Wave Optics

Class 12 Physics · Chapter 10 · CBSE

Handwritten Notes · Sequence: NCERT + S.L. Arora

How to use these notes: Topics follow the NCERT order. Extra topics from S.L. Arora are added where they fit and marked [S.L. Arora]. Derivations and sample problems follow the reference theory material, written step by step. Boxed formulas are the ones to remember. Sections marked not in current CBSE syllabus are kept for JEE / NEET and S.L. Arora coverage. **20 CBSE-pattern questions** are at the end.

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1. Introduction — Theories of Light NCERT 10.1

→ **Newton's corpuscular theory:** light consists of tiny particles (corpuscles). It explains rectilinear propagation and reflection, but predicts that light travels **faster** in a denser medium — this was proved wrong.

→ **Huygens' wave theory (1678):** Christiaan Huygens proposed that **light is a wave**. It explains reflection, refraction, interference, diffraction, rectilinear propagation, and that light is **slower in a denser medium**.

→ Huygens' theory could **not** explain the photoelectric effect and polarisation (he assumed longitudinal waves in an "ether" medium — later proved wrong).

Wave optics studies the phenomena that depend on the wave nature of light — interference, diffraction and polarisation.

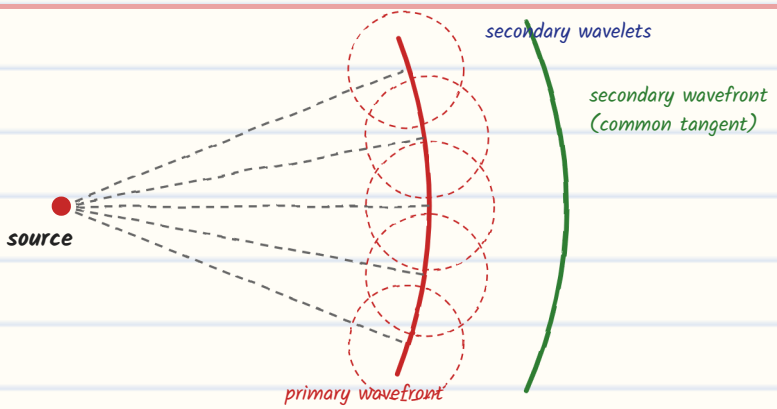
2. Wavefront & Huygens' Principle NCERT 10.2

Wavefront: the locus of all particles of the medium vibrating in the **same phase**. Light travels in the form of a wavefront; a ray is always perpendicular to the wavefront.

Huygens' principle

→ Every point on a wavefront acts as a source of **secondary wavelets**, which spread out in all directions with the speed of light in that medium.

→ The **common tangent (envelope)** to these secondary wavelets in the forward direction gives the new position of the wavefront.



Types of wavefront

⇒ **Spherical** (point source): $I \propto \frac{1}{\text{Area}} = \frac{1}{4\pi r^2} \Rightarrow I \propto \frac{1}{r^2}$; $I \propto A^2 \Rightarrow A \propto \frac{1}{r}$

⇒ **Cylindrical** (linear source / slit): $I \propto \frac{1}{2\pi rh} \Rightarrow I \propto \frac{1}{r}$; $I \propto A^2 \Rightarrow A \propto \frac{1}{\sqrt{r}}$

⇒ **Plane** (source at very large distance): area constant ⇒ **I = constant, A = constant**

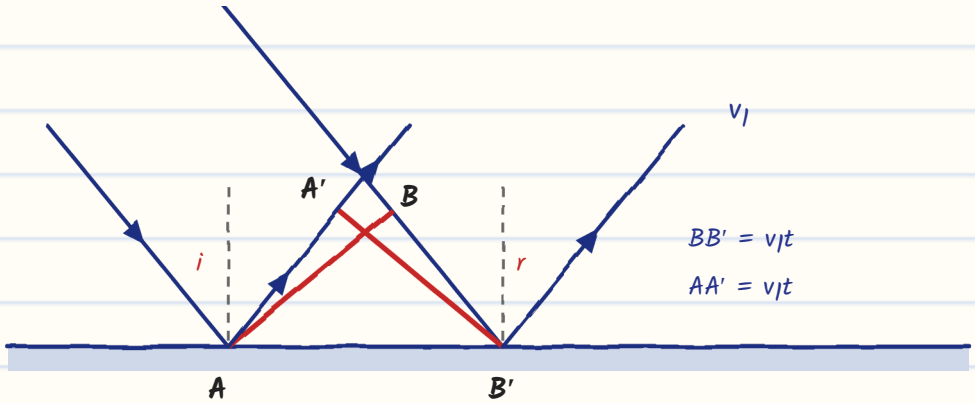
Sample problem: The amplitude of light at 10 m from a small bulb is A_0. Find the amplitude at 50 m.

Point source ⇒ $A \propto 1/r$: $A_1/A_2 = r_2/r_1 \Rightarrow A_0/A_2 = 50/10 \Rightarrow A_2 = A_0/5$

3. Reflection & Refraction using Huygens' Principle

NCERT 10.3

Law of reflection — derivation



Incident wavefront AB; reflected wavefront A′B′. Both travel in the same medium with speed v_1.

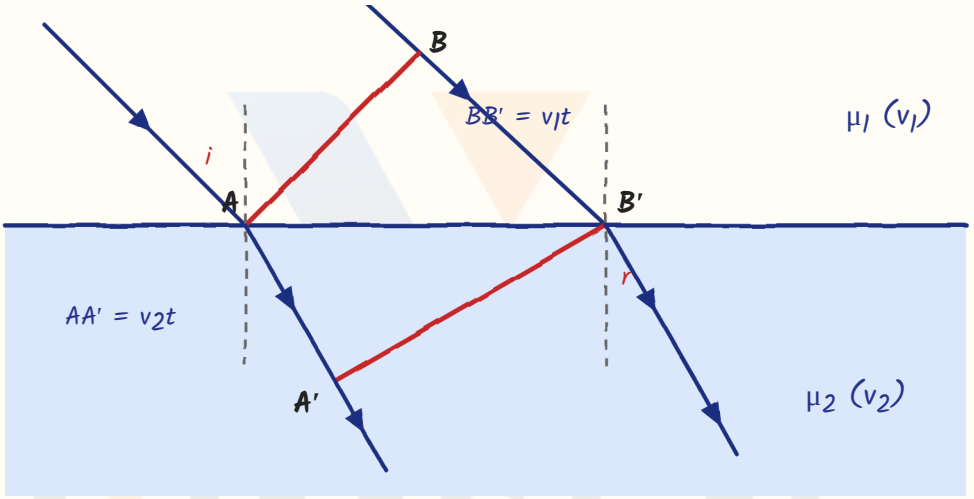
⇒ In time t, the wavelet from B reaches B′ and the wavelet from A spreads to radius AA′: $BB' = v_1 t$, $AA' = v_1 t \Rightarrow \mathbf{AA' = BB'}$

⇒ In $\Delta ABB'$: $\sin i = \frac{BB'}{AB'}$ … (i) In $\Delta B'A'A$: $\sin r = \frac{AA'}{AB'}$ … (ii)

⇒ Divide (i) by (ii): $\frac{\sin i}{\sin r} = \frac{BB'}{AA'} = 1$

$$\sin i = \sin r \Rightarrow i = r$$

Law of refraction (Snell's law) — derivation



⇒ In time t: $BB' = v_1 t$ (in medium 1) and $AA' = v_2 t$ (in medium 2). A′B′ is the refracted wavefront.

⇒ In $\Delta ABB'$: $\sin i = \frac{BB'}{AB'}$ … (i) In $\Delta AA'B'$: $\sin r = \frac{AA'}{AB'}$ … (ii)

⇒ Divide (i) by (ii): $\frac{\sin i}{\sin r} = \frac{BB'}{AA'} = \frac{v_1 t}{v_2 t} = \frac{v_1}{v_2} = \frac{\mu_2}{\mu_1}$

$$\mu_1 \sin i = \mu_2 \sin r$$

→ Frequency stays the same on refraction; speed and wavelength change: $\frac{v_1}{v_2} = \frac{\lambda_1}{\lambda_2}$.

4. Doppler Effect of Light NCERT 10.3 not in current CBSE syllabus

→ The apparent change in frequency (or wavelength) of light due to relative motion between source and observer.

→ Speed of light does not depend on the motion of source or observer, so only the **relative speed v** matters — Doppler effect of light is **symmetrical** (unlike sound).

	Approach (blue shift)	Recession (red shift)
Frequency	$f' = f\,\frac{(1+v/c)^{1/2}}{(1-v/c)^{1/2}}$	$f' = f\,\frac{(1-v/c)^{1/2}}{(1+v/c)^{1/2}}$
Wavelength	$\lambda' = \lambda\,\frac{(1-v/c)^{1/2}}{(1+v/c)^{1/2}}$	$\lambda' = \lambda\,\frac{(1+v/c)^{1/2}}{(1-v/c)^{1/2}}$

⇒ If $v \ll c$: $f' \approx f(1 \pm \frac{v}{c}) \Rightarrow f' - f = \pm \frac{vf}{c}$

$$\frac{\Delta f}{f} = \frac{v}{c} \qquad \frac{\Delta \lambda}{\lambda} = -\frac{v}{c} \quad (v = \text{radial speed})$$

→ **Approach**: frequency increases, λ decreases → blue shift. **Recession**: λ increases → red shift (shows galaxies are moving away).

Sample problem: A star emitting light of wavelength 5000 Å moves away from earth at 3×10^6 m/s. Find the Doppler shift in wavelength.

$\Delta\lambda = (v/c)\,\lambda = (3 \times 10^6/3 \times 10^8) \times 5000$ Å = **50 Å** (red shift)

5. Coherent & Incoherent Sources NCERT 10.4

Coherent sources: two sources that emit light waves of the **same frequency** with a **constant phase difference**. They are obtained from a single source.

Incoherent sources: sources whose phase difference changes with time. Two independent bulbs are incoherent — atoms emit light randomly, not in the same phase.

Methods of obtaining coherent sources

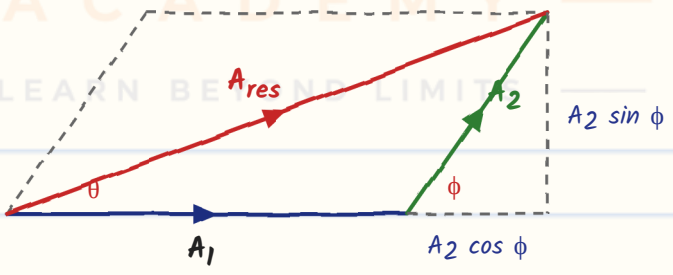
→ **Division of wavefront:** the wavefront is divided into two parts by slits, mirrors, lenses or prisms — e.g. Young's double slit, Fresnel's biprism, Lloyd's mirror.

→ **Division of amplitude:** the amplitude of the incoming beam is divided into two parts by partial reflection and refraction; the parts reunite and interfere — e.g. thin films (soap bubble, oil film).

6. Interference of Light NCERT 10.4

When waves from coherent sources moving in the same direction superpose, the energy gets **redistributed** in space — this is **interference**. Total energy remains constant (law of conservation of energy).

Mathematical analysis — resultant amplitude and intensity



⇒ Two waves of the same frequency and constant phase difference ϕ: $y_1 = A_1 \sin \omega t$, $y_2 = A_2 \sin(\omega t + \phi)$

⇒ Phase difference $\Delta\phi = (\omega t + \phi) - \omega t = \phi$. Adding as phasors (vectors at angle ϕ):

$$A_{res}^2 = A_1^2 + A_2^2 + 2A_1A_2\cos\Delta\phi \qquad \tan\theta = \frac{A_2\sin\phi}{A_1 + A_2\cos\phi}$$

⇒ Since $I \propto A^2$:

$$I = I_1 + I_2 + 2\sqrt{(I_1I_2)}\cos\Delta\phi$$

→ $2\sqrt{(I_1I_2)}\cos\Delta\phi$ is called the **interference term**.

Constructive interference	Destructive interference
$\Delta x = 0, \lambda, 2\lambda, \ldots n\lambda$	$\Delta x = \lambda/2, 3\lambda/2, \ldots (2n-1)\lambda/2$
$\Delta\phi = 0, 2\pi, 4\pi, \ldots 2n\pi$	$\Delta\phi = \pi, 3\pi, \ldots (2n-1)\pi$
$A_{max} = A_1 + A_2$	$A_{min} = A_1 \sim A_2$
$I_{max} = (\sqrt{I_1} + \sqrt{I_2})^2$	$I_{min} = (\sqrt{I_1} - \sqrt{I_2})^2$

Important results

→ $\frac{I_1}{I_2} = \frac{w_1}{w_2} = (\frac{A_1}{A_2})^2$ (intensity ∝ width of slit ∝ amplitude²)

→ $\frac{I_{max}}{I_{min}} = (\frac{\sqrt{I_1} + \sqrt{I_2}}{\sqrt{I_1} - \sqrt{I_2}})^2 = (\frac{A_1 + A_2}{A_1 - A_2})^2$

→ Average intensity $= \frac{I_{max} + I_{min}}{2} = I_1 + I_2$. Fringe visibility $V = \frac{I_{max} - I_{min}}{I_{max} + I_{min}}$ (100% when $I_1 = I_2$).

Equal intensities — derivation [S.L. Arora]

⇒ Put $I_1 = I_2 = I_0$: $I = I_0 + I_0 + 2\sqrt{(I_0I_0)}\cos\Delta\phi = 2I_0(1 + \cos\Delta\phi) = 2I_0 \cdot 2\cos^2(\Delta\phi/2)$

$$I = 4I_0\cos^2\left(\frac{\Delta\phi}{2}\right) \qquad I_{max} = 4I_0,\ I_{min} = 0$$

Conditions for sustained interference: (1) sources must be coherent; (2) separation between the sources should be small; (3) distance of the screen should be large; (4) amplitudes should be nearly equal for good contrast.

Sample problem 1: Two waves with intensities in the ratio 16 : 9 interfere. Find $I_{max} : I_{min}$.

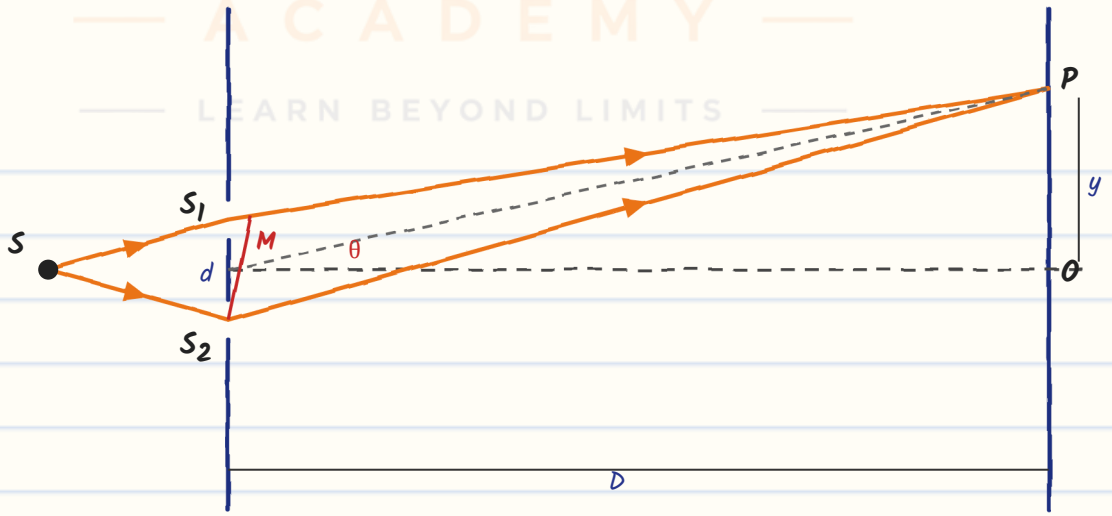
$I_{max}/I_{min} = [(\sqrt{16} + \sqrt{9})/(\sqrt{16} - \sqrt{9})]^2 = (7/1)^2 = \mathbf{49 : 1}$

Sample problem 2: Find the resultant amplitude of $y_1 = 6 \sin \omega t$ and $y_2 = 8 \cos \omega t$.

$y_2 = 8 \sin(\omega t + 90°) \Rightarrow \Delta\phi = 90°$. $A_{res} = \sqrt{(6^2 + 8^2 + 2 \cdot 6 \cdot 8 \cos 90°)} = \sqrt{100} = \mathbf{10}$

7. Young's Double Slit Experiment NCERT 10.5

YDSE proved that light is a wave. Coherent sources S_1 and S_2 are obtained by **division of wavefront**. At the centre O, path difference = 0 → **central maximum** (central bright fringe).



Path difference at point P — derivation

⇒ $\Delta x = SS_2P - SS_1P = S_2P - S_1P = (S_2M + MP) - S_1P$

⇒ Since $MP = S_1P$: $\Delta x = S_2M = d \sin\theta$

⇒ For small θ: $\sin\theta \approx \tan\theta = \frac{y}{D}$

$$\Delta x = \frac{yd}{D}$$

Bright fringe at P	Dark fringe at P
$\Delta x = n\lambda$	$\Delta x = (2n-1)\lambda/2$
$\frac{yd}{D} = n\lambda$	$\frac{yd}{D} = \frac{(2n-1)\lambda}{2}$
$y_{n\,(max)} = \frac{n\lambda D}{d}$	$y_{n\,(min)} = \frac{(2n-1)\lambda D}{2d}$

Fringe width (β)

Distance between two successive bright fringes or two successive dark fringes.

⇒ Bright: $\beta = y_{max\,2} - y_{max\,1} = \frac{2\lambda D}{d} - \frac{\lambda D}{d} = \frac{\lambda D}{d}$

⇒ Dark: $\beta = y_{min\,2} - y_{min\,1} = \frac{3\lambda D}{2d} - \frac{\lambda D}{2d} = \frac{\lambda D}{d}$

$$\beta = \frac{\lambda D}{d} \quad \text{(same for bright and dark fringes)}$$

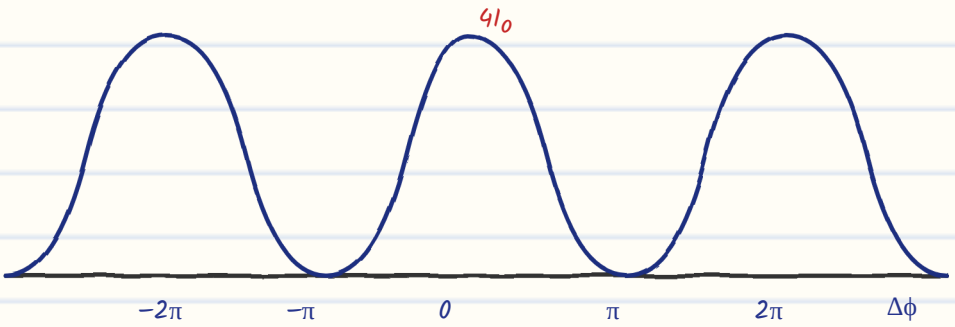
Angular fringe width (α)

⇒ Angle subtended by the fringe width at the plane of the slits: $\alpha = \frac{\beta}{D} = \frac{\lambda D}{dD}$

$$\alpha = \frac{\lambda}{d} \quad \text{(independent of D)}$$

→ In a medium of refractive index μ, λ becomes λ/μ, so β and α become 1/μ times.

Variation of intensity with phase difference



→ For equal slits $I = 4I_0 \cos^2(\Delta\phi/2)$: bright and dark fringes are equally spaced and of equal width.

Sample problem 1: Slits 1 mm apart are lit by 500 nm light; screen 2 m away. Find the fringe width and the position of the 3rd bright fringe.

$\beta = \lambda D/d = (5 \times 10^{-7} \times 2)/10^{-3} = 10^{-3}$ m = **1 mm**; $y_3 = 3\beta =$ **3 mm**

Sample problem 2: Fringe width is 0.2 mm. λ is increased by 10% and d is increased by 10%. Find the new fringe width.

$\beta' = (1.1\lambda)D/(1.1d) = \lambda D/d =$ **0.2 mm** (unchanged)

Sample problem 3: D = 1.5 m; with λ = 500 nm the 2nd bright fringe is 10 mm from the centre. Find its shift when λ = 550 nm.

$y \propto \lambda \Rightarrow y' = 10 \times 550/500 = 11$ mm. Shift = 11 − 10 = **1 mm**

8. Thin Film in Front of a Slit [S.L. Arora] not in current CBSE syllabus

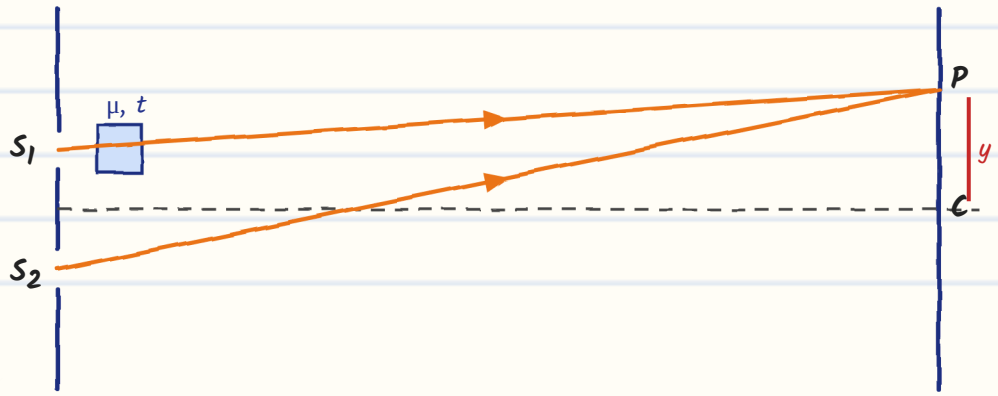
Optical path length

⇒ Time taken to cover distance x in medium μ: $t = \frac{x}{v} = \frac{\mu x}{c}$ $(v = c/\mu)$

⇒ Distance covered in vacuum in the same time: $d = c \times t = c \times \frac{\mu x}{c} \Rightarrow$ **optical path = μx**

→ A path x in a medium of refractive index μ is equivalent to a path μx in vacuum (same phase change).

Shift of central maximum — derivation



⇒ Film of thickness t, refractive index μ in front of S_1. Effective path $S_1P_{eff} = S_1P - t + \mu t$

⇒ $\Delta x = S_2P - S_1P_{eff} = S_2P - S_1P - (\mu - 1)t = d \sin\theta - (\mu - 1)t$

⇒ Small angle: $\Delta x = \frac{yd}{D} - (\mu - 1)t$

⇒ Central maximum at P ⇒ $\Delta x = 0$: $\frac{yd}{D} = (\mu - 1)t$

$$y_{cm} = \frac{(\mu - 1)tD}{d} \qquad \text{fringes crossed } n = \frac{y_{cm}}{\beta} = \frac{(\mu - 1)t}{\lambda}$$

→ Central maximum shifts towards the side of the film; the whole pattern shifts by the same amount. Fringe width does **not** change.

→ Films on both slits: $y_{cm} = \frac{[(\mu_2 - 1)t_2 - (\mu_1 - 1)t_1]D}{d}$ — shifts towards the side with larger $(\mu - 1)t$.

Sample problem 1: λ = 6000 Å, D = 2 m, d = 6 mm. A film of μ = 1.5 in front of the lower slit shifts the 4th maximum to the centre. Find t.

$4\beta = (\mu - 1)tD/d \Rightarrow 4\lambda D/d = 0.5tD/d \Rightarrow 4 \times 6 \times 10^{-7} = 0.5t \Rightarrow$ **t = 4.8 μm**

Sample problem 2: $\lambda = 400$ nm; a film of $\mu = 1.5$ and thickness 4 μm is placed in front of the upper slit. How many maxima cross the centre?

$n = (\mu - 1)t/\lambda = (0.5 \times 4 \times 10^{-6})/(4 \times 10^{-7}) = 5$

9. Effect of White Light in YDSE [S.L. Arora]

not in current CBSE syllabus

→ Patterns of different colours overlap. At the centre $\Delta x = 0$ for all colours ⇒ **central fringe is white**.

→ Where $S_2P - S_1P = \lambda_b/2$ (≈ 2000 Å) blue is absent → fringe looks **red**. A little farther, where $\Delta x = \lambda_r/2$, red is absent → fringe looks **blue**.

→ So the fringe closest to the white centre is red and the farthest is blue; after a few fringes no clear pattern is seen.

Missing wavelengths in front of a slit — derivation

⇒ Point P directly in front of S_1: $y = \frac{d}{2} \Rightarrow \Delta x = \frac{yd}{D} = \frac{d^2}{2D}$

⇒ Missing wavelength ⇒ minimum at P: $(2n-1)\frac{\lambda}{2} = \frac{d^2}{2D}$

$$\lambda = \frac{d^2}{(2n-1)D} = d^2/D,\ d^2/3D,\ d^2/5D \ldots$$

Sample problem: White light, $D = \frac{1}{3}$ m, $d = 1$ mm. Find the missing wavelengths in front of a slit.

$\lambda = (10^{-3})^2/[(2n-1)(1/3)] = 3000/(2n-1)$ nm

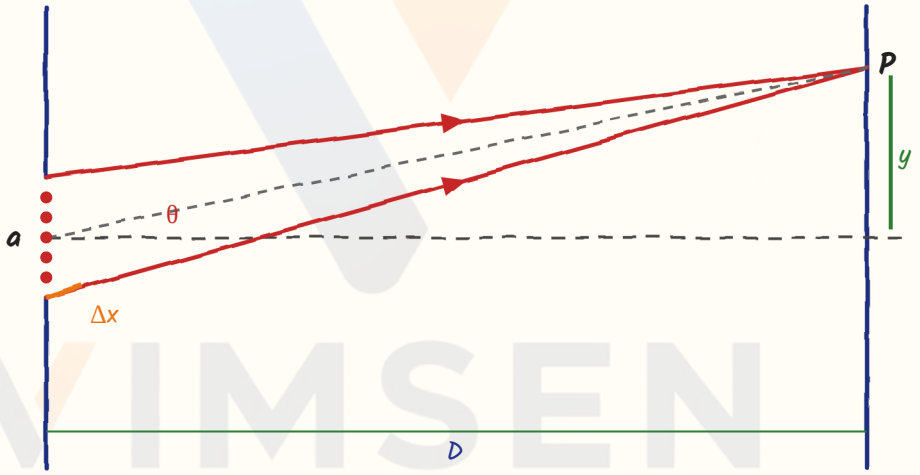
$n = 1$: 3000 nm, $n = 2$: 1000 nm (not visible); $n = 3$: **600 nm**; $n = 4$: **≈ 428 nm** → missing in the visible range.

10. Diffraction at a Single Slit NCERT 10.6

Diffraction: bending of light around the sharp edges of an obstacle or aperture and its spreading into the region of geometrical shadow. Discovered by **Grimaldi**.

→ **Condition:** size of the obstacle or aperture should be comparable to the wavelength. Light ($\lambda \sim 10^{-7}$ m) rarely shows diffraction in daily life; sound ($\lambda \approx$ 16 mm – 16 m) diffracts easily.

→ **Fresnel diffraction** — source and screen at finite distance. **Fraunhofer diffraction** — source and screen effectively at infinity (plane wavefront).



Path difference and positions of minima / maxima

⇒ Path difference between the extreme rays from the two edges of slit (width a): $\Delta x = a \sin\theta$

⇒ **1st minimum:** $\Delta x = \lambda$ ($\Delta\phi = 2\pi$) $\Rightarrow a \sin\theta = \lambda$. **2nd minimum:** $a \sin\theta = 2\lambda$ ($\Delta\phi = 4\pi$)

⇒ **n^{th} minimum:** $\Delta\phi = 2n\pi \Rightarrow a \sin\theta = n\lambda$. Small angle: $a \tan\theta = n\lambda \Rightarrow a\frac{y}{D} = n\lambda$

$$\text{Minima: } a\sin\theta = n\lambda, \quad y_n = \frac{n\lambda D}{a}$$

⇒ **1st secondary maximum:** $\Delta\phi = 3\pi \Rightarrow a\sin\theta = \frac{3\lambda}{2}$; 2nd: $a\sin\theta = \frac{5\lambda}{2}$ ($\Delta\phi = 5\pi$)

$$\text{Secondary maxima: } a\sin\theta = \frac{(2n+1)\lambda}{2} \quad y_n = \frac{(2n+1)\lambda D}{2a}$$

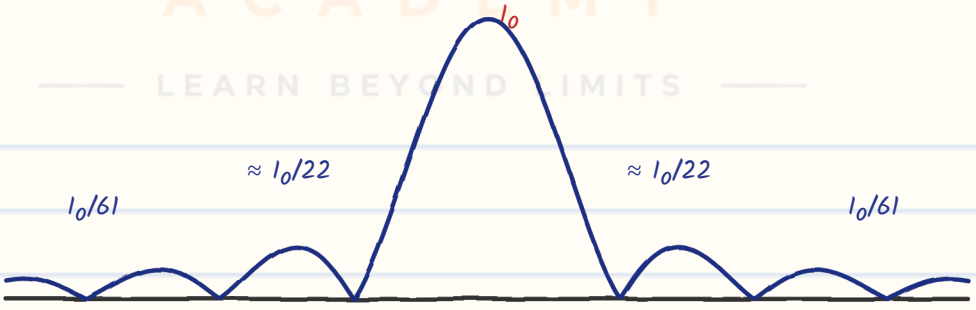
Central bright fringe (CBF)

⇒ CBF is the region between the first minima on both sides of the centre: linear width = $2y_1$, angular width = 2θ

$$\text{Linear width} = \frac{2\lambda D}{a}$$

$$\text{Angular width} = 2\sin^{-1}\left(\frac{\lambda}{a}\right) \approx \frac{2\lambda}{a}$$

Intensity distribution



→ CBF has intensity I_0; 1st secondary maximum $\approx I_0/22$ ($\approx 4\%$); 2nd $\approx I_0/61$ ($\approx 1.6\%$). The CBF is **twice as wide** as the other maxima.

Interference (YDSE)	Diffraction (single slit)
Superposition of waves from two coherent sources	Superposition of wavelets from different parts of the same wavefront
All fringes of equal width	Central maximum is twice as wide
All bright fringes of equal intensity	Intensity falls rapidly for higher orders

→ **Double slit diffraction** [S.L. Arora]: the observed pattern is double-slit interference fringes inside the single-slit diffraction envelope; number of fringes in the CBF depends on d/a.

Sample problem 1: $\lambda = 6000$ Å falls normally on a slit of width 0.3 mm; screen at 8 m. Find the distance of the 1st minimum.

$y = \lambda D/a = (6 \times 10^{-7} \times 8)/(0.3 \times 10^{-3}) = 16 \times 10^{-3}$ m = **16 mm**

Sample problem 2: The CBF is 3 mm wide, $\lambda = 600$ nm, screen at 30 cm. Find the slit width.

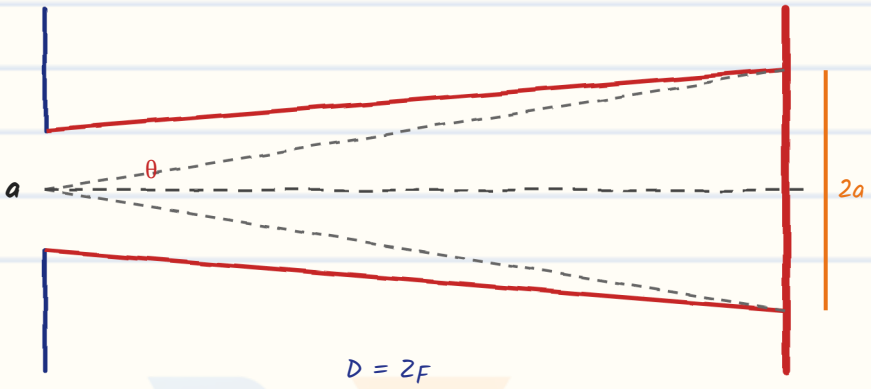
$2\lambda D/a = 3 \times 10^{-3} \Rightarrow a = (2 \times 600 \times 10^{-9} \times 0.30)/(3 \times 10^{-3}) =$ **1.2×10^{-4} m**

Sample problem 3: Slits 2 mm apart, screen 1 m, $\lambda = 500$ nm. Find the width of each slit so that 8 maxima of the double slit lie within the CBF of single-slit diffraction.

$8\beta = CBF \Rightarrow 8\lambda D/d = 2\lambda D/a \Rightarrow a = 2d/8 =$ **0.5 mm**

11. Fresnel Distance – Validity of Ray Optics NCERT

10.6 not in current CBSE syllabus



Fresnel distance is the distance up to which ray optics is a good approximation — the minimum distance a beam travels before its spreading due to diffraction becomes significant.

⇒ Spreading becomes significant when the width of the CBF equals the aperture size 2a: $\frac{2\lambda D}{a} = 2a$

⇒ At $D = Z_F$: $\frac{2Z_F\lambda}{a} = 2a$

$$Z_F = \frac{a^2}{\lambda}$$

→ Up to Z_F diffraction is not noticeable and ray optics is valid; beyond Z_F spreading due to diffraction dominates.

Sample problem: For what distance is ray optics valid for an aperture of 3 mm and λ = 500 nm?

$Z_F = a^2/\lambda = (3 \times 10^{-3})^2/(5 \times 10^{-7}) = 9 \times 10^{-6}/5 \times 10^{-7} =$ **18 m**

12. Resolving Power [S.L. Arora] not in current CBSE syllabus

Circular aperture — Airy disc

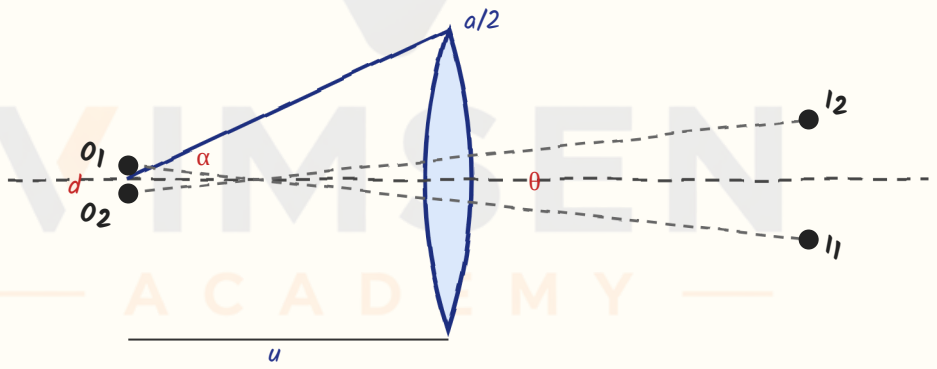
→ Light through a small circular aperture gives a central bright spot (**Airy disc**) surrounded by fainter rings.

⇒ First minimum: $\sin\theta = 1.22\,\frac{\lambda}{a}$; small angle ⇒ $\theta = 1.22\,\frac{\lambda}{a}$, radius $r = 1.22\,\frac{\lambda D}{a}$

Rayleigh's criterion: two point objects are **just resolved** when the central maximum of the diffraction pattern of one falls on the first minimum of the other.

→ **Resolving limit (R.L.):** the minimum distance (or angle) between two objects that are just resolved. **Resolving power** R.P. = 1/R.L.

Resolving limit of a microscope — derivation



⇒ Angle for just resolved images: $\theta = \frac{1.22\lambda}{a}$; also $\theta = \frac{d}{u} \Rightarrow \frac{d}{u} = \frac{1.22\lambda}{a}$ … (i)

⇒ Half-angle of the cone of light: $\tan\alpha = \frac{a/2}{u}$; small angle ⇒ $2\sin\alpha = \frac{a}{u}$ … (ii)

⇒ From (i) and (ii): $d = \frac{1.22\lambda}{2\sin\alpha}$; in a medium of refractive index μ:

$$d = \frac{1.22\lambda}{2\mu \sin\alpha} \qquad \text{R.P.} = \frac{2\mu \sin\alpha}{1.22\lambda}; \ \mu \sin\alpha = \text{numerical aperture}$$

Resolving limit of a telescope

⇒ Smallest angular separation between two distant objects whose images are just resolved (a = aperture of objective):

$$d\theta = \frac{1.22\lambda}{a} \qquad \text{R.P.} = \frac{a}{1.22\lambda}$$

→ R.P. $\propto 1/\lambda$ — violet light gives better resolution. Limit of resolution of the human eye $\approx 1' = (1/60)°$.

Sample problem 1: The Mount Palomar telescope has a 6 m objective. Find its limiting angle of resolution for 600 nm light.

$d\theta = 1.22\lambda/a = (1.22 \times 6 \times 10^{-7})/6 = \mathbf{1.22 \times 10^{-7}\ rad}$

Sample problem 2: Find the limit of resolution of a microscope with numerical aperture 0.12 for light of 4800 Å.

$d = 1.22\lambda/(2\mu \sin\alpha) = (1.22 \times 4.8 \times 10^{-7})/(2 \times 0.12) = \mathbf{2.44\ \mu m}$

13. Polarisation

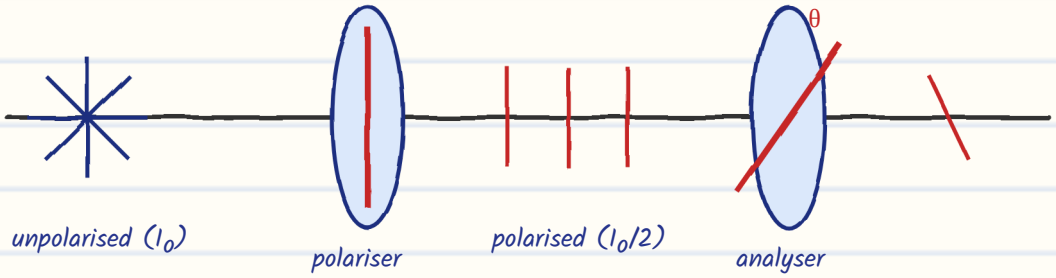
NCERT 10.7 — not in current CBSE syllabus

Polarisation: the phenomenon of restricting the vibrations of light (electric vector) to a particular direction perpendicular to the direction of propagation.

→ Interference and diffraction show light is a wave; **polarisation proves light is a transverse wave**. Longitudinal waves (sound, ultrasonic) cannot be polarised.

→ **Unpolarised light:** electric vectors point in random directions about the direction of propagation (atoms emit short wave trains of 10^{-9}–10^{-8} s independently).

→ **Plane polarised light:** the electric vector vibrates in only one direction.



→ **Polariser:** a device (tourmaline crystal, Nicol prism, polaroid) that converts unpolarised light into plane polarised light. **Analyser:** the same device used to check whether light is polarised.

→ **Transmission (optic) axis:** the direction along which light gets polarised after passing through the polariser.

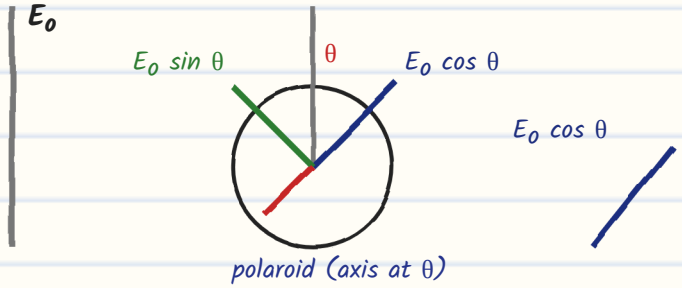
→ **Plane of vibration** — plane in which E vibrates. **Plane of polarisation** — plane perpendicular to the plane of vibration.

→ Unpolarised light through a polaroid → intensity becomes $I_0/2$, whatever the orientation.

14. Malus' Law

NCERT 10.7 not in current CBSE syllabus

When plane polarised light of intensity I_0 passes through a polaroid whose axis makes angle θ with the vibration of the light, the emergent intensity is $I = I_0 \cos^2\theta$.



⇒ Polarised light has E confined to one axis. On reaching the polaroid, E_0 splits into two components.

⇒ Component perpendicular to the optic axis ($E_0 \sin\theta$) is absorbed; only the component along the axis ($E_0 \cos\theta$) passes.

⇒ $I \propto A^2$: $\frac{I}{I_0} = \left(\frac{E_0 \cos\theta}{E_0}\right)^2$

$$I = I_0 \cos^2\theta$$

→ When the analyser is rotated through 360°: intensity becomes maximum twice ($\theta = 0°, 180°$) and zero twice ($\theta = 90°, 270°$).

Sample problem 1: Unpolarised light I_0 falls on a polariser; the analyser is at 30°. Find the output intensity.

After polariser $I' = I_0/2$; $I = (I_0/2)\cos^2 30° = (I_0/2)(3/4) = \mathbf{3I_0/8}$

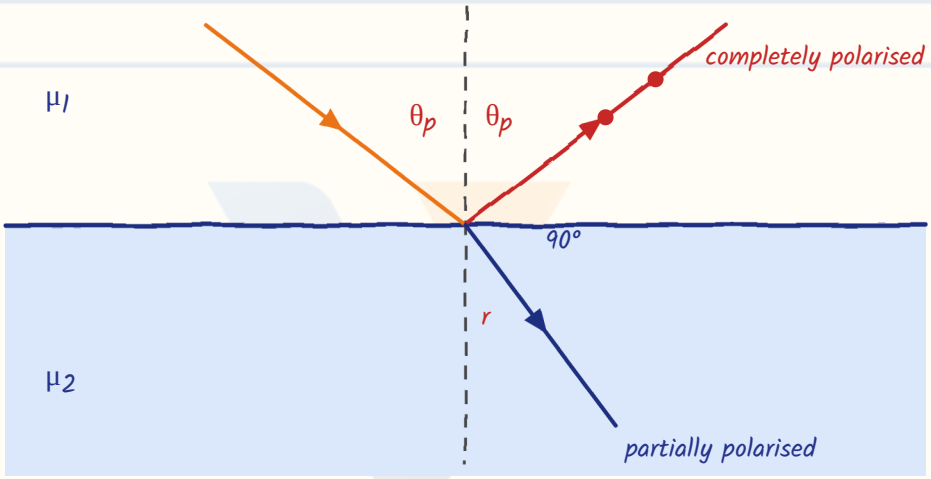
Sample problem 2: P_1 and P_2 are crossed. P_3 is placed between them at 45° to P_1. Find the intensity through P_2 for unpolarised light I_0.

After P_1: $I_0/2$; after P_3: $(I_0/2)\cos^2 45° = I_0/4$; after P_2: $(I_0/4)\cos^2 45° = \mathbf{I_0/8}$

15. Brewster's Law – Polarisation by Reflection

NCERT 10.7 | not in current CBSE syllabus

When unpolarised light falls on an interface such that the **reflected and refracted rays are perpendicular**, the reflected light is completely plane polarised (vibrations perpendicular to the plane of incidence) and the refracted light is partially polarised.



⇒ At the polarising angle: $\theta_p + 90° + r = 180° \Rightarrow r = 90° - \theta_p$

⇒ Snell's law: $\mu_1 \sin\theta_p = \mu_2 \sin r = \mu_2 \sin(90° - \theta_p) = \mu_2 \cos\theta_p$

⇒ $\frac{\sin\theta_p}{\cos\theta_p} = \frac{\mu_2}{\mu_1}$

$$\tan\theta_p = \frac{\mu_2}{\mu_1}$$ from air: $\tan\theta_p = \mu$

→ θ_p is the **polarising (Brewster) angle**. Light from a denser to rarer medium → $\theta_p < 45°$; rarer to denser → $\theta_p > 45°$.

Sample problem: The polarising angle for a medium is 53°. Find its critical angle.

$\mu = \tan 53° = 4/3$; $\sin\theta_c = 1/\mu = 3/4 \Rightarrow \theta_c = \sin^{-1}(3/4)$

16. Other Methods of Polarisation NCERT 10.7

not in current CBSE syllabus

- **Polarisation by refraction (pile of plates)** [S.L. Arora]: at each surface at θ_p, about 15% of the light with vibrations perpendicular to the plane is reflected. After many plates, the transmitted light becomes plane polarised with vibrations in the plane of incidence.
- **Polarisation by scattering:** light scattered by small particles (dust, air molecules) is absorbed by electrons and re-radiated. Light scattered at **right angles** to the incident light is plane polarised — the blue sky seen at 90° to the Sun is polarised.
- **Double refraction** [S.L. Arora]: in crystals like calcite and quartz, unpolarised light splits into two beams with perpendicular polarisations — the **O-ray** (obeys the laws of refraction) and the **E-ray** (does not). Rotating the crystal makes the E-image rotate around the O-image.
- **Uses of polaroids:** sunglasses, reducing glare from wet roads, 3-D movie glasses, LCD screens, camera filters.

VIMSEN — ACADEMY — LEARN BEYOND LIMITS

17. Formula Sheet — Quick Revision

Wavefronts	spherical $A \propto 1/r$; cylindrical $A \propto 1/\sqrt{r}$; plane A = const
Huygens (refraction)	$\sin i / \sin r = v_1/v_2 = \mu_2/\mu_1$
Doppler ($v \ll c$)	$\Delta f/f = v/c$, $\Delta\lambda/\lambda = -v/c$ (approach)
Resultant	$A^2 = A_1^2 + A_2^2 + 2A_1A_2 \cos\Delta\phi$
Intensity	$I = I_1 + I_2 + 2\sqrt{(I_1I_2)}\cos\Delta\phi$; equal: $4I_0\cos^2(\Delta\phi/2)$
I_{max}/I_{min}	$[(\sqrt{I_1} + \sqrt{I_2})/(\sqrt{I_1} - \sqrt{I_2})]^2$
Phase / path	$\Delta\phi = (2\pi/\lambda)\,\Delta x$
YDSE path diff.	$\Delta x = d\sin\theta = yd/D$
Bright / dark	$y = n\lambda D/d$; $y = (2n-1)\lambda D/2d$
Fringe width	$\beta = \lambda D/d$, $\alpha = \lambda/d$; in medium β/μ
Thin film	$y_{cm} = (\mu-1)tD/d$, $n = (\mu-1)t/\lambda$
Single slit minima	$a\sin\theta = n\lambda$, $y = n\lambda D/a$
Secondary maxima	$a\sin\theta = (2n+1)\lambda/2$
CBF width	$2\lambda D/a$; angular $2\lambda/a$
Fresnel distance	$Z_F = a^2/\lambda$
Resolving limit	microscope $1.22\lambda/(2\mu\sin\alpha)$; telescope $1.22\lambda/a$
Malus' law	$I = I_0\cos^2\theta$; unpolarised → $I_0/2$
Brewster's law	$\tan\theta_p = \mu$, $\theta_p + r = 90°$

18. CBSE Previous Year Questions

20 questions of the kind asked in CBSE Class 12 board papers — MCQs, assertion–reason, short and long answers, numericals and a case study. Questions on Doppler effect, polarisation and resolving power come from earlier syllabus years. Short answers / hints are given in **green**.

Section A — MCQ & Assertion–Reason (1 mark each)

Q1. The wavefront due to a source situated at infinity is [1]

(a) spherical (b) cylindrical (c) planar (d) none of these

Ans: (c) planar

Q2. In Young's double slit experiment, if the separation between the slits is halved and the distance of the screen is doubled, the fringe width becomes [1]

(a) half (b) double (c) four times (d) unchanged

Ans: (c) — $\beta = \lambda D/d \Rightarrow \beta' = \lambda(2D)/(d/2) = 4\beta$.

Q3. The YDSE apparatus is immersed in water ($\mu = 4/3$). The fringe width [1]

(a) increases to $4\beta/3$ (b) decreases to $3\beta/4$ (c) remains same (d) becomes zero

Ans: (b) — λ becomes λ/μ.

Q4. Two coherent sources of intensity ratio 9 : 4 interfere. The ratio $I_{max} : I_{min}$ is [1]

(a) 13 : 5 (b) 25 : 1 (c) 9 : 4 (d) 5 : 1

Ans: (b) — $[(3 + 2)/(3 - 2)]^2 = 25$.

Q5. In single slit diffraction, if the slit width is decreased, the width of the central maximum [1]

(a) decreases (b) increases (c) remains same (d) first increases then decreases

Ans: (b) — width = $2\lambda D/a$.

Q6. Unpolarised light of intensity I_0 passes through two polaroids with axes at 60°. The transmitted intensity is [1]

(a) $I_0/2$ (b) $I_0/4$ (c) $I_0/8$ (d) zero

Ans: (c) — $(I_0/2)\cos^2 60° = I_0/8$.

Q7. The polarising angle for glass is 60°. The refractive index of glass is [1]

(a) 1.5 (b) $\sqrt{3}$ (c) $1/\sqrt{3}$ (d) 2

Ans: (b) — $\mu = \tan 60°$.

Q8. **Assertion (A):** No interference pattern is seen with two independent sodium lamps. **Reason (R):** The two lamps are not coherent sources. [1]

(a) Both true, R explains A (b) Both true, R does not explain A

(c) A true, R false (d) A false, R true

Ans: (a)

Q9. **Assertion (A):** Sound waves cannot be polarised. **Reason (R):** Sound waves are longitudinal in nature. [1]

(a) Both true, R explains A (b) Both true, R does not explain A

(c) A true, R false (d) A false, R true

Ans: (a) — only transverse waves can be polarised.

Q10. **Assertion (A):** In YDSE with white light, the central fringe is white. **Reason (R):** At the centre, the path difference is zero for all wavelengths. 1

(a) Both true, R explains A (b) Both true, R does not explain A

(c) A true, R false (d) A false, R true

Ans: (a)

Section B — Short & Long Answer

Q11. State Huygens' principle. Using it, draw a diagram and verify Snell's law of refraction for a plane wave incident on a plane surface. 3

Ans: see Topics 2 and 3 — $\sin i / \sin r = v_1/v_2 = \mu_2/\mu_1$.

Q12. Using Huygens' construction, verify the law of reflection for a plane wavefront. 2

Ans: see Topic 3 — $AA' = BB' \Rightarrow \sin i = \sin r \Rightarrow i = r$.

Q13. Define coherent sources. Two waves of intensities I_1 and I_2 superpose with phase difference ϕ. Derive the resultant intensity and show that for $I_1 = I_2 = I_0$, $I = 4I_0 \cos^2(\phi/2)$. 3

Ans: see Topics 5 and 6.

Q14. Describe Young's double slit experiment and derive the expression for the fringe width. 5

Ans: see Topic 7 — $\Delta x = yd/D$, $y_n = n\lambda D/d$, $\beta = \lambda D/d$.

Q15. A beam of light of two wavelengths 650 nm and 520 nm is used in YDSE (d = 2 mm, D = 1.2 m). (a) Find the distance of the 3rd bright fringe for 650 nm. (b) Find the least distance from the central maximum where bright fringes of both wavelengths coincide. 3

Ans: (a) $y = 3\lambda D/d = 3 \times 650 \times 10^{-9} \times 1.2/(2 \times 10^{-3})$ = **1.17 mm**. (b) $n \times 650 = (n + 1) \times 520 \Rightarrow n = 4$: $y = 4 \times 650 \times 10^{-9} \times 1.2/(2 \times 10^{-3})$ = **1.56 mm**.

Q16. Describe diffraction at a single slit. Show that the angular width of the central maximum is twice that of the other maxima. How does it change when the slit width is doubled? 3

Ans: see Topic 10 — central $2\lambda/a$, others λ/a; doubling a halves the central width.

Q17. In a single slit experiment, light of 600 nm is used. Find the slit width for which the first minimum is at 30°. 2

Ans: $a \sin 30° = \lambda \Rightarrow a = 600\ nm/0.5 =$ **1.2 µm**

Q18. State Malus' law. Unpolarised light passes through two crossed polaroids P_1 and P_2. A third polaroid P_3 is placed between them with its axis at angle θ to P_1. Find the transmitted intensity and the value of θ for maximum intensity. 3

Ans: $I = (I_0/2)\cos^2\theta \cos^2(90° - \theta) = (I_0/8)\sin^2 2\theta$; maximum **$I_0/8$ at $\theta = 45°$**.

Q19. State Brewster's law and derive $\tan \theta_p = \mu$. What is the angle between the reflected and refracted rays at this angle? 2

Ans: see Topic 15 — the angle is **90°**.

Q20. Case study — Resolving power. *The ability of an optical instrument to show two close objects as separate is its resolving power. According to Rayleigh, two images are just resolved when the central maximum of one falls on the first minimum of the other. Answer:* 4

(i) Write the limit of resolution of a telescope with objective of aperture a.

(ii) How does resolving power change if the aperture of the objective is doubled?

(iii) Why does a microscope give better resolution with blue light than with red light?

(iv) For a telescope with a 5 m objective and λ = 600 nm, find the limiting angle of resolution.

Ans: (i) $d\theta = 1.22\lambda/a$. (ii) It doubles (R.P. $\propto a$). (iii) R.P. $\propto 1/\lambda$ and $\lambda_{blue} < \lambda_{red}$. (iv) $d\theta = 1.22 \times 6 \times 10^{-7}/5 \approx \mathbf{1.46 \times 10^{-7}\ rad}$.