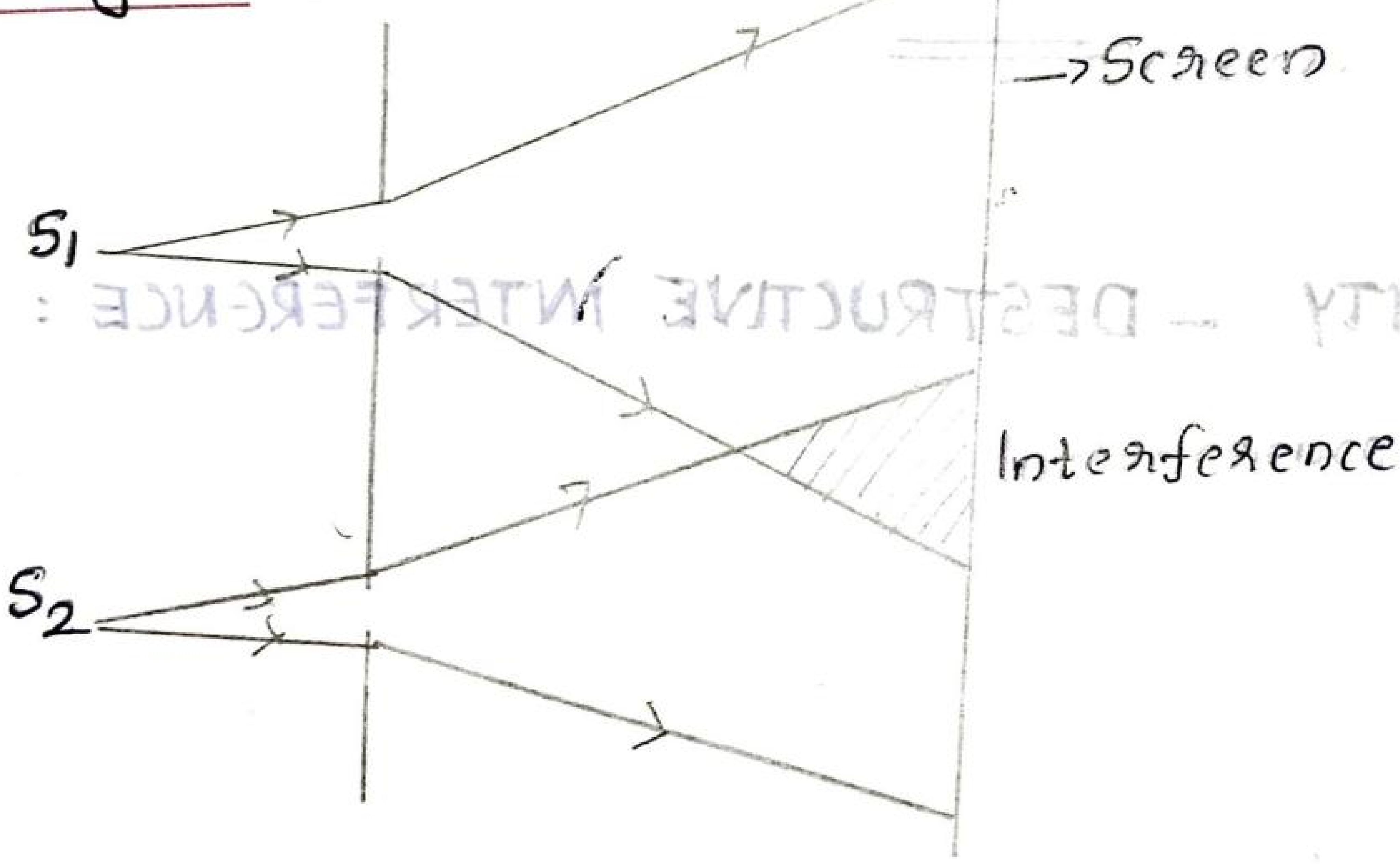
MODULE - 2

CHAPTER 1 - INTERFERENCE

* INTERFERENCE :

Interference is the modification of light intensity or energy distribution due to the superposition of two or more light waves. It is the superposition of two or more light waves having same amplitude, frequency and a constant phase difference. As a result of interference alternate bright and dark regions are obtained called interference fringes

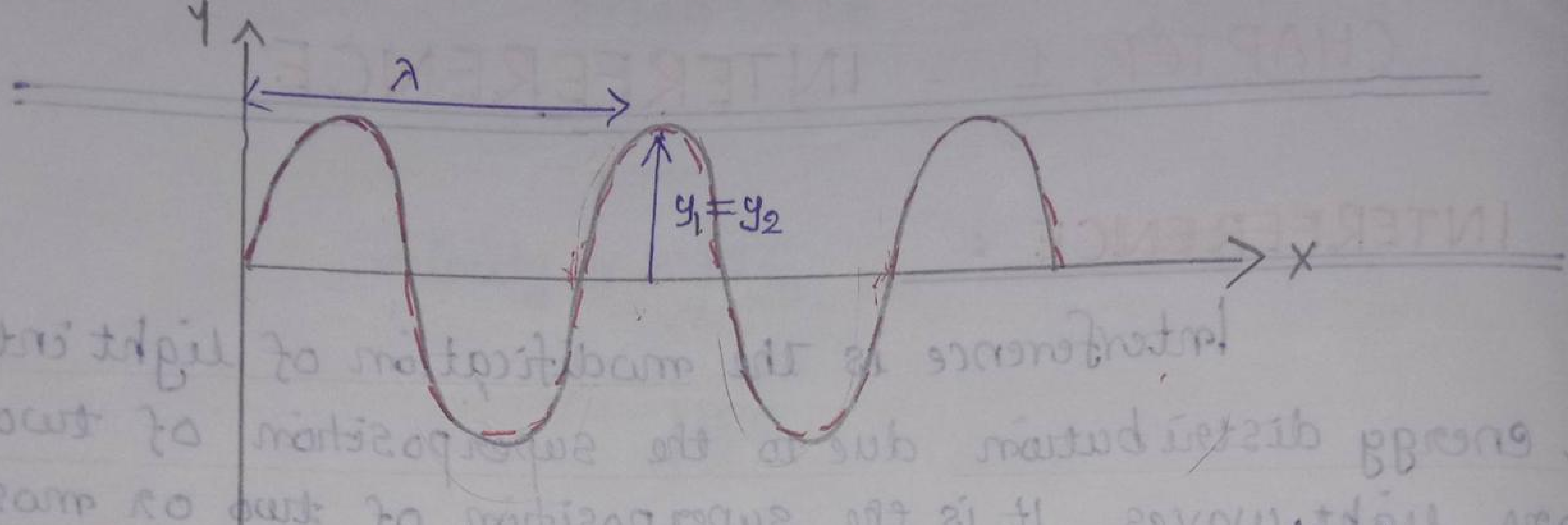


* Conditions of interference :

1. Sources must be coherent ie, the light emitting from 2 sources must have same amplitude, wavelength, frequency and a constant phase difference.
2. The plane of polarization of the sources must be same.
3. The sources must be as close and as narrow as possible.

CONDITIONS OF MAXIMUM AND MINIMUM INTENSITY :

* MAXIMUM INTENSITY - CONSTRUCTIVE INTERFERENCE :



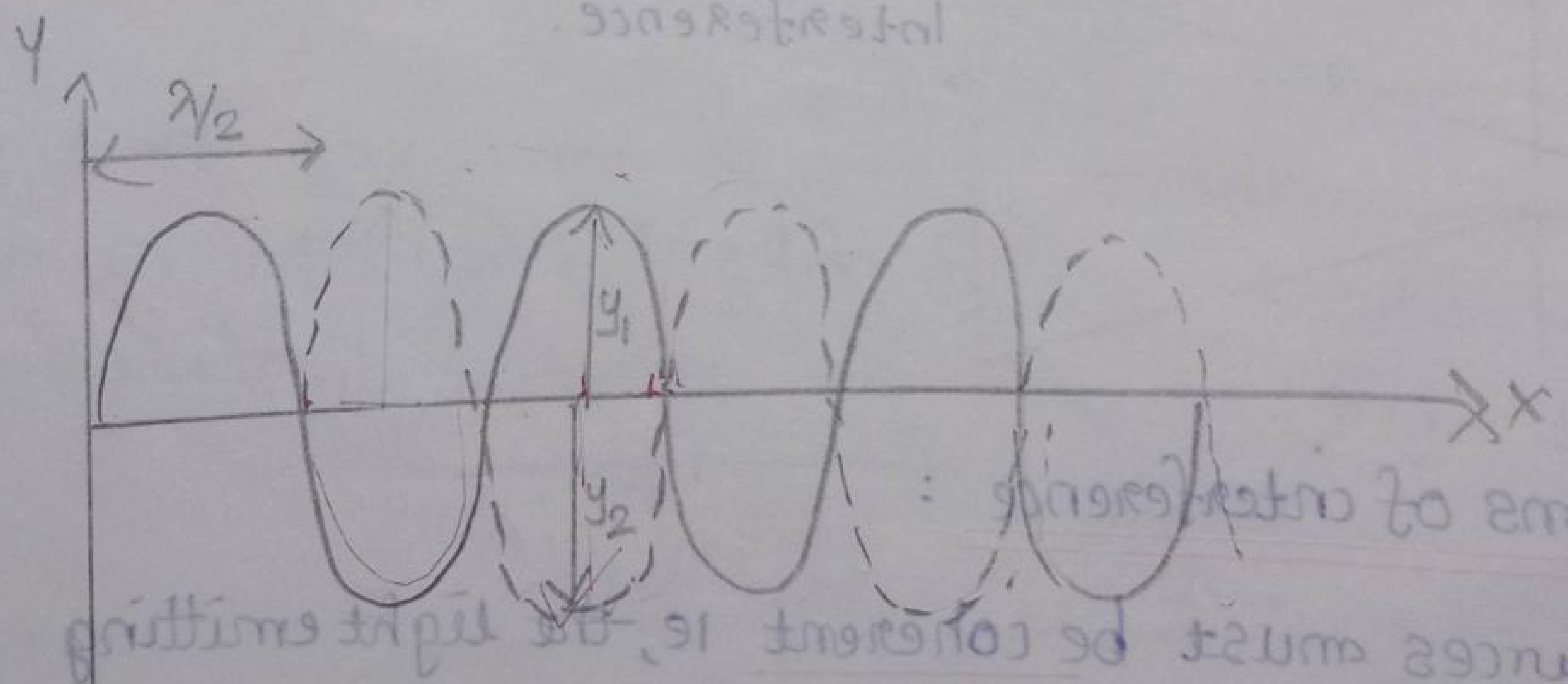
1) For maximum intensity, the resultant displacement

$y = y_1 + y_2$ $\quad y_1, y_2 \rightarrow$ individual displacements.

2) Path difference b/w 2 sources $= n\lambda$, $n = 0, 1, 2, 3 \ldots$

ie, path dif $= 0, \lambda, 2\lambda, 3\lambda \ldots$

* MINIMUM INTENSITY - DESTRUCTIVE INTERFERENCE :



1) For minimum intensity, resultant displacement

$y = y_1 - y_2$

2) path difference b/w 2 sources $= (2n+1)\frac{\lambda}{2}$, $n = 0, 1, 2, 3 \ldots$

ie, path dif $= \frac{\lambda}{2}, \frac{3\lambda}{2}, \frac{5\lambda}{2} \ldots$

* PRINCIPLE OF SUPERPOSITION :

It states that the resultant displacement at a point due to the superposition of two or more light waves is the algebraic sum of individual components.

Resultant displacement

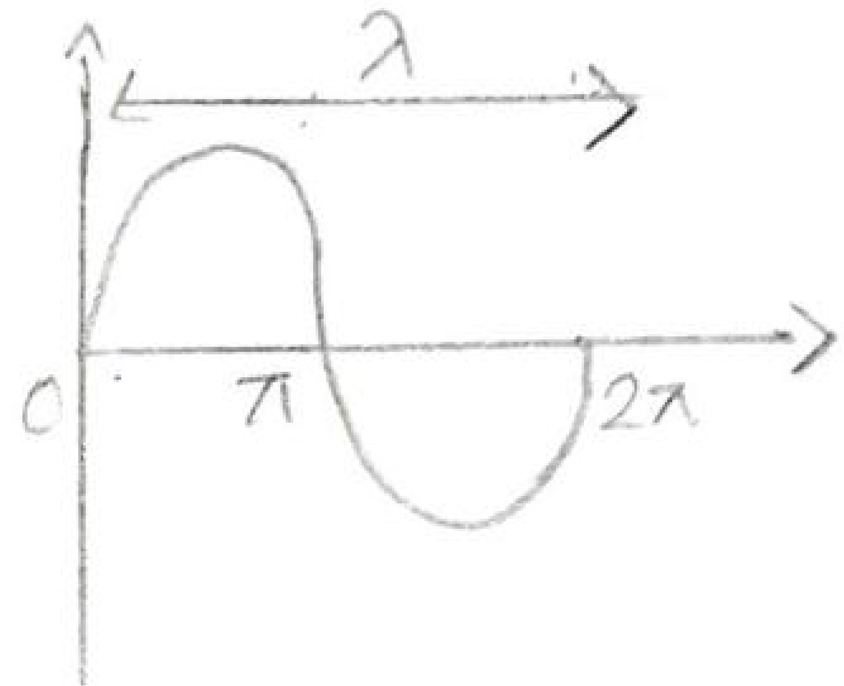
$y = y_1 + y_2$ ⟹ constructive interference

$y = y_1 - y_2$ ⟹ destructive interference

*

λ path dif $= 2\pi$ phase dif

$\therefore$ unit path dif $= \frac{2\pi}{\lambda}$ phase dif.



*) Why two independent sources are not coherent?

ans) They can ~~be~~ never be coherent because atomic emissions are random and can't be controlled. ∴ different sources should produce light waves of different amplitude, frequency and phase.

*

OPTICAL PATH AND ACTUAL PATH OR GEOMETRICAL PATH:

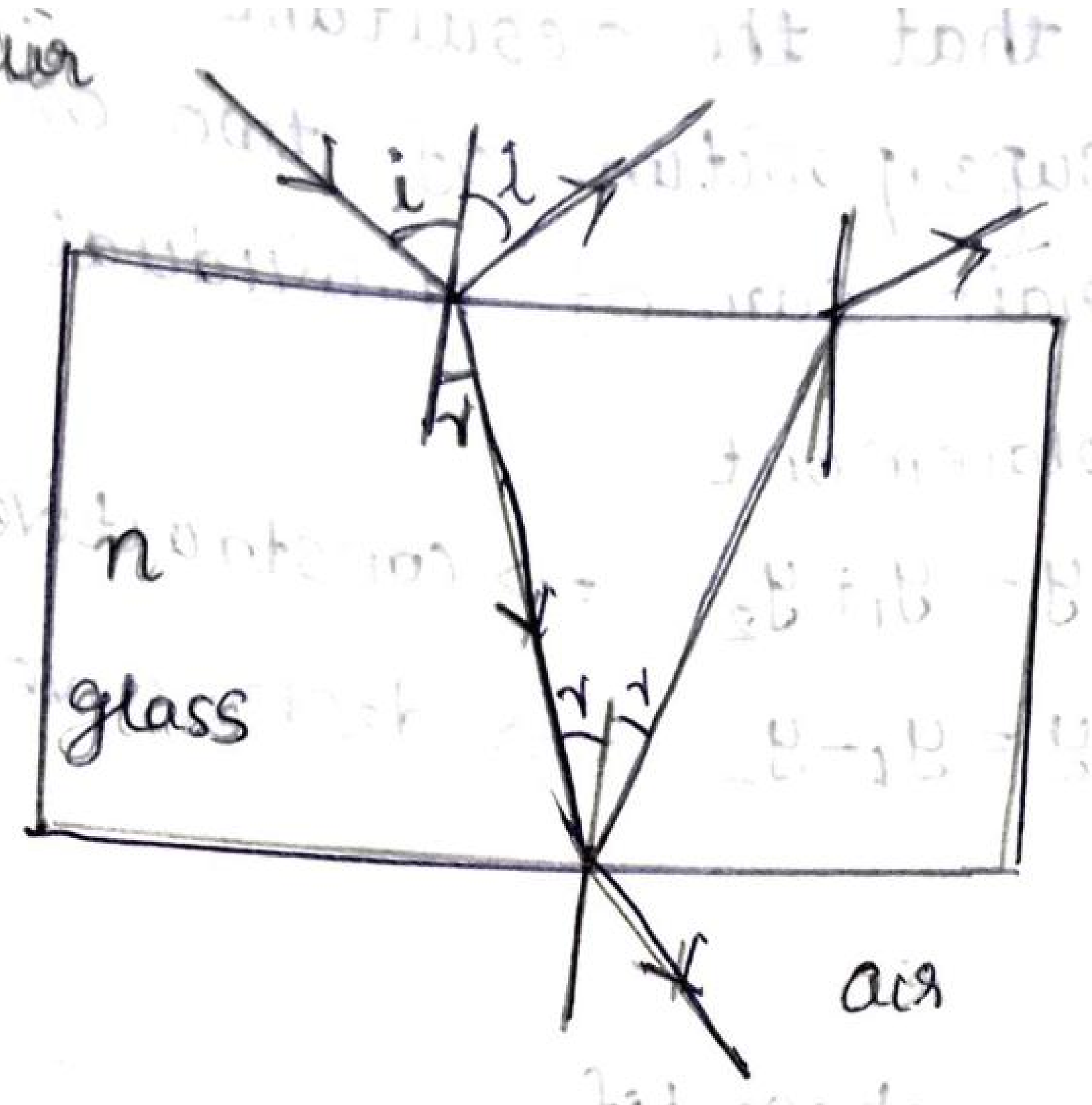
Geometrical path : actual path travelled by the light in a medium.

Optical path : product of geometrical path and refractive index of the medium.

Optical path = R.I × actual path

RI ~~of~~ the medium $= \frac{\text{Velocity of light in air}}{\text{Velocity of light in medium}}$

$RI = n = \frac{c}{v} = \frac{3 \times 10^8}{v}$



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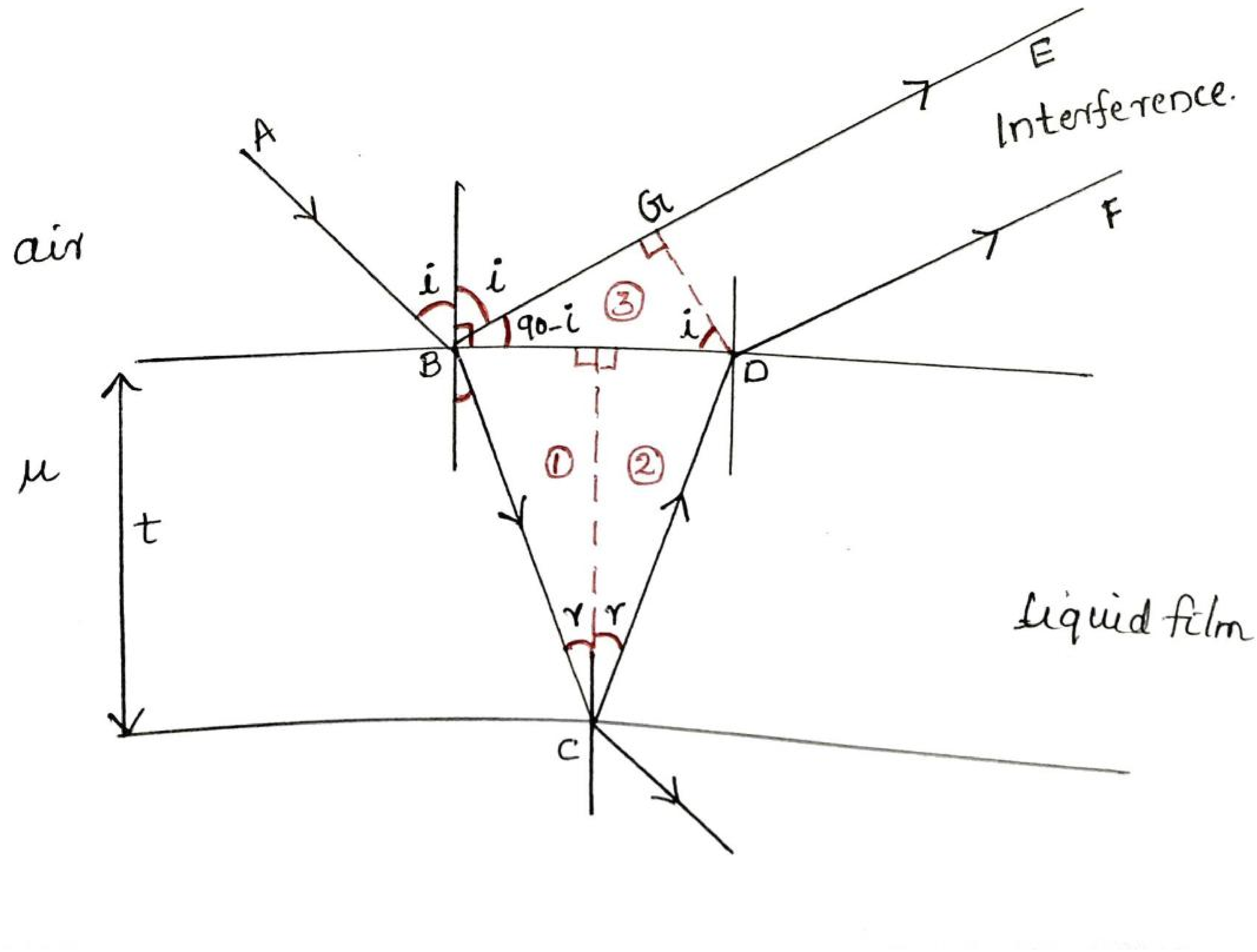
* THEORY OF THIN FILM - (REFLECTED SYSTEM)

Thin film interference produces colour. The colour formation is due to the interference of reflected light from the top and bottom surfaces of the thin film



Consider a thin transperent liquid film of thickness t and refractive index μ. Suppose a ray of light AB is incident on the surface. The light is partially reflected along BG and partially refracted along BC. Similar reflections and refractions ~~are~~ occur at the interfaces C and D. Light rays BE from the top surface and CDF from lower surface of the film interfere each other produces colour.

Optical path difference b/w reflected components,

$$(BC+CD)\mu_{liq} - BG\,\mu_{air} = OPD. \qquad \mu_{air} = 1.$$

or $$(BC+CD)\mu - BG = OPD \text{ ——— (1)}$$

From Δ (3)

$$\sin i = \frac{BG}{BD} \text{ or}$$

$$\underline{BG = BD\sin i} \text{ ——— (2)}$$

from figure $BD = BH + HD$.

but $BH = HD$ ($\because \Delta$(1) and Δ(2) are similar Δ).

$$\therefore BD = BH + BH$$

$$\underline{BD = 2BH}.$$

Substitute this in (2)

$$\underline{BG = 2BH\sin i} \text{ ——— (3)}$$

From Δ(1) and Δ(2)

$$BC = CD$$

$$\therefore BC + CD = BC + BC = 2BC$$

$$\underline{BC + CD = 2BC} \text{ ——— (4)}$$

Substituting (3) and (4) in (1)

$$2BC\cdot\mu - 2BH\sin i = OPD \text{ ——— (5)}$$

From Δ 1

$$\cos r = \frac{HC}{BC} = \frac{t}{BC}$$

or $BC = \frac{t}{\cos r}$

$$\tan r = \frac{BH}{HC} = \frac{BH}{t} \text{ or}$$

$$BH = t \cdot \tan r$$

Substituting for BC and BH in 5

$$2\mu \cdot \frac{t}{\cos r} - 2t \cdot \tan r \cdot \sin i = OPD.$$

$$\frac{2\mu t}{\cos r} - 2t \cdot \frac{\sin r}{\cos r} \cdot \sin i \times \frac{\sin r}{\sin r} = OPD$$

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

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

$$\frac{2\mu t}{\cos r}\left[1 - \sin^2 r\right] = OPD$$

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

$$\boxed{2\mu t \cos r = OPD} \longrightarrow (6)$$

This is known as Cosine Law.

$\mu \rightarrow$ R.I of the film.
$t \rightarrow$ thickness of the film
$r \rightarrow$ angle of refraction
OPD $\rightarrow$ optical path difference

Here B and C are the point of reflection. According to EM theory, rarer medium reflection and denser medium reflection differ by a path difference $\frac{\lambda}{2}$.

$$\therefore \boxed{\text{net path difference} = 2\mu t \cos r - \frac{\lambda}{2}} \longrightarrow (7)$$

$\lambda \rightarrow$ wavelength of light.

1) Condition for maxima (constructive interference)

path dif $= n\lambda$, $n = 0, 1, 2, 3 \ldots$

ie, $\boxed{2\mu t \cos r - \frac{\lambda}{2} = n\lambda}$

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

$= \frac{2n\lambda + \lambda}{2} = \frac{\lambda}{2}(2n+1)$

$\boxed{2\mu t \cos r = (2n+1)\frac{\lambda}{2}}$ $n, 0, 1, 2 \ldots$

2) Condition for minima (destructive interference)

path dif $= (2n+1)\frac{\lambda}{2}$

ie, $\boxed{2\mu t \cos r - \frac{\lambda}{2} = (2n+1)\frac{\lambda}{2}}$

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

$= \frac{\lambda}{2}(2n+1+1)$

$= \frac{\lambda}{2}(2n+2)$

$= \frac{\lambda}{\cancel{2}}\cancel{2}(n+1)$

$= \lambda(n+1)$

$2\mu t \cos r \approx n\lambda$ or

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

Conditions for Maxima	Condition for minima
1) $2\mu t \cos r - \frac{\lambda}{2} = n\lambda$ or $2\mu t \cos r = (2n+1)\frac{\lambda}{2}$	$2\mu t \cos r - \frac{\lambda}{2} = (2n+1)\frac{\lambda}{2}$; $2\mu t \cos r = n\lambda$.

* Write a short note on colour of thin film :

ans) Colour of a thin film is due to the interference of light reflected from top and bottom surfaces of the thin film. It depends on the path dif b/w reflected components

$$\text{path dif} = 2\mu t\cos r - \frac{\lambda}{2}.$$

∴ the colour depends on the factor

1. μ refractive index of the film.
2. t thickness of the film
3. r angle of refraction and incidence
4. wavelength λ.

If the film is extremely thin, the path dif will be $\frac{\lambda}{2}$ and the film appears dark.

If the film is extremely thick, the path dif is λ and the film appears bright

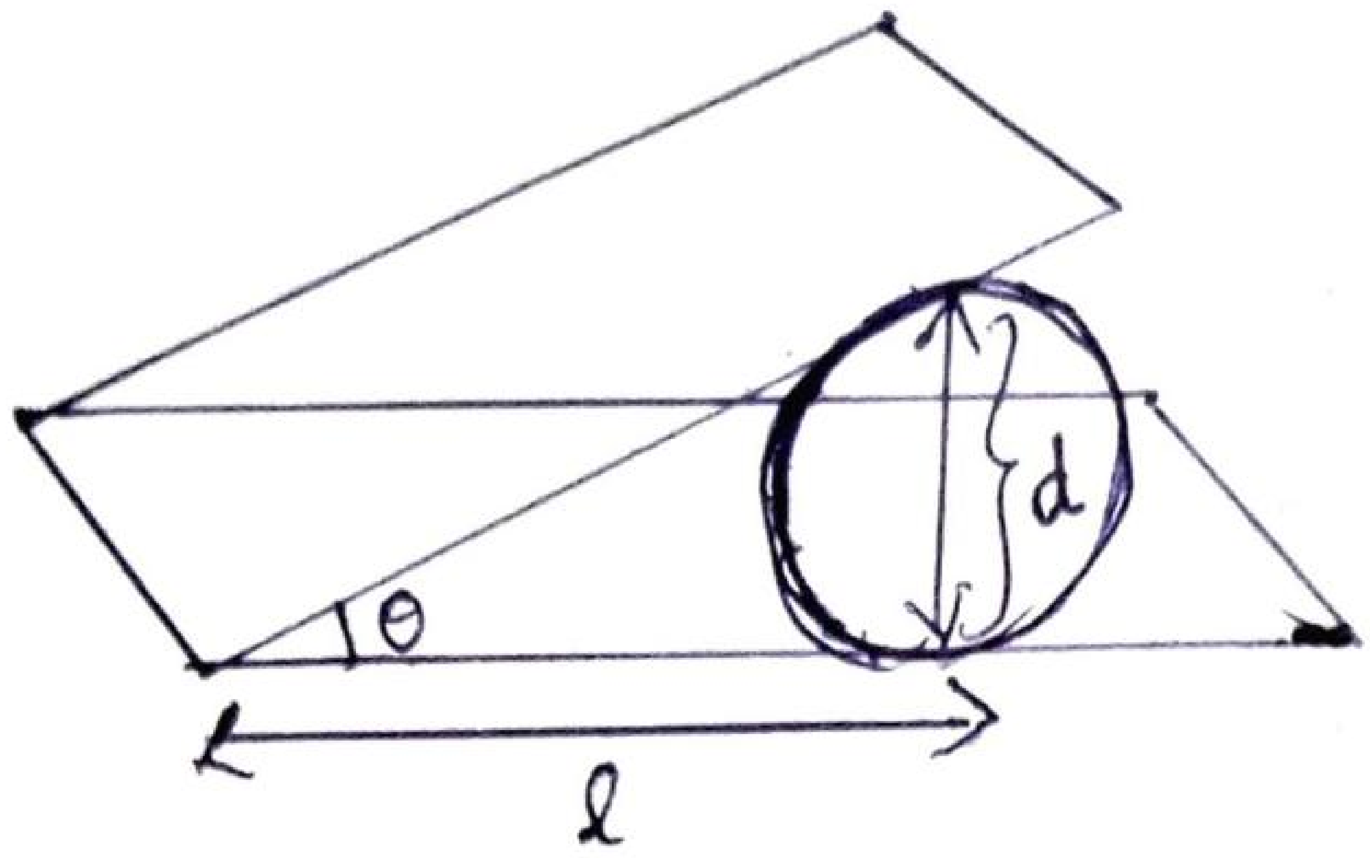
APPLICATIONS OF THIN FILM :

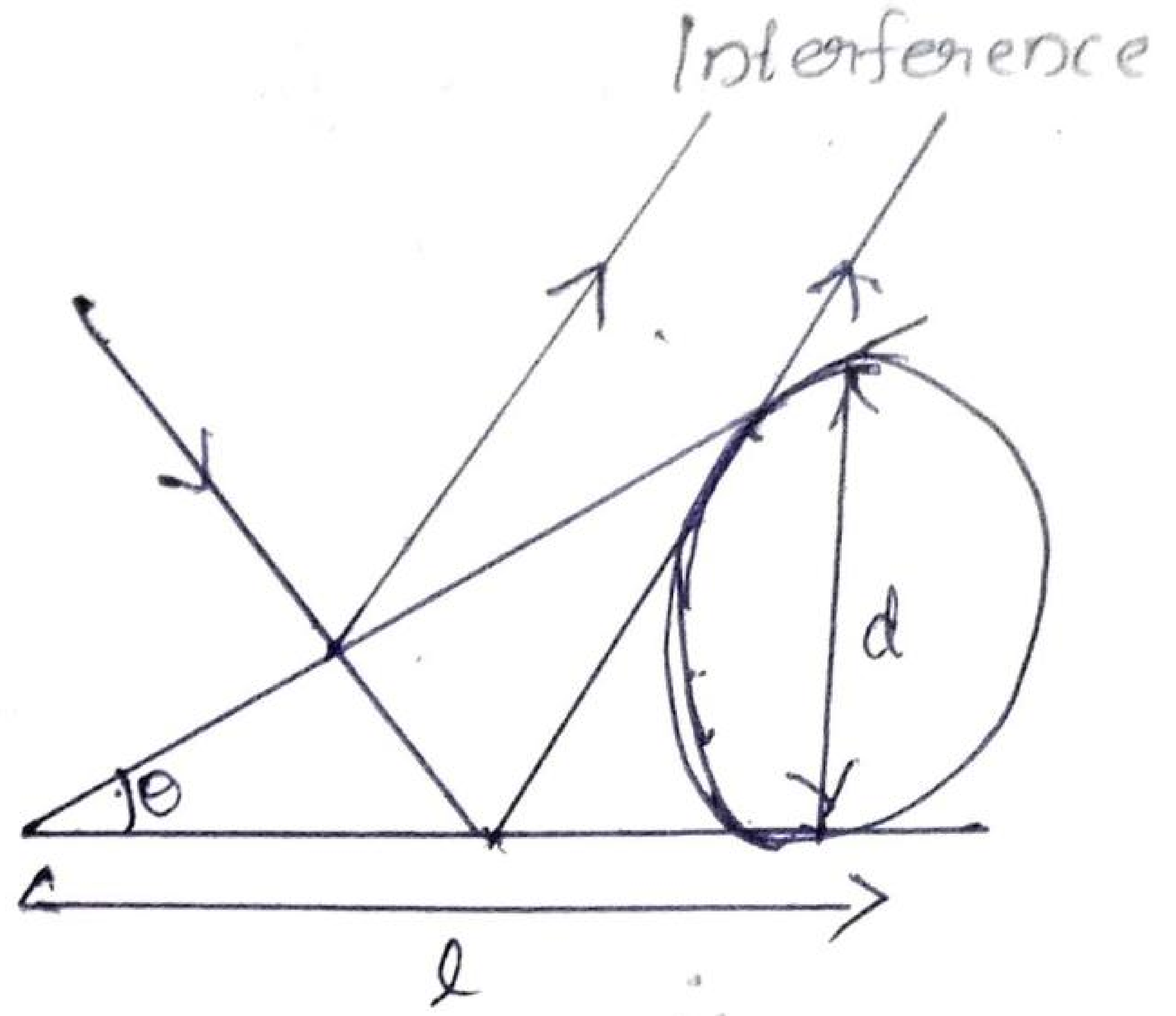
① AIRWEDGE

② NEWTON'S RING EXPT

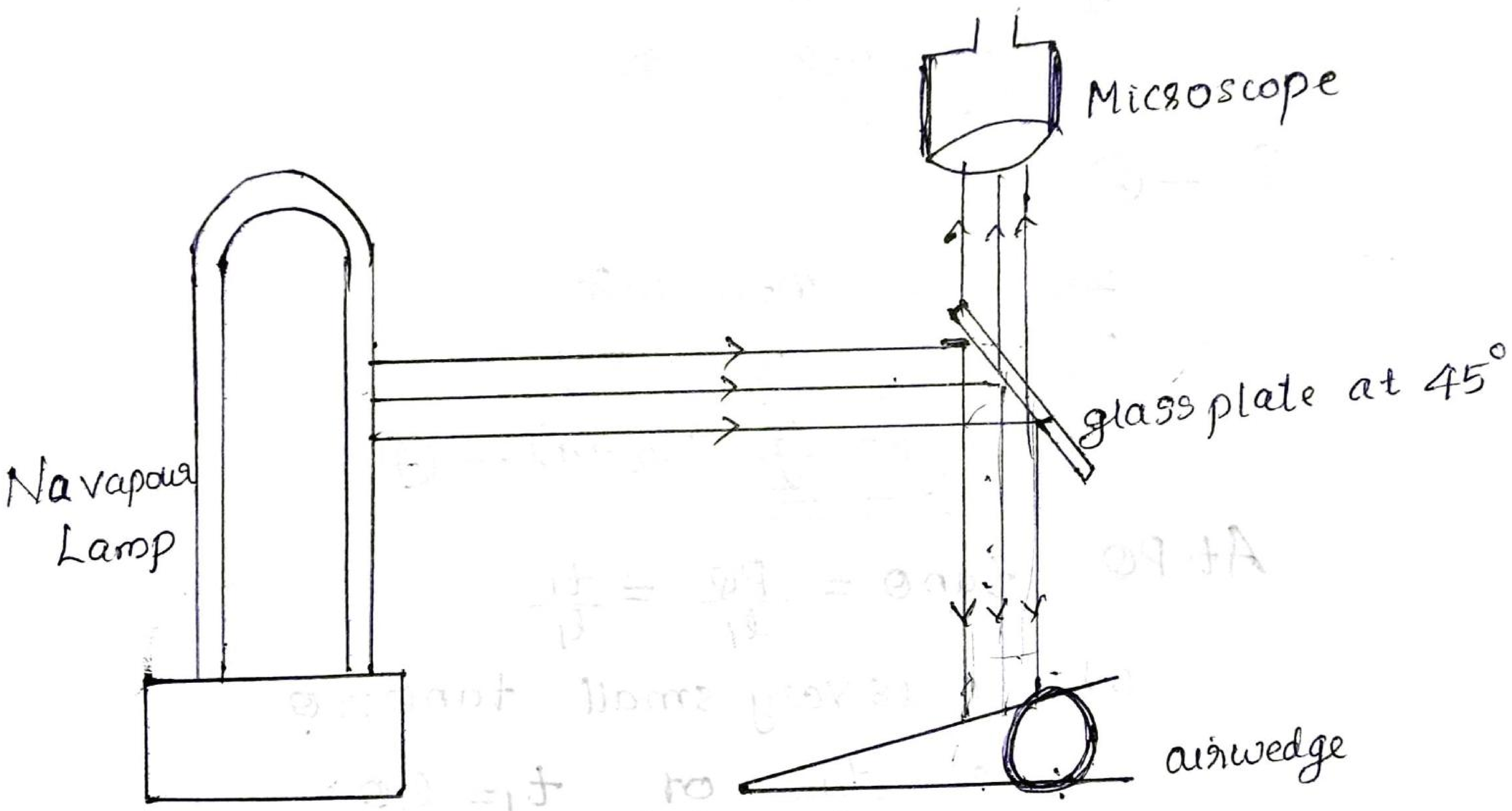
1. AIRWEDGE :

An airwedge consists of 2 optically plane rectangular glass plates whose one end is kept in contact with the other and the other end is separated by a thin wire / thin sheet.





Expt diagram



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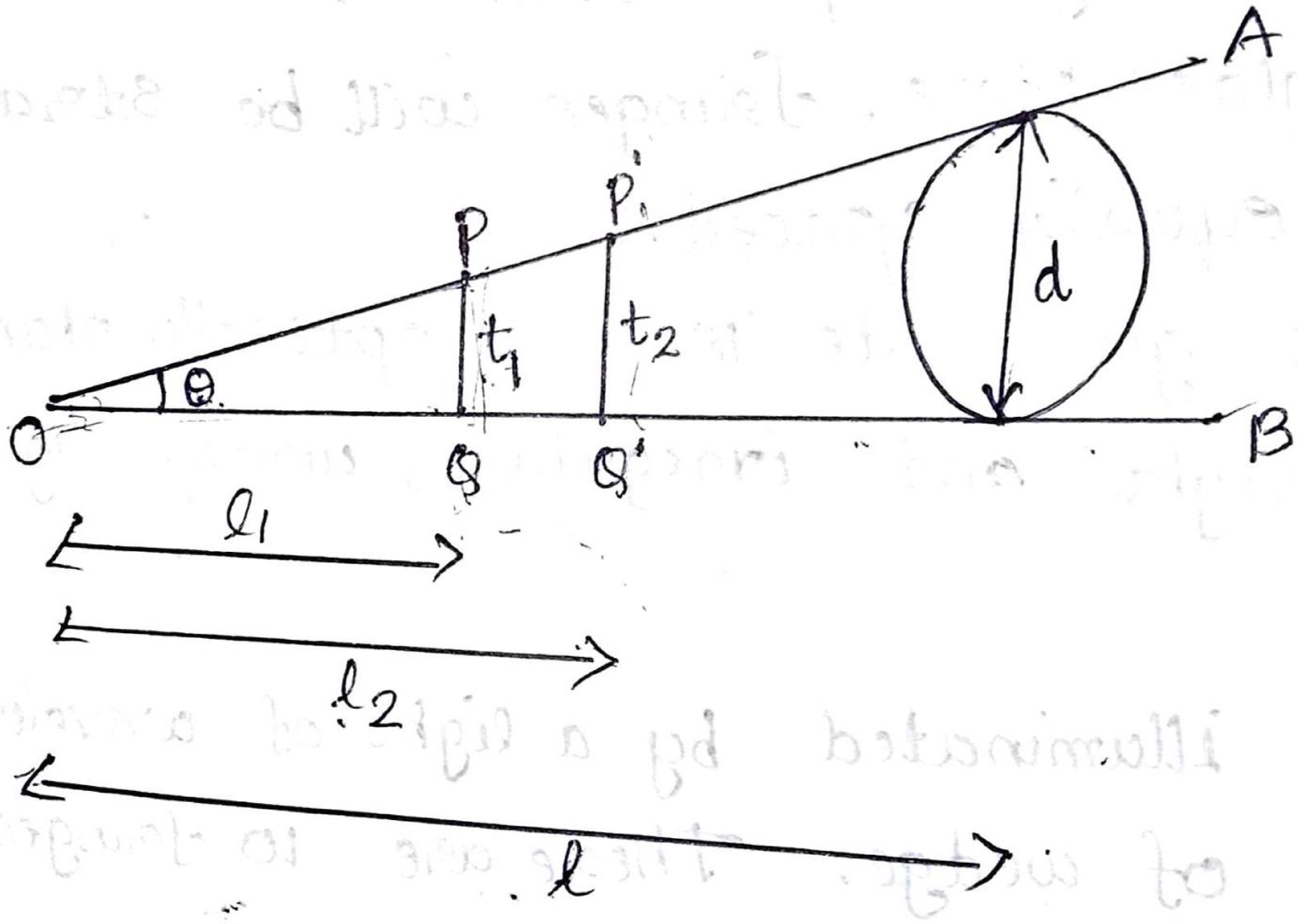
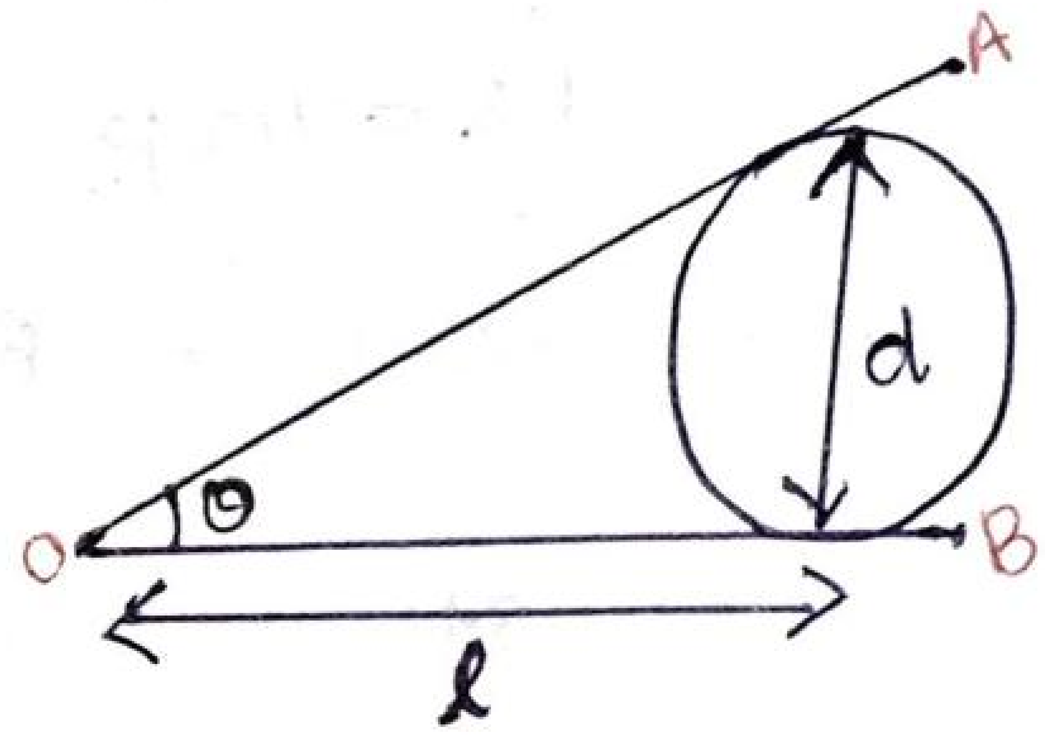


A
P
P_1
d
t_1
t_2
θ
O
Q
Q'
B
l_1
l_2
l

* Applications of ~~then~~ Airwedge :

1. To find the diameter of thin wire or thickness of a thin sheet :



From figure

$$\tan\theta = \frac{d}{l}$$

when θ is very small

$$\tan\theta \simeq \theta$$

then $\theta = \frac{d}{l}$ — (8)

equating (7) and (8)

$$\frac{\lambda}{2\beta} = \frac{d}{l}$$ then

diameter of thin wire $\boxed{d = \frac{\lambda l}{2\beta}}$ — (9)

where λ = wavelength of light
l = length of the airwedge
β = bandwidth

2. To test the optical planeness of a surface :

If a wedge shaped film is formed b/w an optically planeglass plate, fringes will be straight, regular and equally spaced..

If the glassplate is not optically plane, fringes will not be straight and irregular, unequally separated.

* An airwedge is illuminated by a light of wavelength 600nm. Find the angle of wedge. There are 10 fringes in 1 cm.

ans)
$\lambda = 600nm$
$= 600 \times 10^{-9}$ m.

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10 fringes in 1cm ⇒

$$10\beta = 1\,cm$$
$$\beta = \frac{1}{10}\,cm = 0.1\,cm = 0.1\times10^{-2}\,m$$

then angle of wedge $\theta = \frac{\lambda}{2\beta} = \frac{600\times10^{-9}}{2\times0.1\times10^{-2}}$

$$\theta = 0.0003 \text{ radian}$$
$$\theta = 0.0003\times\frac{180}{\pi} \text{ degree}$$
$$\theta = 0.01719^\circ$$

HW

* Two glass plates enclose a wedge shaped film. The glass plates touch each other at one edge and are separated by a wire of diameter 0.05mm at a distance of 0.15m from the edge. If monochromatic light of wavelength 6000 Å falls normally on the wedge, calculate the fringe width.

ans) Given $d = 0.05\,mm = 0.05\times10^{-3}\,m$.

$$l = 0.15\,m.$$
$$\lambda = 6000\,Å = 6000\times10^{-10}\,m.$$

we have $d = \frac{\lambda l}{2\beta}$

Or bandwidth $\beta = \frac{\lambda l}{2d}$

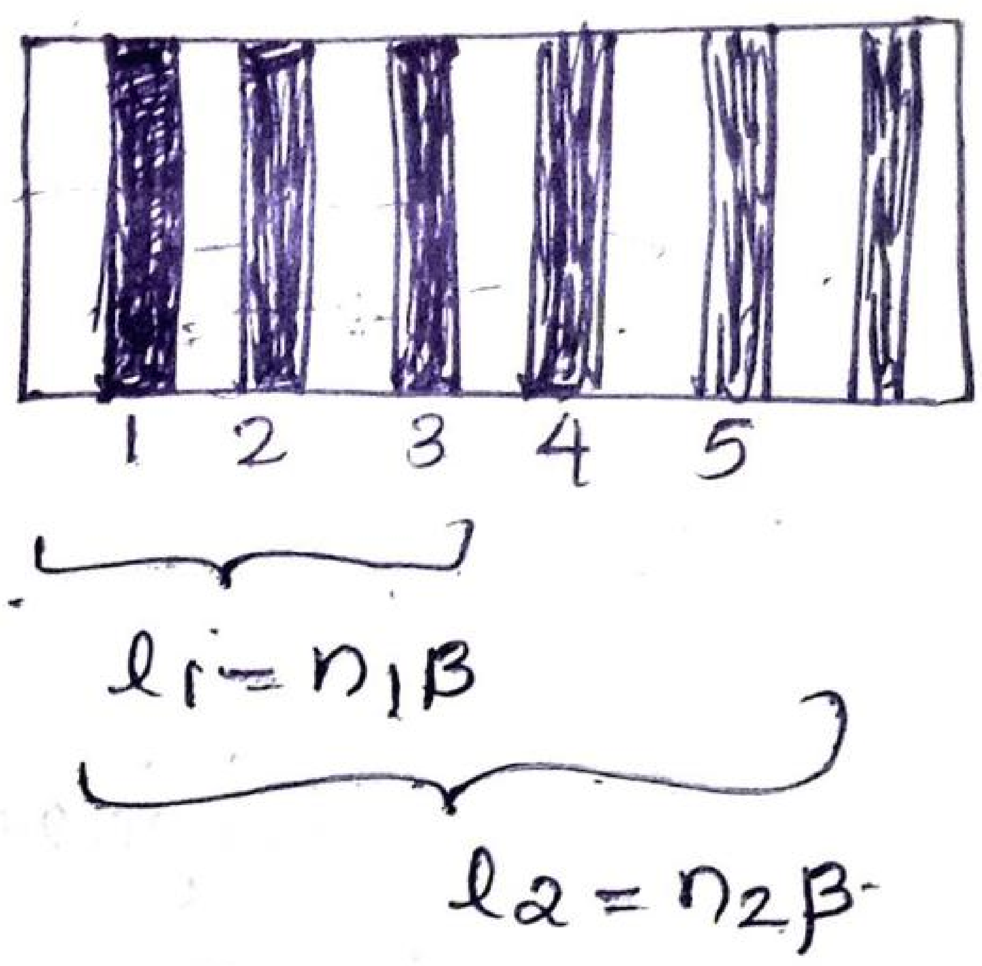
$$= \frac{6000\times10^{-10}\times0.15}{2\times0.05\times10^{-3}}$$

$$\beta = 0.0009\,m.$$

Consider a wedge shaped film formed between the surfaces of two plane glass plates. Interference occurs between ~~surfaces~~ the rays reflected from the top and bottom surfaces of the film. Alternate bright and dark bands are observed.

Let PQ and P'Q' are 2 sections of thin film.

Bandwidth β is the distance b/w 2 consecutive dark fringes or bright fringes



let $l_1 = n_1\beta$.

$l_2 = n_2\beta$

then $l_2 - l_1 = \beta(n_2 - n_1)$.

Substitute this in (6)

$$(6) \Rightarrow \quad \theta = \frac{\lambda}{2}\frac{\cancel{(n_2-n_1)}}{\beta\cancel{(n_2-n_1)}}$$

$$\boxed{\theta = \frac{\lambda}{2\beta}} \quad \text{—— (7)}$$

$\theta \rightarrow$ angle of wedge

$\lambda \rightarrow$ wavelength of the light

$\beta \rightarrow$ Bandwidth.

having thickness t_1 and t_2.

We have for darkness

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

Consider PQ :

$$(1) \Rightarrow 2\mu t_1 \cos r = n_1 \lambda$$

for air film $\mu = 1$ and

for normal incidence $i = 0$ and $r = 0$.

$$\therefore \quad 2t_1 \cos 0 = n_1 \lambda$$

$$2t_1 = n_1 \lambda \quad \text{--- (2)}$$

Similarly for $P'Q'$

$$2t_2 = n_2 \lambda \quad \text{--- (3)}$$

(3) − (2) ⟹

$$2t_2 - 2t_1 = n_2\lambda - n_1\lambda$$

$$2(t_2 - t_1) = \lambda(n_2 - n_1)$$

$$t_2 - t_1 = \frac{\lambda}{2}(n_2 - n_1) \quad \text{--- (4)}$$

At PQ $\quad \tan\theta = \frac{PQ}{l_1} = \frac{t_1}{l_1}$

when θ is very small $\tan\theta \approx \theta$

$$\therefore \quad \theta = \frac{t_1}{l_1} \quad \text{or} \quad t_1 = l_1\theta$$

Similarly at $P'Q'$ $\quad t_2 = l_2\theta$

then $t_2 - t_1 = l_2\theta - l_1\theta$.

$$t_2 - t_1 = \theta(l_2 - l_1). \quad \text{--- (5)}$$

equating (4) and (5).

$$\theta(l_2 - l_1) = \frac{\lambda}{2}(n_2 - n_1)$$

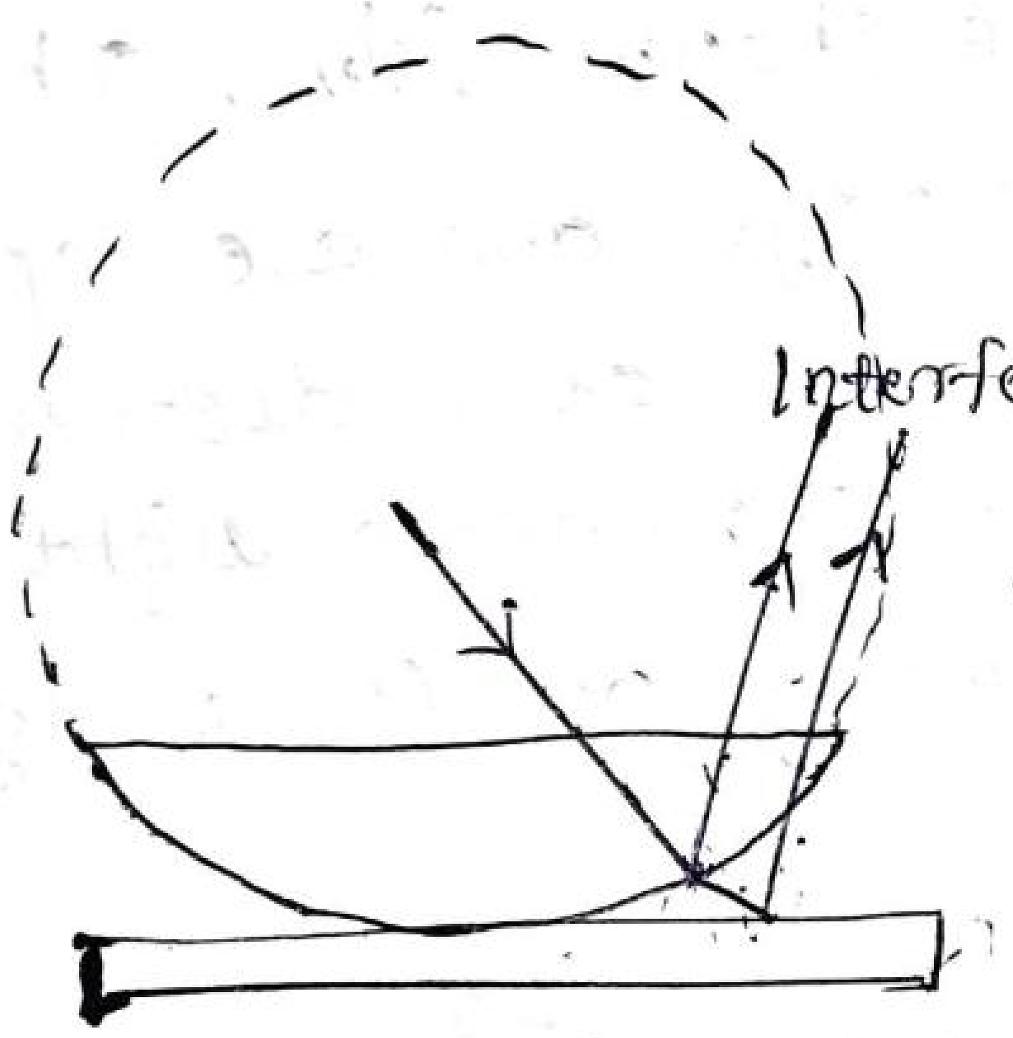
or

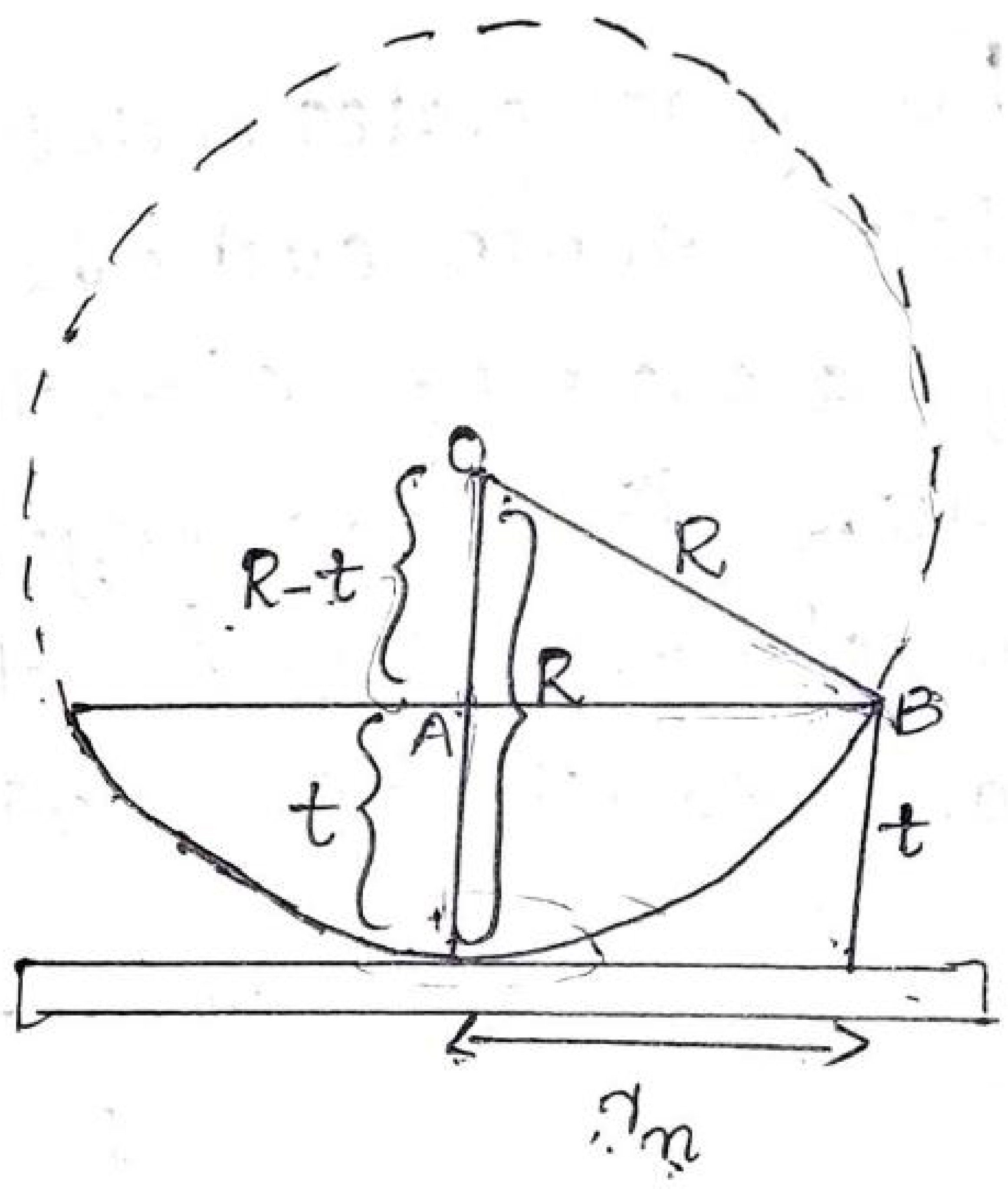
$$\theta = \frac{\lambda}{2}\frac{(n_2 - n_1)}{(l_2 - l_1)} \quad \text{--- (6)}$$

(2) Newton's Ring Experiment

Newton's ring apparatus consists of an optically plane glass plate above which a plano convex lens of radius of curvature R is placed.

A thin air film is placed b/w the lens and glass plate. The light reflected from the top and bottom surfaces of the thin film interfere each other produces concentric rings of decrease in thickness, called newton's rings.

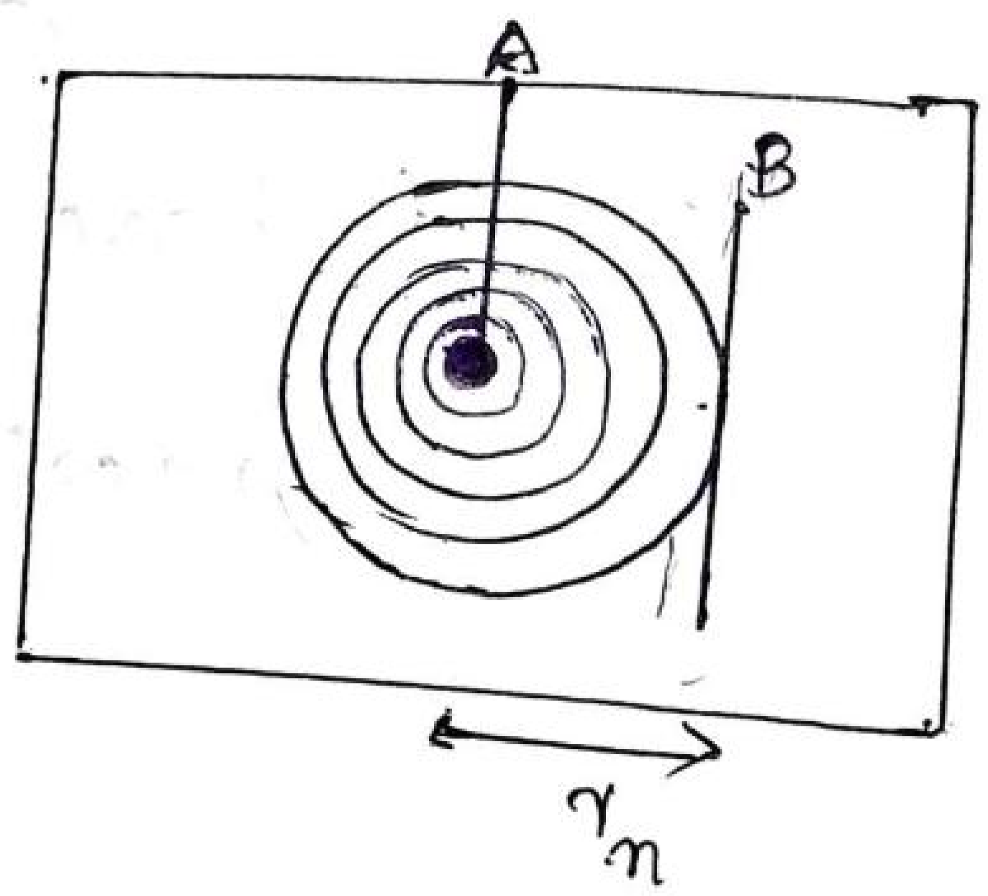




From figure

$$OB^2 = OA^2 + AB^2$$

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



where R = radius of curvature of lens.

t = thickness of the film

r_n = radius of n^{th} ring.

then $\cancel{R^2} = \cancel{R^2} - 2Rt + t^2 + r_n^2$

t^2 can be neglected since it is very small.

$\therefore$ $2Rt = r_n^2$ or

$$2t = r_n^2/R \quad \text{—— (1)}$$

we have equation (4)

$$r_n = \sqrt{\frac{n\lambda R}{\mu}} \Rightarrow \boxed{r_n \propto \sqrt{n}.}$$

ie, radius of n^{th} dark ring is proportional to the squareroot of the integer n.

From (6)

$$D_n = \sqrt{\frac{4n\lambda R}{\mu}} \Rightarrow \boxed{D_n \propto \sqrt{n}}$$

ie, diameter of n^{th} dark ring is proportional to the square root of the integer n.

* Uses of Newton's Ring expt :

1. Determination of wavelength λ :

we have $D_n^2 = \frac{4n\lambda R}{\mu}$ —(1)

for air film

$$D_n^2 = 4n\lambda R \quad \text{—(2)}$$

$$D_{n+k}^2 = 4(n+k)\lambda R \quad \text{—(3)}.$$

In order to eliminate the possible errors, we find the diameter of $(n+k)^{th}$ ring

(3) − (2) ⇒

$$D_{n+k}^2 - D_n^2 = 4(n+k)\lambda R - 4n\lambda R$$
$$= \cancel{4n\lambda R} + 4k\lambda R - \cancel{4n\lambda R}$$

$$D_{n+k}^2 - D_n^2 = 4k\lambda R$$

or $$\boxed{\lambda = \frac{D_{n+k}^2 - D_n^2}{4kR}} \quad \text{—(4)}$$

where D_n → diameter of n^{th} ring
D_{n+k} → diameter of $(n+k)^{th}$ ring
k → integer, R → Radius of curvature.

For darkness, we have

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

For normal incidence $i = 0, r = 0$.

$$\therefore\ 2\mu t\cos 0 = n\lambda$$

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

or $$2t = \frac{n\lambda}{\mu} \quad \text{--- (2)}$$

Equating (1) and (2)

$$\frac{r_n^2}{R} = \frac{n\lambda}{\mu} \quad \text{or}$$

$$\boxed{r_n^2 = \frac{n\lambda R}{\mu}} \quad \text{--- (3)}$$

Or $$\boxed{r_n = \sqrt{\frac{n\lambda R}{\mu}}} \quad \text{--- (4)}$$

r_n is the radius of nth dark ring, then

$$r_n = \frac{D_n}{2}$$ where D_n = diameter of nth dark ring

squaring $$r_n^2 = \frac{D_n^2}{4}$$

Substituting this in (3)

$$\frac{D_n^2}{4} = \frac{n\lambda R}{\mu}$$

or $$\boxed{D_n^2 = \frac{4n\lambda R}{\mu}} \quad \text{--- (5)}$$

or $$\boxed{D_n = \sqrt{\frac{4n\lambda R}{\mu}}} \quad \text{--- (6)}$$

D_n : diameter of nth dark ring
n : no. of ring
λ : wavelength
R : radius of curvature
μ : R.I of film.

for air film $\mu = 1$

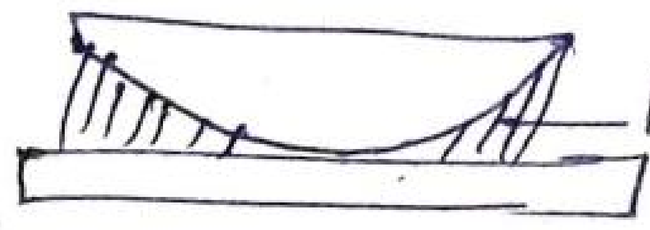
then

$$\boxed{D_n^2 = 4n\lambda R} \quad \text{--- (7)}$$

2. Determination of refractive index (μ) of liquid

$$D_n^2 = \frac{4n\lambda R}{\mu}.$$

here μ is the R I of the medium of the film.


liquid

For liquid film,

$$d_n^2 = \frac{4n\lambda R}{\mu_{liquid}} \quad \text{— (1) and}$$

$$d_{n+k}^2 = \frac{4(n+k)\lambda R}{\mu_{liquid}} \quad \text{— (2)}$$

(2) − (1) $\Rightarrow$

$$d_{n+k}^2 - d_n^2 = \frac{4(n+k)\lambda R}{\mu_{liquid}} - \frac{4n\lambda R}{\mu_{liquid}}$$

$$= \cancel{\frac{4n\lambda R}{\mu_{liquid}}} + \frac{4k\lambda R}{\mu_{liquid}} - \cancel{\frac{4n\lambda R}{\mu_{liquid}}}$$

$$d_{n+k}^2 - d_n^2 = \frac{4k\lambda R}{\mu_{liquid}} \quad \text{— (3).}$$

for air film, $\mu = 1$

ie, $$D_{n+k}^2 - D_n^2 = 4k\lambda R \quad \text{— (4)}$$

$$\frac{(4)}{(3)} \Rightarrow \frac{D_{n+k}^2 - D_n^2}{d_{n+k}^2 - d_n^2} = \frac{4k\cancel{\lambda R}}{\frac{4\cancel{k}\lambda R}{\mu_{liquid}}} = \frac{1}{\frac{1}{\mu_{liquid}}}$$

ie,

$$\boxed{\mu_{liquid} = \frac{D_{n+k}^2 - D_n^2}{d_{n+k}^2 - d_n^2}} \quad \text{— (5)}$$

$D_n, D_{n+k} \rightarrow$ diameter of n^{th} and $(n+k)^{th}$ ring when film is air

$d_n, d_{n+k} \rightarrow$ diameter of n^{th} and $(n+k)^{th}$ ring when film is liquid

HW * Why central fringe of Newton's rings are dark on reflected system?

ans). ~~Locus of~~

Path difference between reflected lights is $\lambda/2$ at the centre ie, destructive interference takes place resulting darkness or minimum intensity.

* What will happen to the diameter of Newton's ring when the air film is replaced by water.

ans)
$$D_n^2 = \frac{4n\lambda R}{\mu}$$

ie, as μ increases, D_n decreases

$\mu_{air} = 1$, $\mu_{water} = 1.33$

ie, when airfilm is replaced by water, μ increases means diameter of ring decreases

* Why Newton's rings are circular?

Locus of all points having same thickness, amplitude and phase of vibration of particles are circular in shape. Hence Newton's rings are circular in shape.

* HW. Airwedge - straight lines - reason. ?

Points having same thickness, amplitude and phase of vibration of particles lie on a straightline. Hence Airwedge pattern involves straight line fringes

* Newton's rings are observed in the reflected light of wavelength $5900\,\text{Å}$. The diameter of tenth dark ring is 0.5cm. Find the radius of curvature of the lens used.

ans).

$$\lambda = 5900\,\text{Å} = 5900\times10^{-10}\,m$$

$$D_{10} = 0.5\,cm = 0.5\times10^{-2}\,m.$$

$$D_n^2 = \frac{4n\lambda R}{\mu} \quad ; \quad \mu = 1$$

$$D_n^2 = 4n\lambda R.$$

$$D_{10}^2 = 4\times10\times\lambda R$$

$$R = \frac{D_{10}^2}{4\times10\times\lambda} = \frac{(0.5\times10^{-2})^2}{4\times10\times5900\times10^{-10}}$$

$$R = 1.0593\,m.$$

* In Newton's ring expt, the diameters of 4^{th} and 12^{th} dark rings are 0.4 cm and 0.7 cm respectively. Find the diameter of 20^{th} dark ring.

ans)

here $D_4 = 0.4$ cm

$D_{12} = 0.7$ cm.

we have $D_n^2 = 4n\lambda R.$

then $D_4^2 = 4\times4\lambda R$ —① .

$D_{12}^2 = 4\times12\lambda R$ —②

② − ① ⟹

$$D_{12}^2 - D_4^2 = 48\lambda R - 16\lambda R$$

$$0.7^2 - 0.4^2 = 32\lambda R$$

$$\lambda R = \frac{0.33}{32}$$

then diameter of 20^{th} ring

$$D_{20}^2 = 4\times20\times\lambda R$$

$$= 4\times20\times\frac{0.33}{32} = 0.825\,cm$$

$$\therefore D_{20} = \sqrt{0.825} = 0.908\,cm.$$

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* With a Newton's ring arrangement diameter of n^{th} ring formed by light of wavelength 6000Å coincide with $(n+1)^{th}$ dark ring of light of wavelength 4500Å. If the radius of curvature of surface is 90cm, Find the diameter of n^{th} dark ring of 6000Å.

ans) here $\lambda_1 = 6000Å = 6000\times10^{-10} m$

$\lambda_2 = 4500Å = 4500\times10^{-10} m$.

$R = 90cm = 0.9\cancel{\times10^{-2}} m$.

$D_n^2 = 4n\lambda_1 R = 4\times n\times 6000\times10^{-10}\times 90\times10^{-2}$

$D_{n+1}^2 = 4(n+1)\lambda_2 R = 4(n+1)\times 4500\times10^{-10}\times 90\times10^{-2}$

Given $D_n^2 = D_{n+1}^2$

$4n\cdot 60\cancel{00}\times\cancel{10^{-10}}\times\cancel{90\times10^{-2}} = 4(n+1)\times 45\cancel{00}\times\cancel{10^{-10}}\times\cancel{90\times10^{-2}}$

$4n\times60 = 4(n+1)\times45$

$240n = (4n+4)\times45$

$240n = 180n+180$.

$240n-180n = 180$

$60n = 180$

$n = \frac{180}{60}$

$n = 3$.

then diameter of n^{th} ring of 6000Å

$D_n^2 = 4n\times6000\times10^{-10}\times90\times10^{-2}$

$D_3^2 = 4\times3\times6000\times10^{-10}\times90\times10^{-2}$

$D_3^2 = 0.00000648$

$D_3 = 0.0025 m$.

* HW A parallel beam of light ($\lambda = 5890 \times 10^{-8}$ cm) is incident on a thin glass plate ($\mu = 1.5$) such that angle of refraction into the glass plate is 60°. Calculate the smallest thickness of the glass plate which will appear dark by reflection.

ans) $\lambda = 5890 \times 10^{-8}$ cm

$\lambda = 5890 \times 10^{-10}$ m

$\mu = 1.5$

$r = 60^\circ$

For darkness, $2\mu t \cos r = n\lambda$ $n = 1$ for smallest thickness.

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

then thickness $t = \dfrac{\lambda}{2\mu \cos r}$ $= ?$

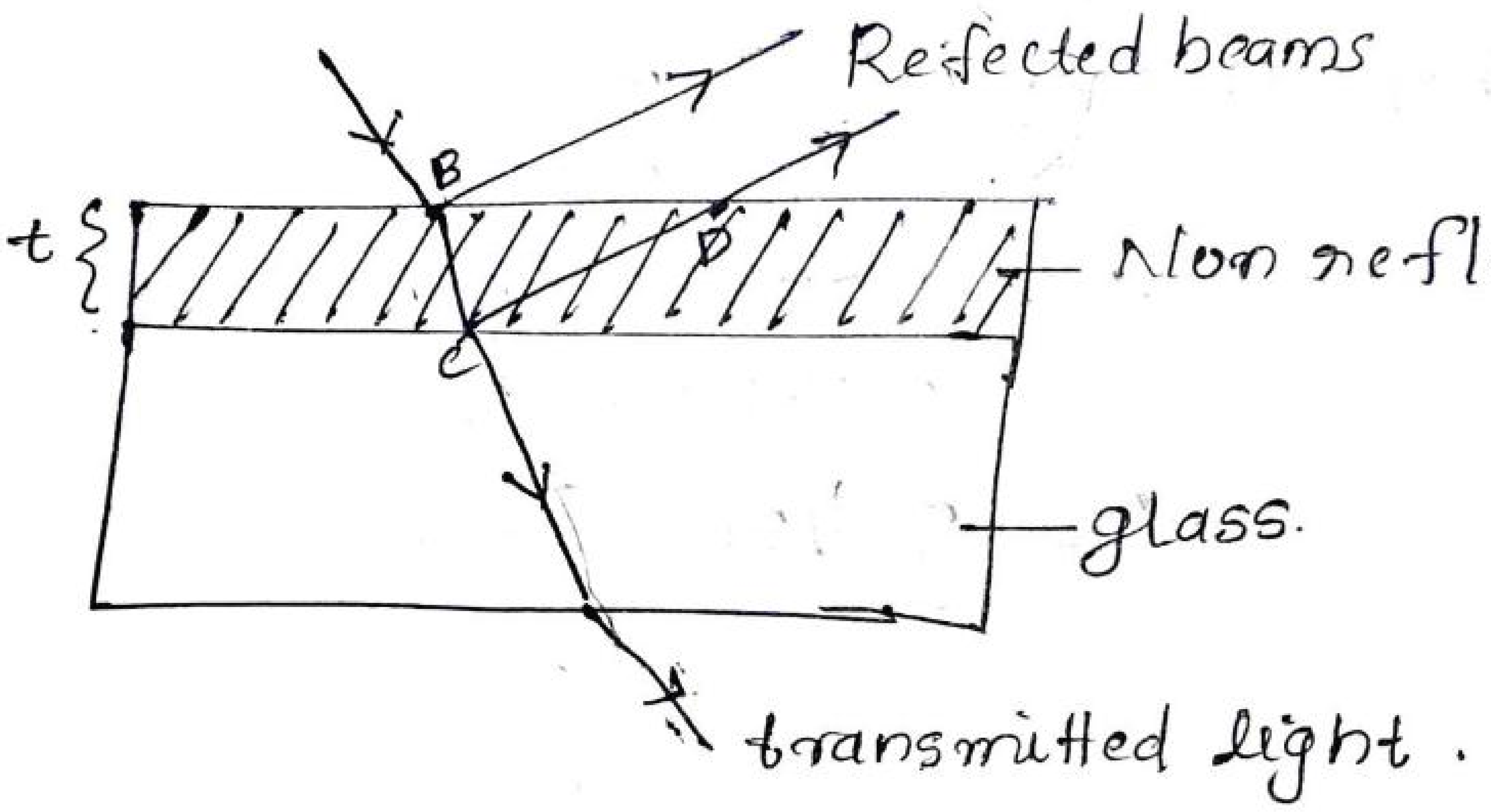
$$t = \frac{5890 \times 10^{-10}}{2 \times 1.5 \times \cos 60}$$

$$t = 3.926 \times 10^{-7}\,\text{m}.$$

* ANTIREFLECTION COATING OR NON REFLECTING FILM:

It is used to protect the instrument from entering extra wavelength and intensity. It consists of a thin layer of cryolite coated on the surface of the instrument. (objective of the lens of camera, binoculars etc).

Only a selected wavelength can be transmitted to it and the wavelengths are destructively interfere each other, depends on the thickness of the film.



When a parallel beam of light is incident on the film, part of the light is reflected from the upper and lower surfaces of the film, which reduce the intensity of transmitted light and quality of image. Thickness of the film is adjusted such that interference of reflected beams is destructive. Thus Loss of intensity during reflection is reduced and beam is transmitted with max intensity.

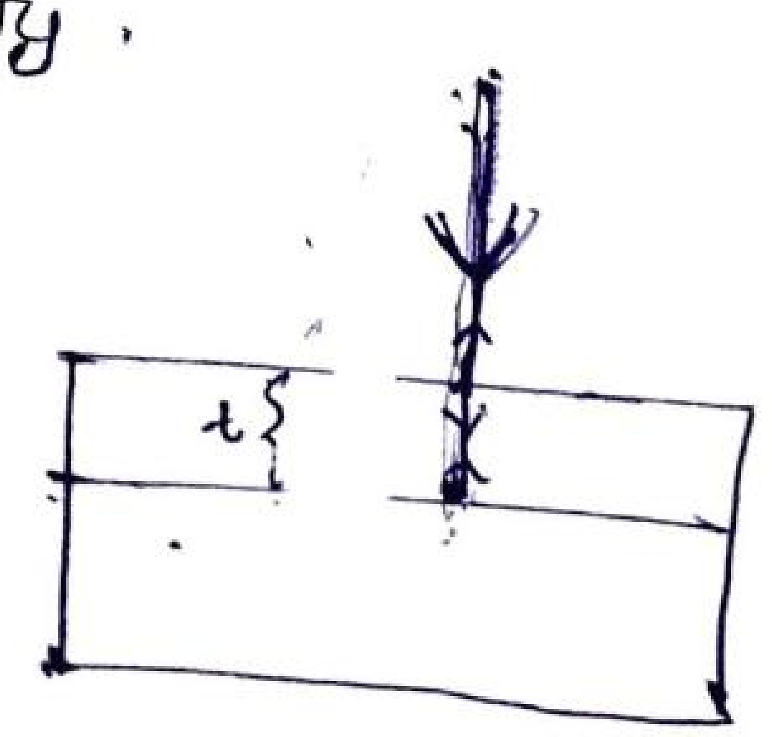
For normal incidence

path diff $= BC + CD$

$= 2(BC)$

$= \underline{\underline{2t}}$

OPD $= \underline{\underline{2\mu t}}$



For destructive interference

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

Taking $n=0$

$$2\mu t = \frac{\lambda}{2}$$

$$\text{or } t = \frac{\lambda}{4\mu}$$

$\therefore$ ~~optical~~ thickness of coating $= \frac{\lambda}{4\mu}$.

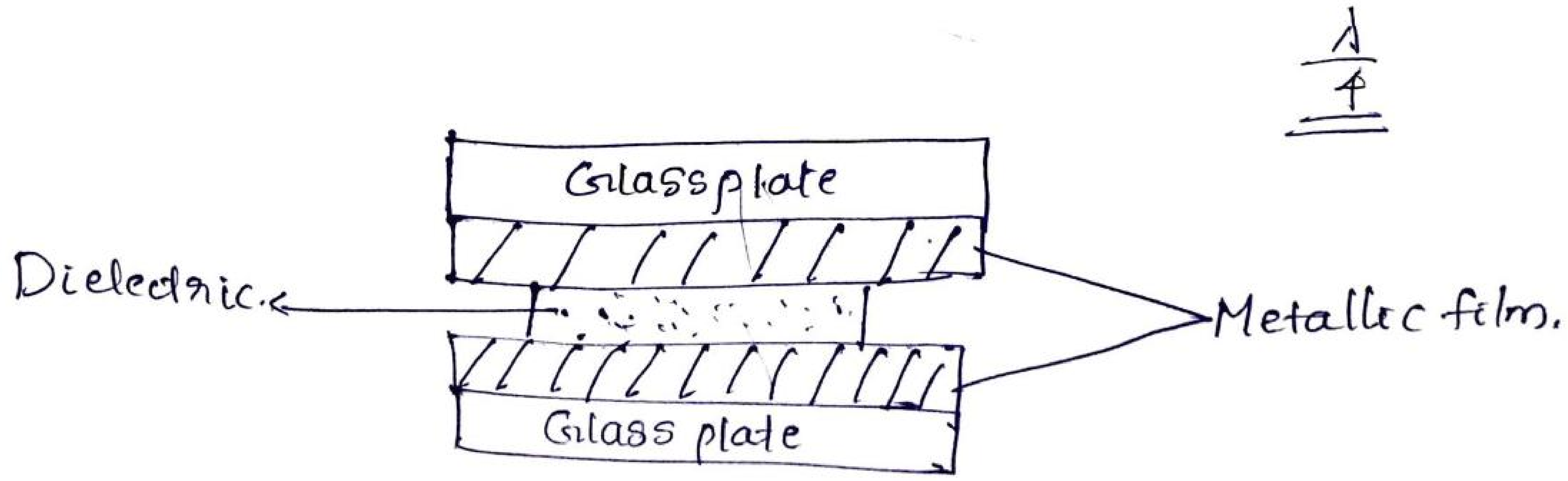
Such coating eliminate reflections and allow more light to pass through the instrument, hence are called antireflection coating. Technique of reducing the reflectivity is called blooming.

* INTERFERENCE FILTER :

A filter is used to eliminate most of the wavelengths except a narrow band, thus provides a monochromatic beam of light.

Construction :

A thin metallic film usually of Al or Ag is deposited on a glass. Then a thin layer of cryolite ($3NaF AlF_3$) is deposited over this. The structure is again covered by another metallic film. Another glass plate is placed over it to protect the film.



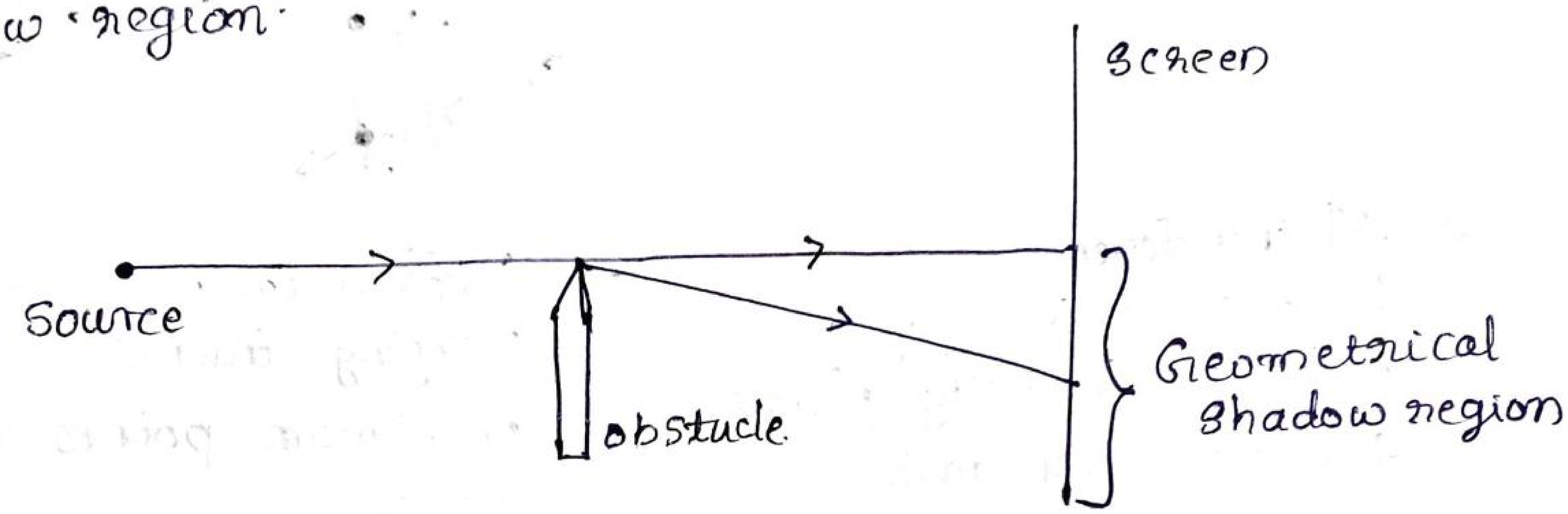
By varying the thickness of dielectric film, any particular wavelength can be filtered out. It is not possible to increase the thickness of metallic films indefinitely, therefore metallic films are replaced by dielectric films. To obtain interference ~~fit~~ filter, $\frac{\lambda}{4}$ thick film of titanium oxide is deposited on the glass plate. Then a film of cryolite or MgF_2 is deposited. Again a $\frac{\lambda}{4}$ thick layer of titanium oxide is deposited. In this way multilayer filter is produced.

CHAPTER-2 - DIFFRACTION

DIFFRACTION:

Diffraction is the bending of light when it crosses sharp obstucles, or

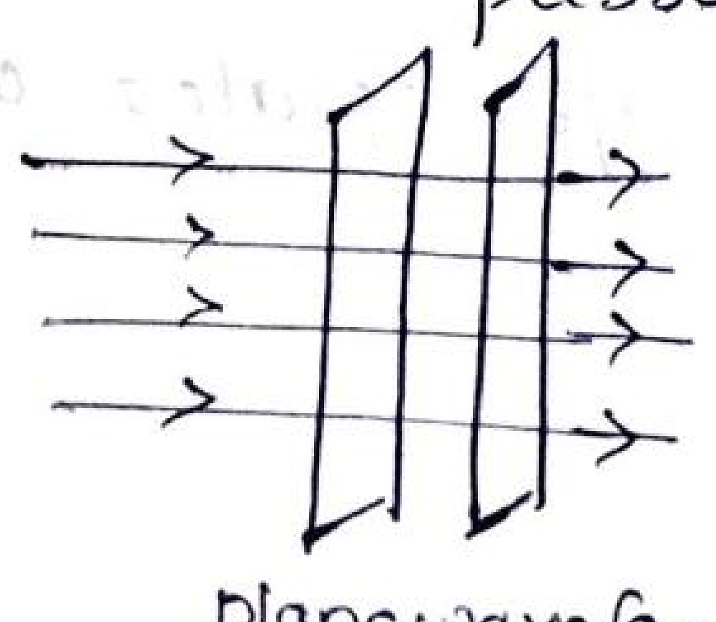
It is the enchroachment of light in the geometrical shadow region.

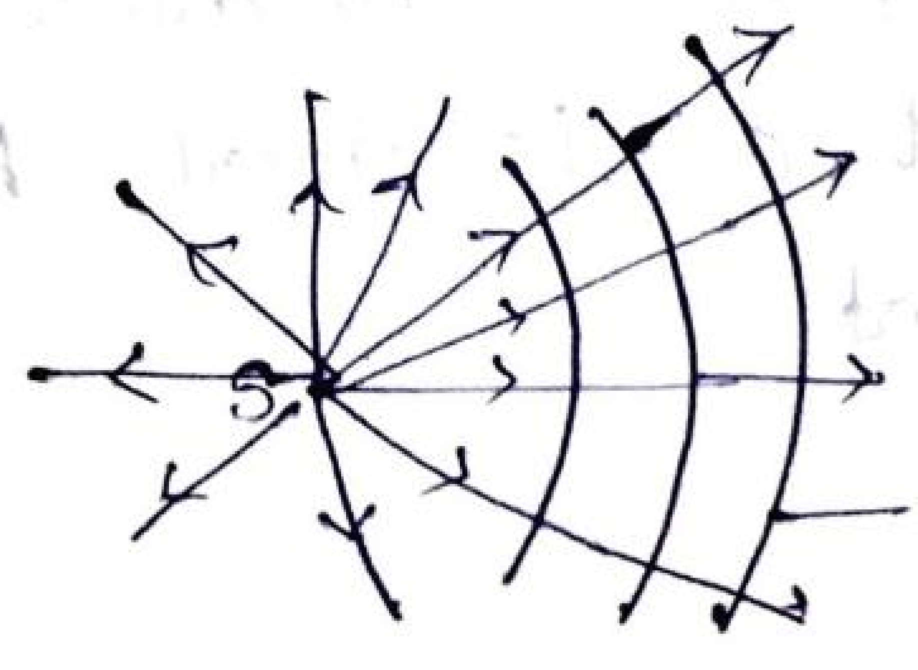


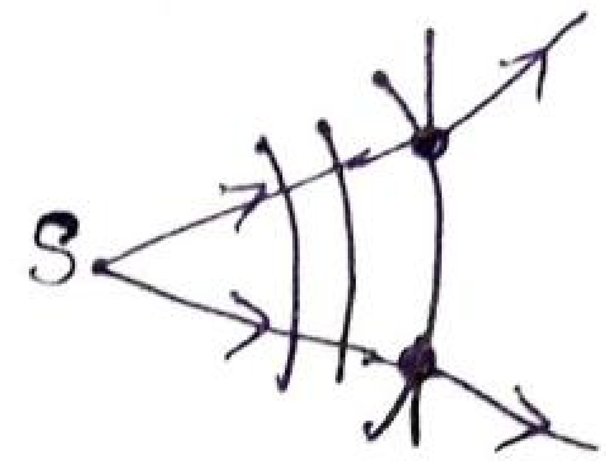
Diffraction can be classified into two:

Fresnel diffraction	Fraunhofer diffraction
-> source and screen are at finite distance from the obstucle.	-> Source and screen are at infinite distance from the obstucle.
-> Spherical wavefront is considered	-> plane wave front is considered.
-> No lenses are required	-> lenses are required.
-> image is not clear	-> image is clear.
-> Eg: diffraction at straight edge, thin wire, sharp pin.	-> single slit and double slit expt, grating expt.

* Wavefront - imaginary surfaces through which the rays passes.





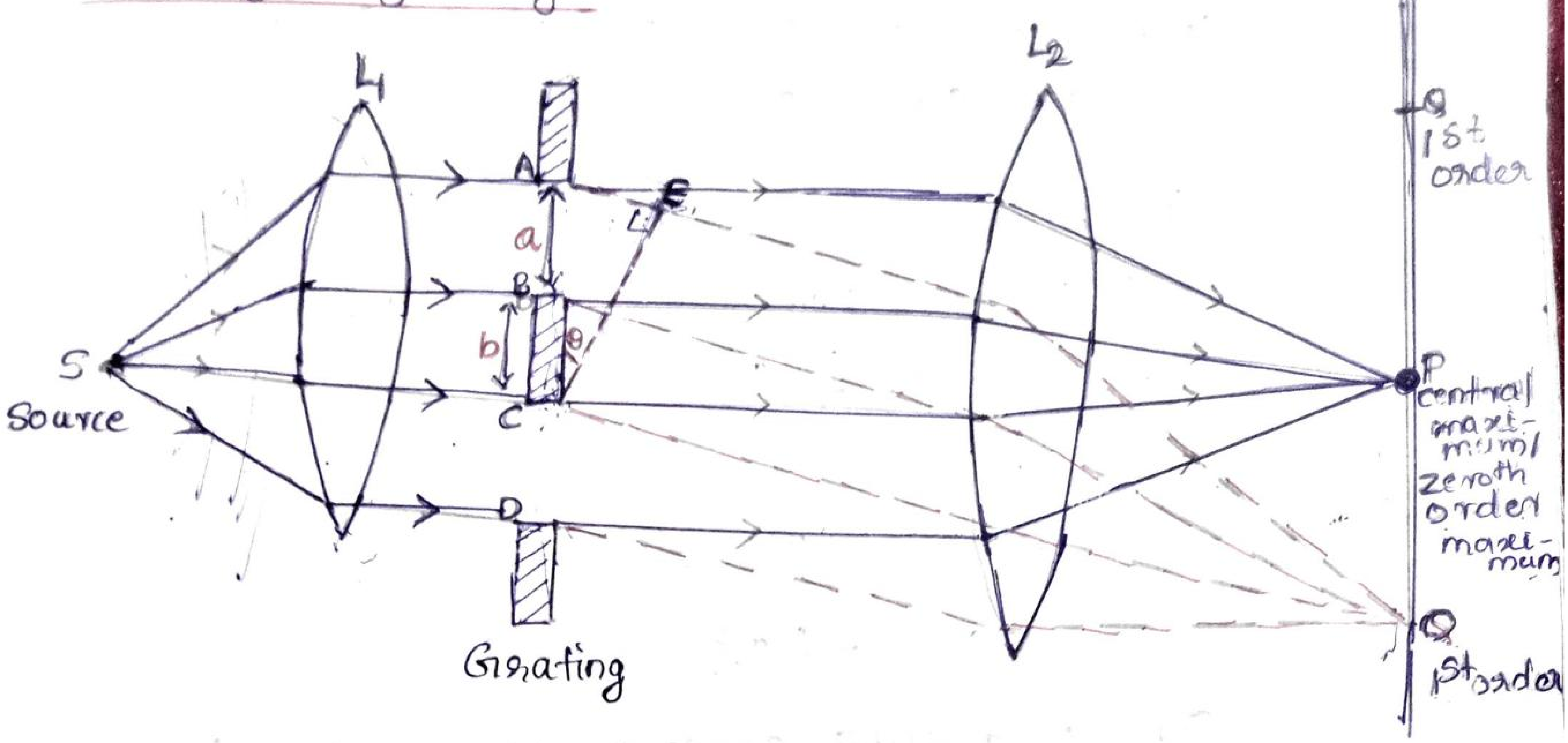
* Interference	Diffraction.
→ joining of two or more light waves	→ bending of light at sharp edges.
→ 2 coherent sources are required	→ any two points in the primary wavefront act as the sources of diffraction.
	
→ All interference maxima have same intensity and minimum intensity points are perfectly dark.	→ Diffraction maxima have varying intensities and minimum points are not dark.
→ equidistant or unequidistant fringes are formed	→ fringes are unequally separated always.
→ Eg: Airwedge, Newton's ring.	→ Eg: Grating expt.

* PLANE TRANSMISSION GRATING :- FRAUNHOFER DIFFRACTION

A grating consists of a large no. of equidistant parallel slit separated by equal opaque spaces, formed on a glass plate ~~in~~ within a small distance. Eg: 6000 lines/cm

A grating can be constructed by drawing equidistant parallel lines on an optically plane glass plate using a diamond tip. Replica of grating can be constructed by forming a thin film of gelatin solution on an original grating, and it is allowed to harden. The thin film is separated and is placed, between 2 glassplates whose ends are sealed.

Theory of grating :



A plane wavefront from a monochromatic source is incident on a grating. Let 'a' be the width of the opening or transparent region and 'b' be the width of opaque region. The distance 'a+b' is called grating element / grating constant.

After diffraction diffraction fringes are formed on the screen. Since the path difference b/w AP and CP is zero, P will be a point of maximum intensity and is called zeroth order maximum or principal maximum.

To find the intensity at Q, path difference b/w AQ and CQ is calculated.

Path difference $= AQ - CQ = AE$

from $\triangle ACE$

$$\sin\theta = \frac{AE}{AC}$$

$AC = a+b.$

or $AE = AC\sin\theta$

ie, path dif $= AE = (a+b)\sin\theta$ —— (1).

If $AE = n\lambda \implies Q$ is a maximum point of intensity

If $AE = (2n+1)\lambda/2 \implies Q$ is minimum.

Let Q is a maximum intensity point.

then $AE = n\lambda$; $n = 0, 1, 2 \dots$

$$(a+b)\sin\theta = n\lambda \quad \text{——} (2)$$

Let 'N' be the no. of lines in 1 cm, then

$$N(a+b) = 1\ \text{cm}$$

1 line means $a+b$.

$$\text{or } (a+b) = \frac{1}{N}\ \text{cm}.$$

$\therefore$ (2) $\Rightarrow$

$$\frac{1}{N}\sin\theta = n\lambda \quad \text{or}$$

$$\boxed{\sin\theta = Nn\lambda} \quad \text{——} (3)$$

This is grating equation or grating Law.

$\theta \rightarrow$ angle of diffraction
$N \rightarrow$ No. of lines / cm of grating
$n \rightarrow$ order of the slit (0, 1, 2, 3..)
$\lambda \rightarrow$ wavelength of light.

Grating equation in terms of grating element:

grating eq^n. $\sin\theta = Nn\lambda$

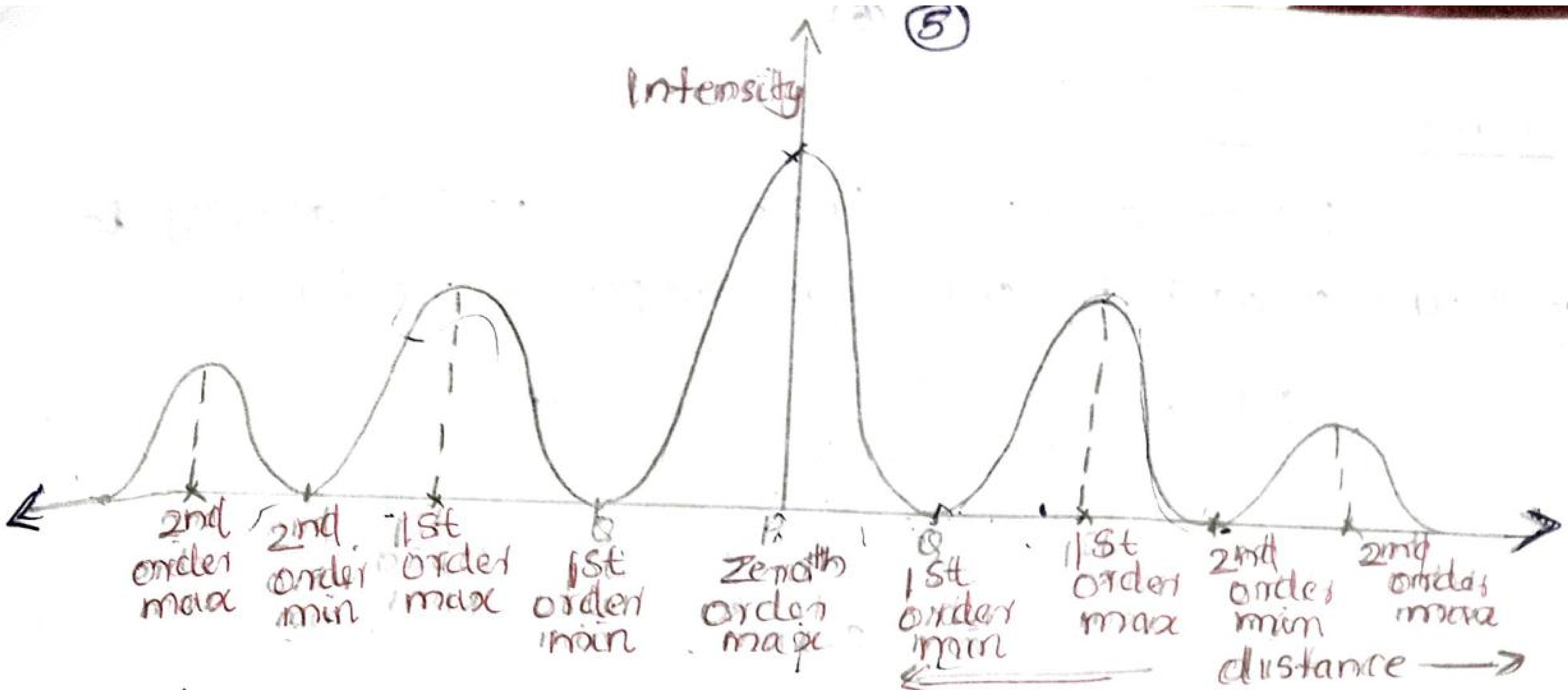
we have $N(a+b) = 1$ cm

or $N = \frac{1}{a+b}$ = grating element.

$\therefore$ grating eq^n $\Rightarrow$

$$\sin\theta = \frac{1}{a+b}\, n\lambda$$

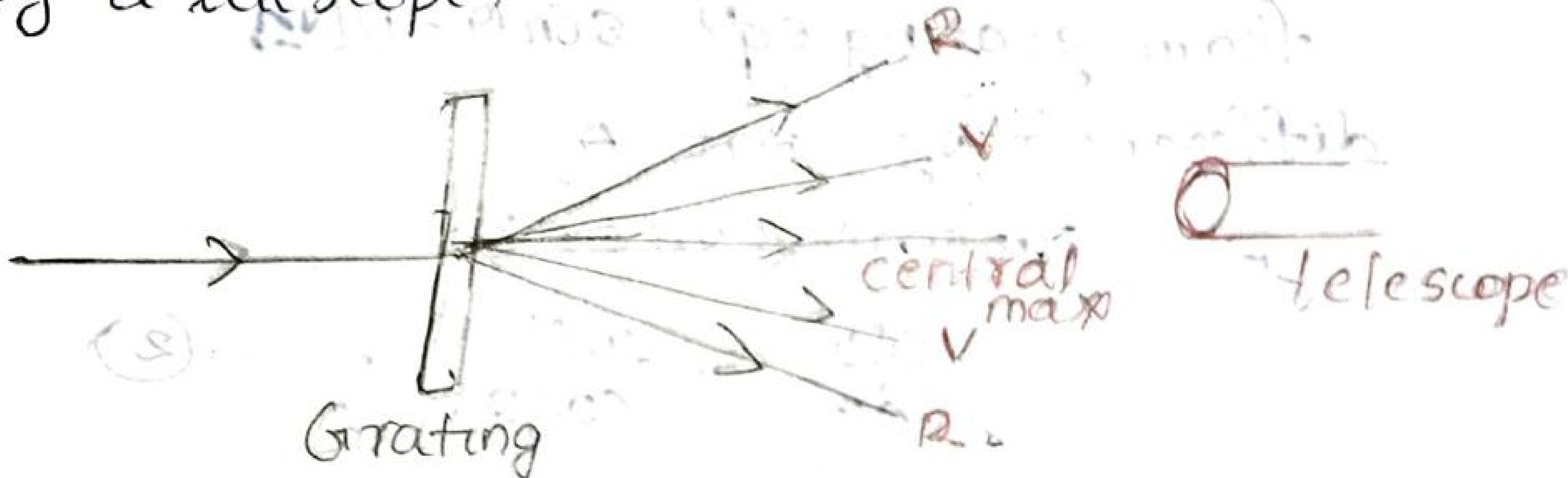
$$\text{or } \boxed{(a+b)\sin\theta = n\lambda}.$$



Grating expt :

To find λ of different spectral lines using grating :

Spectrometer is used to find the wavelength of a spectral line using grating. The given grating is set for normal incidence. Spectral lines are obtained on both sides of central maximum after diffraction. It can be viewed by a telescope.



Using green line, grating element N can be calculated. Angle of diffraction θ_g for green line is calculated from the readings of spectrometer. Then from grating equation

$$\sin\theta_g = Nn\lambda_g \qquad (n=1)$$

or $$\boxed{N = \frac{\sin\theta_g}{n\lambda_g}} \quad ; \quad \lambda_g = 546.1\,nm$$

wavelength of green.

This process of finding N is called standardization of grating. Angle of diffractions for different colours are measured and λ of each colour is calculated from the equation

$$\boxed{\lambda = \frac{\sin\theta}{nN}} \quad ; \quad (n=1)$$

HW * How many lines per metre there in a plane diffraction grating which gives on the second order of an angle of diffraction 30° for the light of wavelength 520 nm incident normally on it ?

ans) Order $n = 2$

angle of diffraction $\theta = 30^\circ$

$N = ?$

$\lambda = 520 nm = 520 \times 10^{-9} m.$

$\sin\theta = Nn\lambda$

$N = \frac{\sin\theta}{n\lambda} = \frac{\sin 30}{2 \times 520 \times 10^{-9}}$

$N = 480769.230$ lines/m.

HW * Light of wavelength 5000 Å is incident normally on a plane transmission grating. Find the ~~diffraction~~ dif in angle of deviation in the first and 3rd order spectra. No. of lines /cm on the grating is 6000.

ans) $\lambda = 5000 Å = 5000 \times 10^{-10} m.$

$N = 6000$ lines/cm

N 6000 lines/$10^{-2} m$

$N = 600000$ lines/m

N

for first order $n=1$

$$\sin\theta_1 = nN\lambda$$

$$\sin\theta_1 = 1\times 600000\times 5000\times10^{-10}$$

$$\sin\theta_1 = 0.3$$

$$\theta_1 = \sin^{-1}(0.3)$$

$$\theta_1 = 17.46^\circ.$$

for 3rd order spectra, $n=3$

$$\sin\theta_2 = 3\times N\times\lambda$$

$$\sin\theta_2 = 3\times 600000\times 5000\times10^{-10}$$

$$\sin\theta_2 = 0.9$$

$$\theta_2 = \sin^{-1}(0.9)$$

$$\theta_2 = 64.15^\circ.$$

difference in angle of deviation

$$\theta_2-\theta_1 = 64.15^\circ - 17.46^\circ$$

$$\theta_2-\theta_1 = 47.8^\circ.$$

1) * A grating has 6000 lines/cm. Find the angular separation (HW) of two yellow lines of mercury of wavelengths 577nm and 579nm in the second ~~nth~~ order.

HW 2)

* A grating is illuminated at normal incidence. At an angle of diffraction 45°, a certain order of light of wavelength 500nm is superimposed on another one of wavelength 400nm in the next higher order. Evaluate the no. of lines/m of the grating used.

$\theta_1 = 45°$, $\theta_2 = 45°$

$\lambda_1 = 500nm$ $\lambda_2 = 400nm$

$\lambda_1 = 500 \times 10^{-9} m$. for order n.

$\lambda_2 = 400 \times 10^{-9} m$ for order $n+1$

for n, $\sin\theta_1 = n N \lambda_1$ —— (1)

for $n+1$, $\sin\theta_2 = (n+1) N \lambda_2$ —— (2).

(1) $\Rightarrow$ $\sin\theta_1 = nN \times 500 \times 10^{-9}$

$\sin 45 = nN \times 500 \times 10^{-9}$

$\frac{1}{\sqrt{2}} = nN \times 500 \times 10^{-9}$

$nN = \frac{1}{\sqrt{2} \times 500 \times 10^{-9}}$

$nN = 1414213.56$

(2) $\Rightarrow$ $\sin\theta_2 = (n+1) N \lambda_2$

$\sin 45 = (n+1) N \times 400 \times 10^{-9}$

$\frac{1}{\sqrt{2}} = \cancel{nN \times 400} (nN + N) \, 400 \times 10^{-9}$

$$\frac{1}{\sqrt{2}} = (1414213.56 + N) \times 400 \times 10^{-9}$$

$$N = \frac{1}{\sqrt{2} \times 400 \times 10^{-9}} - 1414213.56$$

$$N = \underline{\underline{353539.096}} \text{ lines/m.}$$

* DISPERSIVE POWER (D.P) :

D.P of an optical instrument is its ability to split the white light into its component colours.

$$\boxed{D.P = \frac{d\theta}{d\lambda} = \frac{\theta_1 - \theta_2}{\lambda_1 - \lambda_2}} \quad \text{——} (1)$$

where λ_1, λ_2 are wavelengths and θ_1, θ_2 are the angle of diffraction of two different colours.

D.P is the ratio of angular dispersion to the change in wavelength. or

$$\boxed{DP = \frac{\text{change in angle of diffraction}}{\text{change in wavelength}}}$$

D.P of grating :

from grating eq^n $\sin\theta = nN\lambda$

differentiating ~~w.r.t.~~ θ

$$\cos\theta \, d\theta = nN \, d\lambda$$

$$\boxed{\frac{d\theta}{d\lambda} = \frac{nN}{\cos\theta}} \quad \text{——} (2)$$

* RESOLVING POWER (R.P)

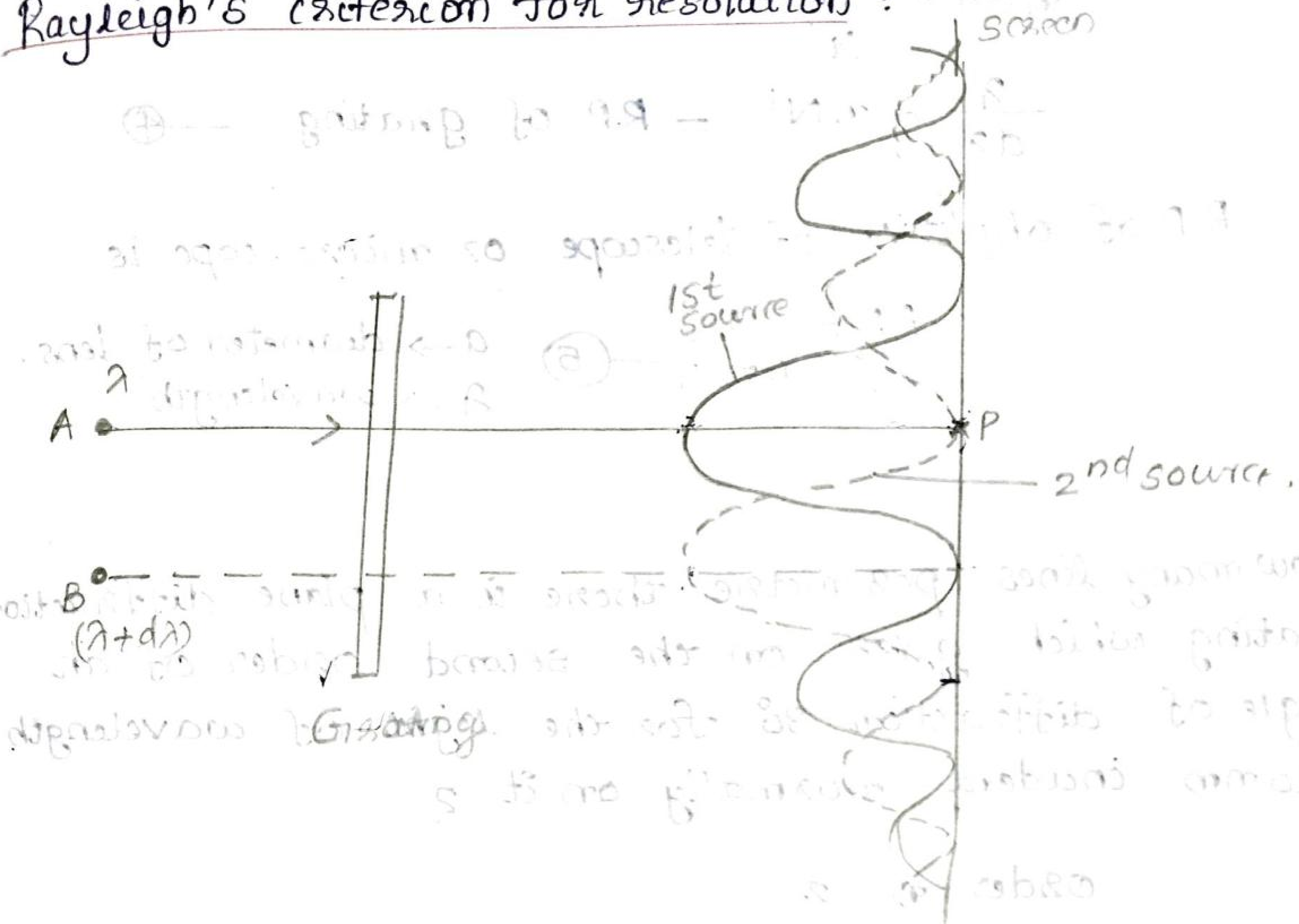
It is the ability of an optical instrument to separate two closed objects or two closed spectral lines.

$$\boxed{RP = \frac{\lambda}{d\lambda}} \quad \text{——} (1)$$

$d\lambda$: change in wavelength.

λ : average of λ of two spectral lines

Rayleigh's criterion for resolution :



In order to resolve two objects, principal maximum of one of the source (λ) must fall on the 1st order minimum of second source $(\lambda+d\lambda)$. This is known as Rayleigh's criterion for resolution.

Following equations must be satisfied.

$$(a+b)\sin\theta = n(\lambda+d\lambda) \quad \text{——} (2)$$

and $$(a+b)\sin\theta = n\lambda + \frac{\lambda}{N'} \quad \text{——} (3).$$

where N' = total no. of lines in the grating.

$N' = NL$, where

$N \rightarrow$ no. of lines /cm.

$L \rightarrow$ Length of the grating

$\frac{\lambda}{N'} \rightarrow$ path dif b/w max and min.

equating (1) and (2)

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

$$\cancel{n\lambda} + nd\lambda = \cancel{n\lambda} + \lambda/_{N'}$$

$$n\,d\lambda = \frac{\lambda}{N'}$$

$$\boxed{\frac{\lambda}{d\lambda} = nN' = \text{RP of grating}} \quad \text{—(4)}$$

R.P of objective of telescope or microscope is

$$\boxed{RP = \frac{a}{1.22\lambda}} \quad \text{—(5)}$$

$a \rightarrow$ diameter of lens.

$\lambda \rightarrow$ wavelength

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