror, $f = R/2$.
- The images formed by a concave mirror can be real as well

3. Refraction of light at spherical surfaces

- Refraction at a single spherical surface

  $$\frac{\mu_2}{v} - \frac{\mu_1}{u} = \frac{\mu_2 - \mu_1}{R}$$

  Transverse magnification produced is $m = \dfrac{\mu_1}{\mu_2}\dfrac{v}{u}$
- Lens maker's formula $\dfrac{1}{f} = \left(\dfrac{\mu}{\mu_0} - 1\right)\left[\dfrac{1}{R_1} - \dfrac{1}{R_2}\right]$.
- Lens formula $\dfrac{1}{v} - \dfrac{1}{u} = \dfrac{1}{f}$
- Linear magnification produced by a lens $m = \dfrac{I}{O} = \dfrac{v}{u}$.
- Power of a lens $P = 1/f$.
- Two thin lenses in contact $\dfrac{1}{F} = \dfrac{1}{f_1} + \dfrac{1}{f_2} + ...$

  Two thin lenses separated by a distance d

  $$\frac{1}{F} = \frac{1}{f_1} + \frac{1}{f_2} - \frac{d}{f_1 f_2}$$
- Lenses with a one surface silvered behaves as a spherical mirror. The equivalent focal length of the spherical mirror is given by $\dfrac{1}{F} = \Sigma\dfrac{1}{f_i}$, where f_i is to be repeated as many times as reflection or refraction is taking place.
- Displacement method:

  $$f = \frac{D^2 - L^2}{4D}, O = \sqrt{I_1, I_2}$$

2. Refraction of light at a plane surface

- In case of refraction of a ray at plane or spherical surface,

  $$\frac{\sin i}{\sin r} = \frac{\mu_2}{\mu_1} = {}_1\mu_2$$
- Lateral shift produced by a glass slab is $d = \dfrac{t}{\cos r}\sin(i - r)$
- When an object in denser medium is viewed almost normally by an observer in rarer medium, we have

  $${}_R\mu_D = \frac{\text{Real depth}}{\text{Apparent depth}}$$
- When an object in rarer medium is viewed almost normally by an observer in denser medium, we have

  $${}_R\mu_D = \frac{\text{Apparent height}}{\text{Real height}}$$
- $\sin c = 1/{}_R\mu_D$
- In case of refraction through prism, $r_1 + r_2 = A$.

  Deviation produced by a prism $\delta = (I + e) - A$
- Condition for minimum deviation for a prism

  $i = e$ and $r_1 = r_2$
- $\mu = \dfrac{\sin(A + \delta_m/2)}{\sin(A/2)}$
- Deviation produced by a prism of small angle $= (\mu - 1)A$.
- Angular dispersion$=(\mu_V - \mu_R)A$; Dispersive power$= \dfrac{\mu_V - \mu_R}{\mu - 1}$.
- Condition for dispersion without deviation is $\dfrac{A'}{A} = -\left(\dfrac{\mu - 1}{\mu' - 1}\right)$

  Net angular dispersion produced = $(\mu - 1)A[\omega - \omega']$.

4. Wave optics

- In case of superposition of two waves,

  $I_R = I_1 + I_2 + 2\sqrt{I_1 I_2}\cos\phi$, or $I_R \,\alpha\, (A_1^2 + A_2^2 + 2A_1A_2\cos\phi)$.
- Condition for constructive interference

  $\phi = \pm 2\pi n$, $n = 1, 2, 3, ...$

  $(\Delta x) = \pm n\lambda$, $n = 1, 2, 3, ...$
- Condition for destructive interference

  $\phi = \pm (2n - 1)\pi$, $n = 1, 2, 3, ...$

  $(\Delta x) = \pm (2n - 1)\lambda/2$, $n = 1, 2, 3, ...$
- Distance of nth bright fringe from $C.B.F.$ is

  $(y_n)_B = \pm n\lambda\dfrac{D}{d}$, $n = 0, 1, 2, 3, ...$

  Distance of nth dark fringe from C.B.F. is

  $(y_n)_D = \pm (2n - 1)\dfrac{\lambda D}{2d}$, $n = 0, 1, 2, 3, ...$
- Fringe width $(\omega) = \lambda D/d$, Angular fringe width $= \omega/D = \lambda/d$
- Equivalent optical path of a medium of $R.I.$ μ and distance d is μd.
- Displacement of fringe pattern due to introduction of a transparent sheet of $R.I.$ μ and thickness t in $YDSE$ $= Y_0 = (\mu - 1)t(D/d)$, in the same side in which the transparent sheet is introduced.