✡ Wave Optics — Manoj Kumar [9013656741]

#CBSE Syllabus →

1) Wavefront and Huygen Principle

2) Reflection & Refraction of Plane Wave at a plane surface using wave fronts.

V.Imp.* 3) Proof of laws of reflection & refraction using Huygen's Principle.

4) Interference

V.V.Imp.**5) Young's double slit Experiment and Expression for fringe width.

6) Coherent sources and sustained interference of light

Imp. 7) Diffraction due to a single slit

8) Width of Central Maximum

9) Resolving power of Microscope and Astronomical telescope

10) Polarisation

11) Plane Polarised light

Imp. 12) Brewster's law

13) Use of plane polarised light and Polaroids.

✡ Nature of Light

① Ray.

(Macro)

Explaination of Phenomenon ⇒ DR². S
- b) Reflection
- c) Refraction
- d) Scattering
- a) Dispersion

↳ &* Light is a Kid.
  ↳ Travels in a Straight Path. [Rectilinear Motion]
  ↳

② Wave

(Micro)

Explaination of Phenomenon ⇒ (D) I P
- b) Interference
- a) Diffraction
- c) Polarisation.

& * Light learns how to bend as it grows up!
  * Take a DIP in microscopic physics.

③ Quanta

Explaination of Phenomenon ⇒
- a) Photo-Electric Effect
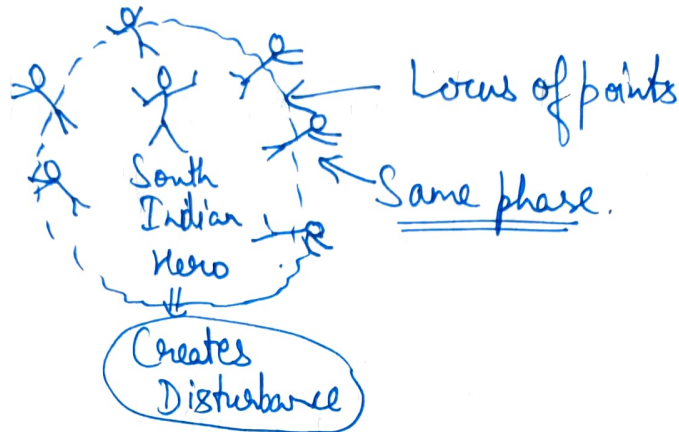- b) Compton Effect
- c) Raman Effect, etc.

* Light got Power

✡ Note:- Ultimately De-Broglie gave a __Dual Nature__ theory.

जैसा देश वैसा भेष

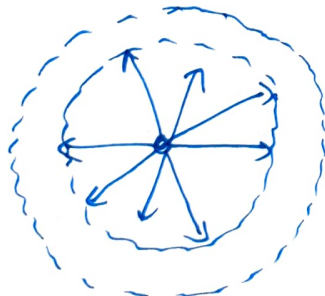1) **Wavefront** : A locus of points, which oscillate in phase.
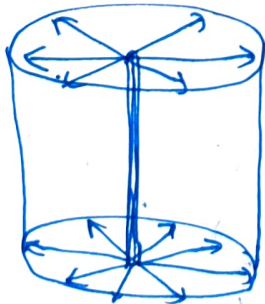
\# **Note** :a) Locus → Location

b)

Locus of points

Same phase.

South Indian Hero

Creates Disturbance

\# **Types of Wavefront** ← depend upon the source of disturbance

1) **Spherical Wavefront** → (Point Source)

2) **Cylindrical Wavefront** → (Slit or Extended Object)
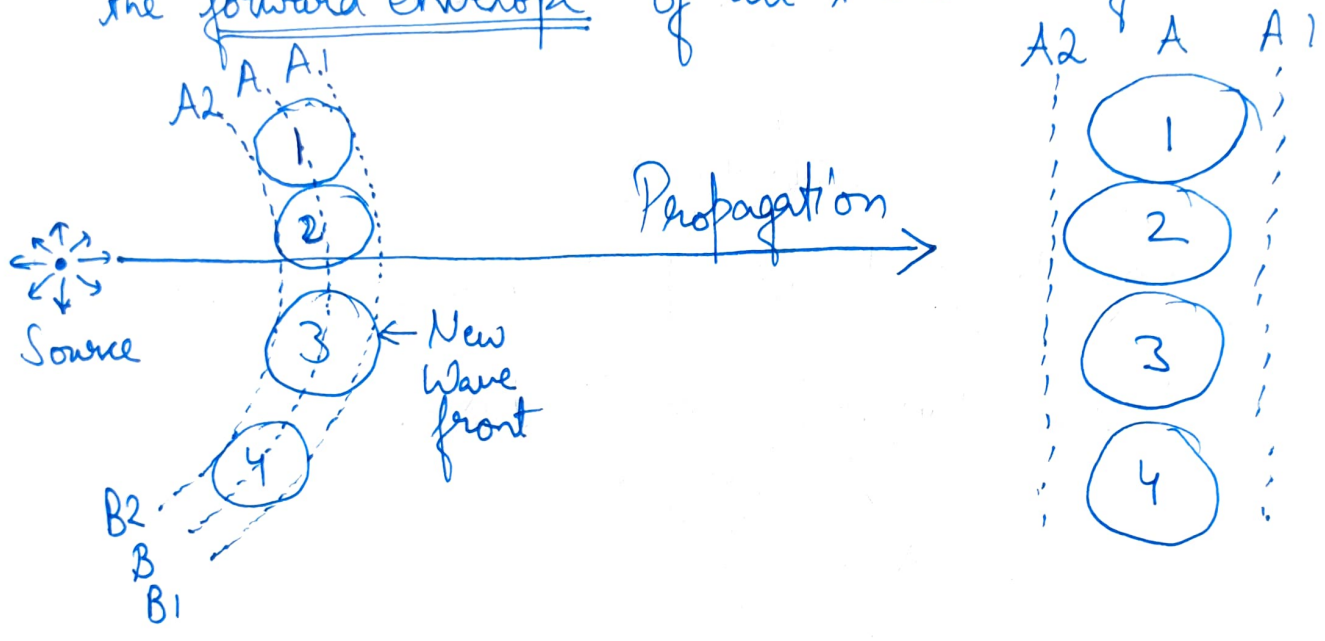

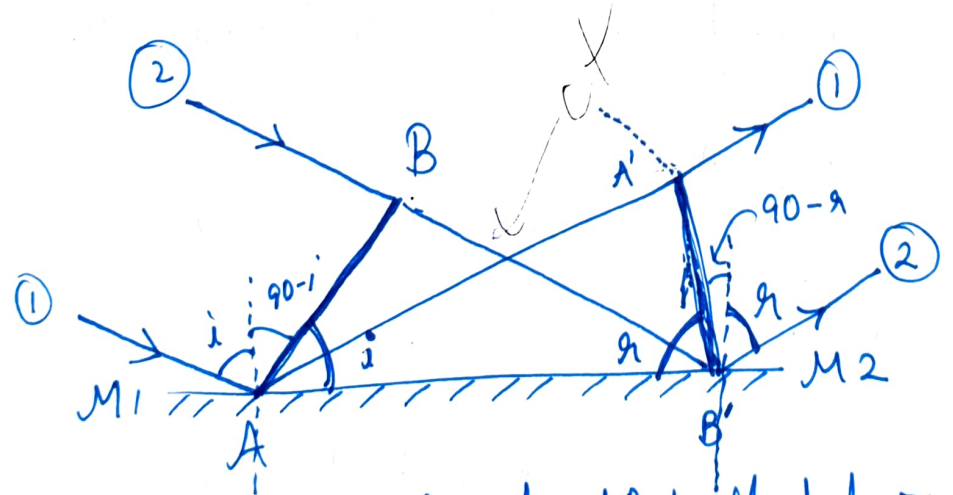3) **Plane Wavefront** ⇒ (Objects kept at Infinite) → including above 2

☆ Huygen Principle :

1) Every point on the given wavefront ($1°$) acts as a __fresh source__ of new disturbance for $2°$ wavefront.

2) The new wavefront at any time is obtained by taking the __forward envelope__ of all the secondary wavelets.

Source → Propagation →

New Wave front

☆ Laws of Reflection ☆

Consider, a plane wavefront AB incidented on plane mirror $M_1 M_2$.
Acc. to huygen principle, every point acts as a fresh source.

∴ B strikes the mirror at B' after t-second

$$\text{distance } BB' = ct \qquad [\because d = Speed \times time]$$

Similarly A reach A' after t-second.

Prove $\rightarrow \triangle ABB' \cong \triangle B'A'A$ [RHS]

$90°$ (AB') $\rightarrow$ AA' & BB'
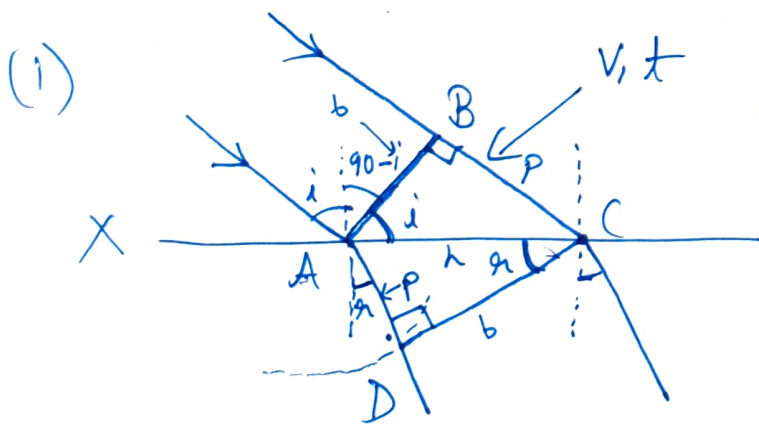
$\therefore \angle BAB' = \angle A'B'A$

$$\boxed{\angle i = \angle r} \leftarrow 1^{st} \text{ law of Reflection}$$

(ii) Second law of Reflection

MM' and AB are $\perp^{ar}$ to the plane of paper.

$\therefore$ AB, A'B' and Normal all lies in the same plane.

——— ✕ ——— ✕ ———

✡ Laws of Refraction ✡

(1)

$\leftarrow n_1$ (Rarer)

$$\boxed{n_2 > n_1}$$

$\leftarrow n_2$ Denser   Rarer

$V_1 \leftarrow$ Speed in medium ①

$V_2 \leftarrow$ Speed in medium ②

$BC = v_1 t$ —— ①

$AD = v_2 t$ —— ②

$$\frac{BC}{AD} = \frac{V_1}{V_2}$$

In $\triangle ABC$

$$\sin i = \frac{BC}{AC}$$

$$BC = \sin i \, AC — ③$$

In $\triangle ACD$

$$\sin r = \frac{AD}{AC}$$

$$AD = \sin r \, AC — ④$$

$$\frac{\sin i \, \cancel{AC}}{\sin r \, \cancel{AC}} = \frac{V_1}{V_2} \qquad \left[\because {}^1 n_2 = \frac{n_2}{n_1} = \frac{V_1}{V_2} \right]$$

$$\therefore \boxed{\frac{\sin i}{\sin r} = {}^1 n_2} \leftarrow \text{Snell's law}$$

(ii) AB, CD and Normal all lies in the same plane

— — — ✕ — — — ✕ — —

✡ Change in Nature of Wave front :-

a) Prism

Incident   B   C   Emergent

b) Lens

c) Mirror

Incident   Reflected
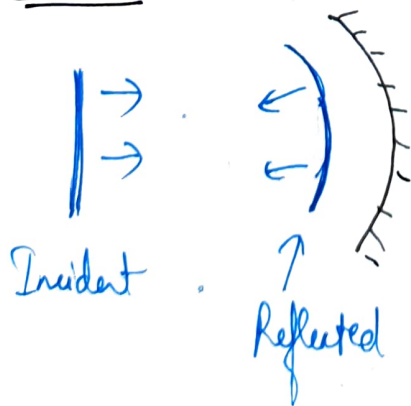
✪ Doppler's Effect – The apparent change in the frequency or wavelength of the light due to the relative motion between the source and observer.

Moves Towards

Freq. → Increase

λ → Decrease

⇓

Blue Shift

$$f' = f\left(1 + \frac{V}{C}\right)$$

Moves Away

Freq → Decrease

λ → Increase

⇓

Red Shift

$$f' = f\left(1 - \frac{V}{C}\right)$$

✪ Coherent Sources → Source which emit continuous light waves of the a) same wavelength,

b) Same freq. and

c) Same phase or Constant phase difference.

(Conditions under which light source can be said coherent)

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✪ Conditions for Obtaining Two Coherent Sources of Light

1) Coherent sources of light should be obtained from a single source by some device.

because phase change in one is simultaneosly accompanied by the phase change in other.

[Sources] → a) Source → Image.

b) 2 Image (Virtual)

c) " (Real)

2) The two sources should give monochromatic light.
↳ because multi-chromatic light may create multi-fringes that becomes hazy.
* For Monochromatic ⇒ Sharp Fringes

3) The path difference between light waves from two sources should be small
↳ because large gap results in mixing at every point & results in uniform illumination.

✡ Methods of Producing Coherent Sources

1) By division of wavefront
   ↳ Point Source
   ↳ Ex: 1) Young's double Slit Experiment
         2) Lloyd's mirror experiment
         3) Fresnel's biprism experiment.
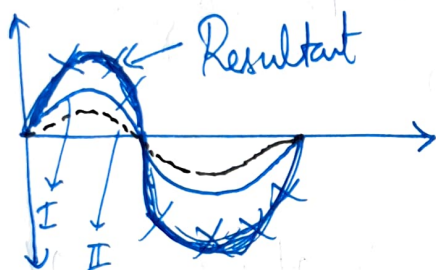
2) By division of Amplitude
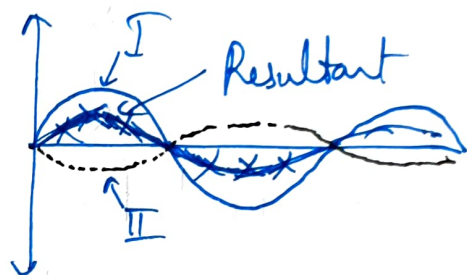   ↳ Extended Source
   ↳ Ex: 1) Michelson's Inferometer
         2) Newton's Ring.

✪ <u>Superposition Principle</u> – The resultant displacement of a particle at any instant is the <u>vector sum</u> of the <u>individual displacements</u> caused to the particle by the two or more waves.

a) Constructive Superposition

← Resultant

I

II

b) Destructive Superposition

I

← Resultant

II

✪ <u>Interference</u> – The phenomenon of redistribution of light energy in a medium on account of superposition of light waves from two coherent sources.

Example a) Color of Peacock. or other birds
b) Soap bubble Color.
c) Oil Color.

✪ <u>Relation b/w Phase Difference and Path difference :-</u>

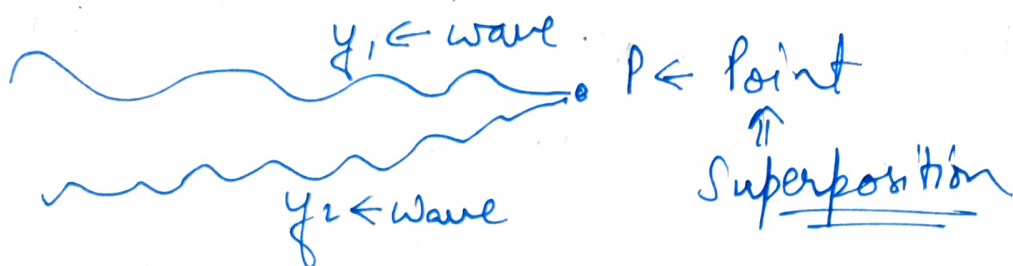If Path diff. = λ then Phase diff. = 2π

$$\boxed{\lambda = 2\pi}$$

∴ If Path diff = Δx then $\boxed{\Delta x = \dfrac{2\pi}{\lambda} \Delta x}$

ϕ due to

$$\boxed{\text{Phase diff} = \dfrac{2\pi}{\lambda} \times \text{Path diff.}}$$

✡ Interference ← Redistribution of energy due to superposition.

y_1 ← wave.

P ← Point

y_2 ← wave

↑ Superposition

Let

$$y_1 = a \sin \omega t$$

$$y_2 = b \sin(\omega t + \phi)$$

Phase diff.

At point P

$$y_{net} = y_1 + y_2 = a \sin \omega t + b \sin(\omega t + \phi)$$

$$= a \sin \omega t + b(\sin \omega t \cos \phi + \cos \omega t \sin \phi)$$

$$= a \sin \omega t + b \sin \omega t \cos \phi + b \cos \omega t \sin \phi$$

$$y_{net} = \sin \omega t \underbrace{(a + b \cos \phi)}_{\Downarrow} + \underbrace{b \cos \omega t \sin \phi}$$

$$R \cos \theta \qquad\qquad R \sin \theta$$

Put

$$a + b \cos \phi = R \cos \theta \quad\text{——①}$$

$$b \sin \phi = R \sin \theta \quad\text{——②}$$

$$y_{net} = R \sin \omega t \cos \theta + R \cos \omega t \sin \theta$$

$$\boxed{y_{net} = R \sin(\omega t + \theta)}$$

Amplitude   Phase diff.

Amplitude of Resultant Wave = ⓡ

Since $\quad a + b\cos\phi = R\cos\theta \quad$ — ①
$\qquad\qquad b\sin\phi = R\sin\theta \quad$ — ②

Squaring & Adding eq. ① & ②, we get :

$$(a + b\cos\phi)^2 + (b\sin\phi)^2 = R^2(\cos^2\theta + \sin^2\theta)$$

$$a^2 + \underline{b^2\cos\phi} + 2ab\cos\phi + \underline{b^2\sin^2\phi} = R^2 \times 1$$

$$a^2 + 2ab\cos\phi + b^2(\sin^2\phi + \cos^2\phi) = R^2$$

$$a^2 + 2ab\cos\phi + b^2 = R^2$$

Amplitude $\quad \boxed{R = \sqrt{a^2 + b^2 + 2ab\cos\phi}}$

Maxima

[Constructive Interference]

Minima.

[Destructive Interference]

Intensity $\propto$ (Amplitude)^2

$$I_R \propto R^2$$

$$I_R = KR^2 = K(a^2 + b^2 + 2ab\cos\phi)$$

$I_a \propto a^2 \qquad\qquad I_b \propto b^2$

$I_a = Ka^2 \qquad\qquad b^2 = \dfrac{I_b}{K}$

$a^2 = \dfrac{I_a}{K}$
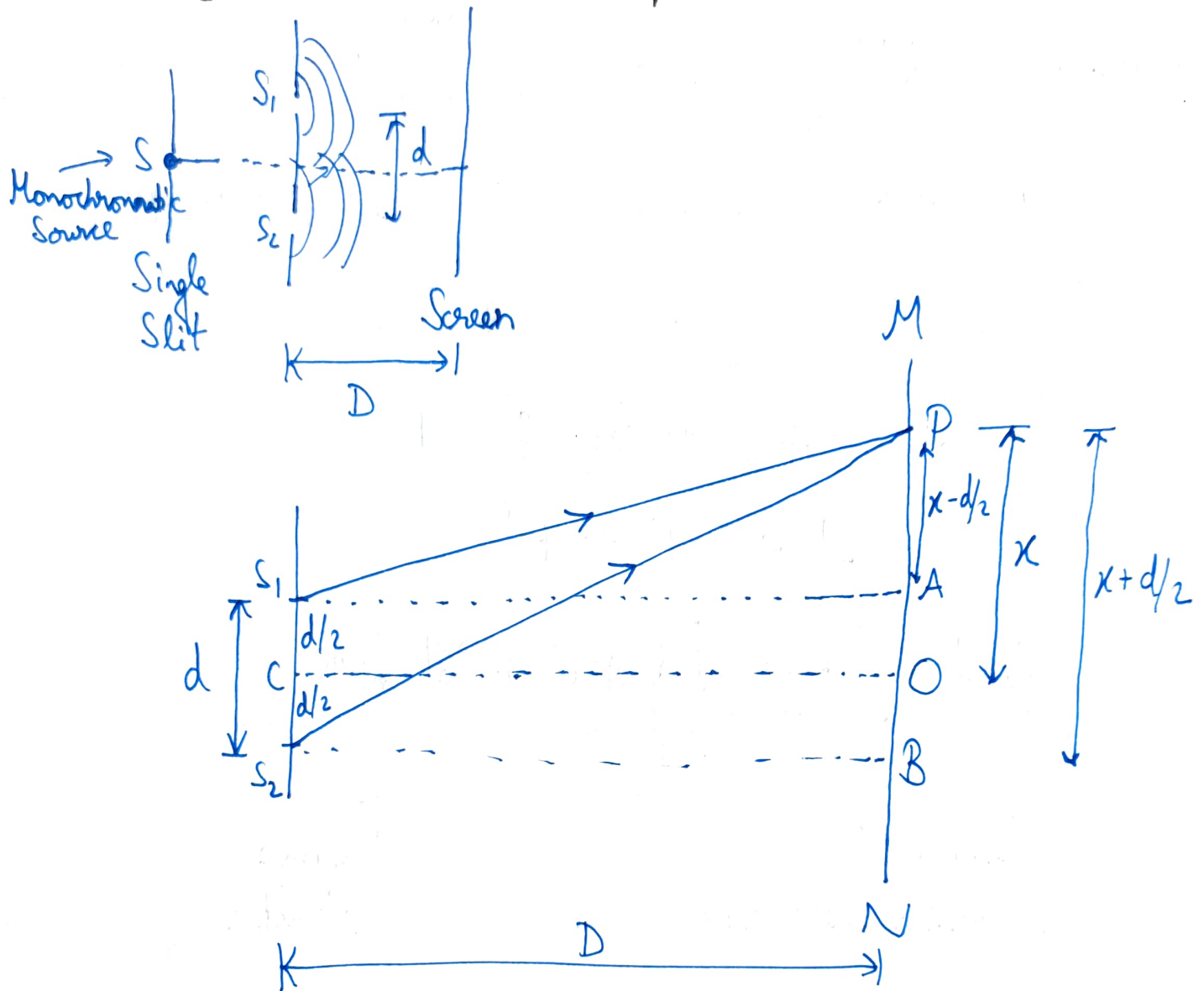
$\therefore \boxed{I_R = I_a + I_b + 2\sqrt{I_a I_b}\cos\phi}$

→ Max^m $\cos\phi = 1$

→ Min^m $\cos\phi = -1$

✡ Young's Double Slit Experiment :-

Let S_1 and S_2 are two coherent sources separated
by distance 'd' and generated from single
monochromatic source 'S'

Distance b/w Source and Screen = D

where $\boxed{D >> d}$

$$\boxed{\text{Path difference} = S_2P - S_1P}$$

In $\triangle S_1 AP$

Pythagoras theorem

$$S_1P^2 = AP^2 + AS_1^2$$
$$S_1P^2 = \left(x - \frac{d}{2}\right)^2 + D^2 \quad \textcircled{1}$$

In $\triangle S_2 BP$

Pythagoras theorem

$$S_2P^2 = BP^2 + BS_2^2$$
$$S_2P^2 = \left(x + \frac{d}{2}\right)^2 + D^2 \quad \textcircled{2}$$

$$S_2P^2 - S_1P^2 = \left(x + \frac{d}{2}\right)^2 + D^2 - \left(x - \frac{d}{2}\right)^2 - D^2$$

$$= x^2 + \left(\frac{d}{2}\right)^2 + 2 \cdot x \cdot \frac{d}{2} - \left(x^2 + \left(\frac{d}{2}\right)^2 - 2x \cdot \frac{d}{2}\right)$$

$$= x^2 + \left(\frac{d}{2}\right)^2 + 2 \cdot x \cdot \frac{d}{2} - x^2 - \left(\frac{d}{2}\right)^2 + 2 \cdot x \cdot \frac{d}{2}$$

$$= xd + xd$$

$$S_2P^2 - S_1P^2 = 2xd$$

$$(S_2P - S_1P)(S_2P + S_1P) = 2xd$$

$$\boxed{S_2P - S_1P = \text{Path diff.} = \frac{2xd}{S_2P + S_1P}}$$

Let $S_2P \approx S_1P = D$

$$\text{Path diff} = \frac{2xd}{2D} = \frac{xd}{D}$$

$$\boxed{S_2 - P_1 = \text{Path diff} = \frac{xd}{D}}$$

For Constructive Interference

$$\text{Path diff} = n\lambda \quad \text{where } n = 0, 1, 2, 3 \text{ ---}$$

$$\frac{xd}{D} = n\lambda$$

$$\boxed{x = \frac{nD\lambda}{d}}$$

For Destructive Interference

$$\text{Path diff} = (2n-1)\frac{\lambda}{2} \quad \text{where } n = 1, 2, 3 \text{ ---}$$

$$\boxed{n \neq 0} \leftarrow \text{Remember}$$

$$\frac{xd}{D} = (2n-1)\frac{\lambda}{2}$$

$$\boxed{x = \frac{(2n-1)D\lambda}{2d}}$$

Fringe Width ← The distance b/w two successive maxima or minima.

$$\text{Fringe width } (\beta) = X_{n+1} - X_n$$

$$\text{For Bright} = \frac{(n+1)D\lambda}{d} - \frac{nD\lambda}{d}$$

$$\boxed{\beta = \frac{D\lambda}{d}}$$

✡ **Conditions for Sustained Interference / Fringe Width.**

① Sources must be coherent
②   "   "   "   monochromatic
③   "   "   "   same amplitude
④ $\boxed{D \gg d}$

Q. If monochromatic source is replaced by white light?

Ans. ↳ Fringes ⇒ Colored, Dull and Varying Width

       → Pattern may appear at Centre point only with white and surrounded by blue & red.

       ↳ After few fringes no pattern.

Q. What if whole apparatus is immersed in water?

Ans. Wavelength (λ) of Source changes.

$$\boxed{\lambda' = \frac{\lambda}{\mu_w}} \leftarrow > 1$$

$$\boxed{\lambda' < \lambda}$$

Fringe width will decrease ($\because \beta \propto \lambda$)

✡ Solve NCERT Example 10.3 & 10.4
       Exercise — 10.4, 10.5, 10.6 and 10.7

✡ <u>Diffraction</u>: The Bending of light around the corners of an obstacle into the region of geometrical shadow of obstacle.

Example : a) Color of CD
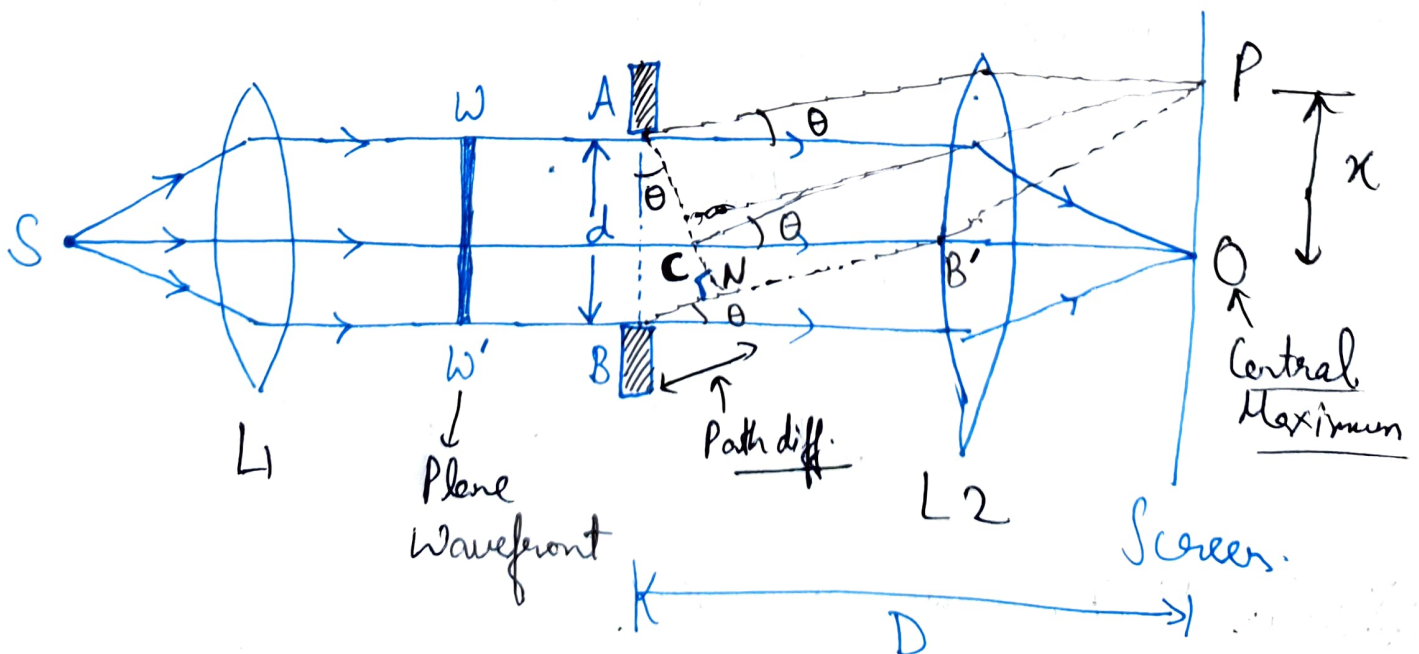 b) Luminous Border around clouds, mountain etc.

<u>Types of Diffraction</u>

1) <u>Fresnel</u>

• Source & Screen are at FINITE distance
 ↓
• No use of lens

2) <u>Fraunhoffer</u>

• Source & Screen are at INFINITE distance
 ↓
• Use of Convex lens

✡ <u>Diffraction at a Single Slit</u>

Consider, S → Diverging Source

L₁ → Convex lens that makes the light source parallel

WW' → Plane Wavefront

A & B → Obstacle that generate new disturbance as per Huygen's Principle

L₂ → Convex lens that converge the light on Screen.

Path difference = BN

In $\triangle ABN$

$$\sin \theta = \frac{BN}{AB}$$

$$BN = AB \sin \theta$$

Path diff. ⇒ $\boxed{BN = d \sin \theta}$

For Minima (Destructive)

Path diff = $n \lambda$ where $n = 1, 2, 3 \ldots$

$$d \sin \theta = n \lambda$$

If θ → Small

$$d \theta = n \lambda$$

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

For Maxima (Constructive)

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

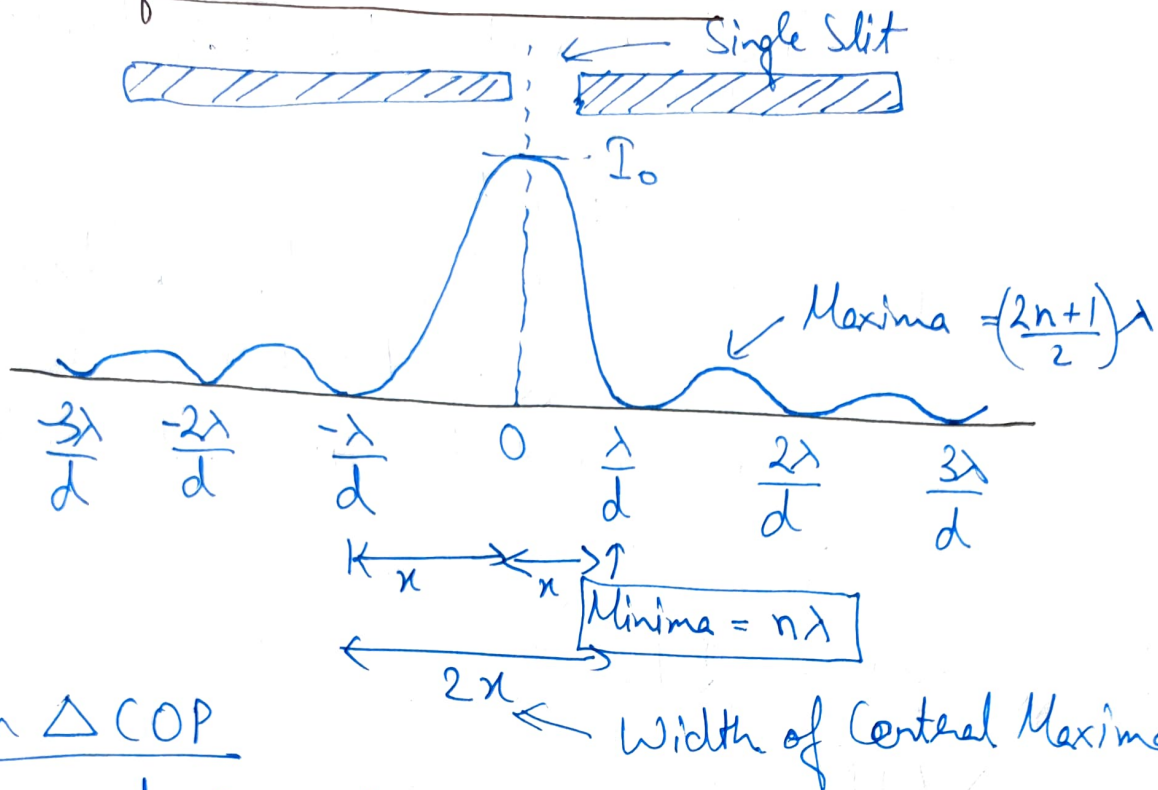$$d \sin \theta = (2n+1) \frac{\lambda}{2}$$

If θ → Small

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

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

Width of Central Maximum :-

$\text{Maxima} = \left(\frac{2n+1}{2}\right)\lambda$

$\text{Minima} = n\lambda$

$2x \leftarrow$ Width of Central Maxima.

In $\triangle COP$

$$\tan\theta = \frac{OP}{OC} = \frac{x}{D}$$

If $\theta \rightarrow$ Small

$$\therefore \tan\theta = \sin\theta = \frac{x}{D} \quad\quad\text{————}\quad ①$$

1st Minima $\Rightarrow \lambda d$

$d\sin\theta = \lambda$

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

$$\frac{x}{D} = \frac{\lambda}{d} \quad\quad \text{From eq. } ①$$

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

Width of Central Maximum $= 2x = \dfrac{2\lambda D}{d}$

✡ **Resolving Power** ← The ability of an optical instrument to form distinctly separate images of the two closely placed points or objects is called resolving power.

✡ **Limit of Resolution** ← The minimum distance of separation (θ) between two points so that they can be seen as separate by the optical instrument

$$\boxed{\text{Resolving Power} \propto \frac{1}{\text{Limit of Resolution}}}$$

1) Resolving Power of Eye $= \dfrac{D}{1.22\lambda}$

2) " " " Telescope $= \dfrac{D}{1.22\lambda}$

3) " " " Microscope $= \dfrac{\cancel{D}\,2n\,\sin\beta}{1.22\lambda}$

where β ← Semi Angle b/w Lens & Object.

n ← Refractive Index

✡ Interference

1) It is due to superposition of two **wavefronts** originating from **two coherent sources**.

2) Fringe width are equal

3) Bands are equally spaced

4) Bands are large in number

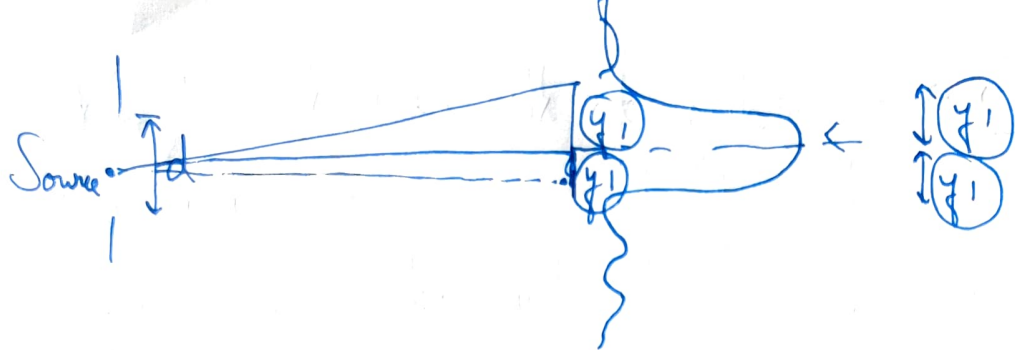5) All maxima are of same intensity

6) Dark bands are perfectly dark.

✡ Diffraction

1) It is due to superposition of **two secondary wavelets** originating from **same wavefront**

2) Fringe width are unequal

3) Bands are unequally spaced

4) Bands are few in number.

5) All maxima are of varying intensity.

6) Dark bands are not perfectly dark

✡ Fresnel Distance → (Z_f) ← The distance of the screen from the slit when the spreading of light due to diffraction from the centre of the screen is equal to the size of the slit.

$$\boxed{\theta = \frac{\lambda}{d}}$$ ← For Minima

↳ Half Angular Width of Central Maxima

Source

$$y_1 = \frac{\lambda D}{d}$$

$$\text{If} \quad y_1 = d \quad \text{and} \quad D = Z_F$$

$$d = \frac{\lambda Z_F}{d}$$

$$\boxed{Z_F = \frac{d^2}{\lambda}} \quad \leftarrow \text{Fresnel distance.}$$

(i) Size of slit (d)
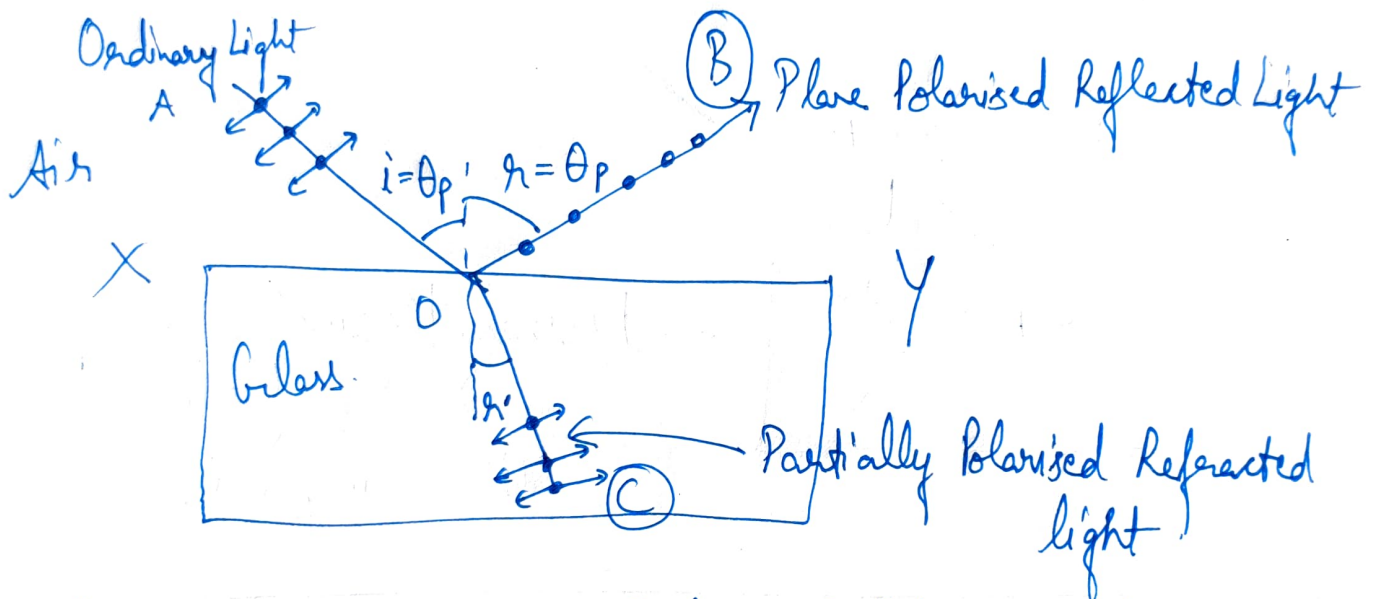(ii) Wavelength (λ)

✡ **Polarisation** → The phenomenon of restricting the vibrations of a light wave in a particular direction in a plane perpendicular to the direction of propagation of light.

Source   Polarizer   Polarised Light

← Only in Y axis

✡ **Polaroids** ← Device used to produce the plane polarised light.

✡ Brewster's Law →

According to this law, the refractive index of the refractive medium (μ) is numerically equal to the tangent of the angle of polarisation (θ_p)

Mathematically. $\boxed{\mu = \tan \theta_p}$

When $i = \theta_p$ then Reflected & Refracted light are mutually ⊥ar

$$\therefore \angle BOY + \angle COY = 90°$$
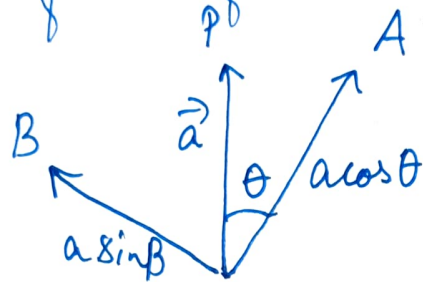
$$(90 - r) + (90 - r') = 90°$$

$$\boxed{r' = 90 - r}$$

$$r' = 90 - \theta_p \qquad [\because r = \theta_p]$$

$$\mu = \frac{\sin i}{\sin r'} = \frac{\sin \theta_p}{\sin(90 - \theta_p)}$$

$$\boxed{\mu = \frac{\sin \theta_p}{\cos \theta_p} = \tan \theta_p}$$

✡ <u>Malus Law</u> – When a beam of completely plane polarised light is incident on an analyser, the resultant intensity (I) varies directly as the square of the cosine of the angle (θ) between plane of transmission of analyser & polariser.

<u>Mathematically</u>

$$\boxed{I \propto \cos^2 \theta} \Rightarrow \boxed{I = I_0 \cos^2 \theta}$$

✡ <u>Note</u> : When unpolarized light of intensity I_0 gets polarised on passing through a polaroid, its intensity becomes half.

$$\boxed{I_{pol} = \frac{I_0}{2}} \leftarrow \text{Unpolarised}.$$

✡ <u>Detection of Polarised light</u>

1) If there is no change in intensity of emergent light, incident light is unpolarized.

2) If there is change in intensity of emergent light with min^m not equal to zero, the incident light is partially polarized.

3) If intensity of emergent light changes with min^m equal to zero the incident light is plane polarized.

____×____ ____×____