Unit - I

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CSE-B 18911A05A3

Interference, Diffraction & polarization

Superposition principle :-

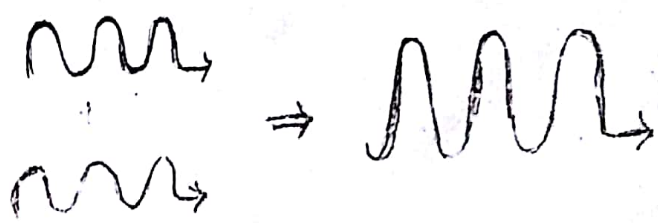
When two (or) more waves are passing through the same medium, the resultant displacement at any point is equal to the vector sum of the displacements of individual waves. This is the "principle of superposition"

if $y_1, y_2, y_3 \ldots$ are the displacements of individual waves, then the resultant displacement is

$$\boxed{Y = y_1 + y_2 + y_3 + \ldots}$$

→ if two waves are moving in same direction, the resultant displacement is

$$\boxed{Y = y_1 + y_2}$$



→ if two waves are moving in opposite direction, the resultant displacement is

$$\boxed{Y = y_1 - y_2}$$

Coherence:-

Two light waves which are having same wavelength, same frequency, same amplitude and constant phase difference are called as "Coherent waves". This phenomenon is known as "Coherence".

→ Spatial Coherence:- Spatial Coherence means the two light waves maintain a constant phase difference for long ~~time~~ distance.

→ Temporal Coherence:- Temporal Coherence means the ~~lag~~ phase difference between any two points on the wave is constant at regular intervals of time.

Interference:-

When two coherent light waves are superimposed, then the resultant intensity is modified in the region of superposition. This phenomenon is known as "interference".

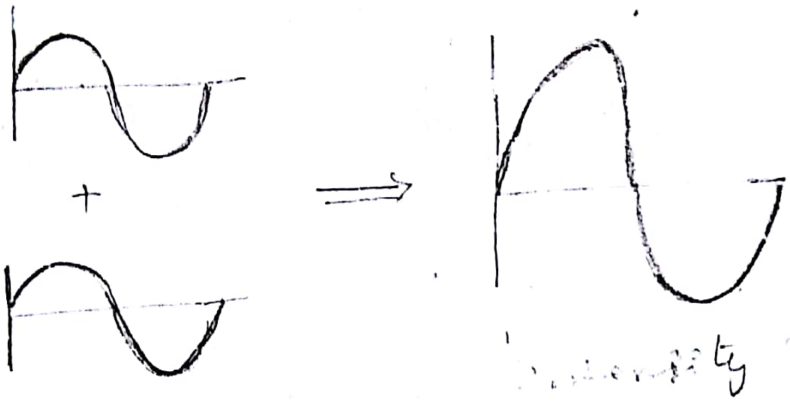
The nature of interference is classified into 2 types:

→ 1) constructive interference.

→ 2) destructive interference.

① Constructive interference :-

In case of constructive interference, two inphase waves are superimposed with each other to produce maximum intensity.



intensity is maximum

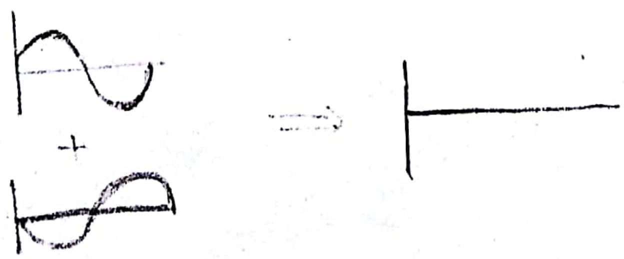
Fig:- constructive interference.

Condition for constructive interference is the path difference between two waves is "nλ".

i.e; $\boxed{\Delta = n\lambda}$

② Destructive interference :-

In case of destructive interference, two out of phase waves are superimposed with each-other to produce minimum intensity.



intensity is minimum

Fig:- destructive interference

Condition for destructive interference is path difference $\boxed{(\Delta) = (2n+1)\frac{\lambda}{2}}$.

1A (Interference in thin-films (by Reflection) :—

In thin-film interference is due to superposition of light reflected from the top and bottom surfaces of the film.

Consider a thin film of thickness "t" and refractive-index "μ". Let a monochromatic light ray (A) is incident on the top surface of the film, then some part of light is reflected and some part is refracted. The refracted ray is reflected at point (C) from the bottom surface and finally comes out along R'. The reflected rays R and R' are superimposed to produce interference pattern. The nature of the interference is depends on the path difference between these two reflected rays.

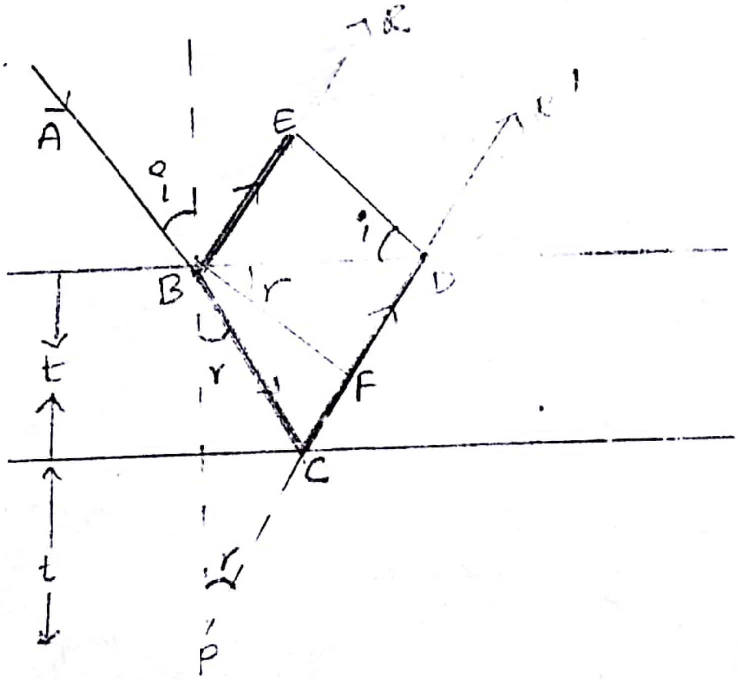


Fig: interference in thin film (by reflection) from the diagram, (3)

Path difference between R & R' is

$$\Delta = (BC + CD)\mu - BE$$

$$\Delta = (BC + CF + FD)\mu - BE \quad \text{--- (1)} \qquad \because [CD = CF + FD]$$

from ΔBDE

$$\sin i = BE/BD$$

from ΔBFD

$$\sin r = FD/BD$$

According to snell's Law

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

$$\mu = \frac{BE/\cancel{BD}}{FD/\cancel{BD}} \Rightarrow \frac{BE}{FD}$$

$$BE = \mu . FD$$

Substitute "BE" value in eqn (1)

$$\Delta = (BC + CF + FD)\mu - \mu . FD$$

$$\Delta = (BC + CF)\mu$$

$$\Delta = (CP + CF)\mu \qquad \because [\text{from fig } BC = CP$$

$$\Delta = PF\mu \quad \text{--- (2)}$$

from ΔBPC,

$$\cos r = \frac{PF}{BP} = \frac{PF}{2t} \qquad \because [\text{from fig: } BP = 2t.$$

$$\Rightarrow PF = 2t \cos r$$

Substitute this value in eqn (2)

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

when the light ray is reflected from the glass surface (denser medium), it undergoes an additional path difference "$\lambda/2$".

$\therefore$ total path difference is

$$\Delta = 2\mu t \cos r + \lambda/2 \quad \text{--- (3)}$$

→ 1) constructive interference:-

condition for constructive interference is

path difference $(\Delta) = n\lambda$ — (4)

$\therefore$ from eqn (3) & (4)

$$2\mu t \cos r + \lambda/2 = n\lambda$$

$$2\mu t \cos r = n\lambda - \lambda/2$$

$$\boxed{2\mu t \cos r = (2n-1)\lambda/2}$$

→ 2) destructive interference:-

condition for destructive interference is

path difference $(\Delta) = (2n+1)\lambda/2$ — (5)

$\therefore$ from eqn (3) & (5)

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

$$2\mu t \cos r = 2n \times \lambda/2 + \cancel{\lambda/2} - \cancel{\lambda/2}$$

$$\boxed{2\mu t \cos r = n\lambda}$$

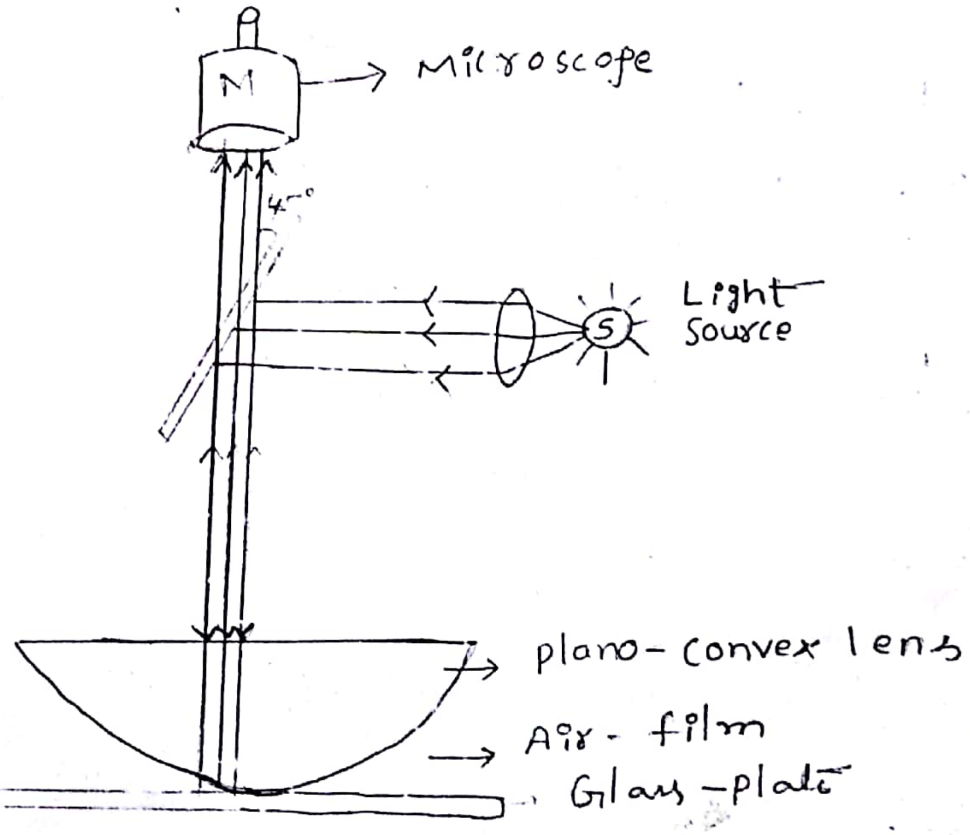
1A (LAQ)

2A, 3A (LAQ)

Newton's Rings :-

When a plano-convex lens with its convex surface is placed on a glass plate, an air film of gradually increasing thickness is formed between the two. The thickness of the film at the point of contact is zero. When such a film is illuminated normally by a monochromatic light, alternate dark and bright circular rings around the point of contact are observed. Since, this phenomenon was first described by Newton scientist; Hence, these rings are called as Newton's rings.

Experimental arrangement :-



Fig(1):- Experimental arrangement of Newton's Rings

The experimental arrangement of Newton's rings is shown in fig ①. The monochromatic light from sodium lamp is allowed to incident on the glass-plate (P), arranged at an angle 45° with vertical. The reflected rays from thin glass plate, are incident on the air film formed between plano-convex lens and glass plate. A part of the incident light is reflected from the top and bottom glass surfaces of the air-film. these reflected rays superimposed to produce interference ~~rings~~ pattern. An interference pattern, in the form of alternate dark and bright circular-rings around the point of contact can be viewed through a microscope (M).

→ The path difference between reflected rays is

$$\Delta = 2\mu t \cos r + \lambda/2$$

for air film $\mu = 1$

for normal incidence $r = 0$,

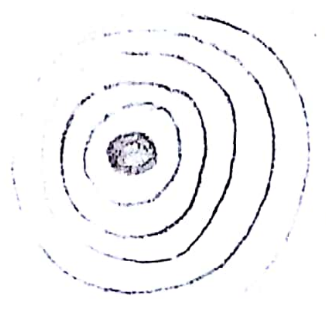


Fig ①: Newton's rings

$$\therefore \Delta = 2t + \frac{\lambda}{2}$$

at the point of contact, the air film thickness (t) is zero.

$$\therefore \Delta = \lambda/2$$

the path difference is equal to "$\lambda/2$", which is condition for destructive-interference. Hence, we can see the dark spot at the center of the film.

→ Condition for bright-ring :-

Condition for bright-ring is

$2\mu t \cos r = (2n-1)\lambda/2$ $\quad \because \begin{bmatrix} \mu = 1 \\ r = 0 \\ \cos r = 1 \end{bmatrix}$

$$\boxed{2t = (2n-1)\lambda/2}$$

→ condition for dark-ring :-

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

$$\boxed{2t = n\lambda} \text{ --- (1)}$$) 2A (LAQ).

3A (LAQ)

→ Consider 'R' is radius of plano-convex lens, 'r_n' is the radius of n^{th} Newton ring and 't' is thickness of air film

From fig (3),

from Δ CNP,

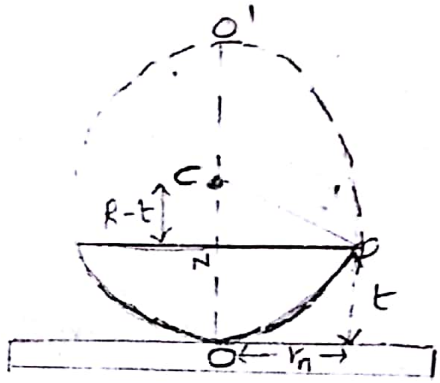


Fig: (3)

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

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

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

$2Rt = r_n^2$

$t = \dfrac{r_n^2}{2R}$ $\quad \because$ [t is very small hence t^2 neglected

Substitute the 't' value in eqn (1)

$2 \times \dfrac{r_n^2}{2R} = n\lambda$

$r_n^2 = nR\lambda$

$\therefore \boxed{r_n = \sqrt{nR\lambda}}$ radius of n^{th} dark ring.

determination of wavelength of a light :-

radius of n^{th} dark ring is

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

diameter of n^{th} dark ring is

$$D_n = 2r_n = 2\sqrt{nR\lambda}$$

$$D_n = \sqrt{4nR\lambda}$$

$$D_n^2 = 4nR\lambda$$

diameter of m^{th} dark ring is

$$D_m = \sqrt{4mR\lambda}.$$

$$D_m^2 = 4mR\lambda$$

$$D_m^2 - D_n^2 = 4mR\lambda - 4nR\lambda$$

$$D_m^2 - D_n^2 = 4R\lambda(m-n)$$

$$\boxed{\lambda = \frac{D_m^2 - D_n^2}{4R(m-n)}}$$

in this way we can determine the wave-length (λ) of the given light source by using Newton's rings experiment.) 3A (LAQ)

8A, 9A

Diffraction :-

Bending of light ray at the edge of the obstacle is known as "diffraction".) 8A.

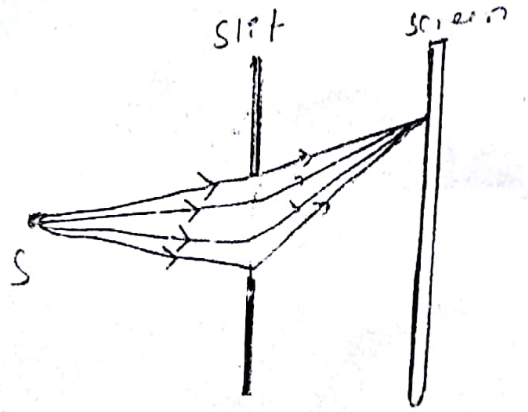
diffraction phenomenon can be devided into 2 classes:

→ 1) fraunhofer's diffraction

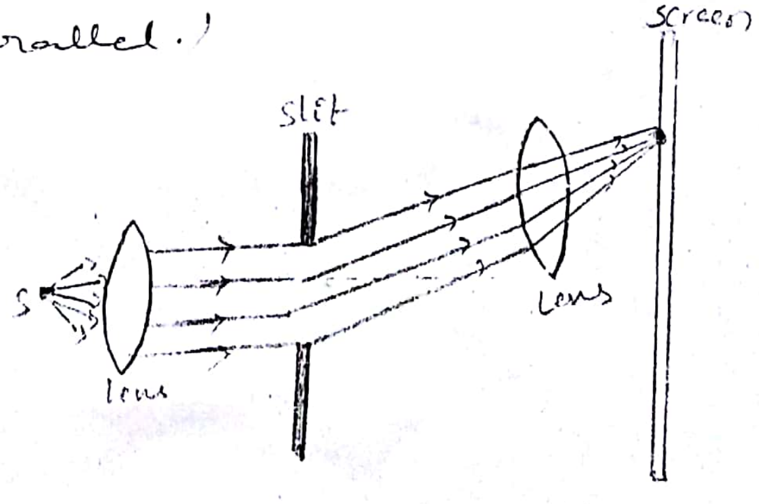
→ 2) Fresnel's diffraction.) 9A, 8A

① fraunhofer's diffraction:- In this case, Source and screen are placed at infinite distance from the obstacle. The incident wave-front is in plane form. In this case lenses are used to make the rays parallel.

② Fresnel's diffraction :- In this case, Source and screen are placed at finite distance from the obstacle. The incident wave-front are either spherical or cylindrical form. In this case no lenses are used to make the rays parallel.



Fresnel diffraction.



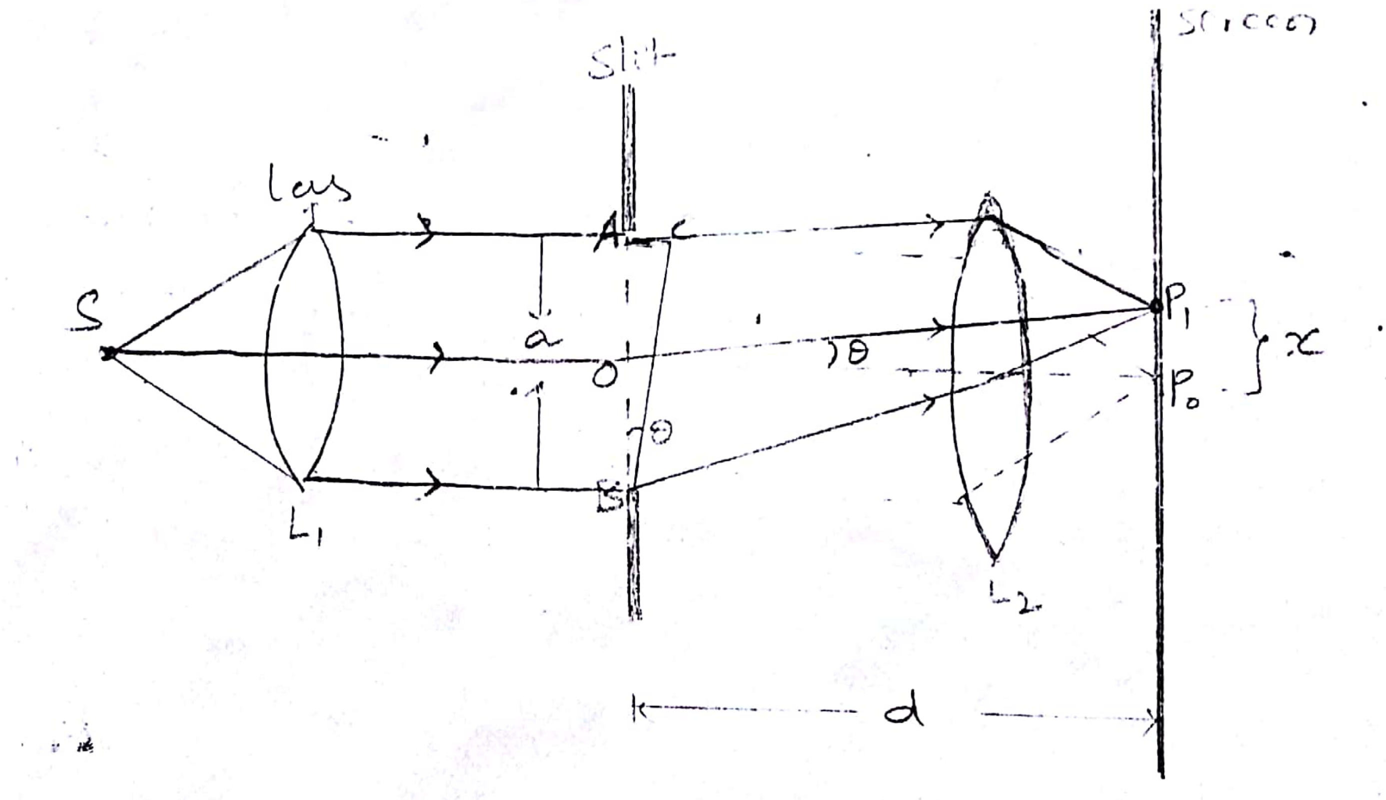
fraunhofer's diffraction.

Difference between Fraunhofer and Fresnel diffraction

Fraunhofer Diffraction	Fresnel Diffraction.
→ In this diffraction, source and screen are at an infinite distance from obstacle.	→ In this diffraction, source & screen are at finite distance from the obstacle.
→ The incident wave-front is a plane wave-front.	→ The incident wave-front is a spherical (or) cylindrical wavefront
→ Lenses are used to produce a plane wavefronts	→ Lenses are not required.

10A

A(Fraunhofer Diffraction at Single slit :-
Q)



Let 'S' is a point source of monochromatic light. (1)
When light is incident on the lens L_1, it will convert into plane parallel rays, these rays are incident on the slit (AB) of width 'a'. The light passes through the slit collected by the lens (L_2) and focused on the screen.

When light is incident at the slit, the unscattered light is focused on the screen at point P_0, which has maximum intensity and is known as the central maximum. The diffracted wavelents at angle 'θ' are focused at P_1. The intensity distribution at P_1 is depends upon the path difference between the secondary wavelets which are produced at point A and B.

The path difference between two diffracted rays is AC.

from Δ ABC

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

$$AC = a\sin\theta \quad -(1)$$

The path difference between two secondary waves which are produced at A and B is $\lambda/2$.

$\therefore$ The total path difference is

$$\boxed{\Delta = a\sin\theta + \frac{\lambda}{2}} \quad -(2)$$

→ Condition for maximum:-

Condition for maximum is, the path difference $n\lambda$

$\therefore \Delta = n\lambda$ — (3)

from eqn (2) & (3)

$a \sin\theta + \lambda/2 = n\lambda$

$$\boxed{a \sin\theta = (2n-1)\lambda/2}$$

→ condition for minimum:-

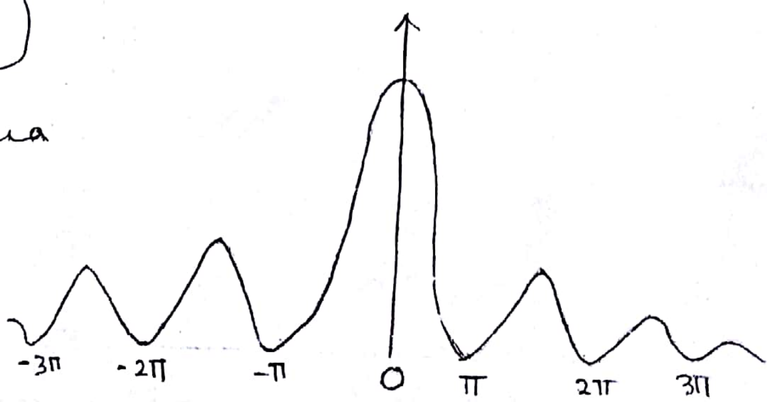
Condition for minimum is the path difference is

$\Delta = (2n+1)\lambda/2$ — (4)

from eqn (2) & (4)

$a \sin\theta + \lambda/2 = (2n+1)\lambda/2$

$$\boxed{a \sin\theta = n\lambda}$$



for first order minima

$n = 1$

$a \sin\theta = \lambda$

$\sin\theta = \lambda/a$

$\theta \simeq \lambda/a$ — (5)

from ΔOP_1P_0

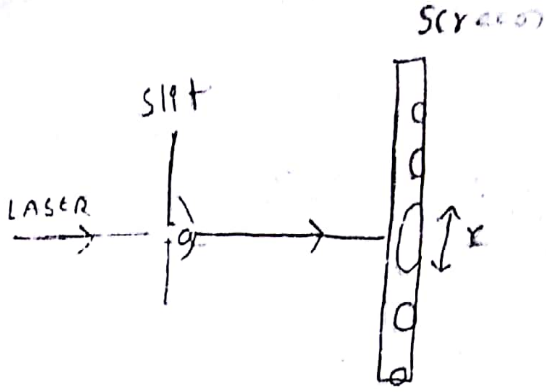
$\sin\theta = \frac{P_1P_0}{OP_0} = \frac{x}{d}$

$\theta \simeq \frac{x}{d}$ — (6)

$\because$ [if 'θ' is small $\sin\theta \simeq \theta$

5

from eqn (5) & (6)



$$\frac{\lambda}{a} = \frac{x}{d}$$

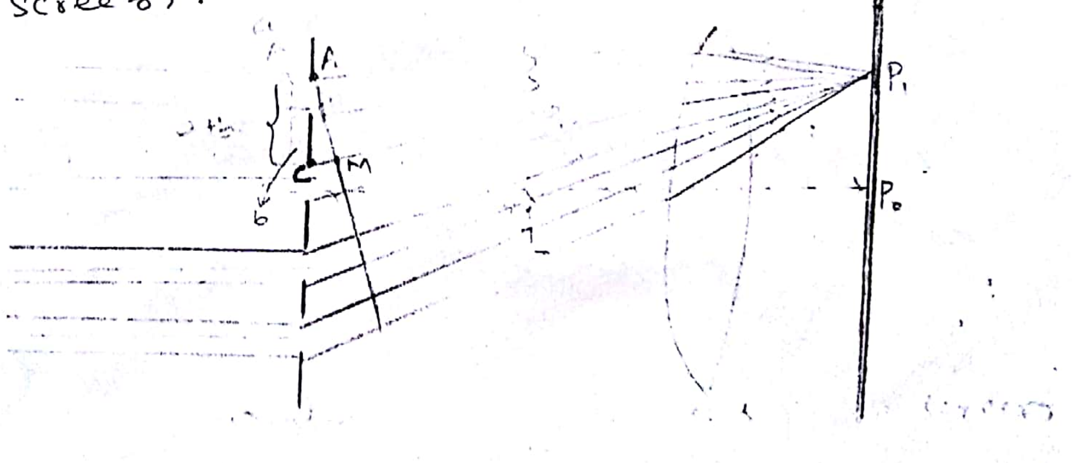
$$\therefore \boxed{a = \frac{d\lambda}{x}}$$

This means, with decrease of slit width, the fringe width increases. i.e; when slit becomes narrower, the fringe becomes broad. 4A (LAQ)

SA (LAQ)

Diffraction Grating :-

Diffraction grating is nothing but closely placed multiple slits. Generally grating is a glass plate on which a number of rules are made with a diamond point. The rules are opaque and the space between the rules acts as slit. The combined width of a ruling and a slit is called "grating element." when light passes through the grating, each slit diffracts the light and the diffracted light rays are combined to produce sharper maxima on the screen.



from figure,

the grating element (AC) = a+b

the path difference is CM.

from Δ ACM,

$$\sin\theta = \frac{CM}{AC} = \frac{CM}{(a+b)}$$

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

$$\Delta = (a+b)\sin\theta \quad \text{--- (1)}$$

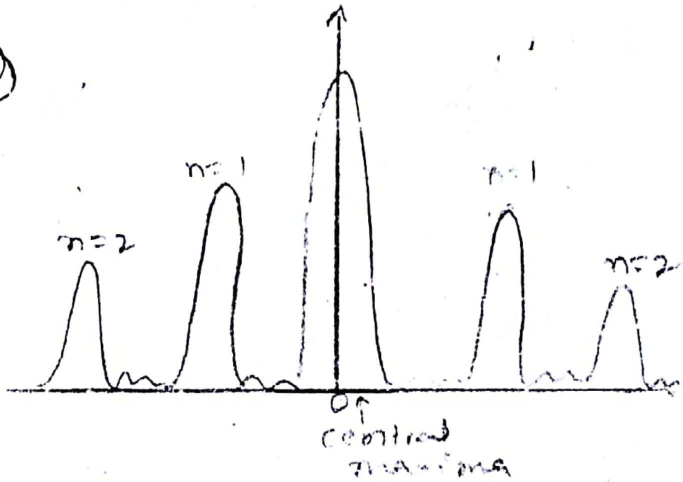
condition for the maxima at point P_1 is

$$\Delta = n\lambda \quad \text{--- (2)}$$

$\therefore$ from eqn (1) & (2)

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

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



where $\frac{1}{a+b} = N$ = no: of lines/cm on grating.

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

$$\Rightarrow \boxed{\lambda = \frac{\sin\theta}{nN}}$$

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

Resolving Powers:-

17A

The resolving power of a grating is defined as its ability to form separate diffraction maxima of two closely spaced wavelengths.

(or)

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

$$\boxed{\text{Resolving power} = \frac{\lambda}{d\lambda}}$$) 17A

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

The n^{th} principal maxima of λ & $\lambda+d\lambda$ wavelength are given by

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

$$(a+b)\sin(\theta + d\theta) = n(\lambda + d\lambda) \quad -(1)$$

The path difference between these wavelengths is

$$(a+b)\sin(\theta+d\theta) = n\lambda + \frac{\lambda}{N} \quad -(2)$$

$\therefore$ from eqn (1) & (2),

$$n(\lambda + d\lambda) = n\lambda + \frac{\lambda}{N}$$

$$n\,d\lambda = \lambda/N$$

$$\therefore \boxed{\frac{\lambda}{d\lambda} = nN \text{ - Resolving power}}$$

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

5A if asked (LAQ)

13A (plane of vibration:- The plane in which the light vibration takes place is called "plane of vibration".

plane of polarization:- The plane which is perpendicular to the plane of vibration is called "plane of polarization")

13A

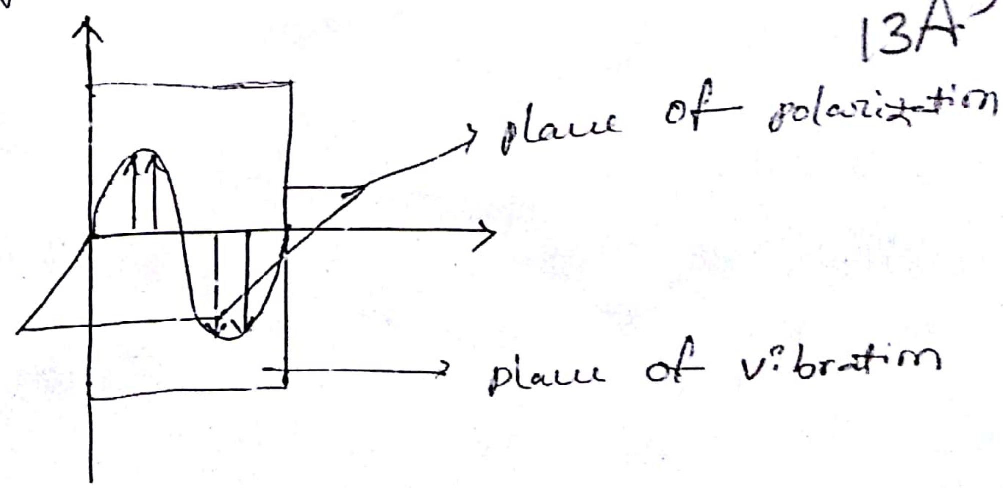


fig: plane of vibration & plane of polarization.

Polarization :-

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

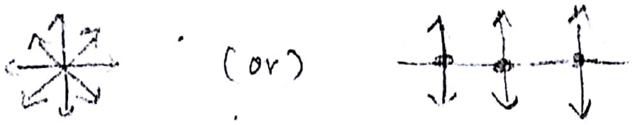


Fig:- Unpolarized light.

→ **Polarized light :-** If the oscillations are confined to only one direction, then it is called as plane polarized light.

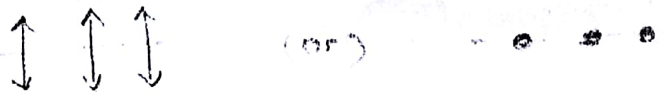
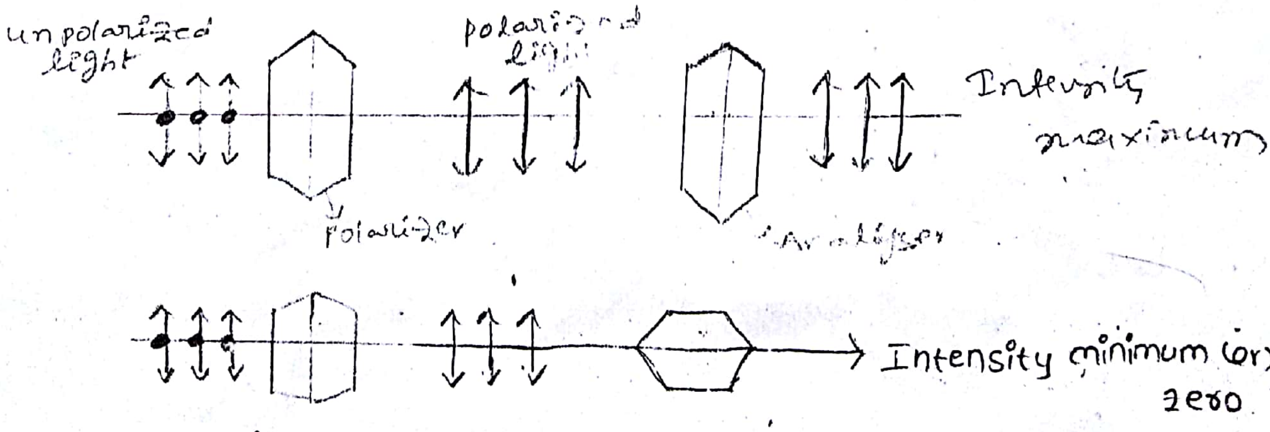


Fig:- plane polarized light.

12A

→ **Polarization:-**

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



12A

Fig:- Polarization through tourmaline crystals.

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Double refraction (Birefringence):—

When unpolarized light passes through certain anisotropic crystals, the refracted light is split into two rays. One is ordinary ray and another is extra ordinary ray. Both rays are plane polarized lights. This phenomenon is known as "double refraction". 14A

The crystals which are showing this phenomenon are called as double refracting crystals. 14A

Ex:- Calcite, ~~quartz~~ Quartz and tourmaline

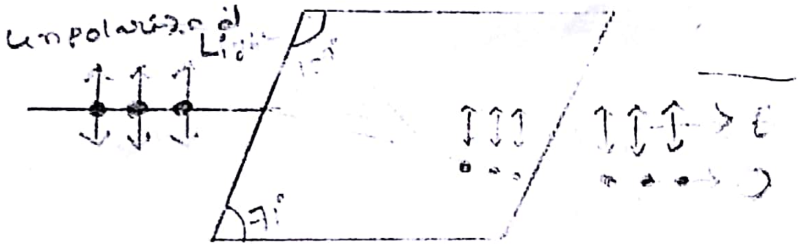

Fig:- Double refraction in calcite crystal

→ The ordinary ray travels with the same velocity in all direction.

→ The extra ordinary ray velocity is not same in all direction. 15A

→ ordinary ray refractive index (μ_o) is more than the extra-ordinary refractive index (μ_e)

i.e; $\boxed{\mu_o > \mu_e}$.

→ Hence velocity of e-ray is more than that of o-ray.

i.e; $\boxed{V_e > V_o}$

Nicol Prism:-

Nicol's prism is a device which is used to produce and analyse the plane polarized light. This was invented by William Nicol, in 1828.

Construction:-

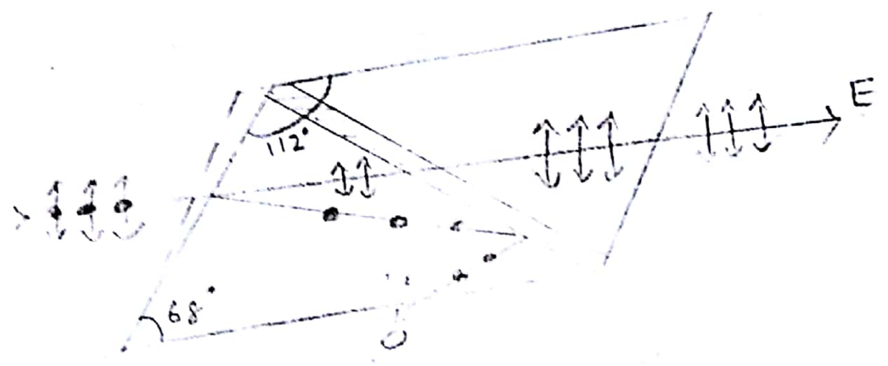

Fig:- Nicol's prism.

A calcite crystal whose length is three times as its width is taken. The end faces of the crystal are cut down in such a way that the angles in the principle section become 68° & 112° instead of 71° & 109°. The crystal is then cut into 2 pieces along the diagonal and the two surfaces are polished and cemented together by Canada balsam which is a transparent material. The refractive index of canada balsam is lies between the refractive indices of ordinary and extra-ordinary rays.

i.e; Refractive index of ordinary ray $\mu_0 = 1.658$
Refractive index of extra-ordinary ray $\mu_e = 1.486$
Refractive index of Canada balsam $\mu = 1.55$

working:-

when an unpolarised light is incident on the Nicol's prism, it splits into O-ray and e-ray. Canada balsam is rarer medium for O-ray. Because of the shaping of the crystal face, the O-ray incident on the Canada balsam at the angle greater than critical angle and suffers total internal reflection and leaves the crystal through its side as shown in figure. The extra-ordinary 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 plane polarised light.

Nicol's prism can be used to produce and analyse plane polarized light.) 6A

(LAQ)

→ Applications of polarized light

The phenomenon of polarization has many practical applications in daily life.

→ The polarized sun glasses are used to eliminate the glare ~~glass~~ ~~from~~ produced by light

→ The intensity of light coming inside the aeroplanes can be controlled using polaroids.

→ Colours contrast in old oil paintings can be improved using polaroids.

→ Polaroid glasses are used to produce motional pictures in three dimensions (3D-movie).

→ ~~[illegible]~~ enhancing visibility of digital display)

18A.