Applied Physics

I Year, I semester

Course Outcomes:

1. Identify various optical phenomena of light
2. Discuss the basic principles of quantum mechanics
3. Classify solids based on the band theory
4. Elucidate the characteristics of semiconductors and semiconductor devices
5. Explain the working principle of optical fibers and lasers

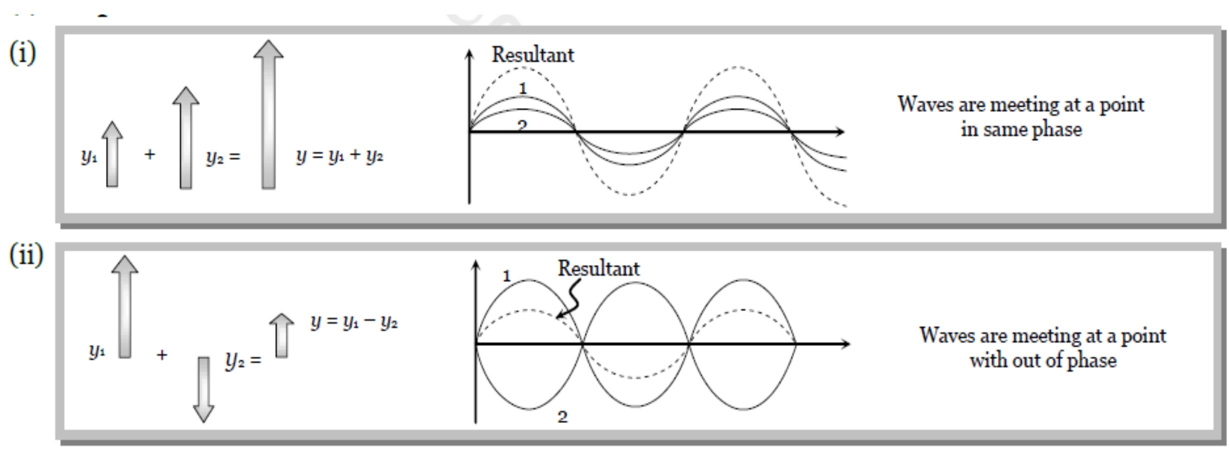
UNIT – I:
Wave Optics:
Course Outcome: Identify various optical phenomena of light.

Principle of Superposition, coherence. Interference - Interference in thin films by reflection, Newton's Rings. Diffraction – Fraunhofer and Fresnel Diffraction, Farunhofer diffraction due to single slit, Plane Diffraction Grating, resolving power of Grating (qualitative treatment). Polarization – Polarization of light waves, Plane of vibration, plane of polarization, Double refraction, Nicol's Prism, Applications of Polarization.

Principle of Superposition:-

When two or more waves are passing through the same medium at the same time, the resultant displacement at any point is equal to vector sum of the displacements of individual waves. This is called **superposition principle**.

$$\mathbf{Y} = \vec{\mathbf{Y}}_1 + \vec{\mathbf{Y}}_2 + \vec{\mathbf{Y}}_3 \ldots\ldots\ldots\ldots$$



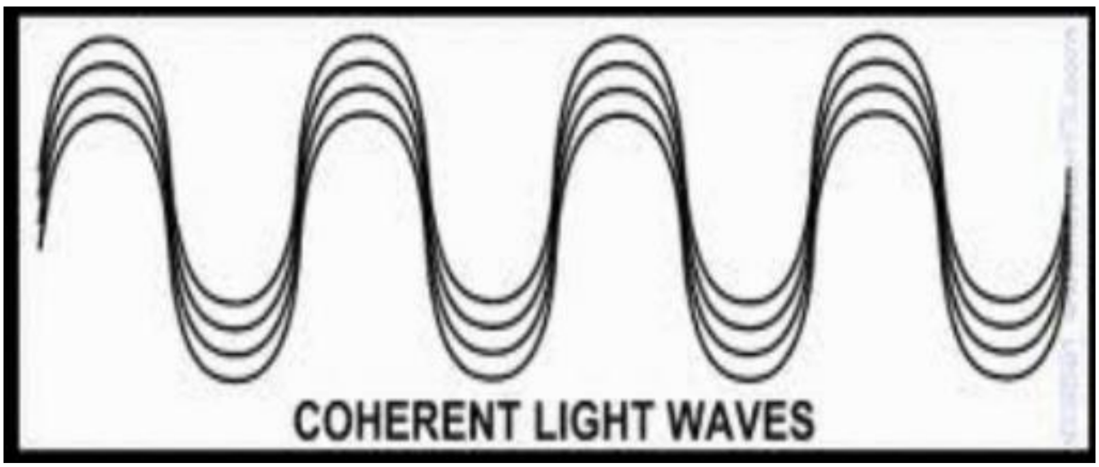
Coherent source:-

The sources of light which emits continuous light waves of the same wavelength, same frequency and in same phase or having a constant phase difference are called coherent sources.

Coherent waves:-

Two light waves which are having same wavelength, same frequency and in same phase or having a constant phase difference are called **coherent waves**. This phenomenon is known as **coherence**

Ex: - Laser light is highly coherent

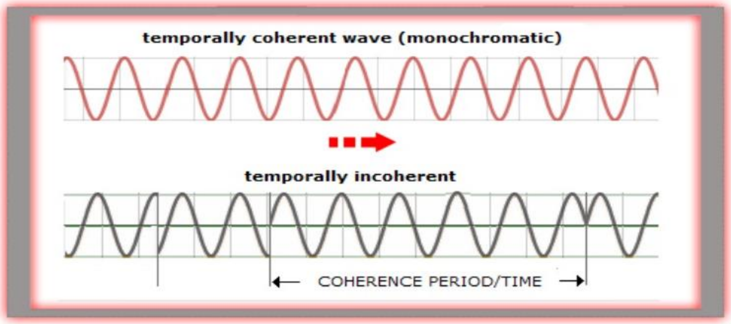


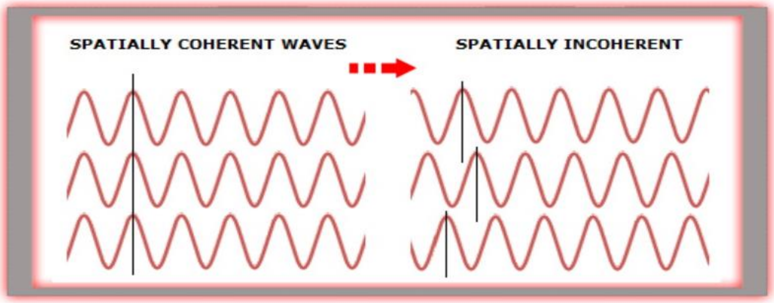
The light waves which are highly coherent if they maintain

1) Spatial coherence and
2) Temporal coherence.

Spatial coherence is a measure of the correlation between the phases of light waves at different points transverse to the direction of propagation. Spatial coherence tells us how uniform the phase of the wave front is.

Temporal coherence is a measure of the correlation between the phases of a light wave at different points along the direction of propagation. Temporal coherence tells us how monochromatic a source is.





Coherent waves can be obtained by two methods.

1) Division of wave front: The incident wave front is divided into two or more wave fronts.
   Eg: young's double slit experiment
2) Division of amplitude: The amplitude or intensity of incident light is divided by partial reflection.
   Ex: Newton's rings.

<u>**Interference**</u>:-

When coherent light waves are superimposed, then the resultant intensity is modified in the region of superposition is called <u>**interference**</u>.

Ex: Colours observed on soap bubbles, oil film formed on water when viewed under sunlight, etc.

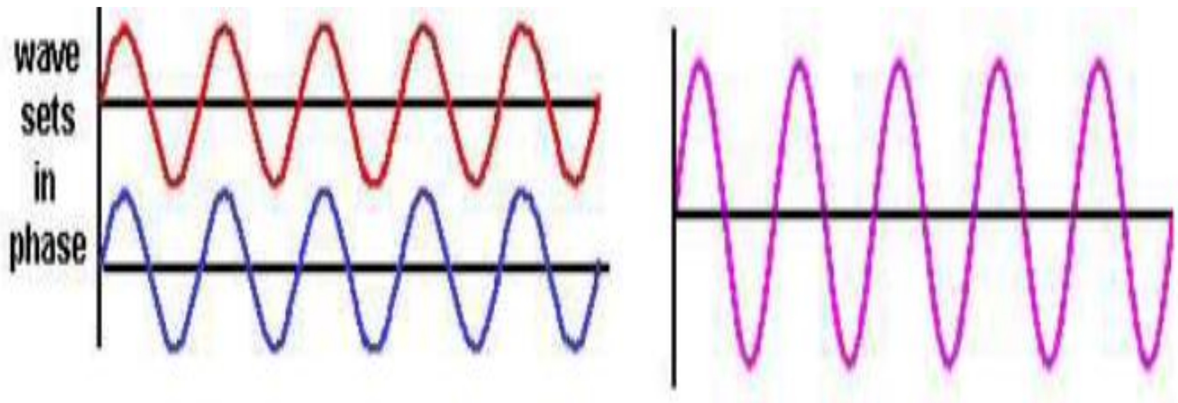
The Nature of Interference is classified into 2 types:

- Constructive Interference
- Destructive Interference

Constructive Interference:-

If two **in-phase** waves are superimposed with each other, the resultant intensity is maximum. This is known as **Constructive Interference**

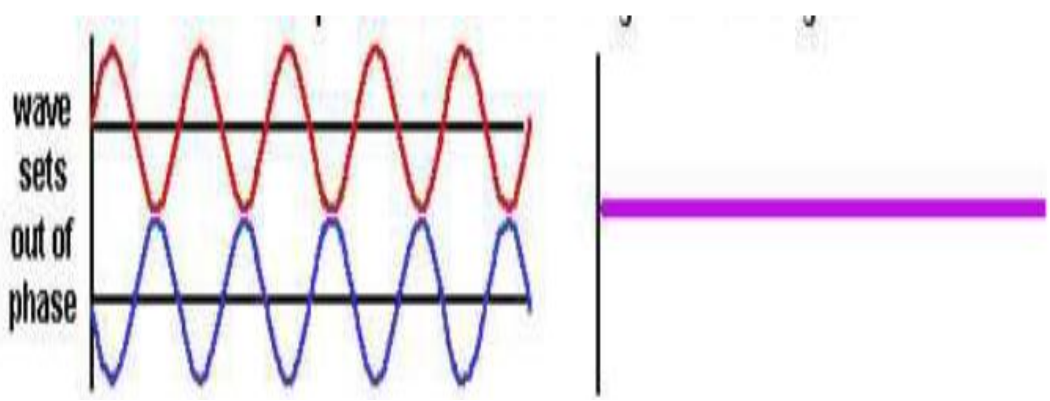
Condition: Path difference between the waves **(Δx) = nλ**

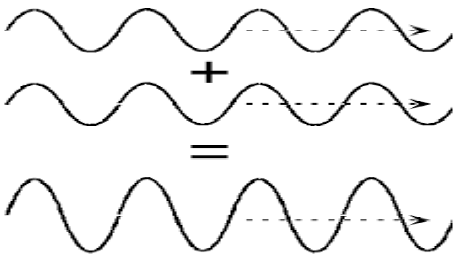
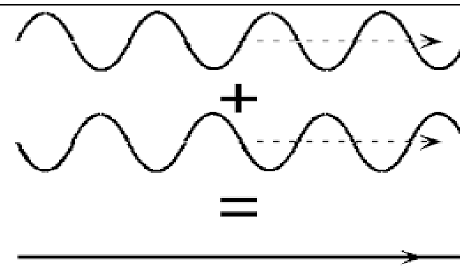


Destructive Interference:-

If two **out-of-phase** (or opposite phase) waves are superimposed with each other, the resultant intensity is minimum. This is known as **destructive Interference**

Condition: Path difference between the waves **(Δx) = $(2n\pm1)\lambda/2$**



Constructive interference	**Destructive interference**
	
1) If two in phase waves interfere, gives constructive interference.	If two out of phase waves interfere, gives destructive interference
2) Path difference between the waves at the point of observation $\Delta = n\lambda$	Path difference between the waves at the point of observation $\Delta = (2n \pm 1)\lambda/2$
3) Phase difference between the waves at the point of observation $Ø = 0°$ or $2n\pi$	phase difference between the waves at the point of observation $Ø = 180°$ or $(2n \pm 1)\pi$
4) Resultant intensity is maximum.	Resultant intensity is minimum.
5) Bright bands or fringes can be observed	Dark bands or fringes can be observed

<u>Conditions for sustained Interference of Light Waves</u>:-

For sustained interference of light to occur, the following conditions must be met:

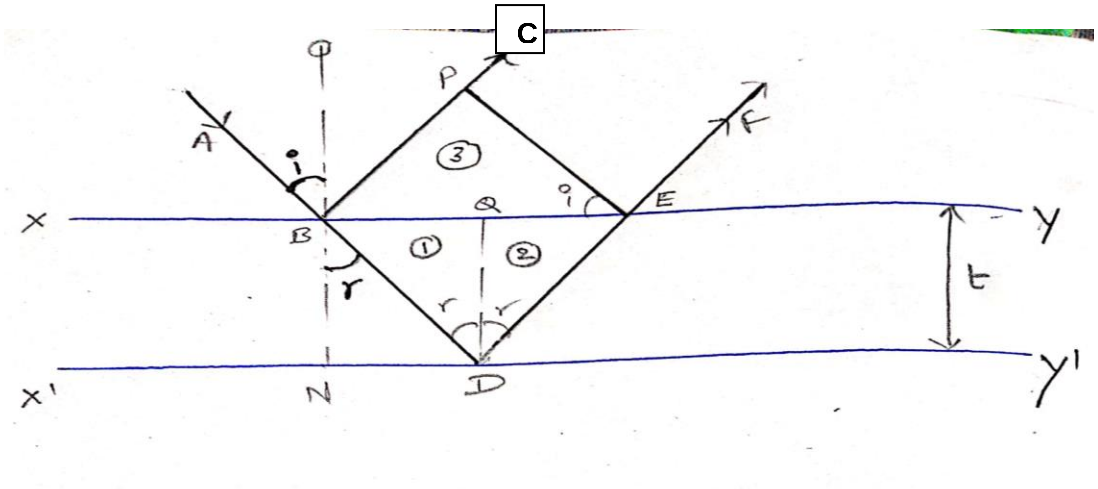
1. The two sources of light must be coherent
2. Amplitudes and intensities of the two sources must be nearly equal to produce sufficient contrast between maxima and minima.
3. The source must be small enough that it can be considered a point source of light.
4. The two sources must be very close to each other to produce wide fringes.
5. The sources should emit light waves continuously.
6. The sources must be monochromatic.

<u>Interference in thin film (by reflected rays)</u>:-

Thin - film:

A very thin layer of material and its thickness is ranging from fractions of a nanometer to several micrometers is known as **<u>thin-film.</u>**

Ex: coatings, glass, air enclosed between two transparent sheets, and soap bubble, etc.



- Let us consider a thin film of thickness 't' bound by two surfaces XY and X'Y'. Let "μ" be the refractive index of the material of thin film.
- In thin film, the interference of light is due to superposition of light reflected from top and bottom surface of the film.
- A ray of light AB incident on surface XY(top surface) at an angle 'i' is partially reflected along BC and partially refracted along BD. Let the angle of refraction be "r".
- At the surface X'Y'(bottom surface), the ray is again reflected along DE.
- The rays BC and EF constitute reflected system and interfere to produce interference pattern.
- To find the path difference between these reflected rays, a line perpendicular to BC is drawn, labeled as PE.

  From the figure, path difference = (BD+DE) in the medium - BP in air

  = (BD+DE) μ - BP ------ (1) (for air, μ=1)

In Δ^{le} BDQ, $\cos r = \frac{DQ}{BD} = \frac{t}{BD}$

$$BD = \frac{t}{\cos r} = DE$$

$$BD+DE = \frac{t}{\cos r} + \frac{t}{\cos r}$$

$$BD+DE = \frac{2t}{\cos r} \text{ ----------- } (2)$$

In Δ^{le} BPE, $\sin i = \frac{BP}{BE}$

$$BP = BE \sin i$$

$$BP = (BQ+QE) \sin i \text{ -------- } (3)$$ [From Fig. BE= BQ+QE]

In Δ^{le} BDQ, $\tan r = \frac{BQ}{DQ} = \frac{BQ}{t}$

$$BQ = t \tan r = QE$$

$$BQ+QE = t \tan r + t \tan r$$

$$BQ+QE = 2t \tan r$$

Therefore, equation (3) become

$$BP = 2t.\ \tan r.\ \sin i$$

According to snell's law, $\mu = \frac{\sin i}{\sin r}$

$$\text{Sin}\, i = \mu \sin r$$

$$BP = 2t \frac{\sin r}{\cos r} \mu \sin r$$

$$BP = 2\mu t \frac{\text{Sin}^2 r}{\cos r} \text{ ------------ } (4)$$

Now, substitute equation (2) & (4) in equation (1)

Therefore Path difference (Δ) $= \frac{2\mu t}{\cos r} - \frac{2\mu t\ \text{Sin}^2 r}{\cos r}$

$$= \frac{2\mu t}{\cos r}(1 - \sin^2 r)$$

$$= \frac{2\mu t}{\cos r} \cos^2 r$$

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

Since, BC is reflected from a denser medium, it undergoes an additional phase change of "φ" or path difference of "λ/2".

Hence, Path Difference between BC & EF

$$\boldsymbol{\Delta = 2\ \mu t \cos r - \frac{\lambda}{2}} \text{ ....}(1)$$

- **<u>Condition for Bright band</u>:**

Condition for constructive interference, path difference = n λ

The thin film appears bright, if path difference is 2 μt cosr - λ / 2 = n λ

$$\mathbf{2\ \mu t \cos r = (2n+1)\ \lambda / 2} \quad \text{where, } n = 0,1,2,\ldots..$$

- **<u>Condition for Dark band</u>:**

Condition for constructive interference, path difference = (2n+1) λ / 2

The thin film appears dark, if path difference

$$2\ \mu t \cos r - \lambda / 2 = (2n+1)\ \lambda / 2$$

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

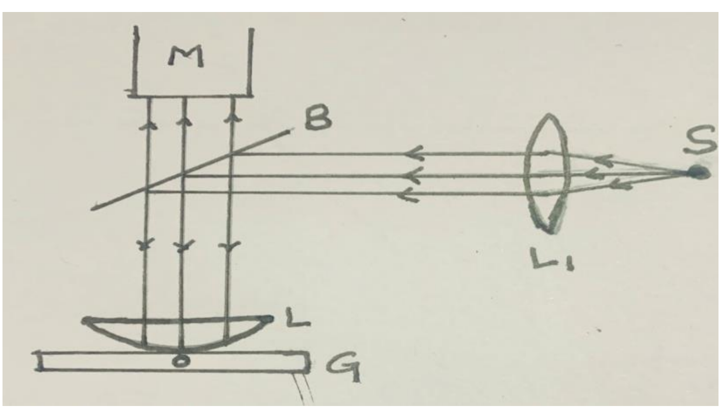
or

$$\mathbf{2\ \mu t \cos r = n\lambda} \qquad \text{where } n = 0,1,2,\ldots\ldots$$

<u>Newton's Rings experiment</u>:

When a plano-convex lens with its convex surface is placed on a plane glass plate, an air film of increasing thickness is formed between these two. The thickness of the film at the point of contact is zero. If monochromatic light is allowed to fall normally and the film is viewed in the reflected light, alternate dark and bright circular rings are seen. These circular rings were discovered by Newton. Hence, these are called Newton's Rings.

<u>Experimental arrangement:</u>



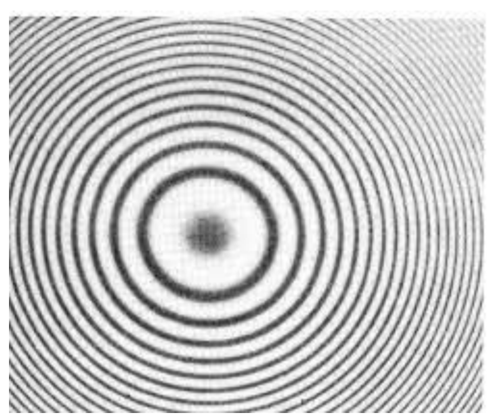
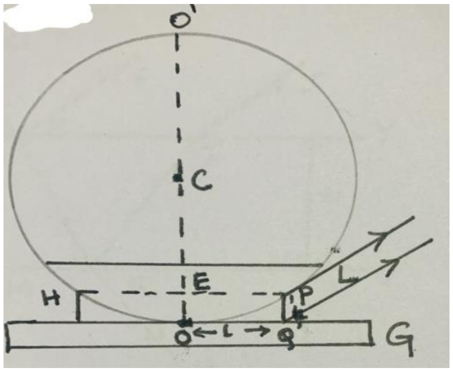


Fig. Experimental arrangement is as shown in figure and Newton's rings

- L is plano convex lens placed on an flat glass plate G. The lens touches the glass plate at ‘O’.
- S be the monochromatic source of light falls on a on a glass plate B held at 45^0inclination.
- The glass plate B reflects part of light incident on it towards the air film enclosed between the lens L and glass plate G. A part of light reflected from bottom surface of the lens L and top surface of glass plate G.
- These reflected rays interfere and produce an interference pattern in the form of circular rings (Newton’s Rings).
- These rings can be viewed by microscope M.



The path difference between the reflected rays is **$(\Delta) = 2\,\mu t \cos r + \lambda / 2$**

For Air medium, $\mu = 1$

For normal incidence, r=0, $\cos r = 1$

Path difference $(\Delta) = 2\,(1)(t)\,(1) + \lambda / 2$

$= 2t + \lambda / 2$

Path difference $(\Delta) = 2t + \lambda / 2$ -------------- (1)

<u>Case 1: Condition for central dark spot</u>:-

From Equation (1)

Path difference $(\Delta) = 2t + \lambda / 2$

at point of contact ‘O’ , t=0

Path difference $(\Delta) = 2\,(0) + \lambda / 2$

$= 0 + \lambda / 2$

Path difference $(\Delta) = \lambda / 2$

If path difference is equal to $\lambda / 2$, it leads to destructive interference.

Hence, **central spot is always dark.**

Case 2: Condition for bright rings (constructive interference):

Path difference(Δ) = $2t + \lambda / 2$ ------(1)

Condition for constructive Interference is $\Delta = n\lambda$ -----(2)

From eq.1 and 2

$$2t + \lambda / 2 = n\lambda$$

$$\mathbf{2t = (2n-1)\,\lambda / 2} \text{ -----------(3)}$$

Case 3: Condition for dark rings (destructive interference):

Path difference (Δ) = $2t + \lambda / 2$ ------(1)

Condition for destructive Interference is $\Delta = (2n+1)\lambda/2$ -----(2)

From eq.1 and 2

$$2t + \lambda / 2 = (2n+1)\lambda/2$$

$$\mathbf{2t = n\lambda} \text{ -----------(4)}$$

Determination of Wavelength of given light source using Newtons rings:

Let us consider the curved surface of lens as an arc of the circle whose center is at C and radius is 'R' and λ the wavelength of light used.

From ΔCNP

$CP^2 = CN^2 + NP^2$

$R^2 = (R-t)^2 + r_n^2$

$R^2 = R^2 + t^2 - 2Rt + r_n^2$

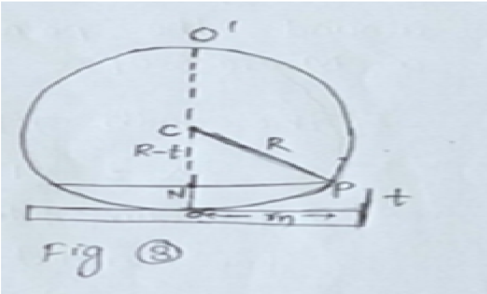
(t^2 is neglected)

$2Rt = r_n^2$

$t = r_n^2 / 2R$

substitute t value in eqn. (4)

$2 \times r_n^2 / 2R = n\lambda$



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

r_n is radius of n^{th} dark ring

The diameter of the nth dark ring is

$D_n = 2\, \mathbf{r_n} = 2\sqrt{\boldsymbol{nR\lambda}}$

$D^2_n = 4nR\lambda$

Similarly, the diameter of m^{th} ring dark ring is

$D^2_m = 4mR\lambda$

By subtracting above equations,

$D^2_m - D^2_n = 4mR\lambda$

Or $\boldsymbol{\lambda} = \frac{\mathbf{D^2m - D^2n}}{\mathbf{4}(\boldsymbol{m-n})\boldsymbol{R}}$

Hence by measuring the diameter of rings of different order, Knowing the radius of curvature of lens R, we can determine the 'λ' of given monochromatic source.

OR

Knowing the wavelength of light, radius of curvature of lens can be calculated.

DIFFRACTION

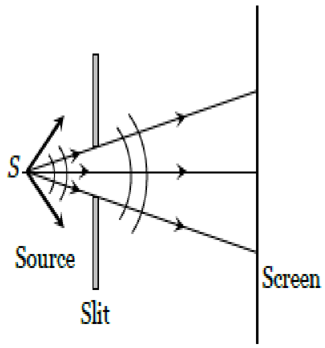
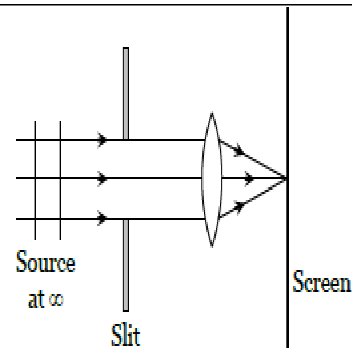
Definition: The bending of light waves around the edges of an obstacle/aperture is called **diffraction**.

Condition for Diffraction: Diffraction phenomenon can be observed when the size of obstacle/aperture is comparable to wavelength of light.

Types of diffraction:

The diffraction phenomenon is divided into two types

1. Fresnel diffraction
2. Fraunhofer diffraction

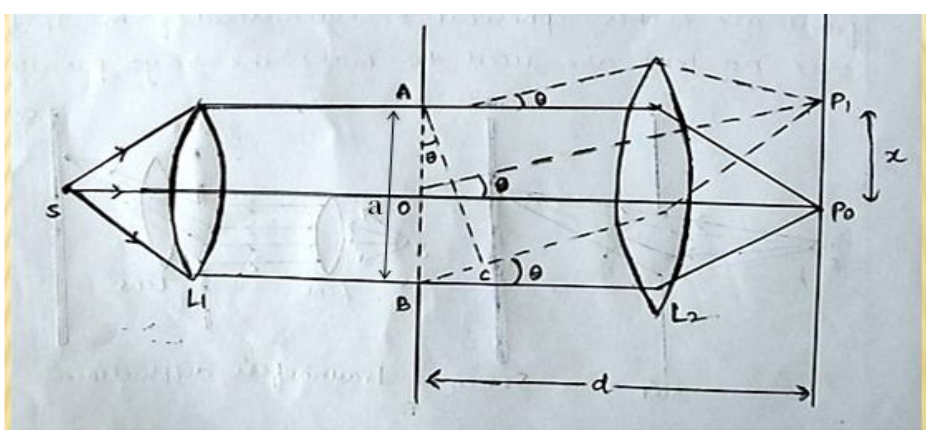
Fresnel diffraction	Fraunhofer diffraction
	
In this diffraction, either source or screen or both kept at **finite** distance from obstacle	In this diffraction, source and screen are effectively at **infinite** distance from obstacle.
This is near- field diffraction	This is far- field diffraction
In this case, incident wave front is either spherical or cylindrical.	In this case, incident wave front is a plane.
Experiment is simple but analysis is difficult.	Experiment is simple but analysis also simple.
lens are not required to study the diffraction	To study the diffraction, lenses are necessary

<u>Fraunhofer diffraction due to single slit:</u>

Introduction:

In Fraunhofer diffraction incident wave front must be plane wave front, hence two lenses are used one is collimating and another is converging.

Experimental arrangement:



- Let S be the monochromatic source of light.
- L_1 be the collimating lens of focal length f at a distance from source, so that lens produces the parallel beam of rays.
- AB is the slit of width ‘a’.
- The light passing through the slit is collected by lens L_2 which forms image on screen as shown in figure.

Working:

- Let us consider a plane wave front incident normally on the slit AB, each and every point on wave front acts as secondary source of light waves from the source travels after AOB in all possible directions.
- The undiffracted light travel straight and focus on the screen at point Po. Since all the light waves have travelled the same optical distance, there is no path difference between them and they produce the constructive interference and hence, point Po appears bright with maximum intensity. This is known as **central maxima**
- The diffracted rays at angle θ are focused at point P_1. The intensity distribution at point P_1 depends on the path difference between the secondary wavelets, which are produced at point A and point B
- From figure, the path difference between diffracted rays $\Delta = BC$

From Δ ABC,

$\sin\theta = \frac{BC}{AB} = \frac{BC}{a}$

$BC = a \sin\theta$

or $\boldsymbol{\Delta = a \sin\theta}$

Where, a = slit width, θ = angle of diffraction

Condition for Minima:

If path difference $\Delta = \lambda, 2\lambda, 3\lambda, \ldots\ldots,$

Point P_1 appears with minimum intensity called minima

Therefore the General condition for minima is

$\boldsymbol{a\sin\theta_n = n\lambda}$ ………….(1)

Where, n= 1,2,3,…….

θ_n= corresponding directions of n^{th} minima

Condition for Maxima:

If path difference is odd multiple of $\frac{\lambda}{2}$, ie. $\Delta = \frac{3\lambda}{2}, \frac{5\lambda}{2}, \frac{7\lambda}{2}, \ldots\ldots (2n+1)\frac{\lambda}{2}$

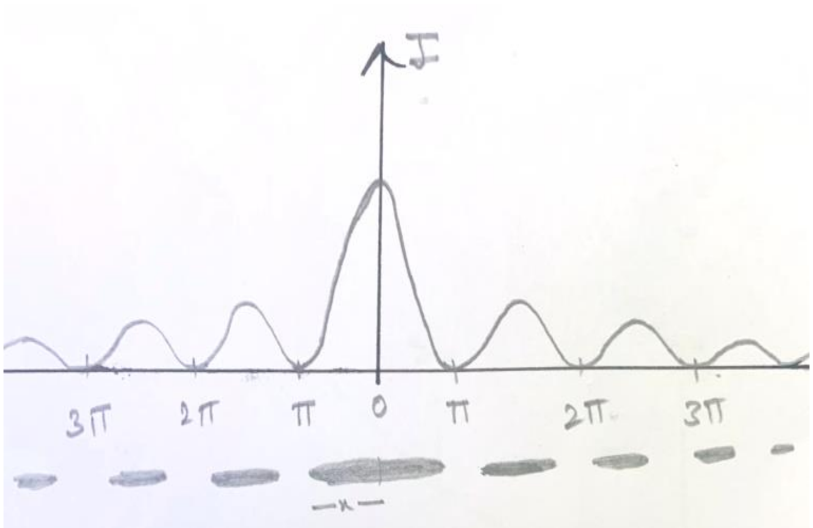
Point P_1 appears bright called maxima

Therefore the General condition for maxima is

$$\mathbf{a\sin\theta_n = (2n+1)\frac{\lambda}{2}} \ldots\ldots\ldots\ldots(2)$$

Where, n= 1,2,3,……., θ_n= corresponding directions of n^{th} maxima

Diffraction pattern due to single slit consists of central maxima and secondary maximas and minimas on both sides is shown in the following figure.



Calculation of the slit width:

W.K.T , From eqn (1)

$a \sin\theta = n\lambda$

$\sin\theta = \lambda/a$ (n=1 for first order)

From fig: $\sin\theta = x/d$ (From ΔOP_0P_1)

Therefore, from above equations,

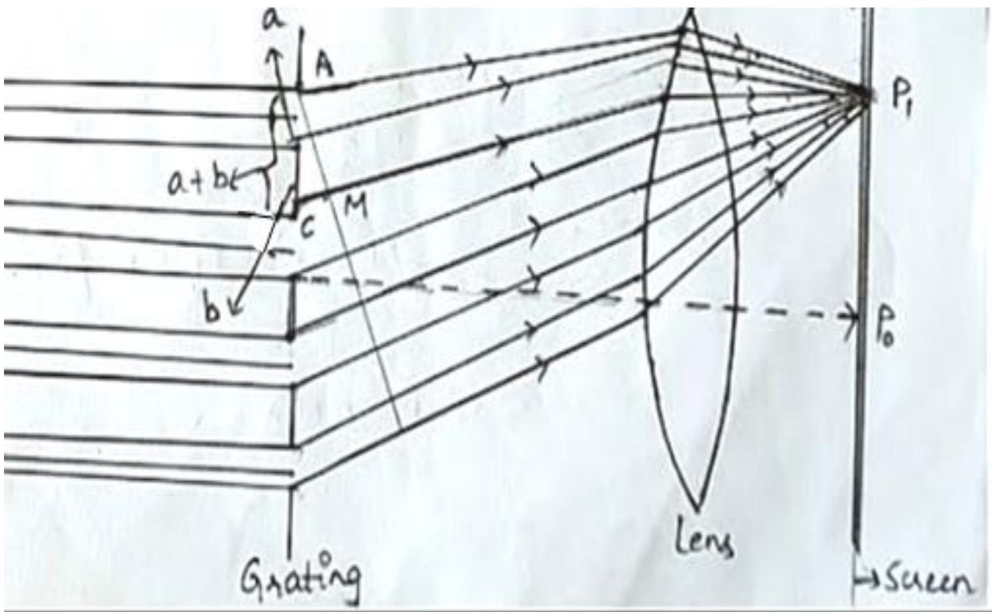
$\lambda/a = x/d$

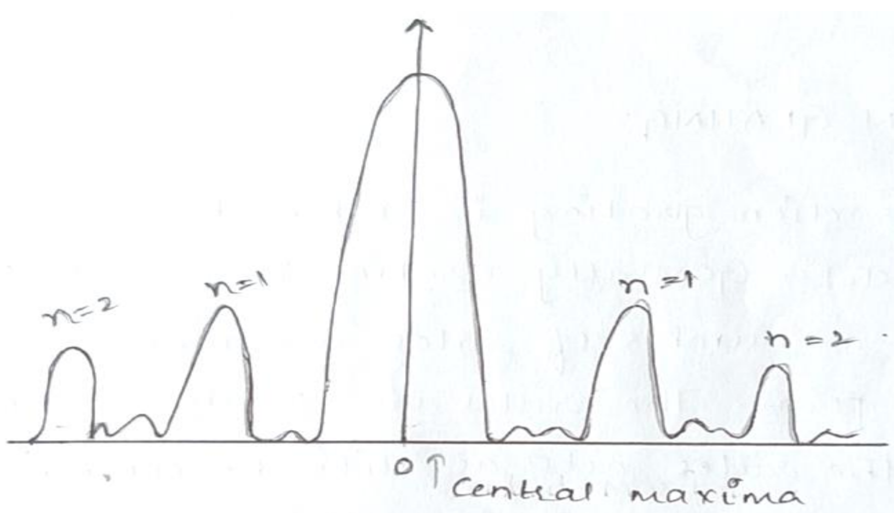
$$\mathbf{a = d\lambda/x}$$

Where, **a** is slit width

Fraunhofer diffraction due to N- slit (Diffraction Grating):-

- Diffraction grating is nothing but closely placed multiple slits (N-slits).
- Grating is a transparent material (glass plate) on which ruling are made with a diamond point, they are parallel this type of grating is called plane transmission grating.
- The rules are opaque and the space between the rules acts as a slit. The combined equal width of ruling and slit is called **grating element**.
- When light passes through the grating, each slit diffracts the light and the diffracted light waves are combined to produce sharper maxima on the screen as shown in the following figure.





- Let AB represents slit of width ‘a’ and BC represents opaque ruling of width ‘b’ each. ie. (a+b) is combined width of slit and ruling is called grating element.
- Let a plane wave front be incident normally on the grating. The slits act as secondary source of lights gives secondary waves.
- These waves spread in all directions on either side of the grating.
- The secondary waves are travelling same direction as that of the incident rays focused at point P_0. They reinforce constructively and hence point P_0 is position of central bright maxima.
- Now let us consider secondary diffracted waves moving in a direction which makes an angle θ with respect normal to grating and reaching at point P_1 as shown in figure.
- The intensity at point P_1 is depends on the path difference between the diffracted rays

From figure,

The grating element (AC) = a+b

The path difference is CM

From Δ ACM, $\sin\theta = \frac{CM}{AC} = \frac{CM}{(a+b)}$

$CM = (a+b)\sin\theta$

Path difference (Δ) = CM = (a+b) sinθ ------------ (1)

Condition for the maximum at point P_1 is

Path difference (Δ) = n λ ------------ (2)

From equations (1) & (2)

$(a+b)\sin\theta = n\lambda$ Where, n = 1, 2, 3,……

$$\sin\theta = \frac{n\lambda}{(a+b)}$$

$$\sin\theta = nN\lambda$$

Where, $\frac{1}{(a+b)}$ = N called number of lines per unit width of the grating.

$$\boldsymbol{\lambda = \frac{\mathbf{Sin\theta}}{\mathbf{nN}}}$$

By using above equation, we can find out the wavelength (**λ**) of the light source.

Calculation of maximum number of orders possible with grating

W.K.T $\mathbf{sin\theta = nN\lambda}$

The maximum possible value of θ is 90^0 ie. **sin**90^0=1

above equation become, $\mathbf{1= nN\lambda}$

$$\mathbf{(n)_{max} \le \frac{1}{N\lambda}}$$

Therefore above relation gives the maximum number of orders possible by the grating which is having N no. of lines per unit width.

Resolving power of Grating:-

One of the important properties of a diffraction grating is its ability to resolve spectral lines which have nearly the same wavelengths.

The resolving power of a grating is defined as its ability to form separate spectral lines of two very closely spaced wavelengths

(or)

Resolving power of grating is defined as the ratio of the wavelength (λ) of a line in the spectrum to the least difference in wavelength ($d\lambda$) of the next spectral line.

$$\text{Resolving power of grating} = \frac{\lambda}{d\lambda}$$

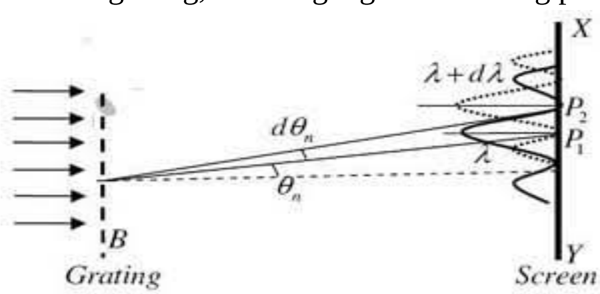
Let parallel beam of light of two wavelengths λ and $\lambda + d\lambda$ are incident normally on grating

$$\textbf{Resolving power of grating} = \frac{\lambda}{d\lambda} = \mathbf{nN}$$

where, n is the order of the spectrum,

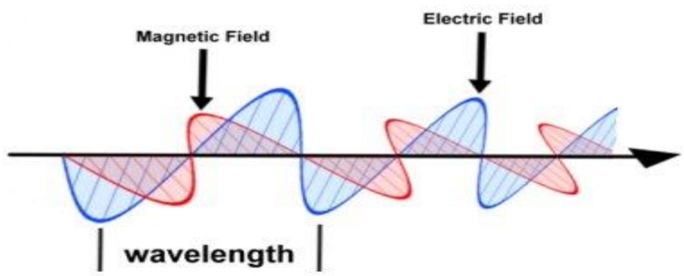
N is the no. of lines on the grating

Therefore, resolving power of the grating is directly proportional to total no. of lines on the grating. By increasing the no. of lines on grating, we can get good resolving power.



POLARIZATION

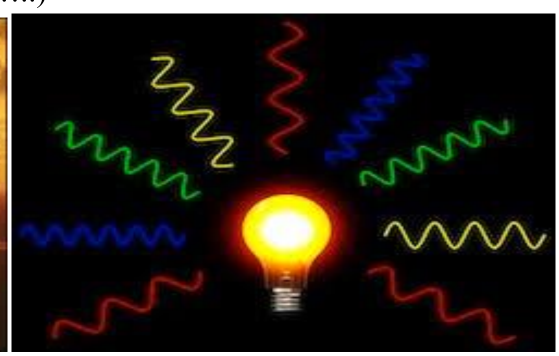
The phenomenon of polarization, establishes the transverse nature of light. Light is electromagnetic in nature. It consists of oscillating electric and magnetic fields perpendicular to each other and also to the direction of propagation of the wave.



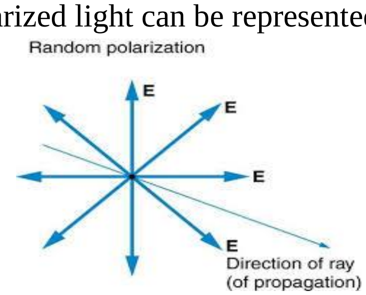
Unpolarized light :-

In case of ordinary light, oscillations or vibrations are at random. Hence, this light is known as **unpolarized light.**

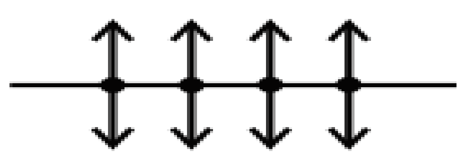
Ex: Ordinary light (bulb, sunlight, candle…..)



unpolarized light can be represented as follows



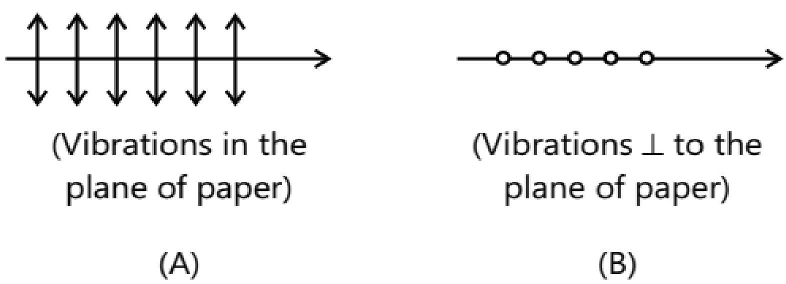
(OR)



Polarized light :-

If oscillations or vibrations are confined to only one direction, then this light is known as **polarized light**

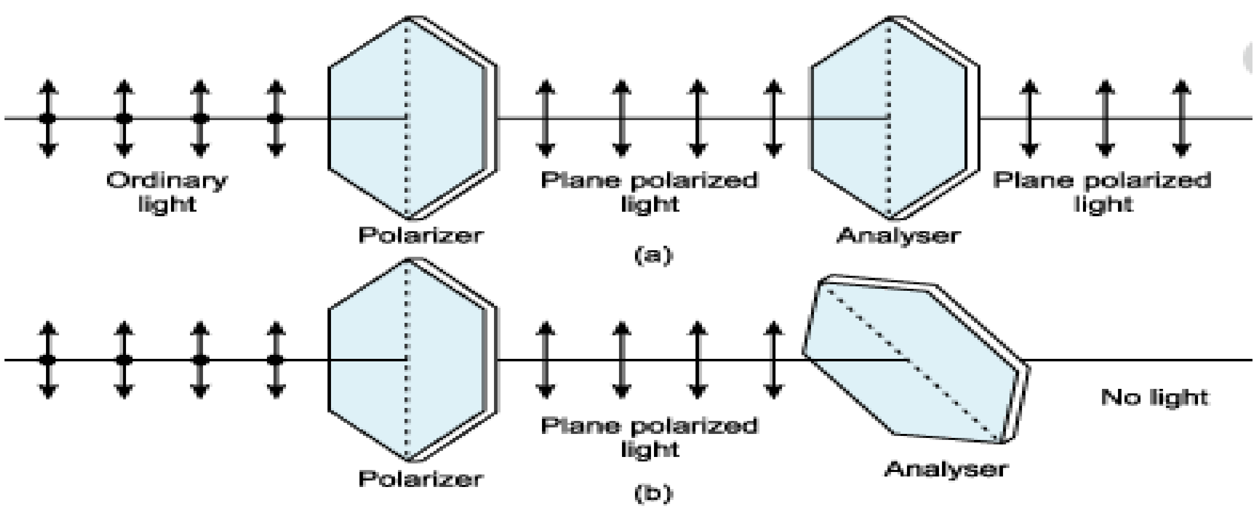
Pictorial representation of polarised light shown figure (A) and (B)



- Vertical component
  The vibrations along the plane of paper (Fig A).
- Horizontal component
  Vibrations perpendicular to plane of paper (Fig B)

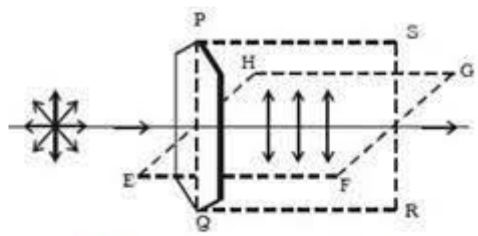
Polarization:-

The process by which an unpolarized light is converting into plane polarized light is known as **polarization**.



<u>Plane of Vibration</u>: The plane in which the vibrations occur is called plane of vibrations (plane PQRS).

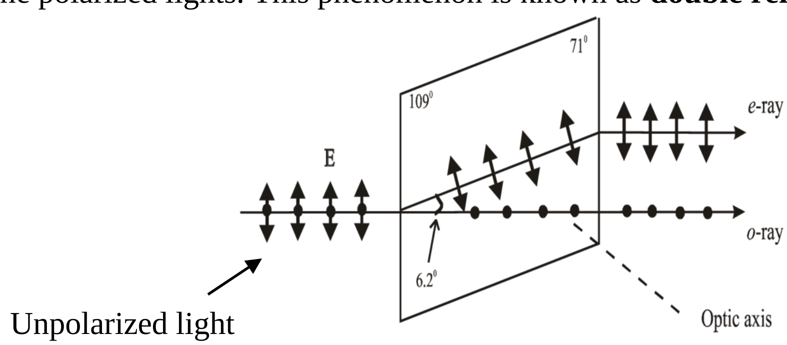
<u>Plane of polarization</u>: The plane which is perpendicular to the plane of vibrations is called plane of polariazation (plane EFGH).



PQRS = Plane of vibration
EFGH = Plane of polarization

Double Refraction (Birefringence):

When unpolarized light passes through certain anisotropic crystals, the refracted ray split into two rays one is ordinary ray (O-ray) and another ray is extraordinary ray (E-ray). Both rays are plane polarized lights. This phenomenon is known as **double refraction**.



The crystals which are showing this phenomenon are called as double refracting crystals examples calcite, quartz, tourmaline

- The ordinary ray travels with the same velocity in all directions
- the extraordinary ray travels with non uniform velocity (not same in all directions)
- ordinary ray refractive index (μ_o) is more than the extraordinary ray refractive index (μ_e)

  $$(\mu_o) > (\mu_e)$$

- Velocity of Extraordinary ray is more than that of ordinary ray

  $$(V_e) > (V_o)$$

Nicols Prism:-

Nicol’s Prism is a device which is used to produce and analyze the plane polarized light. This was invented by William Nicol, in the year 1828.

Construction:-

A calcite crystal whose length is three times of its breadth is taken. The end faces of the crystal are cut down in such a way that angles in the principle section become 68° and 112° instead of 71° and 109°. The crystal is then cut in to two halves along the diagonal and two cut faces are well polished and cemented together by using Canada balsam which is a transparent material. The refractive index of a Canada balsam is lies between the refractive index of ordinary and extra-ordinary rays.

i.e, Refractive index of O-ray (μ_o) = 1.658

Refractive index of Canada balsam (μ_{CB}) = 1.55

Refractive index of O-ray (μ_e) = 1.486

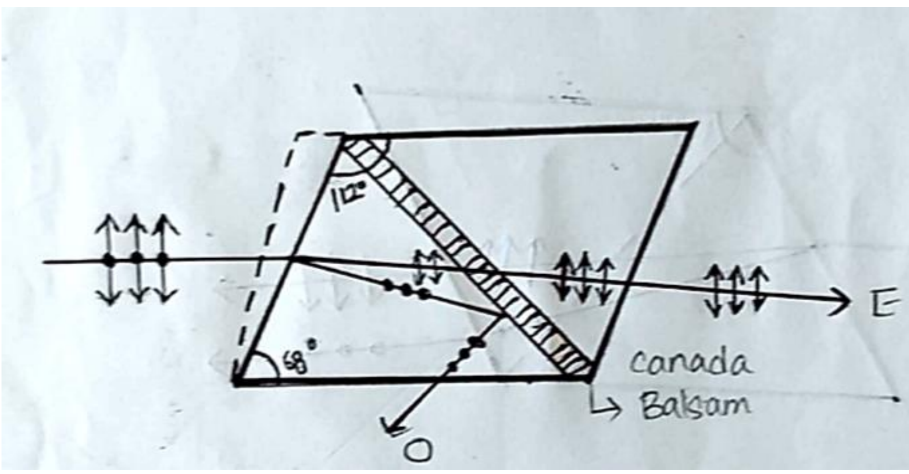


Fig. Nicol’s Prism

Working:-

When an unpolarized light is incident on Nicol’s prism, it splits in to ordinary ray (O-ray) and extraordinary (E-ray). Canada balsam is rarer medium for O-ray. Because of the shaping of the crystal face, the O-ray is incident on the Canada balsam at an angle greater than critical angle and suffers total internal reflection and leaves the crystal through its side as shown in figure. The

E-ray is transmitted through the Canada balsam and emerges out of the Nicol's prism. Hence, in this way we can use Nicol's prism to produce the plane polarized light.

Therefore, Nicols prism can be used to produce and analyze the plane polarized light.

Applications of Polarization:

The phenomenon of polarization has many practical applications in daily life

- The polarized sun-glasses are used to eliminate the glare of light
- The intensity of light coming inside the aero plane can be controlled using polaroids
- The polaroids are used to improve colour contrast in old oil paints
- polaroids are used to produce three-dimensional moving pictures (3D movies)
- They are used for enhancing visibility of digital displays
- They are used in calculators, watches, monitors of laptop which have LCD screens