PHYSICAL OPTICS

DUAL NATURE OF LIGHT

AS PARTICLE According to Newton's corpuscular theory, light behave as a particle. He performed 2 successful experiment that explain the particle nature of the light.

(1) Compton Effect (2) Photoelectric effect

AS WAVE According to Huygen's, light has a wave nature. It was further proved when Maxwell showed that light is form of high frequency electromagnetic waves. He predicted that EMW has same speed as the speed of light 3×10^8 m/s. Thomas Young did the experiment of interference of light which proved that light behave as wave as well.

CONCLUSION

1. In case of photoelectric effect and compton shift light behave as particle.
2. In case of reflection, diffraction, rarefaction, interference and polarization, light behave as wave

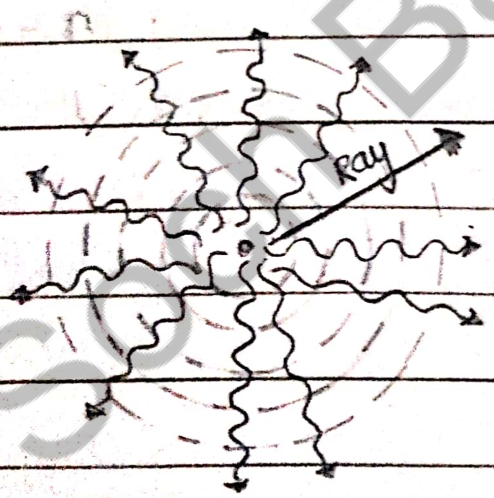
WAVE FRONT

"Such surface in which all the particles are in the same phase of vibration is known as wave front"

RAY: A line perpendicular to the wave front indicating direction of motion of a wave is called ray.

SPHERICAL WAVE FRONT

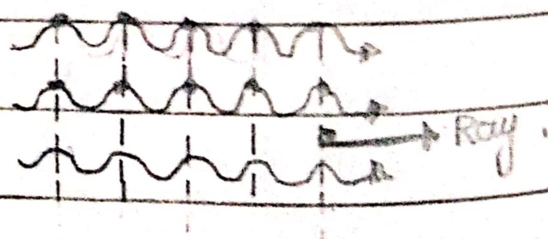
When there is a point source and medium is homogenous and isotropic then we have spherical wave front.



• As wave travel from the source, its curvature decreases.

PLANE WAVE FRONT

A disturbance is propagated in a single direction, the wa[ves] are then represented by plane waves and its corresponding wave fronts are plane wave front.



e.g light from Sun reaches the earth with plane wave front.

HUYGEN'S PRINCIPLE

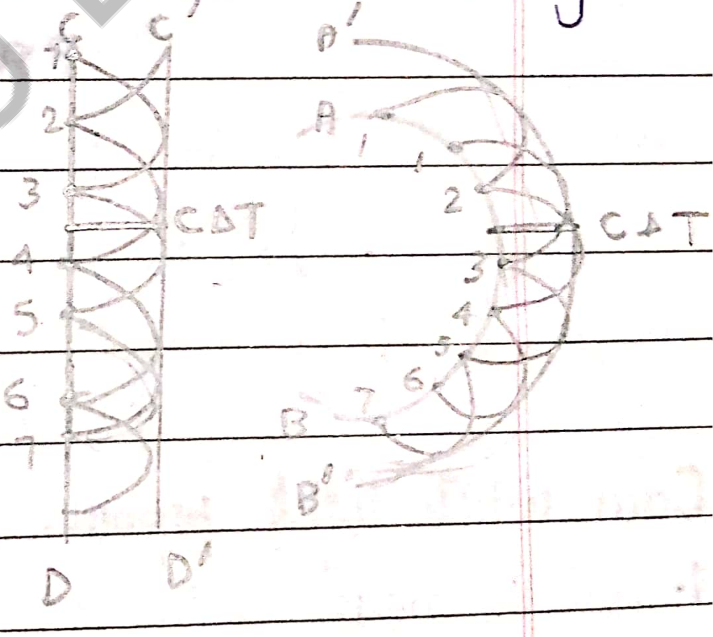
→ Tells about shape and location of wave front.

PART - 1

Every point of a wave front may be considered as a source of secondary wavelet which spreads out in a forward direction with a speed equal to speed of propagation of wave.

PART - 2

The new position of the wave front after time "$t + \Delta t$" can be found by drawing a plane tengential to all secondary wavelets.



1. At some time "t" wave front AB
2. At time $(t + \Delta t)$ wave front A'B'
3. Take points on wave front AB 1, 2, 3, ...
4. Draw spherical hemisphere of radius $(c\Delta t)$ at these points.
5. Draw a surface that touches all secondary wavelets.

CONSTRUCTIVE INTERFERENCE	DESRUCTIVE INTERFERENCE
2 sets of coherent waves of light meet in phase and reinforce the effect of each other	2 sets of waves meet in opposite waves, they cancel the effect of each other
FRINGE	
Bright fringe is observed	dark fringe is observed
PHASE DIFFERENCE	
Phase difference : $0, 2\pi, 4\pi$	Phase difference $\pi, 3\pi, 5\pi, \ldots$
PATH DIFFERENCE	
Path difference : $d = m\lambda$ $(m = 0, 1, 2, \ldots)$ $0, \lambda, 2\lambda, 3\lambda, \ldots$	Path difference : $d(m+\frac{1}{2})\lambda$ $(m = 0, 1, 2, \ldots)$ $\frac{\lambda}{2}, \frac{3\lambda}{2}, \frac{5\lambda}{2}, \ldots$

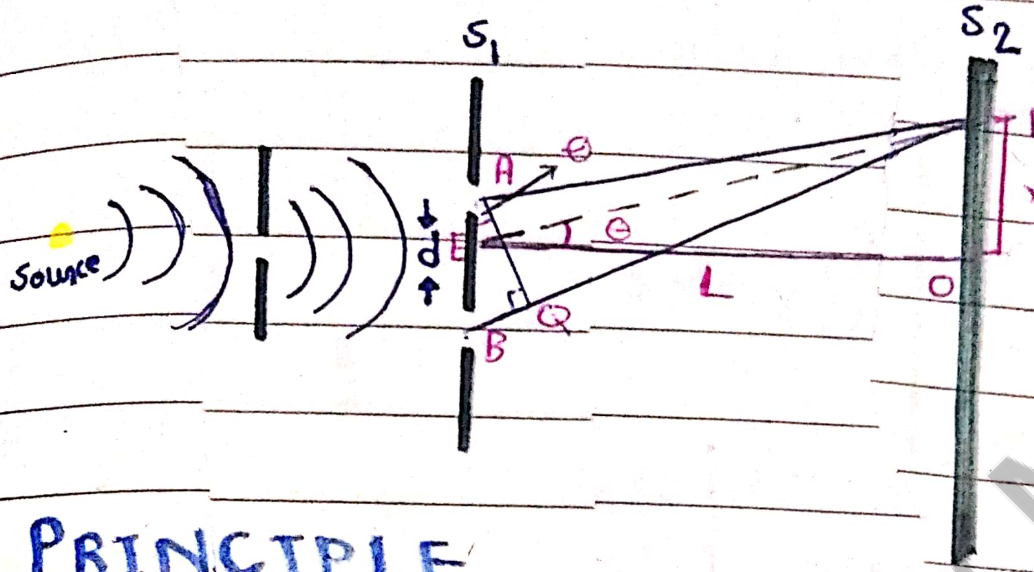
Can white light produce interference?

1. No it never interfere as it consists of seven different colors, it is not monochromatic

Acc to condition of interference light Ray must be monochromatic white light is multi chromatic

2. Yes, each every spectral color intefere separately depending on path difference.

YOUNG'S DOUBLE SLITS EXPERIMENT



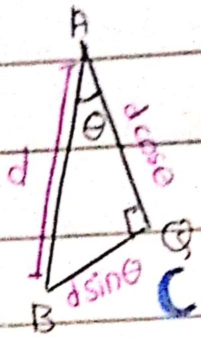
PRINCIPLE

The Principle for this experiment is based on the division of a wave front. To get phase coherent b/w interfering light source, Young used a trick and splitted the wave front of same **monochromatic light** into 2 parts and then allowed to interfere.

S = monochromatic source of light
S_1, S_2 = Screen parallel to each other
A, B = Slits at S_1
P = Point of observation at S_2
O = central point of C_2
OE = L = distance b/w S_1 and S_2
AP, BP = Paths of interfering beam.
d = separation b/w 2 slits.

$\overline{BQ}$ = path difference which is responsible for constructive or destructive interference

$AQ \perp BQ$ = such that $AP = QP$

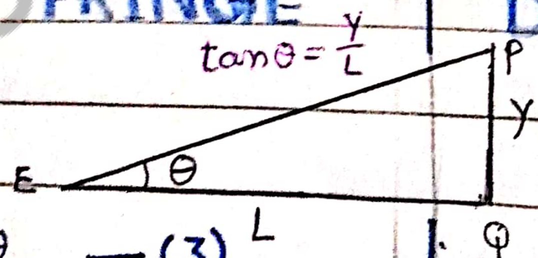


CONDITION

CONSTRUCTIVE INTERFERENCE	DESRUCTIVE INTERFERENCE
$\overline{BQ} = d\sin\theta$	$\overline{BQ} = d\sin\theta$
$\overline{BQ} = d\sin\theta = m\lambda$	$\overline{BQ} = d\sin\theta = \left[m+\frac{1}{2}\right]\lambda$
$\boxed{d\sin\theta = m\lambda}$ —— (1)	$\boxed{d\sin\theta = \left[m+\frac{1}{2}\right]\lambda}$ —— (2)
$m = 0, 1, 2, 3, \ldots$	$m = 0, 1, 2, 3, \ldots$
$1\lambda, 2\lambda, 3\lambda, \ldots$	$\frac{\lambda}{2}, \frac{3\lambda}{2}, \frac{5\lambda}{2}, \ldots$
Bright fringe is observed	dark fringe is observed

POSITIONS

BRIGHT FRINGE	DARK FRINGE



Bright fringe:

$Y = L\tan\theta$ —— (3)

Condition : $\tan\theta \approx \sin\theta$

$Y = L\sin\theta$ —— (4)

Using eq (1)

Dark fringe:

$Y = L\tan\theta$ —— (5)

condition: $\tan\theta \approx \sin\theta$

$Y = L\sin\theta$ —— (6)

using eq (2)

$$d \sin\theta = m\lambda$$
$$\sin\theta = \frac{m\lambda}{d}$$
Putting value of $\sin\theta$ in eq (4)
$$\boxed{Y = L\frac{m\lambda}{d}}$$

$$d\sin\theta = \left[m+\frac{1}{2}\right]\lambda$$
$$\sin\theta = \left[m+\frac{1}{2}\right]\frac{\lambda}{d}$$
Putting value of $\sin\theta$ in eq (6)
$$\boxed{Y = \left[m+\frac{1}{2}\right]\frac{\lambda L}{d}}$$

FRINGE SPACING

The distance b/w 2 consecutive bright or dark fringe is known as fringe spacing.

BRIGHT FRINGE

$$Y_m = \frac{m\lambda L}{d} \quad \text{--- (7)}$$

$$Y_{m+1} = \frac{(m+1)\lambda L}{d} \quad \text{--- (8)}$$

$$Y_{m+1} = \frac{mL\lambda}{d} + \frac{\lambda L}{d} \quad \text{--- (8)}$$

Subtract eq (7) from 8

$$Y_{m+1} - Y_m = \frac{m\lambda L}{d} + \frac{\lambda L}{d} - \frac{m\lambda L}{d}$$

$$\boxed{Y_{m+1} - Y_m = \frac{\lambda L}{d}}$$

DARK FRINGE

$$Y_m = \left[m+\frac{1}{2}\right]\frac{\lambda L}{d}$$

$$Y_m = \frac{m\lambda L}{d} + \frac{\lambda L}{2d} \quad \text{--- (9)}$$

$$Y_{m+1} = \left[m+1+\frac{1}{2}\right]\frac{\lambda L}{d} = \left[m+\frac{3}{2}\right]\frac{\lambda L}{d}$$

$$Y_{m+1} = \frac{m\lambda L}{d} + \frac{3}{2}\frac{\lambda L}{d} \quad \text{--- (10)}$$

Subtracting eq (9) from (10)

$$Y_{m+1} - Y_m = \frac{m\lambda L}{d} + \frac{3}{2}\frac{\lambda L}{d} - \frac{m\lambda L}{d} + \frac{\lambda L}{2d}$$

$$Y_{m+1} - Y_m = \frac{3\lambda L}{2d} + \frac{\lambda L}{2d}$$
$$= \frac{2\lambda L}{2d}$$

$$\boxed{Y_{m+1} - Y_m = \frac{\lambda L}{d}}$$

INTERFERENCE IN THIN FILM

PRINCIPLE Based on division of amplitude by using partial reflection and transmission at the boundary of 2 media.

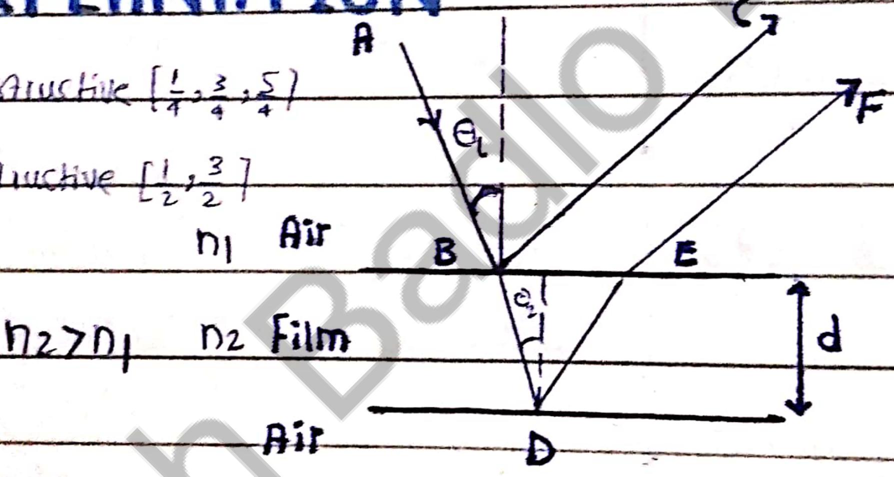
THIN FILM

A thin film is a transparent medium whose thickness is very small comparable with wavelen of light.

EXPLANATION

Constructive $[\frac{1}{4}, \frac{3}{4}, \frac{5}{4}]$

Destructive $[\frac{1}{2}, \frac{3}{2}]$



EF covering more path that is responsible for CI or DI

Consider a thin film of refracting medium.

1. A beam of AB of monochromatic light of wavelength λ is incident on its upper surface.
2. A part of AB will reflect as BC and partly refract into medium as BD
3. At D it is partly reflected as DE
4. At E it is refracted as EF

5. The Ray BC & EF being parts of same beam, will have phase coherence and superpose each other

6. As film is thin so separation b/w BC & EF is very small.

DEPENDENCE OF PATH DIFFERENCE

(1) angle of incidence
(2) thickness of the film
(3) refractive index of the medium.

CASE-1

If the 2 reflected waves reinforce each other then the film will look bright

CASE-2

If the thickness of the film and angle of incidence are such that the 2 reflected waves cancel each other, film will look dark.

LOWER → HIGHER (180°) When wave trave from medium

When a wave travels from a medium of lower refractive index to a medium of higher refractive index, it undergoes a phase change of 180° (π rad) after reflection.

HIGHER TO LOWER

There is no phase change in reflected waves if it travels from a medium of higher refractive index to lower refractive index.

INTERFERENCE OF WHITE LIGHT

CASE - I

If white light is incident on a film of irregular thickness at all possible angles, then interference pattern is observed due to each spectral color separately.

CASE - II

If thickness of film and angle of incidence such that destructive interference takes place from one color, then remaining color of light will appear on film. because different wave length ~~tern~~ reinforce at different places. As a Result, highly colored fringes are observed

MICHELSON'S INTERFEROMETER

Michelson's Interferometer is an optical instrument. It is used to study:

(1) Interference of light

(2) wave-length

PRINCIPLE Based on division of amplitude usually by partial reflection and transmission of light at the boundary of the 2 medium

APPARATUS

It consists of **(i)** 2 plane mirrors **(ii)** 2 glass plates.

M_1 = movable mirror

M_2 = fixed mirror

A = partial silvered plate to reflect & transmit beam of light

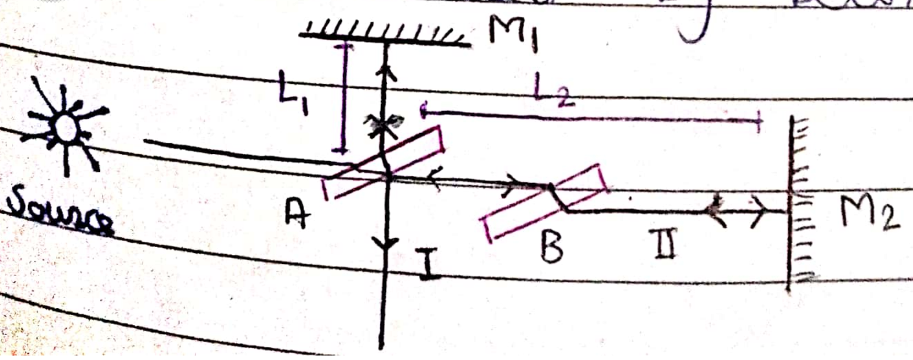
B = compensator plate to equalize the path length of beam 1 and beam 2

I = beam-1 moving toward M_1 after reflection

II = beam-2 moving toward M_2 after transmission

L_1 = distance travelled by beam I.

L_2 = distance travelled by beam II.



WORKING

1. A beam of monochromatic light from source S hits plate A
2. A part of it is reflected toward M_1 from where it is reflected back again toward A
3. After reflection from M_1, it is transmitted through plate A and enters their eye.
4. The other part of light is transmitted through it and move toward plate B from where it is again transmitted toward M_2
5. It will reflect and reaches A through trans-mission from B
6. It is reflected from A and enters the eye.

CONDITIONS FOR CONSTRUCTIVE INTERFERENCE

If path difference is either zero or integral multiple of wavelength

$d = m\lambda$

$m = 0, 1, 2, \ldots$

Brightness will be observed

CONDITIONS FOR DESTRUCTIVE INTERFERENCE

If path difference is odd integral multiple of half wave length

$d = \left[m + \frac{1}{2}\right]\lambda$

$m = 0, 1, 2, \ldots$

Darkness will be observed.

ALTERNATE BRIGHT & DARK FRINGE

CASE -1

If M_1 is moved through a distance $\frac{\lambda}{4}$ backward

Path difference $= \left[\frac{\lambda}{4}\right]_i + \left[\frac{\lambda}{4}\right]_r$

$$\boxed{d = \frac{\lambda}{2}}$$

RESULT Dark fringe will be observed

CASE -2

If M_1 is moved through a distance $\frac{\lambda}{2}$

Path difference $= \left[\frac{\lambda}{2}\right]_i + \left[\frac{\lambda}{2}\right]_r$

$$\boxed{d = \lambda}$$

RESULT Bright fring is observed.

WAVE LENGHT

When M_1 is moved backward through distance $\frac{\lambda}{4}$ each time, the total distance can be calculated as:

$$P = m\left[\frac{\lambda}{4} + \frac{\lambda}{4}\right]$$

$$P = \frac{m\lambda}{2}$$

$$\lambda = \frac{2P}{m}$$

m = No. of fringes.
P = Total distance

DIFFRACTION OF LIGHT

DEFINITION The property of bending light around obstacles and spreading of light into the region behind an obstacle is called diffraction

CONDITION

The diffraction of light can only be observed when the size of opening or obstacle is so small that it is comparalele with wavelength of light used

Size of obstacle ≈ wave length of light

λ < opening: low bending

$\lambda \geq$ opening: high bending

EXAMPLES

(1) When a beam of monochromatic light passes through a narrow slit

(2) When a knife edge is held up against monochromatic light source.

YOUNG DOUBLE SLIT EXPERIMENT AND DIFFRACTION

In Young Double slit experiment, the light from slit C simultaneously illuminates slits A & B. This is only possible if light bends around the corners of C and spreads out in the region b/w C and slits A & B.

FRAUNHOFER DIFFRACTION (Single Slit)

"The diffraction of light produced by narrow slit when plane light waves are incident normally (90°) on the slit and light waves emerging from the slit are also plane is called Fraunhofer diffraction"

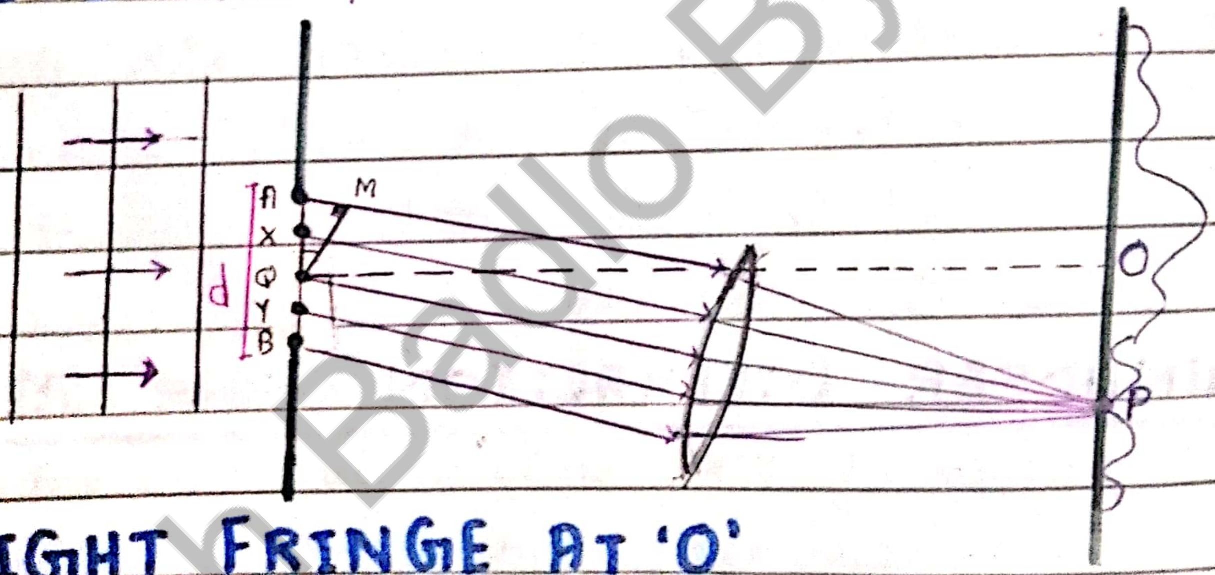
EXPLANATION

(1) Plane wavefronts are incident on a narrow slits AB

(2) Each point of wavefront acts as a source of secondary wavelet according to Huygen's Principle.

(3) Diffracted wave are focused by convex lens.
(4) Patterns are observed on photographic film.

AB = slit
X & Y = points on wave front
Q = central point of slit AB
O = perpendicular bisector on screen (AQ = BQ)
d = size of slit AB.



BRIGHT FRINGE AT 'O'

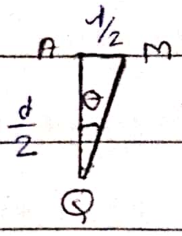
when the waves are coming from points A, B or X, Y, they are in phase $(\Delta\phi = 0)$ so bright fringe will appear at 'O'

DARK FRINGE AT 'P'

- Path difference b/w A & B at P = λ
- Path difference sent out by A & Q to point P = $\frac{\lambda}{2}$
- " " " " X & Y " " = $\lambda/2$
- " " " " Q & B " " = $\lambda/2$

CONCLUSION

At point 'P' wavelets will interfer destructively and dark fringe will be observed.



IN Δ AMQ

$$\sin\theta = \frac{AM}{AQ}$$

$$\sin\theta = \frac{\lambda/2}{d/2}$$

$$\frac{d}{2}\sin\theta = \frac{\lambda}{2} \implies d\sin\theta = \lambda$$

$$d\sin\theta = 2\lambda$$

$$\boxed{d\sin\theta = m\lambda}$$

$$\boxed{\sin\theta_m = \frac{m\lambda}{d}}$$

$m = 1, 2, 3, \ldots$

DIFFRACTION GRATING

1. A diffraction grating is a device that can a separate a beam of light into constituent colors.
2. It is glass or plastic plate 2-3cm in length and 2 to 3 mm in thickness, having large number of close parallel equidistant slits mechanically ruled on it.
3. The space b/w each scratch are transparent to light and act as separate slit.

PRINCIPLE

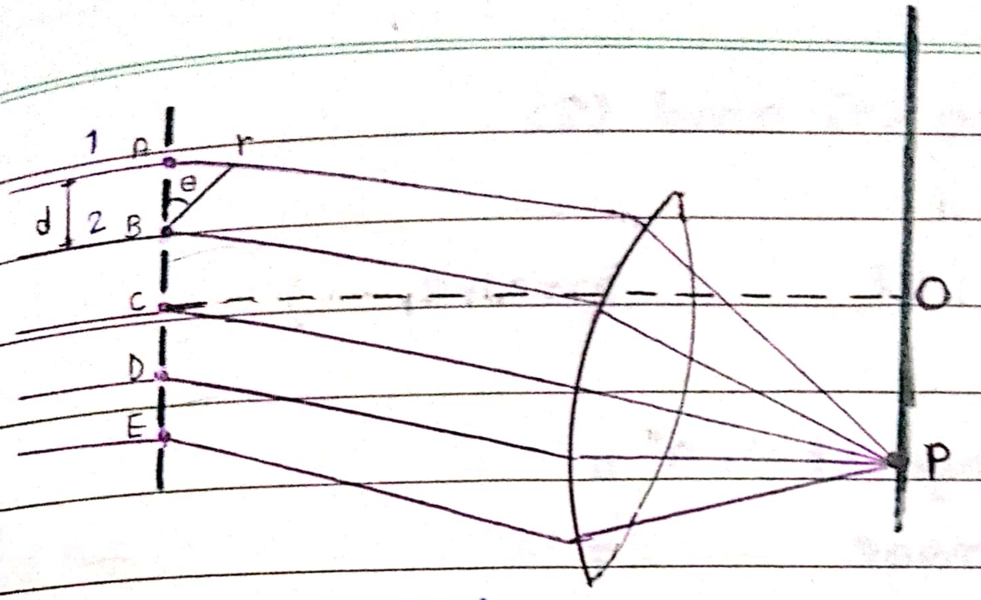
Based on interference and diffraction of light wave. The light waves after diffraction through grating are allowed to interfere.

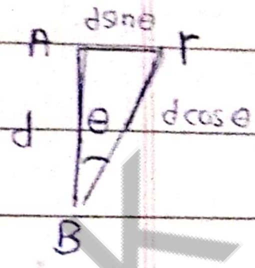
GRATING ELEMENT

The spacing d b/w 2 slits is called grating element.

$$d = \frac{\text{Unit length of grating}}{\text{Total No. of lines ruled on it}}$$

$$d = \frac{1cm}{N}$$





EXPLANATION

1. A parallel beam of monochromatic light falls on grating, all are in phase at slits
2. As the light rays are in phase, they reinforce each other, the result will be bright fringe
3. Parallel rays are then brought to focus on screen at P by convex lense after diffraction through grating.

RESULT

constructive interference occur and bright fringe is observed.

~~IN ΔABr~~

~~$\sin\theta = \frac{Ar}{AB}$~~

~~$\sin\theta = ds$~~

MATHEMATICALLY

Path difference b/w 1 & 2 = λ

So $\overline{Ar} = \lambda$ —— (1)

From ΔABr $\overline{Ar} = d\sin\theta$ —— (2)

Comparing eq (1) and (2)

$d \sin\theta = \lambda$

$d \sin\theta = m\lambda \quad (m = 0, 1, 2, \dots)$

$\because$

Zero order image at $\theta = 0° = 0\lambda$

1^{st} order image $d\sin\theta = 1\lambda$

2^{nd} order image $d\sin\theta = 2\lambda$

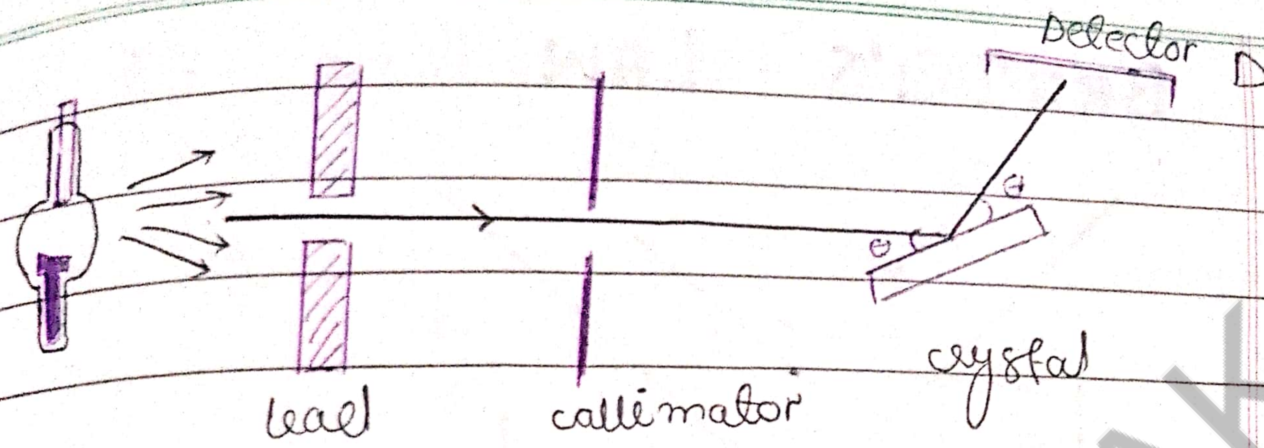
m^{th} order image $d\sin\theta = m\lambda$

DIFFRACTION OF X-RAYS BY CRYSTAL

X-RAY: X rays are electromagnetic waves of very short wavelength of the order of 10^{-10} m

1. Diffraction and interference phenomenon are used to study structure of crystal.

2. Spacing b/w layers of crystal are less then 1nm.



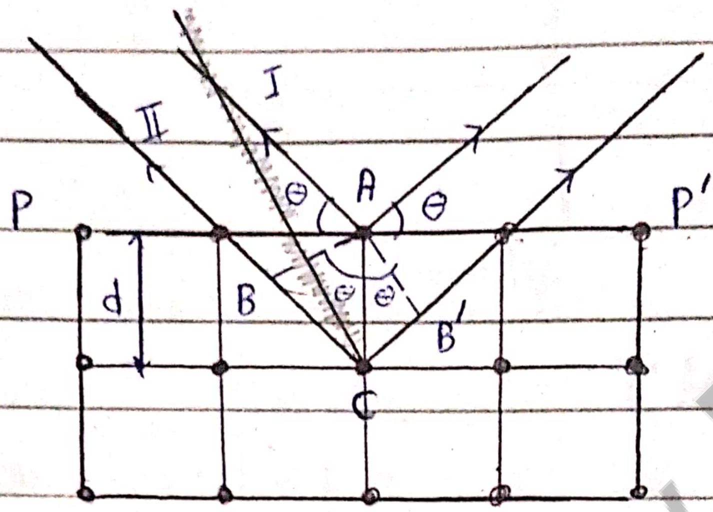
EXPERIMENT

1. A narrow beam of X-ray is collimated and falls on NaCl crystal.
2. The transmitted beam enters the detector D
3. The laue photograph obtained consists of central spot arrange in defined pattern. These spots are known as **laue spots**
4. Arrangement of laue spots for different crystals is different depending on their structure.

CONCLUSION

Such experiment proves that x-rays are electromagnetic waves and crystal atoms are 3- dimensionally arranged.

BRAGG'S LAW



I, II = 2 parallel rays
P, P' = layers of crystal
d = separation b/w 2 layers
θ = complementary glancing angle to angle of inciden

- 2 Reflected rays from successive planes will reinforce each other **if** path difference b/w them is integral multiple of wavelength.
- Ray II covers larger distance than ray-I

PATH DIFFERENCE B/W 2 RAYS

$$BC + CB' = m\lambda$$

$$d\sin\theta + d\sin\theta = m\lambda$$

$$\boxed{2d\sin\theta = m\lambda}$$

USES OF X-ray DIFFRACTION

1. It is used to determine interplanar spacing b/w smaller ∥ planes of crystal.

$$d = \frac{m\lambda}{2\sin\theta}$$

2. It is used in determining the structure of DNA and haemoglobin.

POLARIZATION OF LIGHT

"Polarization is the ~~property~~ process by which Electric and magnetic vibrations of light waves are restricted to single plane of vibration."

* Polarization is the property exhibited by transverse waves only.

BREWSTER'S LAW
[POLARIZATION BY REFLECTION]

SNELL'S LAW

$$n_1 \sin i_p = n_2 \sin r$$

$$i_p + r + 90 = 180$$

$r = 90^\circ - i_p$

$n_1 \sin i_p = n_2 \sin r$

$n_1 \sin i_p = n_2 \sin (90 - i_p)$ ——— (1)

$\sin (\alpha - \beta) = \sin\alpha \cos\beta - \cos\alpha \sin\beta$

$\sin (90 - i_p) = \sin 90 \cos i_p - \cos 90^\circ \sin i_p$

$\sin (90 - i_p) = \sin 90 \cos i_p$

$\sin (90 - i_p) = (1) \cos i_p$

$\sin (90 - i_p) = \cos i_p$

putting in eq (1)

$n_1 \sin i_p = n_2 \cos i_p$

$$\frac{\sin i_p}{\cos i_p} = \frac{n_2}{n_1}$$

$$\tan i_p = \frac{n_2}{n_1}$$

R If $n = 1.55$

then $i_p = 57^\circ$