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WAVE OPTICS CBSE

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WAVE OPTICS
REVISION MODULE
CBSE-PHYSICS

Syllabus

- *Wave Optics: Wave front and Huygens' principle; reflection and refraction of plane wave at a plane surface using wave fronts; Proof of laws of reflection and refraction using Huygens' principle.*
- *Interference; Young's double slit experiment and expression for fringe width; coherent sources and sustained interference of light.*
- *Diffraction due to a single slit, width of central maximum.*

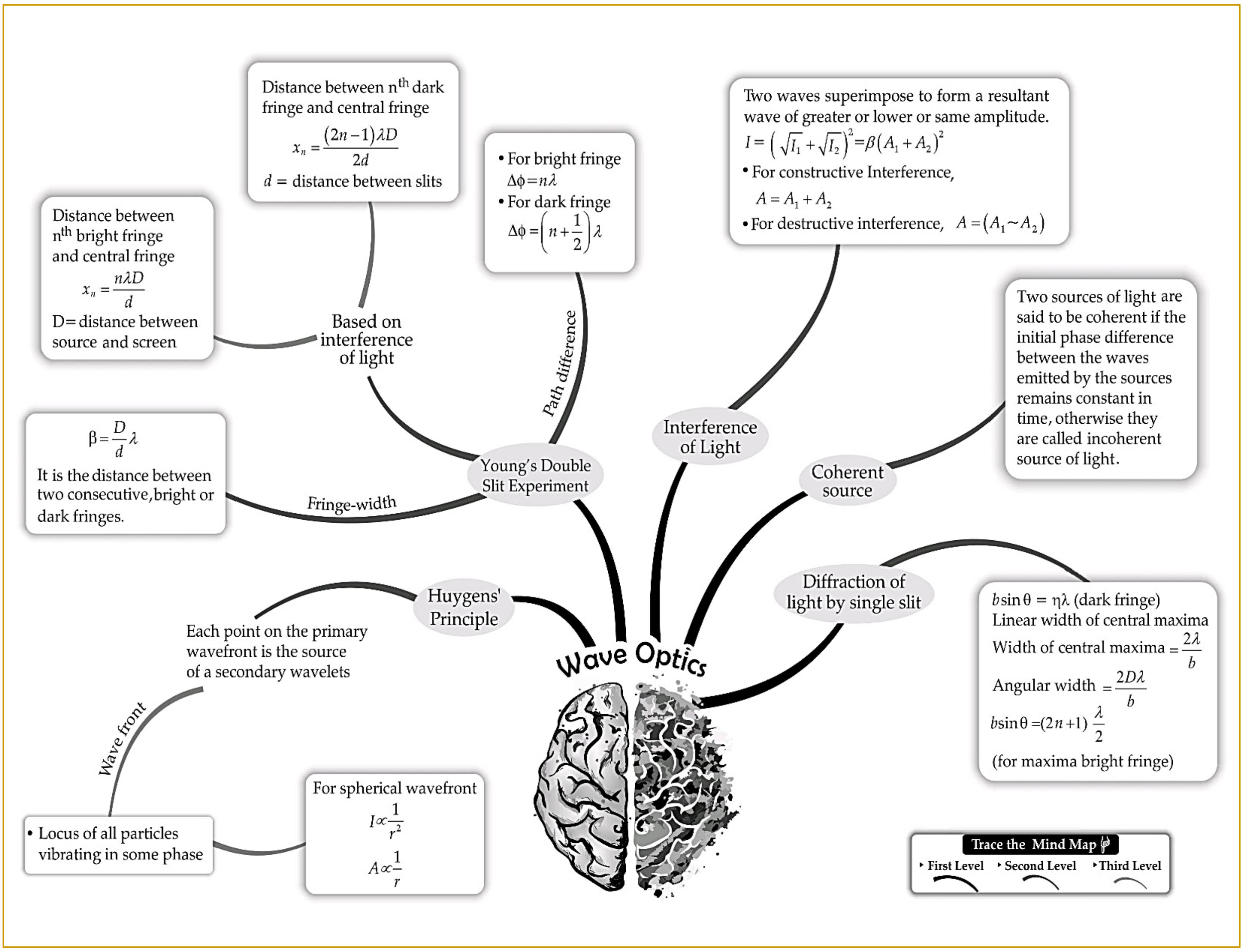
Learning Outcomes

- *Knowledge about the wave nature of light and proof of reflection and refraction of light using wave theory.*
- *Knowledge about different features of interference and diffraction of light.*

Revision Notes

Wave Theory and Huygens' Principle

- Newton supported 'Descartes' corpuscular theory' of light and developed it further.
- According to the corpuscular theory, "sources of light emit large number of tiny massless particles known as corpuscles in a medium surrounding the source. They are perfectly elastic, rigid and have high speed.
  This theory could explain reflection and refraction of light but could not explain many other optical phenomenon like interference and diffraction of light. It was unable to explain the concept of partial reflection and refraction through a transparent surface.
- Huygens' proposed wave theory of light. According to the theory, light travels in the form of longitudinal waves with uniform speed in a homogenous medium. Different wavelengths of light represent different colours of light.
- As longitudinal and mechanical waves need medium to travel, he assumed a hypothetical medium known as 'ether'. He also proved that speed of light is slower in optically denser medium.
- Initially, Huygens' wave theory of light didn't get much success. Its main point of rejection was, that it was considered as longitudinal wave which need medium, but experimentally found that it could also travel in vacuum and there is no medium like ether.
  But later Maxwell's theory of electromagnetic waves and Young's famous double slit experiment firmly established this theory. Maxwell explained that light is an electromagnetic wave which does not need medium and its speed in vacuum is 3×10^8 m/s. Phenomenon of optical interference, diffraction and polarisation can be explained with wave nature of light.
- It had some points of failure. It could not explain photoelectric effect and Compton effect.
- With polarisation, it is established that light is not a longitudinal wave but a transverse wave.
- Huygens' principle brings concept of formation of new wave fronts and its propagation in forward direction.


Wave Optics
Huygens' Principle
Each point on the primary wavefront is the source of a secondary wavelets
Wave front
• Locus of all particles vibrating in some phase
For spherical wavefront
$I \propto \frac{1}{r^2}$
$A \propto \frac{1}{r}$
Young's Double Slit Experiment
Based on interference of light
Distance between n^{th} dark fringe and central fringe
$x_n = \frac{(2n-1)\lambda D}{2d}$
d = distance between slits
Distance between n^{th} bright fringe and central fringe
$x_n = \frac{n\lambda D}{d}$
D= distance between source and screen
Path difference
• For bright fringe
$\Delta\phi = n\lambda$
• For dark fringe
$\Delta\phi = \left(n + \frac{1}{2}\right)\lambda$
Fringe-width
$\beta = \frac{D}{d}\lambda$
It is the distance between two consecutive, bright or dark fringes.
Interference of Light
Two waves superimpose to form a resultant wave of greater or lower or same amplitude.
$I = \left(\sqrt{I_1} + \sqrt{I_2}\right)^2 = \beta\left(A_1 + A_2\right)^2$
• For constructive Interference,
$A = A_1 + A_2$
• For destructive interference, $A = \left(A_1 \sim A_2\right)$
Coherent source
Two sources of light are said to be coherent if the initial phase difference between the waves emitted by the sources remains constant in time, otherwise they are called incoherent source of light.
Diffraction of light by single slit
$b\sin\theta = \eta\lambda$ (dark fringe)
Linear width of central maxima
Width of central maxima $= \frac{2\lambda}{b}$
Angular width $= \frac{2D\lambda}{b}$
$b\sin\theta = (2n+1)\frac{\lambda}{2}$
(for maxima bright fringe)
Trace the Mind Map
First Level
Second Level
Third Level

- Wavefront is locus of all points in which light waves are in same phase. Propagation of wave energy is perpendicular to the wavefront.

Huygens' Principle:

- Every point of a wavefront becomes secondary source of light.
- These secondary sources give their own light waves. Within small time, they produce their own wave called secondary wavelets. These secondary waves have same speed and wavelengths as waves by primary sources.
- At any instant, a common tangential surface on all these wavelets give new wavefronts in forward direction.
- Shapes of wavefronts

Source	Wavefronts
Point source	Spherical wavefront
Line source	Cylindrical wavefront
Plane source	Plane wavefront
Point source very far away	Plane wavefront

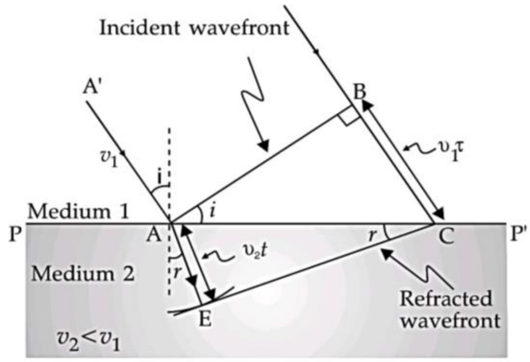
- Concave lens converts plane wavefront to convex wavefront and convex lens convert plane wavefront to concave wavefront.

Refraction of light by Huygens' Principle

Snell's law can be proved by Huygens' principle.

$$\frac{\sin i}{\sin r} = \frac{v_1}{v_2} = \text{constant}$$

It has also been proved that the velocity of light in denser medium is less than velocity of light in rarer medium.



AB = Incident wavefront

EC = Refracted wavefront

$\angle i$ = Angle between incident wavefront AB and interface PP'

$\angle r$ = Angle between refracted wavefront EC and interface PP'

If medium 2 is optically denser than medium 1 and τ is the time in which disturbance from B reaches C. This is the same time t in which disturbance from A reaches E where distance $AE < BC$.

$$\Delta AEC \cong \Delta ABC$$

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

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

$$\frac{\sin i}{\sin r} = \frac{BC}{AE}$$

BC = Distance travelled by wave at B in time τ in medium 1

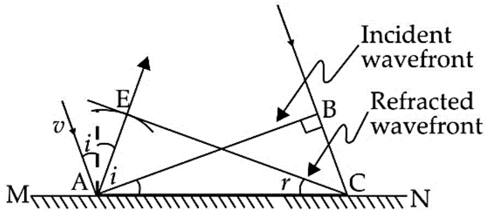
AE = Distance travelled by wave at A in time τ in medium 2

$$\frac{\sin i}{\sin r} = \frac{v_1\tau}{v_2\tau}$$

Hence,
$$\frac{\sin i}{\sin r} = \frac{v_1}{v_2} = \text{constant}$$

This is law of refraction (Snell's law).

- **Reflection of light by Huygens' Principle**



AB = Incident wavefront
EC = Reflected wavefront
$\angle i$ = Angle between incident wavefront AB with the interface AC
$\angle r$= Angle between reflected wavefront EC with the interface AC
If disturbance at A is reflected from the interface AC, then disturbance at B and disturbance at A both travel in same medium. Thus, they will travel equal distance in time τ, where τ is the time in which disturbance from B reaches at C.
Now $AE = BC = v\tau$ (distance travelled in same medium in same time)

$$\Delta AEC \cong \Delta ABC$$
$$\angle i = \angle r$$

This is law of reflection.

Superposition of Light Waves (Interference and Diffraction)

- According to superposition principle, "At a particular point in the medium, the resultant displacement produced by a number of waves is the vector sum of the displacements produced by each wave".
  It means that if individual displacement produced at a point by two coherent waves at any instant is given by
  $$y_1 = a\cos \omega t \text{ and } y_2 = a\cos \omega t.$$
  Then, resultant displacement at that point will be
  $$y = y_1 + y_2 = 2a\cos \omega t.$$
  Hence, the total intensity at that point will be:
  $$I = 4I_0$$
  where, $I_0 \propto a^2$; maximum intensity due to one wave.

Interference

- **Constructive Interference:** If two waves are propagating such that crest and trough of both waves would reach at a point in the same instant, then we say there is constructive interference of two waves at that point. The resultant amplitude of the wave is the sum of individual amplitudes. (We can generalize this to superposition of more than two waves) $a = a_1 + a_2$
- **Destructive Interference:** If two waves are propagating such that crest of one wave and trough of other wave reaching at a point in same instant, then we say that there is destructive interference of two waves at that point. The resultant amplitude of the wave is the difference of individual amplitudes. (We can generalize this to superposition of more than two waves) $a = a_1 - a_2$
- Two independent sources can never be coherent. We may create two coherent sources by deriving them from one source.

Condition for constructive Interference

- Waves would be coherent in nature. Coherent wave means that they should have equal frequency and constant phase difference (0, 2π, --- 2nπ) with each other at any time interval t.
  Path difference between waves at this phase difference = 0 , λ, -----nλ, Here, n = 0, 1, 2, 3 ......

$$a_r = a_1 + a_2$$
if $$a_1 = a_2 = a$$
then $$a_r = 2a$$
∵ $$I \propto a^2$$
$$I_r = 4a^2$$

Condition for destructive interference

- Waves would be coherent in nature. The phase between the waves should be odd multiples of π, *i.e.*, 0, π, ... $(2n-1)\pi$

- Path difference between waves at this phase difference $= \frac{\lambda}{2}, \frac{3\lambda}{2}, (2n-1)\frac{\lambda}{2}$, Here, n = 1, 2, 3, 4....

$$a_r = a_1 - a_2$$

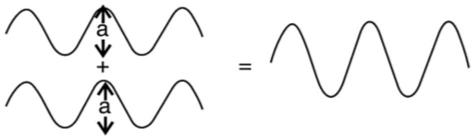
if $\quad a_1 = a_2$

then $\quad a_r = 0$

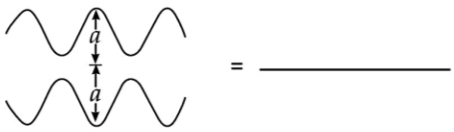
$\because \quad I \propto a^2$

$$I_r = 0$$

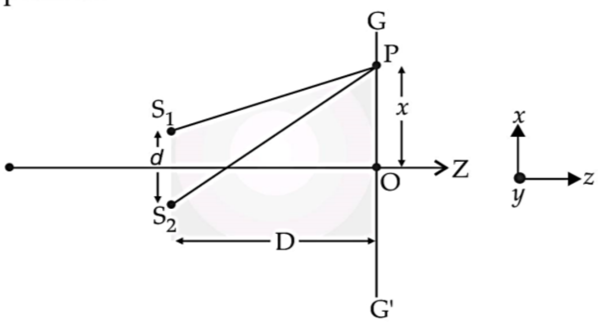
Constructive Interference



Destructive Interface



Young's double slit Experiment



- At "O" we get central maxima. Here, path difference $(S_2P - S_1P) = 0$
- At "P", which is at "x" height from "O" path difference $(S_2P - S_1P) = \frac{xd}{D}$
- **Condition for P to be a bright spot**

$$\frac{xd}{D} = 0, \lambda, 2\lambda........n\lambda$$

$$x_{n\text{th bright}} = \frac{nD}{d}\lambda$$

where, n is number of bright fringes after central fringe.

- **Condition for P to be a dark spot**

$$\frac{xd}{D} = 0, \frac{3\lambda}{2}...........(2n+1)\frac{\lambda}{2}$$

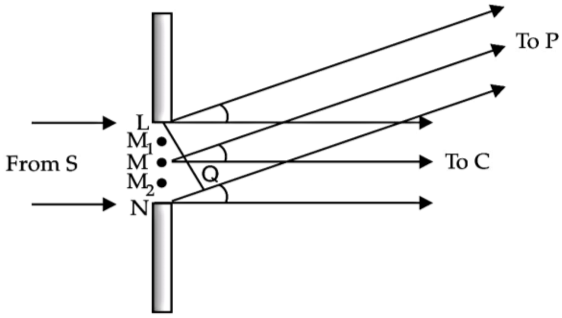
$$x_{n\text{th dark}} = \frac{(2n+1)D}{2d}\lambda$$

Here, n is the number of dark fringes after central fringe.

- Width of the bright fringe $(\omega_B) = x_{nB} - x_{(n-1)}B = \frac{D\lambda}{d}$
- Width of the dark fringe $(\omega_D) = x_{nD} - x_{(n-1)}D = \frac{D\lambda}{d}$
- Width of the central fringe $(\omega_C) = \frac{D\lambda}{d}$
- Hence $\omega_B = \omega_D = \omega_C$

Diffraction

It is defined as the bending of light around the corners of an obstacle or aperture into the region where we expect shadow of the obstacle.



If width of the opening = a

θ is the angle of elevation of point P from principal axis.

Path difference between ray from L and ray from $N = LQ = a\sin\theta$

$$a\sin\theta = \lambda$$

$\because$ for first maxima $\quad \theta = \dfrac{\lambda}{a} \quad (\therefore \sin\theta \cong \theta)\ \sin\theta <<< 1$

It is observed that when path difference = $\lambda, 2\lambda \ldots\ldots (2n-1)\lambda$, P is a dark point.

When $a\sin\theta = \dfrac{3\lambda}{2}, \ldots\ldots(2n+1)\dfrac{\lambda}{2}$, P is a bright point.

Elevation angle for first bright fringe, $\theta_{1D} = \dfrac{3\lambda}{2a}$

- Height of first dark fringe, $x_{1D} = \dfrac{3\lambda D}{2a}$
- Elevation angle for first dark fringe, $\theta_{1D} = \dfrac{\lambda}{a}$
- Width of the bright fringe = $\dfrac{D\lambda}{a}$
- Width of the dark fringe = $\dfrac{D\lambda}{a}$
- Width of the central fringe = $\dfrac{2D\lambda}{a}$
- There is no gain or loss of energy in interference or diffraction, which is consistent with the principle of conservation of energy. Energy only redistributes in these phenomena.

Mnemonics

Phase difference for constructive and destructive interference:

Pranab **D**hawan **d**eparted **O**tty by **C**hennai **E**xpress.

Even [i.e. 2nπ]

For **C**onstructive interference

Odd [i.e. (2n+1)π]

for **D**estructive interference

Difference

Phase

Know the Formulae

- **Condition for constructive interference for coherent waves**
  - Constant phase difference$(0, 2\pi, ... 2n\pi)$
  - Path difference $= 0, \lambda$ ...... $n\lambda$
- **Condition for destructive interference for coherent waves**
  - Phase difference$(0, \pi, ... (2n-1)\pi)$ with each other at any time interval t.
  - Path difference $= \frac{\lambda}{2}$, ... $(2n-1)\frac{\lambda}{2}$
- **In Interference Pattern**
  - Width of the bright fringe $= \frac{D\lambda}{d}$
  - Width of the dark fringe $= \frac{D\lambda}{d}$
  - Width of the central fringe $= \frac{D\lambda}{d}$
  - All fringes have equal fringe width
- **In Diffraction Pattern**
  - Angle of elevation of any point P on screen $= \frac{\lambda}{a}$
  - Condition that P would be dark point when path difference $= \lambda, 2\lambda$ .... $(2n-1)\lambda$
  - Condition that P would be bright point when path difference $= \frac{3\lambda}{2}, ...(2n+1)\frac{\lambda}{2}$
  - Width of the bright fringe $= \frac{D\lambda}{a}$

    Width of the dark fringe $= \frac{D\lambda}{a}$

    Width of the central fringe $= \frac{2D\lambda}{a}$
  - Height of first bright fringe $x_{1B} = \frac{3\lambda D}{2a}$

(A) Objective Questions — 1 Mark Each

Stand Alone MCQs

Q. 1. Wavefront generated from a line source is

(A) cylindrical wavefront
(B) spherical wavefront
(C) plane wavefront
(D) either (A) or (B)

Ans. Option (A) is correct.

Q. 2. Phase difference between any two points of a wavefront is

(A) π (B) $\pi/2$
(C) 0 (D) $\pi/4$

Ans. Option (C) is correct.

Explanation: Wavefront is the locus of all points those are in same phase.

Q. 3. In Huygens theory, light waves

(A) are transverse waves and require a medium to travel.
(B) are longitudinal waves and require a medium to travel.
(C) are transverse waves and require no medium to travel.
(D) are longitudinal waves and require no medium to travel.

Ans. Option (B) is correct.

> *Explanation:* According to Huygens, light waves are longitudinal waves and require a material medium to travel. For this reason Huygens assumed the existence of a hypothetical medium called luminiferous aether.

Q. 4. Huygens theory could not explain

(A) photoelectric effect.
(B) reflection of light.
(C) diffraction of light.
(D) interference of light.

Ans. Option (A) is correct.

> *Explanation:* Wave nature of light cannot explain the photoelectric effect. Particle nature of light can only explain it.

Q. 5. Which of the following statement is true?

(A) According to both Maxwell's electromagnetic theory and Huygens wave theory light is treated as a wave in nature and require medium to travel.
(B) According to both Maxwell's electromagnetic theory and Huygens wave theory light is treated as a particle in nature and require medium to travel.
(C) According to both Maxwell's electromagnetic theory and Huygens wave theory light is treated as a wave in nature and does not require medium to travel.
(D) According to Maxwell's electromagnetic theory light is treated as a wave in nature and require no medium to travel. According to Huygens theory light is treated as a wave in nature and require medium to travel.

Ans. Option (D) is correct.

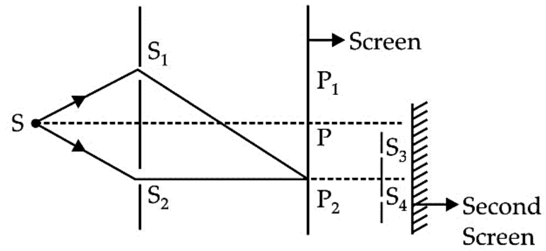
Q. 6. In a Young's double-slit experiment the source is white light. One of the holes is covered by a red filter and another by a blue filter. In this case,

(A) there shall be alternate interference patterns of red and blue.
(B) there shall be an interference pattern for red distinct from that for blue.
(C) there shall be no interference fringes.
(D) there shall be an interference pattern for red mixing with one for blue.

Ans. Option (C) is correct.

> *Explanation:* For sustained interference, the source must be coherent and should emit the light of same frequency.
> In this problem, one hole is covered with red and other with blue, which has different frequency, so no interference takes place.

Q. 7. Figure shows a standard two-slit arrangement with slits S_1, S_2. P_1, P_2 are the two minima points on either side of P shows in Figure. At P_2 on the screen, there is a hole and behind P_2 is a 2-slit arrangement with slits S_3 and S_4 and a second screen behind them.



(A) There would be no interference pattern on the second screen but it would be lighted.
(B) The second screen would be totally dark.
(C) There would be a single bright point on the second screen.
(D) There would be a regular two slit pattern on the second screen.

Ans. Option (D) is correct.

> *Explanation:* At P_2 is minima due to two wave fronts in opposite phase coming from, two slits S_1 and S_2, P_2 will act as a source of secondary wavelets. Wave front starting from P_2 reaches at S_3 and S_4 slits which will again act as two monochromatic or coherent sources and will form pattern on second screen.

Q. 8. In Young's double slit experiment, the distance between the slits is reduced to half and the distance between the slits and the screen is doubled. The fringe width

(A) will be double. (B) will be half.
(C) will remain same. (D) will be four times.

Ans. Option (D) is correct.

> *Explanation:* Fringe width $= \beta = \lambda D/d$
> Initially, $\beta = \lambda D/d$
> Finally, $\beta' = \dfrac{\lambda \times 2D}{d/2} = 4 \times \dfrac{\lambda D}{d} = 4\beta$

Q. 9. A Young's double slit experiment is performed with blue (wavelength 460 nm) and green light (wavelength 550 nm) respectively. If y is the distance of 4th maximum from the central fringe then

(A) $y_B = y_G$ (B) $y_B > y_G$
(C) $y_G > y_B$ (D) $y_B/y_G = 550/460$

Ans. Option (C) is correct.

> *Explanation:* $y_n = n\lambda D/d$
> So, $y_n \propto \lambda$
> Since $\lambda_G > \lambda_B$
> $\therefore$ $y_G > y_B$

Q. 10. A Young's Double slit experiment is performed in air and in water. Which of the following relationship is true regarding fringe width (β)?

(A) $\beta_{AIR} > \beta_{WATER}$ **(B)** $\beta_{WATER} > \beta_{AIR}$

(C) $\beta_{AIR} = \beta_{WATER}$ **(D)** $\beta_{WATER} = 0$

Ans. Option (A) is correct.

> *Explantion:* $\beta \propto \lambda$ and $\lambda \propto 1/\mu$
> So, $\beta \propto 1/\mu$
> Since $\mu_{WATER} > \mu_{AIR}$
> $\therefore$ $\beta_{AIR} > \beta_{WATER}$

Q. 11. The penetration of light into the region of geometrical shadow is known as

(A) interference of light.

(B) diffraction of light.

(C) refraction of light.

(D) polarisation of light.

Ans. Option (B) is correct.

Q. 12. Angular width of central maxima of a single slit diffraction pattern is independent of

(A) slit width

(B) frequency of the light used

(C) wavelength of the light used

(D) distance between slit and screen

Ans. Option (D) is correct.

> *Explanation:* Angular width = $2\sin^{-1}\lambda/d$
> So, it is independent of D (distance between slit and screen).

Q. 13. When a monochromatic light is passed around a fine wire a diffraction pattern is observed. How the fringe width will change by increasing the diameter?

(A) Fringe width has no relation with the diameter of wire

(B) Increases

(C) Decreases

(D) Fringe width changes with change of wavelength only

Ans. Option (C) is correct.

> *Explanation:* $\beta = \lambda D/d$, where d is the diameter of the wire. So, if the diameter increases, fringe with decreases.

Q. 14. The main condition for diffraction to be observed is

(A) size of obstacle should be comparable to the wavelength of the wave

(B) size of obstacle should be much larger than the wavelength of the wave

(C) size of obstacle should be much smaller than the wavelength of the wave

(D) for any size of obstacle

Ans. Option (A) is correct.

Assertion and Reason Based MCQs

Directions: In the following questions, a statement of Assertion (A) is followed by a statement of Reason (R). Mark the correct choice as:

(A) Both (A) and (R) are true, and (R) is the correct explanation of (A).

(B) Both (A) and (R) are true, but (R) is not the correct explanation of (A).

(C) (A) is true, but (R) is false.

(D) (A) is false, but (R) is true.

Q. 1. Assertion (A): According to Huygens theory no back-ward wavefront is possible.

Reason (R): Amplitude of secondary wavelets is proportional to $(1 + \cos\theta)$, where θ is the angle between the ray at the point of consideration and direction of secondary wavelet.

Ans. Option (A) is correct.

> *Explanation:* According to Huygens theory each and every point on a wavefront is the source of secondary wavelets. Secondary wavelets do not proceed backward. So the assertion is true.
>
> Kirchhoff explained that amplitude of secondary wavelets is proportional to $(1+\cos\theta)$, where θ is the angle between the ray at the point of consideration and direction of secondary wavelets. In the backward direction $\theta = 180°$; so $1 + \cos\theta = 0$; so the secondary wavelets do not proceed backward.
>
> Hence assertion and both are true and the reason properly explains the assertion.

Q. 2. Assertion (A): Wavefront emitted by a point source of light in an isotropic medium is spherical.

Reason (R): Isotropic medium has same refractive index in all directions.

Ans. Option (A) is correct.

> *Explanation:* If a medium has same refractive index at every point in all directions, then the wavefront obtained from a point source in such a medium is spherical since wave travels in all direction with same speed. Such a medium is known as isotropic medium. So, the assertion and reason both are true and the reason explain the assertion properly.

Q. 3. Assertion (A): When a light wave travels from rarer to denser medium, its speed decreases. Due to this reduction of speed the energy carried by the light wave reduces.

Reason (R): Energy of wave is proportional to the frequency.

Ans. Option (D) is correct.

> *Explanation:* When a light wave travels from rarer to denser medium, its speed decreases. But this reduction of speed does not imply the loss of energy carried by the light wave. So the assertion is false.
>
> Energy of wave is proportional to the frequency of the wave which remains same in very medium. Hence there is no loss of energy. So, the reason is true.

Q. 4. Assertion (A): No interference pattern is detected when two coherent sources are too close to each other.

Reason (R): The fringe width is inversely proportional to the distance between the two slits.

Ans. Option (A) is correct.

> *Explanation:* No interference pattern is detected when two coherent sources are too close to each other. The assertion is true.
>
> Fringe width is proportional to $1/d$. When d becomes too small, the fringe width becomes too large. So no pattern will be visible. So, the reason is also true. Reason also explains the assertion.

Q. 5. Assertion (A): For best contrast between maxima and minima in the interference pattern of Young's double slit experiment, the amplitudes of light waves emerging from the two sources should be equal.

Reason (R): For interference, the sources must be coherent.

Ans. Option (B) is correct.

> *Explanation:* For destructive interference, $a = a_1 \sim a_2$. When $a_1 = a_2$, only the minima will be completely dark. This will create the best contrast. So the assertion is true.
>
> For interference, the sources must be coherent. Reason is also true. But the reason does not explain the assertion.

Q. 6. Assertion (A): Fringes of interference pattern produced by blue light is narrower than that produced by red light.

Reason (R): In Young's double slit experiment, fringe width= $\lambda D/d$

Ans. Option (A) is correct.

> **Explanation:** Fringes of interference pattern produced by blue light is narrower than that produced by red light. The assertion is true.
>
> Fringe width = $\lambda D/d$. Since blue light has wavelength smaller than that of red light, blue light produces narrower fringes. So, reason is also true and explains the assertion.

Q. 7. Assertion (A): Diffraction takes place with all types of waves.

Reason (R): Diffraction is perceptible when the wavelength of the wave is comparable to the dimension of the diffracting device.

Ans. Option (B) is correct.

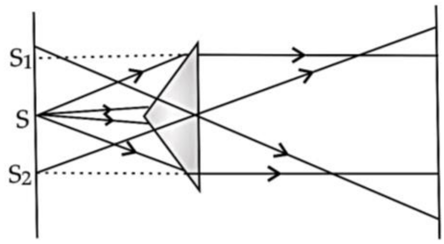
> *Explanation:* Diffraction is spreading of waves around obstacle. It takes place with all types of waves (mechanical, non-mechanical, transverse, longitudinal) and with very small moving particles (atom, neutron, electron etc.) which show wave like property. So, the assertion is true.
>
> Diffraction is perceptible when the wavelength of the wave is comparable to the dimension of the diffracting device. The reason is also true. But it does not explain the assertion.

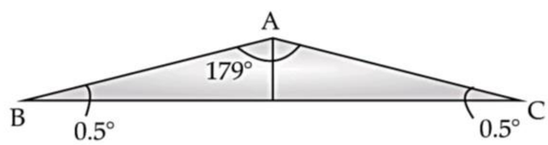
Case-based MCQs

I. Read the following text and answer the following questions on the basis of the same:

In one of his experiments on interference, August Jean Fresnel used a biprism to induce interference between two beams. He split a diverging beam of light into two parts by using the biprism to refract them. This resulted in two split beams which acted as if they were from two coherent sources and which therefore interfered with each other.

A Fresnel Biprism is a thin double prism placed base to base and have very small refracting angle (0.5°). This is equivalent to a single prism with one of its angle nearly 179° and other two of 0.5° each.





In Young's double Slits experiment, a single source is split in two coherent sources. For the Young's slits experiment, we must approximate that the slits act as point sources. This however is not the case, since the slits have finite width. In this way, it gives rise to unwanted diffraction effects that causes errors.

The Fresnel biprism experiment overcomes this problem.

A Fresnel biprism is a variation of Young's Slits experiment. When monochromatic light through a narrow slit falls on biprism that divides it into two components. One of these component is refracted from upper portion of biprism and the other one refracted through lower portion. Two virtual coherent sources formed from the original source. In this case, two virtual coherent sources are point sources and replace slits in Young's experiment.

Q. 1. The Fresnel biprism is:

(A) a combination of two prisms with their bases in contact.

(B) a combination of two prisms with their refracting surfaces in contact.

(C) single prism

(D) not a prism actually.

Ans. Option (A) is correct.

> *Explanation:* A Fresnel Biprism is a thin double prism placed base to base.

Q. 2. Base angles of Fresnel biprism are:

(A) 179° **(B)** 90°

(C) 0.50° **(D)** None of these

Ans. Option (C) is correct.

> *Explanation:* A Fresnel Biprism is a thin double prism placed base to base and have very small refracting angle (0.5°).

Q. 3. Fresnel biprism produces:

(A) two real coherent sources.

(B) two virtual coherent sources.

(C) a number of real coherent sources.

(D) a number of virtual coherent sources.

Ans. Option (B) is correct.

> *Explanation:* When monochromatic light through a narrow slit falls on Fresnel biprism that divides it into two components. One of these component is refracted from upper portion of biprism and the other one refracted through lower portion. Thus, two virtual coherent sources formed from the original source.

Q. 4. What is the difference between the coherent sources produced by Young's double slit arrangement and Fresnel biprism?

(A) Young's double slit arrangement produces virtual coherent sources whereas Fresnel biprism produces real coherent sources

(B) Young's double slit arrangement produces coherent point sources whereas Fresnel biprism produces coherent sources which are not point sources

(C) Both Young's double slit arrangement and Fresnel biprism produce similar coherent sources

(D) Fresnel birism produces virtual coherent point sources whereas Young's double slit arrangement produces real coherent sources which are not point sources.

Ans. Option (D) is correct.

> *Explanation:* In Young's double Slits experiment, a single source is split in two coherent sources. Both are real. Both the slits have finite width. Fresnel biprism divides the beam of monochromatic light incident on it into two components. One of these component is refracted from upper portion of biprism and the other one refracted through lower portion. Thus two virtual coherent sources are formed from the original source.

Q. 5. Which problem of Young's double slit experiment is overcome by Fresnel biprism?

(A) Young's double slit arrangement gives rise to irregular interference fringe pattern which is overcome by Fresnel biprism which produces coherent sources by refraction in a prism

(B) Finite width of slits in Young's double slit experiment gives rise to unwanted diffraction effects that causes errors. This is overcome by Fresnel biprism by producing virtual coherent point sources.

(C) Young's double slit arrangement produces interference fringe pattern of low intensity which is overcome by Fresnel biprism.

(D) All of the above

Ans. Option (B) is correct.

> *Explanation:* In Young's double Slits experiment, a single source is split in two coherent sources. For the Young's slits experiment, we must approximate that the slits act as point sources. This however is not the case, since the slits have finite width. In this way, it gives rise to unwanted diffraction effects that causes errors.
>
> The Fresnel biprism experiment overcomes this problem.
>
> When monochromatic light through a narrow slit falls on biprism that divides it into two components. One of these component is refracted from upper portion of biprism and the other one refracted through lower portion. Two virtual coherent point sources are formed from the original source.

II. Read the following text and answer the following questions on the basis of the same:

Diffraction in a hall:

A and B went to purchase a ticket of a music programme. But unfortunately only one ticket was left. They purchased the single ticket and decided that A would be in the hall during the 1st half and B during the 2nd half.

Both of them reached the hall together. A entered the hall and found that the seat was behind a pillar which creates an obstacle. He was disappointed. He thought that he would not be able to hear the programme properly.

B was waiting outside the closed door. The door was not fully closed. There was a little opening. But surprisingly, A could hear the music programme.

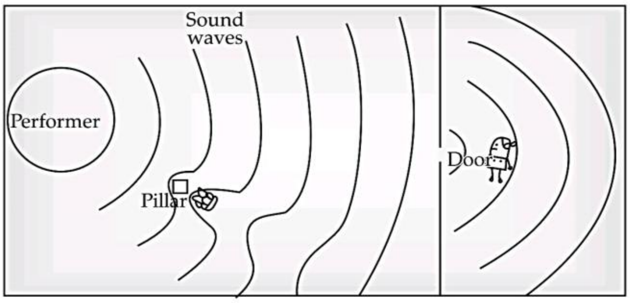
This happened due to diffraction of sound.

The fact we hear sounds around corners and around barriers involves both diffraction and reflection of sound.

Diffraction in such cases helps the sound to "bend around" the obstacles.

In fact, diffraction is more pronounced with longer wavelengths implies that we can hear low frequencies around obstacles better than high frequencies.

B was outside the door. He could also hear the programme. But he noticed that when the door opening is comparatively less he could hear the programme even being little away from the door. This is because when the width of the opening is larger than the wavelength of the wave passing through the gap then it does not spread out much on the other side. But when the opening is smaller than the wavelength more diffraction occurs and the waves spread out greatly – with semicircular wavefront. The opening in this case functions as a localized source of sound.



Q. 1. A and B could hear the music programme due to phenomenon named

(A) interference. (B) scattering.
(C) diffraction. (D) dispersion.

Ans. Option (C) is correct.

> *Explanation:* The fact we hear sounds around corners and around barriers involves both diffraction and reflection of sound.

Q. 2. Diffraction is more pronounced with ______ wavelengths.

(A) Longer (B) Shorter
(C) fluctuating (D) all

Ans. Option (A) is correct.

> *Explanation:* In fact, diffraction is more pronounced with longer wavelengths

Q. 3. The minimum and maximum frequencies in the musical programme were 550 Hz and 10 kHz. Which frequency was better audible around the pillar obstacle?

(A) 10 kHz
(B) 550 kHz
(C) Mid frequency
(D) The complete frequency range

Ans. Option (A) is correct.

> *Explanation:* In fact, diffraction is more pronounced with longer wavelengths implies that you can hear low frequencies around obstacles better than high frequencies.

Q. 4. Diffraction of sound takes place more when :

(A) sound is diffracted through an opening having width equal to the wavelength of the sound.
(B) sound is diffracted through an opening having width more than the wavelength of the sound.
(C) sound is diffracted through an opening having width less than the wavelength of the sound.
(D) diffraction of sound does not depend on the width of the opening.

Ans. Option (C) is correct.

> *Explanation:* When the width of opening is comparatively less than the wavelength of sound wave, the sound spread out much better i.e. better diffraction occurs.
>
> When the width of the opening is larger than the wavelength, the wave passing through the opening does not spread out much on the other side.

Q. 5. How the waveform will look like outside the door of the hall?

(A) Sound repeater
(B) Sound reflector
(C) Localized sound source
(D) None of the above

Ans. Option (C) is correct.

> *Explanation:* Sound spreads out well through a gap whose width is slightly smaller than the wavelength of the sound wave as if it is a localised source of sound.

(B) SUBJECTIVE QUESTIONS

Very Short Answer Type Questions

(1 Mark Each)

Q. 1. What is the phase difference between two points on the same wavefront? R [O.E.B.]

Ans. Phase difference between two points on the same wavefront is zero. 1

Q. 2. What is the type of wavefront generated from

(a) Line source

(b) Point source? R [O.E.B.]

Ans. (a) Cylindrical wavefront is generated from a line source. ½

(b) Spherical wavefront is generated from a near point source. Plane wavefront is generated from a far away point source. ½

Q. 3. Can Huygen's theory explain the photoelectric effect? R [O.E.B.]

Ans. No, Huygen's theory cannot explain the photoelectric effect. 1

AI **Q. 4. When a wave undergoes reflection at an interface from rarer to denser medium, what is the adhoc change in its phase?**

U [CBSE OD SET 1, 2020 / MODIFIED]

Ans. The adhoc change in its phase is π. 1

Q. 5. A plane wavefront is incident on a convex lens. What will be the shape of the wave front emerging from the lens ? U [O.E.B.]

Ans. Emerging wavefront will be spherical. 1

Q. 6. A point source is kept at the focus of a concave mirror. The spherical wavefront emitted by the source get reflected by the mirror. What is the shape of the reflected wavefronts ? U [O.E.B.]

Ans. Reflected wavefronts are plane wavefronts. 1

Q. 7. In a Young's double-slit experiment, the source is white light. One of the holes is covered by a red filter and another by a blue filter.

What will be the change in interference fringes ? U [O.E.B.]

Ans. For sustained interference, the source must be coherent and should emit the light of same frequency.

In this problem, one hole is covered with red and other with blue, which has different frequency, so no interference takes place. 1

Q. 8. Two coherent monochromatic light beams of intensities I and 4I superimpose.

What will be the maximum and minimum intensities ? A [O.E.B.]

Ans. $I_{max} = I_1 + I_2 + 2\sqrt{I_1 \times I_2} = 9I$ ½

$I_{min} = I_1 + I_2 - 2\sqrt{I_1 \times I_2} = I$ ½

Q. 9. The ratio of intensities of two waves is 1: 25, what is the ratio of their amplitudes? A [O.E.B.]

Ans. 1: 5 1

Q. 10. Why does the intensity of the secondary maximum become less as compared to the central maximum? U [O.E.B.]

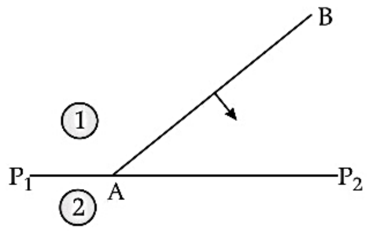
Ans. Since, the intensity of n^{th} order maximum is inversely proportional to n, the secondary maximum is less bright as compared to the central maximum. 1

Short Answer Type Questions-I

(2 Marks Each)

AI **Q. 1. Define the term 'wavefront of light'. A plane wave front AB propagating from denser medium (1) into a rarer medium (2) is incident on the surface P_1P_2 separating the two media as shown in fig.**

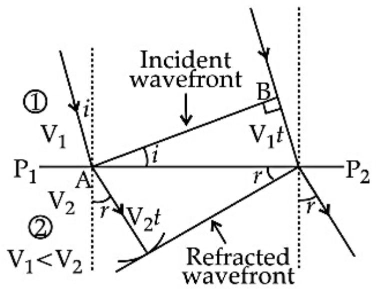
Using Huygen's principle, draw the secondary wavelets and obtain the refracted wavefront in the diagram.



R [CBSE DEL SET I, 2020]

Ans. Wavefront: Wavefront is an imaginary surface over which an optical wave has a constant phase. 1

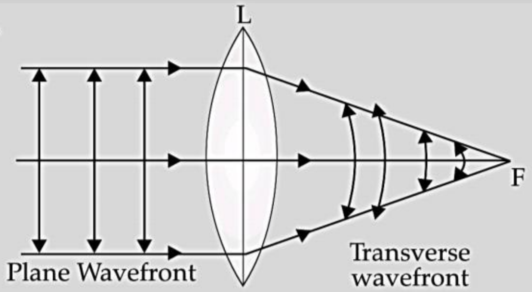
Refraction of light from denser medium to rarer medium:



1

Q. 2. Based on Huygens construction, draw the shape of a plane wavefront as it gets refracted on passing through a convex lens. U [Foreign Comptt. 2016]

Ans.



2

[CBSE Marking Scheme, 2016]

Q. 3. Define secondary wavelets and how can we construct new wavefront with them ? R [O.E.B.]

Ans. According to the Huygens' principle, every particle of the medium, situated on the wavefront, acts as a new source of light wave from which new similar waves originate. These waves are called secondary wavelets. 1

The envelop of the secondary wavelets in the forward direction at any instant gives the new wavefront at that instant. 1

Q. 4. Define the term wavefront. State Huygen's principle. [O.E.B.]

Ans. **Wave front:** Try it yourself Similar to Q. 1. of Short Answer Type Questions - I. 1

Huygens' Principle: Each point of the wavefront is the source of a secondary disturbance and the wavelets emanating from these points spread out in all directions. These travel with the same velocity as that of the original wavefront. 1

Commonly Made Errors

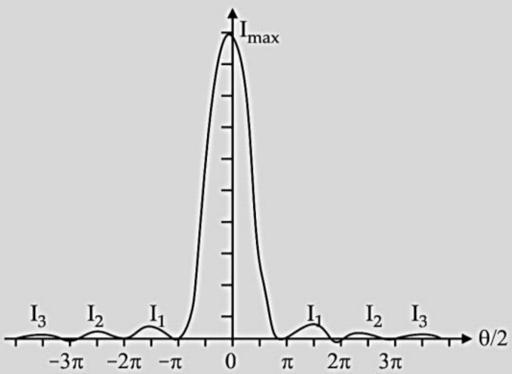
- **(i)** Many students couldn't define wavefront.
  (ii) Many students couldn't write all points of Huygens' principle.

Answering Tip

- The concepts of wavefront and Huygens' principle should be properly revised.

Q. 5. Draw the graph showing intensity distribution of fringes with phase angle due to diffraction through single slit. R [SQP 2020-21]

Ans. Plot of Intensity distribution of diffraction with proper labelling.



2

[CBSE Marking Scheme, 2021]

Q. 6. What should be the width of each slit to obtain n maxima of double slit pattern within the central maxima of single slit pattern? A [SQP 2020-21]

Ans. Let the width of each slit be a

The separation between m maxima in a double slit experiment = y_m

$$y_m = m\frac{\lambda D}{d}$$

D = Distance between screen and slit

d = Separation between slits.

Angular separation between m maxima = θ_m

$$\theta_m = y_m/D = \frac{\lambda m}{d}$$

Now,

Angular separation between n bright fringes = θ_n 1

$$\theta_n = \frac{\lambda m}{d} \quad ...(i)$$

The angular width of central maximum in the diffraction pattern due to single slit = θ_n

$$2\theta_1 = 2\frac{\lambda}{a} \quad ...(ii)$$

a = width of single slit

Equating (i) and (ii)

$$\frac{n\lambda}{d} = 2\frac{\lambda}{a}$$

$\therefore$ $a = 2d/n$ 1

Q. 7. In a single slit diffraction experiment, width of the slit is increased. How will the (a) size and (b) intensity of central bright band be affected? Justify your answer. U [CBSE DELHI SET 1, 2020]

Ans. The width of the central bright band $= 2D\times\frac{\lambda}{d}$

where d = width of the slit.

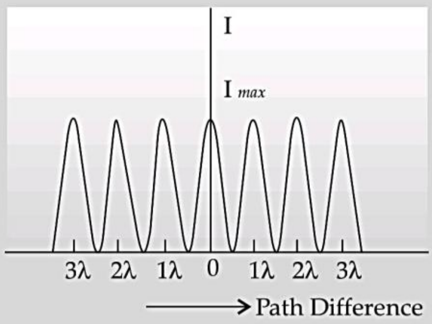
(i) As the width of the slit is doubled, the size of the central diffraction band will be half. 1

(ii) Intensity of central bright band is proportional to d^2.

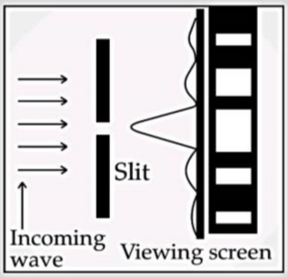
So, the intensity will get quadrupled. 1

AI **Q. 8. Draw the intensity pattern for single slit diffraction and double slit interference. Hence, state two differences between interference and diffraction patterns.** R [CBSE OD, Foreign 2017]

Ans.



½



½

Differences:

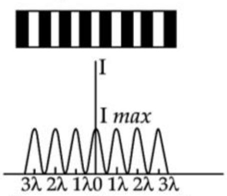
Interference	Diffraction
All maxima have equal intensity	Maxima have different (rapidly decreasing) intensities
All fringes have equal width	All fringes have different (changing) width
Superposition of two wavefronts	Superposition of wavelets from the same wavefront

½+½ (Any two)

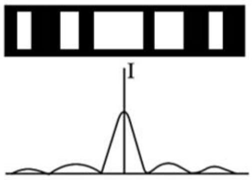
[CBSE Marking Scheme, 2017]

Detailed Answer:

Intensity Pattern:



Inteference fringe pattern



Diffraction fringe pattern

½+½

Difference between Interference and Diffraction:

Interference	Diffraction
Fringe width is constant.	Fringe width varies.
Fringes are obtained with the coherent light coming from two slits.	Fringes are obtained with the monochromatic light coming from single slit.
It is superposition of waves.	It is superposition of many waves.
It depends upon the distance between two openings.	It depends upon the aperture of single slit opening.
Many fringes are visible.	Fewer fringes are visible.
All fringes are of same brightness.	Central fringe has maximum brightness so it reduces gradually.

(Any two) ½ + ½

Commonly Made Error

- Some students do not know the correct difference between interference of light and diffraction of light.

Answering Tip

- The diagrams of the interference and the diffraction should be carefully observed.

Q. 9. A narrow slit is illuminated by a parallel beam of monochromatic light of wavelength λ equals to 6000 Å and the angular width of the central maxima in the resulting diffraction pattern is measured. When the slit is next illuminated by light of wavelength λ′, the angular width decreases by 30%. Calculate the value of the wavelength λ′.

A [SQP 2018-19]

Ans. Angular width, $2\theta = 2\lambda/d$ ½

Given, $\lambda = 6000$ Å

In case of new wavelength (assumed λ′ here), angular width decreases by 30% ½

$$= \left(\frac{100-30}{100}\right)2\theta$$

$$= 0.70\,(2\theta) \quad ½$$

$$\frac{2\lambda'}{d} = 0.70 \times (2\lambda/d)$$

$$\therefore \quad \lambda' = 4200 \text{ Å} \quad ½$$

Q. 10. A parallel beam of light of 500 nm falls on a narrow slit and the resulting diffraction pattern is observed on a screen 1 m away. It is observed that the first minima is at a distance of 2.5 mm from the centre of the screen. Calculate the width of the slit.

A [O.E.B.]

Ans. The distance of the 1st minima from the centre of the screen is,

$$x_1 \text{ dark} = \frac{D\lambda}{a}$$

where, D = Distance of slit from screen,

λ = Wavelength of the light,

a = Width of the slit. ½

According to question,

$D = 1$ m

$\lambda = 500$ nm

height of first minima = 2.5 mm ½

$$2.5 \times 10^{-3} = \frac{1 \times 500 \times 10^{-9}}{a}$$

$$\Rightarrow \quad a = 2 \times 10^{-4} \text{ m} = 0.2 \text{ mm}$$

$$a = 0.2 \text{ mm.} \quad 1$$

Commonly Made Errors

- Number of candidates use incorrect formula.
- Some of the students do not know the correct meaning of the symbols *i.e.*, '*D*' and '*d*', hence they interchanged them.
- Some students do not convert 'nm' to m as well as 'mm' to m.

Answering Tip

- While solving the numerical, the values should be put in SI units and calculations should be done properly.

Short Answer Type Questions-II

(3 Marks Each)

AI **Q. 1. Define the term wavefront. Using Huygen's wave theory, verify the law of reflection.**
R & A **[CBSE DELHI SET I, 2018]**

Ans. Definition of the wavefront 1

Verification of the law of Reflection 2

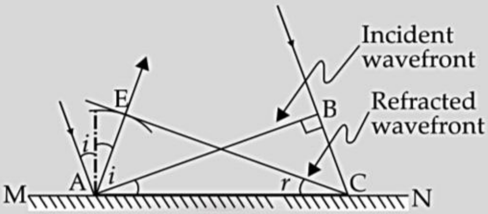
Wave Front: Try it Yourself. See Q1. of Short Answer Type Questions - I. 1

Consider a plane wave AB incident at an angle 'i' on a reflecting surface MN

let t = time taken by the wave front to advance from B to C.

$\therefore \quad BC = vt$

Let CE represent the tangent plane drawn from the point C to the sphere of radius 'vt' having A as its center.



1

then $\quad AE = BC = vt$ ½

it follows that

$$\Delta EAC \cong \Delta BAC$$

Hence $\angle i = \angle r$ ½

$\therefore$ Angle of incidence = angle of reflection

[CBSE Marking Scheme, 2019]

AI **Q. 2. Define the term, "refractive index" of a medium. Verify Snell's law of refraction when a plane wavefront is propagating from a denser to a rarer medium.** R & A **[CBSE DELHI SET 1, 2019]**

Ans. Definition of the refractive index 1

Verification of laws of refraction 2

The refractive index of medium 2, with respect to medium 1 is equal to the ratio of the sine of angle of incidence (in medium 1) to the sine of angle of refraction (in medium 2). 1

Alternatively,

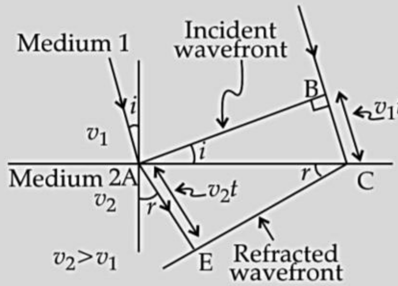
Refractive index of medium 2 w.r.t. medium 1

$$n_{21} = \frac{\sin i}{\sin r}$$

Alternatively,

Refractive index of medium 2 w.r.t. medium 1 1

$$n_{21} = \frac{\text{velocity of light in medium 1}}{\text{velocity of light in medium 2}}$$



The figure drawn here shows the refracted wave front corresponding to the given incident wave front.

It is seen that

$$\sin i = \frac{BC}{AC} = \frac{v_1 t}{AC}$$ ½

$$\sin r = \frac{AE}{AC} = \frac{v_2 t}{AC}$$

$$\therefore \quad \frac{\sin i}{\sin r} = \frac{v_1}{v_2} = \mu_{21}$$ ½

This is Snell's law of refraction.

[CBSE Marking Scheme, 2019]

AI **Q. 3. (a) Compare Maxwell's electromagnetic theory with Huygens wave theory of light.**

(b) Define incident angle of a light wave. R

Ans. (a) Both theories treat light as a wave in nature. However, as per the electromagnetic theory, light does not need any medium to propagate while for Huygens' wave theory, a medium is must. That is why, he assumed a hypothetical medium 'ether' through which light wave travels in vacuum. 2

(b) Angle between incident wavefront with the interface is called the incident angle of light wave. 1

Q. 4. (a) If one of two identical slits producing interference in Young's experiment is covered with glass, so that the light intensity passing through it is reduced to 50%, find the ratio of the maximum and minimum intensity of the fringe in the interference pattern.

(b) What kind of fringes do you expect to observe if white light is used instead of monochromatic light? U **[CBSE 2018]**

Ans. (a) Finding the (modified) ratio of the maximum and minimum intensities 2

(b) Fringes obtained with white light 1

(a) After the introduction of the glass sheet (say, on the second slit), we have — = 50% = $\frac{1}{2}$ ½

∴ Ratio of the amplitudes

$$= \frac{a_2}{a_1} = \sqrt{\frac{1}{2}} = \frac{1}{\sqrt{2}}$$ ½

Hence $\frac{I_{max}}{I_{min}} = \left(\frac{a_1 + a_2}{a_1 - a_2}\right)^2$

$$= \left(\frac{1+\frac{1}{\sqrt{2}}}{1-\frac{1}{\sqrt{2}}}\right)^2 = \left(\frac{\sqrt{2}+1}{\sqrt{2}-1}\right)^2$$ ½

$(\simeq 34)$ ½

(b) The central fringe remains white.

No clear fringe pattern is seen after a few (coloured) fringes on either side of the central fringe. 1

[Note: For part (a) of this question,

The student may

(i) Just draw the diagram for the Young's double slit experiment.

OR

(ii) Just state that the introduction of the glass sheet would introduce an additional phase difference and the position of the central fringe would shift.

For all such answers, the student may be awarded the full (2) marks for this part of this question.

[CBSE Marking Scheme, 2018]

Long Answer Type Questions

(6 Marks Each)

Q. 1. (a) Use Huygens' geometrical construction to show how a plane wave front at t = 0 propagates and produces a wave front at a later time.

(b) Verify, using Huygens' principle, Snell's law of refraction of a plane wave propagating from a denser to a rarer medium.

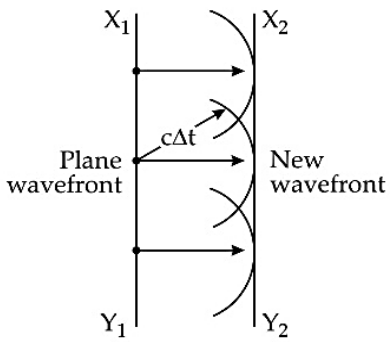
(c) When monochromatic light is incident on a surface separation two media, the reflected and refracted light both have the same frequency. Explain why?

U & A [O.E.B.]

Ans. (a) Let us consider a plane wavefront X_1Y_1 at t = 0.

According to Huygen's principle each point on this wavefront may be considered as a point source.

points are considered for the convenience of drawing. 3 circular arcs are drawn centring each point with radius $c\Delta t$ where c is the velocity of light and Δt is the time difference. A common tangent is drawn to these 3 arcs which gives the new wavefront X_2Y_2 parallel to X_1Y_1 after time Δt.



2

(b) Try yourself. See Q. No. 2 of Short Answer Type Questions II. 2

(c) Both reflection and refraction occur due to interaction of light interaction of corpuscles of incident light and the atoms of matter at the surface of separation. Light incident on such atoms forces them to vibrate with the frequency of light.

According to Maxwell's classical theory, the frequency of light emitted by such oscillation is same as its frequency of oscillation. Hence, both the reflected and refracted lights have the same frequency as the frequency of incident light. 1

AI **Q. 2. (a) Describe any two characteristic features which distinguish interference and diffraction phenomena. Derive the expression for the intensity at a point of the interference pattern in Young's double slit experiment.**

(b) In the diffraction due to a single slit experiment, the aperture of the slit is 3 mm. If monochromatic light of wavelength 620 nm is incident normally on the slit, calculate the separation between the first order minima and the third order maxima on one side of the screen. The distance between the slit and the screen is 1.5 m.

R & A **[CBSE DELHI SET 1, 2019]**

Ans. (a) Two characteristic features of distinction **2**

Derivation of the expression for the intensity **1½**

(b) Calculation of separation between the first order **1½**

(a) Characteristics features of distinction:

Try yourself. See Q. 8 of Short Answer Type Questions -I **2**

Derivation of expression for intensity:

In interference pattern, the first maximum falls at an angle of $\frac{\lambda}{a}$. where a is the separation between two narrow slits, while in diffraction pattern, at the same angle first minimum occurs. (where 'a' is the width of single slit.)

Displacement produced by source S_1

$$Y_1 = a \cos \omega t$$

Displacement produced by the other source 'S_2' ½

$$Y_2 = a \cos (\omega t + \phi)$$

Resultant displacement, $Y = Y_1 + Y_2$

$$= a[\cos \omega t + \cos (\omega t + \phi)$$

$$= 2a\cos\left(\frac{\phi}{2}\right) \cos (\omega t + \frac{\phi}{2})$$ ½

Amplitude of resultant wave

$$A = 2a\cos\left(\frac{\phi}{2}\right)$$

Intensity $I \propto A^2$

$$I = KA^2 = K4a^2\cos^2\left(\frac{\phi}{2}\right)$$ ½

(b) Distance of first order minima from centre of the central maxima $= X_{D_1} = \frac{\lambda D}{a}$ ½

Distance of third order maxima from centre of the central maxima, $X_{B_3} = \frac{7D\lambda}{2a}$ ½

$\therefore$ Distance between first order minima and third order maxima $= X_{B_3} - X_{D_1}$

$$= \frac{7D\lambda}{2a} - \frac{\lambda D}{a}$$

$$= \frac{5D\lambda}{2a}$$

$$= \frac{5 \times 620 \times 10^{-9} \times 1.5}{2 \times 3 \times 10^{-3}}$$

$$= 775 \times 10^{-6} \text{m}$$

$$= 7.75 \times 10^{-4} \text{m}$$ ½

[CBSE Marking Scheme, 2019]

AI **Q. 3. (a) Define a wavefront. Using Huygens' principle, verify the laws of reflection at a plane surface.**

(b) In a single slit diffraction experiment, the width of the slit is made double the original width. How does this affect the size and intensity of the central diffraction band ? Explain.

(c) When a tiny circular obstacle is placed in the path of light from a distant source, a bright spot is seen at the centre of the obstacle. Explain why.

R & U [CBSE 2018]

Ans. (a) Definition of wavefront ½

Verification of laws of reflection 2

(b) Explanation of the effect on the size and intensity of central maxima 1+ 1

(c) Explanation of the bright spot in the shadow of the obstacle ½

(a) Try yourself. See Q. No. 1 of 3 Marks Questions. 2½

(b) Size of central maxima reduces to half, ½

($\therefore$ Size of central maxima $= 2\frac{2\lambda D}{\alpha}$)

Intensity increases. ½

This is because the amount of light, entering the slit, has increased and the area, over which it falls, decreases. ½

(Also accept if the student just writes that the intensity becomes four fold)

(c) This is because of diffraction of light. ½

[Alternatively: Light gets diffracted by the tiny circular obstacle and reaches the centre of the shadow of the obstacle.] ½

[Alternatively: There is a maxima, at the centre of the obstacle, in the diffraction pattern produced by it.]

[CBSE Marking Scheme, 2018]

Q. 4. (a) Explain two features to distinguish between the interference pattern in Young's double slit experiment with the diffraction pattern obtained due to a single slit.

(b) A monochromatic light of wavelength 500 nm is incident normally on a single slit of width 0.2 mm to produce a diffraction pattern. Find the angular width of the central maximum obtained on the screen.

Estimate the number of fringes obtained in Young's double slit experiment with angular fringe width 0.5, which can be accommodated within the region of total angular spread of the central maximum due to single slit.

R [CBSE DELHI SET I, 2017]

Ans. (a) Explanation of two features (distinguishing between interference pattern and diffraction pattern.) 2

(b) Calculation of angular width of central maxima 2

Estimation of number of fringes 1

(a) Try yourself. See Q. 8 of Short answer Type Questions - I. 2

(b) Angular width of central maximum,

$$\omega = \frac{2\lambda}{a}$$

$$= \frac{2 \times 500 \times 10^{-9}}{0.2 \times 10^{-3}} \text{ radian}$$

$$= 5 \times 10^{-3} \text{ radian}$$

$$\beta = \frac{\lambda D}{d}$$ **1**

Linear width of central maxima in the diffraction pattern

$$\omega' = \frac{2\lambda D}{a}$$ **½**

Let 'n' be the number of interference fringes which can be accommodated in the central maxima

$$\therefore \quad n \times \beta = \omega'$$

$$n = \frac{2\lambda D}{a} \times \frac{d}{\lambda D}$$

$$n = \frac{2d}{a}$$ **1½**

[Note: Award the last ½ mark if the student writes the answers as 2 (taking $d = a$), or just attempts to do these calculation.]

[CBSE Marking Scheme, 2017]

AI Q. 5. (a) In Young's double slit experiment, deduce the condition for (a) constructive, and (b) destructive interference at a point on the screen. Draw a graph showing variation of intensity in the interference pattern against position 'x' on the screen.

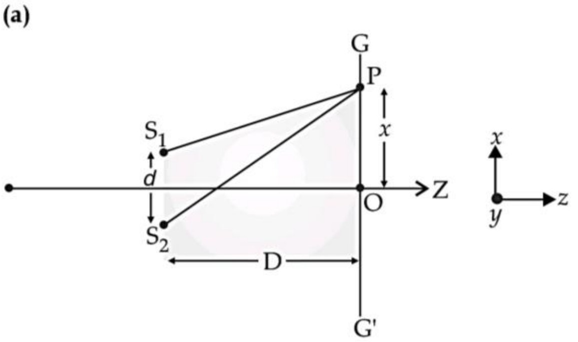
(b) Compare the interference pattern observed in Young's double slit experiment with single slit diffraction pattern, pointing out three distinguishing features. R **[CBSE DELHI SET 1, 2016]**

Ans. (a) Deduce the conditions for (a) constructive and (b) destructive interference **2½**

Graph showing the variation of intensity **1**

(b) Three distinguishing features. **1½**

(a)



½

From figure,

Path difference $= (S_2P - S_1P)$

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

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

$$\Rightarrow \quad S_2P - S_1P = \frac{2xd}{(S_2P + S_1P)}$$ **½**

For $x, d << D$

$$S_2P - S_1P = \frac{2xd}{2D} = \frac{xd}{D}$$ **½**

For constructive interference,

$$S_2P - S_1P = n\lambda, \quad n = 0, 1, 2......$$

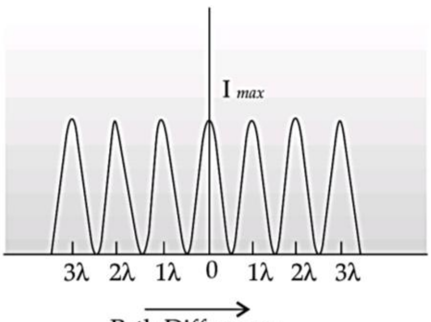
$$\Rightarrow \quad \frac{xd}{D} = n\lambda$$

$$x = \frac{n\lambda D}{d}$$ **½**

For destructive interference,

$$S_2P - S_1P = (2n+1)\frac{\lambda}{2} \quad n = 0, 1, 2, ...$$

$$\Rightarrow \quad \frac{xd}{D} = (2n+1)\frac{\lambda}{2}$$



1

$$\Rightarrow \quad x = (2n+1)\frac{\lambda D}{2d}$$ **½**

(b) Try yourself. See Q. No. 8 of Short answer Type Questions - I. **1½**

Q. 6. (a) State the essential conditions for diffraction of light.

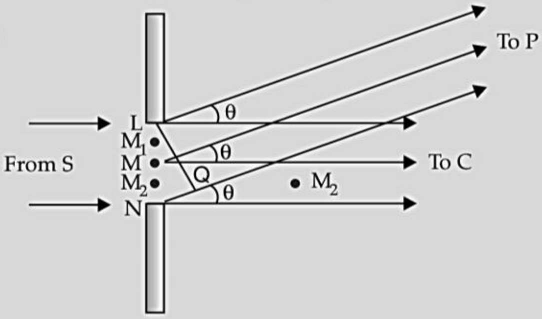
(b) Explain diffraction of light due to a narrow single slit and the formation of pattern of fringes on the screen.

(c) Find the relation for width of central maxima in terms of wavelength 'λ', width of slit 'a', and separation between slit and screen 'D'.

(d) If the width of the slit is made double the original width, how does it affect the size and intensity of the central band ? R & A **[CBSE Foreign 2016]**

Ans. (a) Size of slit/aperture must be smaller than that of the order of wavelength of light. **1**

(b)



½

Single slit diffraction is explained by treating different parts of the wavefront at the slit as sources of secondary wavelets. ½

At the central point C on the screen, θ is zero. All path differences are zero and hence all the parts of the slit contribute in phase and give maximum intensity at C.

At any other point P, the path difference between two edges of the slit is

$$NP - LP = NQ.$$
$$= a\sin\theta \approx a\theta \quad \because \sin\theta \text{ is small}$$

Any point P, in direction θ, is a location of minima if $a\theta = n\lambda$

This can be explained by dividing the slit into even number of parts. The path difference between waves from successive parts is 180° out of phase and hence cancel each leading to a minima. ½

Any point P, in direction Q, is a location of maxima

if $$a\theta = \left(n+\frac{1}{2}\right)\lambda$$

This can be explained by dividing the slit into odd number of parts. The contributions from successive parts cancel in pairs because of 180° phase difference. The unpaired part produces intensity at P, leading to a maxima.

(c) If θ is the direction of first minima, then ½

$$a\theta = \lambda$$

$$\Rightarrow \quad \theta = \frac{\lambda}{a}$$

Angular width of central maxima = 2θ

$$= \frac{2\lambda}{\alpha}$$ ½

Linear width of central maxima,

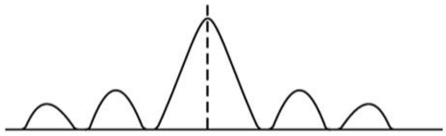
$$\beta = \frac{2\lambda D}{a} = 2\theta \times D$$ ½

(d) If 'a' is doubled, β becomes half ½

Intensity becomes 4 times. ½

[CBSE Marking Scheme, 2016]

Q. 7. When a plane wave front of light, of wavelength λ, is incident on a narrow slit, an intensity distribution pattern, of the form shown is observed on a screen, suitably kept behind the slit. Name the phenomenon observed.



(a) Obtain the conditions for the formation of central maxima and secondary maxima and the minima.

(b) Why there is significant fall in intensity of the secondary maxima compared to the central maxima, where as in double slit experiment all the bright fringes are of the same intensity ?

(c) When the width of the slit is made double the original width, how is the size of the central band affected ? U **[O.E.B.]**

Ans. The phenomenon observed is diffraction. ½

(a) At the central maxima: The contributions due to the secondary wavelets, from all parts of the wave front (at the slit), arrive in phase at the central maxima θ = 0

At the secondary maxima:

It is the contribution from (nearly) 1/3 (or 1/5, or 1/7,...) of the secondary maxima. These occur at points for which **1**

$$\theta \cong \left(n+\frac{1}{2}\right)\frac{\lambda}{a} \quad (n = 0, 1, 2, 3, ...)$$ ½

At the minima:

The contribution, from 'corresponding pairs', of the sub-parts of the incident wavefront, cancel each other and the net contribution, at the location of the minima, is zero. The minima occur at points for which, $$\theta = n\frac{\lambda}{a} \quad (n = 1, 2, 3, ...)$$ **1**

[**Note:** Award these (1 + 1 + 1) marks if the student draws the diagram and writes the conditions, for θ, for the three cases.]

(b) There is a significant fall in intensity at the secondary maxima because the intensity is only due to the contribution of (nearly)(1/3 or 1/5 or 1/7,......) of the incident wavefronts. **1**

(c) Try it yourself. See Q. No. 6(iv) of 5 Marks Question. **1**

[CBSE Marking Scheme, 2016]

Q. 8. (a) Why cannot the phenomenon of interference be observed by illuminating two pin holes with two sodium lamps ?

(b) Two monochromatic waves having displacements $y_1 = a \cos \omega t$ and $y_2 = a \cos (\omega t + \varphi)$ from two coherent sources interfere to produce an interference pattern. Derive the expression for the resultant intensity and obtain the conditions for constructive and destructive interference.

(c) Two wavelengths of sodium light of 590 nm and 596 nm are used in turn to study the diffraction taking place at a single slit of aperture 2×10^{-6} m. If the distance between the slit and the screen is 1.5 m, calculate the separation between the positions of the second maxima of diffraction pattern obtained in the two cases.

U & A [CBSE O.D. I,II, 2019]

Ans. • **Reason** ½

• **Deriving the expression for resultant intensity and condition for constructive and destructive interference** 1½+½+½

• **Calculating the separation** 2

(a) Because two independent sources cannot be coherent OR they are not coherent. ½

(b)
$$y_1 = a\cos \omega t$$
$$y_2 = a\cos (\omega t + \phi)$$

So resultant displacement is give by

$$y = y_1 + y_2$$
$$y = a\cos \omega t + a\cos (\omega t + \phi)$$
$$y = 2a\cos (\phi/2) \cos(\omega t + \phi/2)$$

The amplitude of the resultant displacement is $2a\cos(\phi/2)$ and therefore intensity at that point will be $I = 4I_0 \cos^2 (\phi/2)$ 1

For constructive interference:

$$\phi = 0, \pm 2\pi, \pm 4\pi, ...$$ ½

For destructive interference:

$$\phi = 0, \pm \pi, \pm 3\pi, \pm 5\pi, ...$$ ½

(c) Position of second maxima,

$$y_2 = \frac{5}{2}\frac{\lambda D}{a}$$ ½

Separation between the positions of the second maxima with λ_1 and λ_2 is:

$$\Delta y = \frac{5D(\lambda_2 - \lambda_1)}{2a}$$ 1

$$= \frac{5 \times 1.5 \times (596 - 590) \times 10^{-9}}{2 \times 2 \times 10^{-6}}$$

$$= 11.25 \times 10^{-3} \text{m}$$ 1

[CBSE Marking Scheme, 2019]

Detailed Answer:

(a) The interference phenomenon can not be observed by using two illuminating pin holes with two sodium lamps because the light emitted from sodium lamps undergoes abrupt phase changes in 10^{-10} s which will not have any fixed phase relationship as they are incoherent. 1

(b) The displacement equations for two monochromatic waves are given as

$$y_1 = a\cos \omega t$$

and $y_2 = a\cos (\omega t + \phi)$

Now, net displacement

$$y = y_1 + y_2$$
$$= a\cos \omega t + a\cos (\omega t + \phi)$$
$$= a\cos \omega t + a\cos \omega t \cos \phi - a\sin \omega t. \sin \phi$$
$$= a\cos \omega t (1 + \cos \phi) - a\sin \omega t. \sin \phi$$

put $\alpha(1 + \cos \phi) = A\sin \theta$ ...(i)

and $-\alpha\sin \phi = A\cos \theta$ ...(ii)

$\therefore$ $y = A\sin \theta. \cos \omega t + A\cos \theta \sin \omega t$

$$y = A\sin (\omega t + \theta)$$

Now, from equation (i) and (ii),

$$A^2(\sin^2\theta + \cos^2\theta) = [\alpha(1 + \cos \phi)]^2 + (-\alpha\sin \phi)^2$$
$$A^2 = \alpha^2[1 + \cos^2\phi + 2\cos \phi + \sin^2\phi]$$
$$A^2 = 2\alpha^2 [1 + \cos \phi]$$
$$A^2 = 4\alpha^2 \cos^2 \frac{\phi}{2}$$

This is the required expression.

For constructive interference, I should be maximum

$$I_{max} = 4\alpha^2, \text{ if } \phi = 0, \pm 2\pi, \pm 4\pi...$$

For destructive interference, I should be minimum

$$I_{min} = 0, \text{ if } \phi = \pm \pi, \pm 3\pi, \pm 5\pi....$$ 2

(c) Wavelengths of sodium light,

$$\lambda_1 = 590 \text{ nm and } \lambda_2 = 596 \text{ nm}$$

The general expression for n^{th} secondary maxima is given as

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

The separation between the position of second maxima

$$\beta = (\lambda_1 - \lambda_2)\frac{5D}{2a}$$

Here, $D_\beta = 1.5$ m and $a = 2.0 \times 10^{-6}$ m

$$\beta = \frac{(596-590)\times 10^{-9} \times 1.5 \times 5}{2 \times (2.0 \times 10^{-6})}$$

$$\beta = 11.25 \times 10^{-3} \text{ m}$$

$$\beta = 11.25 \text{ mm.}$$