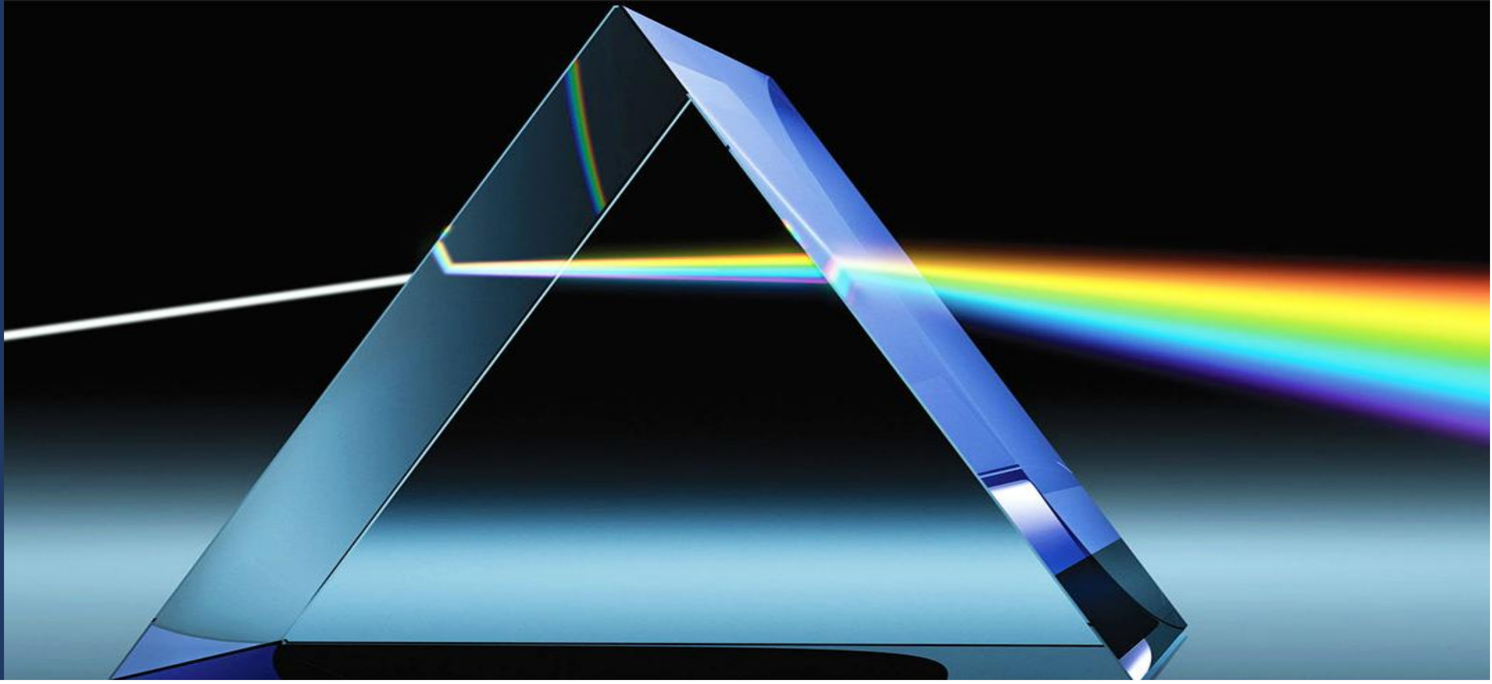


WAVE OPTICS

CHAPTER – 10

WAVE OPTICS

Newton's Corpuscular Theory of Light

This theory was given by Newton

Characteristics of the theory

(i) Extremely minute, very light and elastic particles are being constantly emitted by all luminous bodies (light sources} in all directions which are known as corpuscles.

(ii) These corpuscles travel with the speed of light.

(iii) When these corpuscles strike the retina of our eye then they produce the sensation of vision.

(iv) The velocity of these corpuscles in vacuum is 3 × 108 m/s.

(v) The different colours of light are due to different size of these corpuscles.

(vi) The rest mass of these corpuscles is zero.

(vii) The velocity of these corpuscles in an isotropic medium is same in all directions but it changes with the change of medium.

(viii) These corpuscles travel in straight lines.

(ix) These corpuscles are invisible.

The phenomena explained by this theory

(i) Reflection and refraction of light.

(ii) Rectilinear propagation of light.

(iii) Existence of energy in light.

The phenomena not explained by this theory

(i) Interference, diffraction, polarization, double refraction and total internal reflection.

(ii) Velocity of light being greater in rarer medium than that in a denser medium.

(iii) Photoelectric effect and Compton effect.

Huygens's Wave Theory of Light

This theory was enunciated by Huygens in a hypothetical medium known as luminiferrous ether.

Ether is that imaginary medium ·which prevail~ in all space and is isotropic, perfectly elastic and massless.

The velocity of light in a medium is constant but changes with change of medium.

This theory is valid for all types of waves.

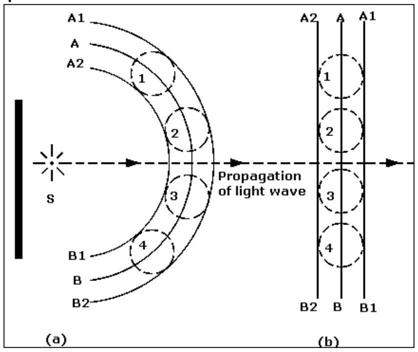
(i) The locus of all ether particles vibrating in same phase is known as wavefront.

(ii) Light travels in the medium in the form of wavefront.

(iii) When light travels in a medium then the particles of medium start vibrating and consequently a disturbance is created in the medium. ·

(iv) Every point on the wavefront becomes the source of secondary wavelets. It emits secondary wavelets in all directions which travel with the speed of light.

(v) The tangent plane to these secondary wavelets represents the new position of wave front.



The phenomena explained by this theory

(i) Reflection, refraction, interference, diffraction.

(ii) Rectilinear propagation of light

(iii) Velocity of light in rarer medium being greater than that in denser medium.

Phenomena not explained by this theory

(i) Photoelectric effect and Raman effect.

Wavefront

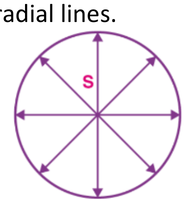
The locus of all the particles vibrating in the same phase in known as wavefront.

Types of wavefronts

The shape of wavefront depends upon the shape of the light source from, the wavefront originates. On this basis there are three types of wavefronts.

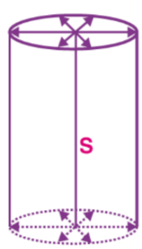
(i) Spherical Wavefront:

If the waves in a medium are originating from a point source, then they propagate in all directions. If we draw a spherical surface centered at point-source, then all the particles of the medium lying on that spherical surface will be in the same phase, because the disturbance starting from the source will reach all these points simultaneously. Hence in this case, the wavefront will be spherical and the rays will be the radial lines.



(ii) Cylindrical Wavefront:

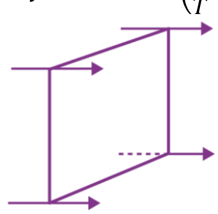
If the waves in a medium are originating from a line source, then they too propagate in all directions. In this case the locus of particles vibrating in the same phase will be a cylindrical surface. Hence in this case the wavefront will be cylindrical.



(iii) Plane Wavefront:

At large distance from the source, the radii of spherical or cylindrical wavefront will be too large and a small part of the wavefront will appear to be plane. At infinite distance from the source, the wavefronts are always plane and the rays are parallel straight lines.

$$y = a\sin 2\pi\left(\frac{t}{T} - \frac{x}{\lambda}\right)$$



Characteristic of wavefront

The phase difference between various particles on the wavefront is zero.

These wavefronts travel with the speed of light in all directions in an isotropic medium.

A point source of light always gives rise to a spherical wavefront in an isotropic medium.

In anisotropic medium it travels with different velocities in different directions.

Normal to the wavefront represents a ray of light.
It always travels in the forward direction in the medium.

Coherent And Incoherent Sources of Light

The sources of light emitting waves of same frequency having zero or constant initial phase difference are called coherent sources. The sources of light emitting waves with a random phase difference are called incoherent sources. For interference phenomenon, the sources must be coherent. Methods of Producing Coherent Sources: Two independent sources can never be coherent sources. There are two broad ways of producing coherent sources for the same source.

(i) **By division of wavefront:** In this method the wavefront (which is the locus of points of same phase) is divided into two parts. The examples are young's double slit and Fresnel's biprism.

(ii) **By division of amplitude:** In this method the amplitude of a wave is divided into two parts by successive reflections, e.g., Lloyd's single mirror method.

Interference Of Light

When two light waves having same frequency and equal or nearly equal amplitude are moving in the same direction superimpose then different points have different light intensities. At some point the intensity of light is maximum and at some paint it is minimum this phenomenon is known as interference of light.

Phasor diagram

By right angle triangle:
$A^2 = (a_1 + a^2 \cos\phi)^2 + (a^2 \sin\phi)^2$

Resultant amplitude $A' = \sqrt{a_1^2 + a_2^2 + 2a_1a_2\cos\phi}$

Phase angle $\phi = \tan^{-1}\left(\dfrac{a_2\sin\phi}{a_1 + a_2\cos\phi}\right)$

Intensity $\propto$ (Amplitude)$^2 \Rightarrow \propto A^2 \Rightarrow I = KA^2$

So, $I_1 = Ka_1^2$ and $I_2 = Ka_2^2$

$$\therefore \quad I = I_1 + I_2 + 2\sqrt{I_1}\sqrt{I_2}\cos\phi$$

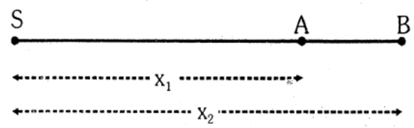
Here, $2\sqrt{I_1}\sqrt{I_2}\cos\phi$ is known as interference factor

If the distance of a source from two points A and B is x_1 and x_2 then Phase difference

$$\phi = \frac{2\pi}{\lambda}(x_2 - x_1)$$

$$\Rightarrow \phi = \frac{2\pi}{\lambda}\delta$$

Time difference $\Delta t = \dfrac{\phi}{2\pi} t$



$$\frac{Phase\ difference}{2\pi} = \frac{Path\ difference}{\lambda} = \frac{Time\ difference}{T}$$

$$\Rightarrow \frac{\phi}{2\pi} = \frac{\delta}{\lambda} = \frac{\Delta t}{T}$$

Types of interference

Constructive Interference

When both waves are in same phase then phase difference is an even multiple of $\pi \Rightarrow \phi = 2n\pi$;

n = 0, 1, 2, ...

Path difference is an even multiple of $\dfrac{\lambda}{2}$

$\because \quad \dfrac{\phi}{2\pi} = \dfrac{\delta}{\lambda}$

$\Rightarrow \quad \dfrac{2n\pi}{2\pi} = \dfrac{\delta}{\lambda} \quad \Rightarrow \quad 2n\left(\dfrac{\lambda}{2}\right)$

$\Rightarrow \quad \delta = n\lambda$ (where m= 0, 1, 2,.....

When time difference is an even multiple of $\frac{T}{2} \therefore \quad \Delta t = 2n\left(\frac{T}{2}\right)$

In this condition the resultant amplitude and intensity will be maximum.

$A_{max} = (a_1 + a_2) \Rightarrow I_{max} = I_1 + I_2 + 2\sqrt{I_1}\sqrt{I_2} = (\sqrt{I_1} + \sqrt{I_2})^2$

Destructive Interference

When both the waves are in opposite phase.

$\phi = (2n - 1)\pi$; n = 1, 2, ...

When path difference is an odd multiple of $\frac{\lambda}{2}$, $\delta = (2n-1)\frac{\lambda}{2}$, $n = 1, 2, \ldots\ldots$

Let two waves having amplitude a_1 and a_2 and same frequency, and constant phase difference ϕ superpose. Let their displacement are:

$y_1 = a_1 \sin \omega t$ and $y_2 = a_2 \sin(\omega t + \phi)$.

$y = y_1 + y_2 = A \sin(\omega t + \theta)$.

Where A = Amplitude of resultant wave

ϕ = New initial phase angle

When time difference is an odd multiple of $\frac{T}{2}$, $\Delta t = (2n - 1)\frac{T}{2}, (n = 1, 2, \ldots\ldots)$

In this condition the resultant amplitude and intensity of wave be minimum

$A\, a_1 - a_2)_{min} \Rightarrow I \sqrt{I_1}\sqrt{I_2}^2{}_{min}$

Q. Two sources of intensity I and 3I are used in an interference experiment. Find the intensity at a point where the waves from the two sources superimpose with a phase difference (1) Zero (2) $\pi/2$

Sol. We know,

$I' = I_1 + I_2 + 2\sqrt{I_1 I_2}\langle\cos(\delta 1 - \delta 2)\rangle \qquad I' = I_1 + I_2 + 2\sqrt{I_1 I_2}\langle\cos(\delta)\rangle$

(i) As $\delta = 0, \cos\delta = 1 \qquad \therefore I' = 3I + I + 2\sqrt{3I \times I} \times 1$

$I' = 4I + 2\sqrt{3I}$

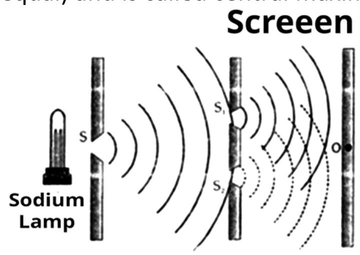
(ii) As $\delta = \pi/2, \cos\delta = 0 \qquad I' = 3I + I + 2\sqrt{3I \times I} \times 0$

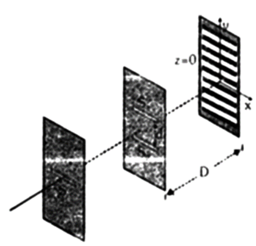
$I' = 4I$

Young's Double Slit Experiment

According to Huygens, light is a wave. It is proved experimentally by YDSE.

S is a narrow slit illuminated by a monochromatic source of light sends wave fronts in all directions. Slits S_1 and S_2 become the source of secondary wavelets which are in phase and of same frequency. These waves are superimposed on each other which give rise to interference. Alternate dark and bright bands are obtained on a screen (called interference fringes) placed certain distance from the plane of slit S_1 and S_2. Central fringe is always bright (due to path length S_1O and S_2O to center of screen are equal) and is called central maxima.





In YDSE division of wavefront takes place.

If one of the two slit is closed, the interference pattern disappears. It shows that two coherent sources are required to produce interference pattern.

If white light is used as parent source, then the fringes will be colored and of unequal width.

(i) Central fringe will be white

(ii) The fringe closest on either side of the central white fringe is red and the farthest will appear blue. After a few fringes, no clear fringe pattern is seen.

Condition For Bright and Dark Fringes

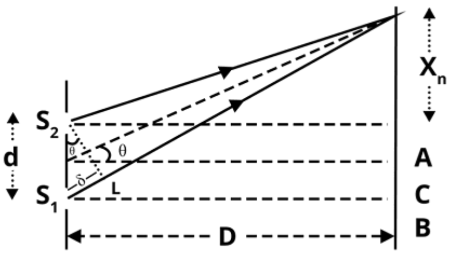
Bright Fringe

D = distance between slit and screen, d = distance between slit S_1 and S_2

Bright fringe occurs due to constructive interference.

$\because$ For constructive interference path difference should be even multiple of $\dfrac{\lambda}{2}$

$\therefore$ Path difference $\delta = PS_2 - PS_1 = S_2L = (2n)\dfrac{\lambda}{2}$



In ΔPCO $\tan\theta = \frac{x_n}{D}$; In ΔS_1S_2L $\sin\theta = \frac{\delta}{d}$

$\delta = n\lambda$ for bright fringes

If θ is small then $\tan\theta \simeq \sin\theta$

$\Rightarrow \quad \frac{x_n}{D} = \frac{\delta}{d}$

The distance of n^{th} bright fringe from the central bright fringe $x_n = n\frac{D\lambda}{d}$

Dark Fringe

Dark fringe occurs due to destructive interference.

∵ For destructive interference path difference should be odd multiple of $\frac{\lambda}{2}$.

∴ Path difference $\delta = (2m-1)\frac{\lambda}{2}$

The distance of the m^{th} dark fringe from the central bright fringe $x_m = \frac{(2m-1)D\lambda}{2d}$

Fringe width

The distance between two successive bright or dark fringe is known as fringe width.

$\beta = x_{n+1} - x_n = \frac{(n+1)D\lambda}{d} - \frac{nD\lambda}{d}$

Fringe Width $\beta = \frac{D\lambda}{d}$

Q. In Young's double slit experiment, angular width of a fringe formed on a distant screen is 0.1O . the wavelength of the light used is 6000Å . What is the spacing between the slit. If above setup is immersed in liquid, it is observed that angular fringe width is decreased by 30% find refractive index of liquid.

Sol. Angular fringe width or angular separation between fringes is

$\theta = \lambda/d$ $\quad$ $d = \lambda/\theta$ $6000 \times \frac{10^{-10}}{0.1 \times \frac{\pi}{180}} = 3.44 \times 10^{-4}m$

(ii) Given that when set up with first light is immersed in liquid angular width decreases by 30% thus wave length of first light in liquid = 4200Å

From formula for refractive index, $\quad \mu = \frac{\lambda_{air}}{\lambda_{liq}} = \frac{6000}{4200} = 1.428$

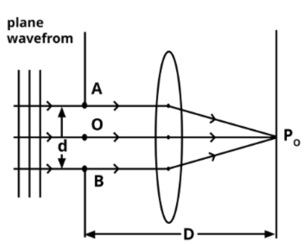
Diffraction Of Light

The bending of light waves around the corners of an obstacle or aperture is called diffraction of light. Smaller is the width of the slit, more will be diffraction for given wavelength. It is also found that if the wavelength and the width of the slit are so changed that ratio (λ/d) remains constant, amount of bending or diffraction does not change. If ratio λ/d is more, then more is the diffraction

Diffraction At a Single Slit

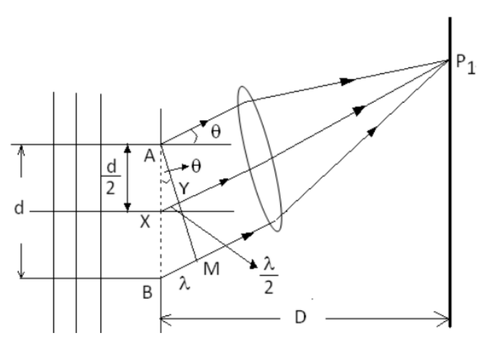
Central Maxima:

Consider a plane wavefront arrive at a plane of slit, according to Huygens's principle all the point on the slit like AOB acts as secondary source having the same phase and produce secondary waves. Those waves originated from each points of a slit and diffracted normal to the plane of the slit or we can say in the direction of incident wave will be concentrated at point Po by lens. In figure out of a many waves only three rays are shown in figure.



Screen is at focal length of lens. Ray emitted from A and B are in phase and passes equal distance through air and lens thus they are in phase when get converged at Po. Now ray emitted from O travel less distance in air but more distance in lens, in lens velocity of light gets reduced thus optical path travelled by the ray emitted by O is equal to optical path due to ray A and B. Thus, all rays meeting at Po are in phase produces central bright fringe. (Optical path in medium is equal to the product of refractive index of the medium to geometrical path length in air)

First minimum As shown in figure consider a waves which is diffracted an angle θ with respect to perpendicular bisector XP_o of the slit. Here, point X is the midpoint of slit AB. Therefore AX = Xb = d/2. Here secondary waves originated from all points A, X, B of slit are through to be divided in two parts Waves from AX and waves from X to B. As per figure, all these waves diffracted at an angle θ are focused at point P_1 of a screen. Draw AM ⊥ BL. It is obvious that all the rays reaching from AM to P_1 have equal optical path.



But rays going from A and X, and reaching to point P1 have path difference of XY Let assume diffraction angle be θ is such that XY = λ/2 In this situation, waves from A and X will follow the condition of destructive interference at point P1 and resultant intensity will be zero Further for all point between AX there exists a point between XB ,such that ray from point between XB have path difference of λ/2 with respect to rays from point between AX Thus in totality, destructive interference will take place at point P_1. Point P_1 is known as first minimum

Condition for minima: From geometry of figure dsinθ = λ
General equation is dsinθ = nλ

For n = 1 we get first minima
n = 2 we get second minima.

Important Point

A soap bubble or oil film on water appears colored in white light due to interference of light reflected

Q. Angular width of central maximum in diffraction obtained by single slit using light of wavelength 6000Å is measured. If light of another wavelength is used, the angular width of the central maximum is found to be decreased by 30%. Determine-

(i) The other wavelength

(ii) If the experiment is repeated keeping the apparatus in a liquid, the angular width of central maxima decreases by the same amount (30%0, find its refractive index).

Sol. (i) Angular fringe width or angular separation between fringes is

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

Here, for first light

$\theta_1 = \frac{\lambda_1}{d}$ and

For second light,

$\theta_2 = \frac{\lambda_2}{d}$

$\frac{\theta_1}{\theta_2} = \frac{\lambda_1}{\lambda_2}$

But, θ2 is 70% of θ_1 That is , $\theta_2 = 0.7\ \theta_1$

$0.7 = \frac{\lambda_1}{\lambda_2}$

$\lambda_2 = 0.7 \times 6000 = 4200Å$

Resolving Power of Optical Instrument

When a beam of light (light waves) from a point like object passes through the objective of an optical instruments, the lens acts like a circular aperture and produces a diffraction pattern instead of sharp point image. If there are two-point objects kept closed to each other, their diffraction pattern may overlap. Then it may be difficult to distinguish them as separate. The criterion to get distinct and separate images of two closely placed point like objects was given by Rayleigh " The images of two point like objects can be seen as separate if the central maximum in the diffraction pattern of one falls either on the first minimum of the diffraction pattern of the other or it is at grater separation" For the case of circular aperture diffraction due to lens of diameter D. Rayleigh's criterion is given by

$\sin\alpha \approx \alpha = \frac{1.22\,\lambda}{D}$

Telescope:
If a is the aperture of telescope and λ the wavelength, then resolving limit of telescope $d\theta \propto \frac{\lambda}{a}$

For spherical aperture,

$d\theta = \frac{1.22\lambda}{a}$

Microscope:
In the case of a microscope, θ is the well resolved semi-angle of cone of light rays entering the telescope, then limit of resolution $= \frac{\lambda}{2n\sin\theta}$ where n sin θ is called numerical aperture.

Q. Huble space telescope is at a distance 600 km from earth's surface. Diameter of its primary lens (objective) is 2.4m. When a light of 550nm is used by this telescope, at what minimum angular distance two objects can be seen separately? Also obtain linear minimum distance between these objects. Consider these objects on the surface of earth and neglect effects of atmosphere.

Sol. $\alpha = \frac{1.22\lambda}{D}$

$\alpha = \frac{1.22\times550\times10^{-9}}{2.4}$

$\alpha = 2.8\times10^{-7}rad$

Linear distance between objects= $\alpha_{min}L$

Where L = distance between object telescope and object

Linear distance between objects = $2.8\times10^{-7}\times600\times10^{3} = 0.17$m

Polarization

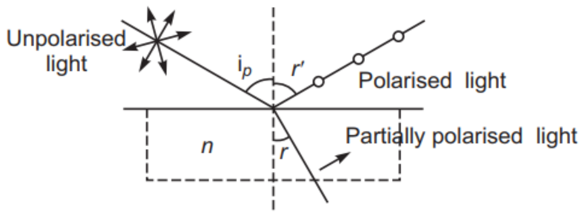
Takes place only for transverse waves such as heat waves, light waves etc.

Unpolarized Light: The light having vibrations of electric field vector in all possible directions perpendicular to the direction of wave propagation is called the ordinary (or unpolarized) light.

Plane (or Linearly) Polarized Light: The light having vibrations of electric field vector in only one direction perpendicular to the direction of propagation of light is called plane (or linearly) polarized light. The unpolarized and polarized light is represented as: (a) Unpolarized light (b) Polarized light (c) Partially polarized light

Brewster's Law

If unpolarized light falls on a transparent surface of refractive index n at a certain angle i_B called polarizing angle, then reflected light is plane polarized. Brewster's law: The polarizing angle (i_B) is given by n = tan i_B This is called Brewster's law.



Under this condition, the reflected and refracted rays are mutually perpendicular, i.e.,

$i_B + r = 90°$

where r is angle of refraction into the plane

Malus' Law

It states that if completely plane polarized light is passed through an analyzer, the intensity of light transmitted ∝ $\cos^2 \theta$, where θ is angle between planes of transmission of polarizer and analyzer i.e.,

$I = I_B cos^2\theta$

If incident light is unpolarized, then $I = \frac{I_0}{2}$

since $(\cos^2 \theta)_{average}$ for all directions = $\frac{1}{2}$.

Doppler effect for light

If there is no medium and the source moves away from the observer, then later wavefronts have to travel a greater distance to reach the observer and hence take a longer time. The time taken between the arrival of two successive wavefronts is hence longer at the observer than it is at the source. Thus, when the source moves away from the observer the frequency as measured by the source will be smaller. This is known as the Doppler effect. Astronomers call the increase in wavelength due to doppler effect as red shift since a wavelength in the middle of the visible region of the spectrum moves towards the red end of the spectrum. When waves are received from a source moving towards the observer, there is an apparent decrease in wavelength, this is referred to as blue shift. For velocities small compared to the speed of light, we can use the same formulae which we use for sound waves. The fractional change in frequency Δν/ν is given by $-V_{radial}/c$, where V_{radial} is the component of the source velocity along the line joining the observer to the source relative to the observer; V_{radial} is considered positive when the source moves away from the observer. Thus, the Doppler shift can be expressed as:

$$\frac{\Delta \nu}{\nu} = \frac{-V_{radial}}{c}$$

Q. Certain characteristic wavelengths of the light from a galaxy in the constellation Virgo are observed to be increased in wave length, as compared with terrestrial sources, by 0.4%. What is the radial speed of this galaxy with respect to the earth? Is it approaching or receding?

Sol. Give, $\frac{\Delta\lambda}{\lambda} = 0.004$

Doppler shift can be expressed as:

$\frac{\Delta \nu}{\nu} = -\frac{V_{radial}}{c}$ But we know,

$\frac{\Delta \nu}{\nu} = -\frac{\Delta\lambda}{\lambda}$ From this we can write,

$\frac{\Delta\lambda}{\lambda} = \frac{V_{radial}}{c}$ $V_{radial} = \frac{\Delta\lambda}{\lambda}c$

V_{radial} = 0.004 × 3 × 10^8 = 1.2 × 10^6 ms^{-1}

Since V_{radial} is positive therefore galaxy is receding

SUMMARY

- **Wave front:**
  It is the locus of points having the same phase of oscillation.
- **Rays:**
  Rays are the lines perpendicular to the wave front, which show the direction of propagation of energy.
- **Time Taken:**
  The time taken for light to travel from one wave front to another is the same along any ray.
- **Huygens' Principle:**
  (a) According to Huygens' Each point on the given wave front (called primary wave front) acts as a fresh source of new disturbance, called secondary wavelet, which travels in all directions with the velocity of light in the medium.
  (b) A surface touching these secondary wavelets, tangentially in the forward direction at any instant gives the new wave front at that instant. This is called secondary wave front,
- **Principle of Huygens' Construction:**
  (a) It is based on the principle that every point of a wave front is a source of secondary wave front.
  (b) The envelope of these wave fronts i.e., the surface tangent to all the secondary wave front gives the new wave front.
- **Snell's law of refraction:**
  $$1\mu_2 = \frac{c_1}{c_2} = \frac{\text{Speed of light in first medium}}{\text{Second of light in second medium}}$$
- **Refraction and Reflection of Plane Waves Using Huygens' Principle:**
  The law of reflection (i = r) and the Snell's law of refraction
  $\frac{\sin i}{\sin r} = \frac{v_1}{v_2} = \frac{\mu_2}{\mu_1} = \mu_{21}$
  can be derived using the wave theory. (Here v1 and v2 are the speed of light in media 1 and 2 with refractive index μ_1 *and* μ_2 respectively).
- **Relation between Frequency and Speed:**
  The frequency v remains the same as light travels from one medium to another. The speed v of a wave is given by
  $v = \frac{\lambda}{T}$
  Where λ is the wavelength of the wave and T (=1/ v) is the period of oscillation.
- **Doppler Effect:**
  It is the shift in frequency of light when there is a relative motion between the source and the observer. The effect can be used to measure the speed of an approaching or receding object.
- **Change in Frequency:**
  For the source moving away from the observer $v < v_0$, and for the source moving towards the observer $v < v_0$, . The change in frequency is
  $\Delta v = v - v_0 = -\frac{v}{c} v_0$
  So, finally,
  $\frac{\Delta v}{v_0} = -\frac{v}{c}$
- **Coherent and Incoherent Addition of Waves:**
  (a) Two sources are coherent if they have the same frequency and a stable phase difference.
  (b) In this case, the total intensity I is not just the sum of individual intensities I_1 and I_2 due to the two sources but includes an interference term,
  $I = I_1 + I_2 + 2k.E_1.E_2$
  Where E_1 and E_2 are the electric fields at a point due to the sources.
  (c) The interference term averaged over many cycles is zero if
  (i) The sources have different frequencies or
  (ii) The sources have the same frequency but no stable phase difference.
  (d) For such coherent sources,
  $I = I_1 + I_2$
  (e) According to the superposition principle when two or more wave motions traveling through a medium superimpose one another, a new wave is formed in which resultant displacements due to the individual waves at that instant.
  (f) The average of the total intensity will be
  $$\bar{I} = \bar{I}_1 + \bar{I}_2 + 2\sqrt{(\bar{I}_1)(\bar{I}_2)}\cos\phi$$
  Where Φ is the inherent phase difference between the two superimposing waves.
  (g) The significance is that the intensity due to two sources of light is not equal to the sum of intensities due to each of them.
  (h) The resultant intensity depends on the relative location of the point from the two sources, since changing it changes the path difference as we go from one point to another.
  (i) As a result, the resulting intensity will vary between maximum and minimum values, determined by the maximum and minimum values of the cosine function. These will be
  $$\bar{I}_{MAX} = \bar{I}_1 + \bar{I}_2 + 2\sqrt{(\bar{I}_1)(\bar{I}_2)} = \left(\sqrt{\bar{I}_1} + \sqrt{\bar{I}_2}\right)^2$$
  $$\bar{I}_{MIN} = \bar{I}_1 + \bar{I}_2 - 2\sqrt{(\bar{I}_1)(\bar{I}_2)} = \left(\sqrt{\bar{I}_1} - \sqrt{\bar{I}_2}\right)^2$$
- **Young's Experiment**
  Two parallel and very close slits S_1 and S_2 (illuminated by another narrow slit) behave like two coherent sources and produce on a screen a pattern of dark and bright bands – interference fringes.

For a point P on the screen, the path difference

$$S_2P - S_2P = \frac{y_1 d}{D_1} 1$$

Where d is the separation between two slits, D_1 is the distance between the slits and the
screen and y1 is the distance of the point of *P* from the central fringe.

For constructive interference (bright band), the path difference must be an integer multiple of λ, i.e.,

$$\frac{y_1 d}{D_1} = n\lambda \text{or} y_1 = n\frac{D_1\lambda}{d} 1\ 1$$

The separation Δy1 between adjacent bright (or dark) fringes is,

$$\Delta y_1 = \frac{D_1\lambda}{d}$$

using which λ can be measured.

- **Young's Double Slit Interference Experiment:**

  Fringe width, $w = \frac{D\lambda}{d}$

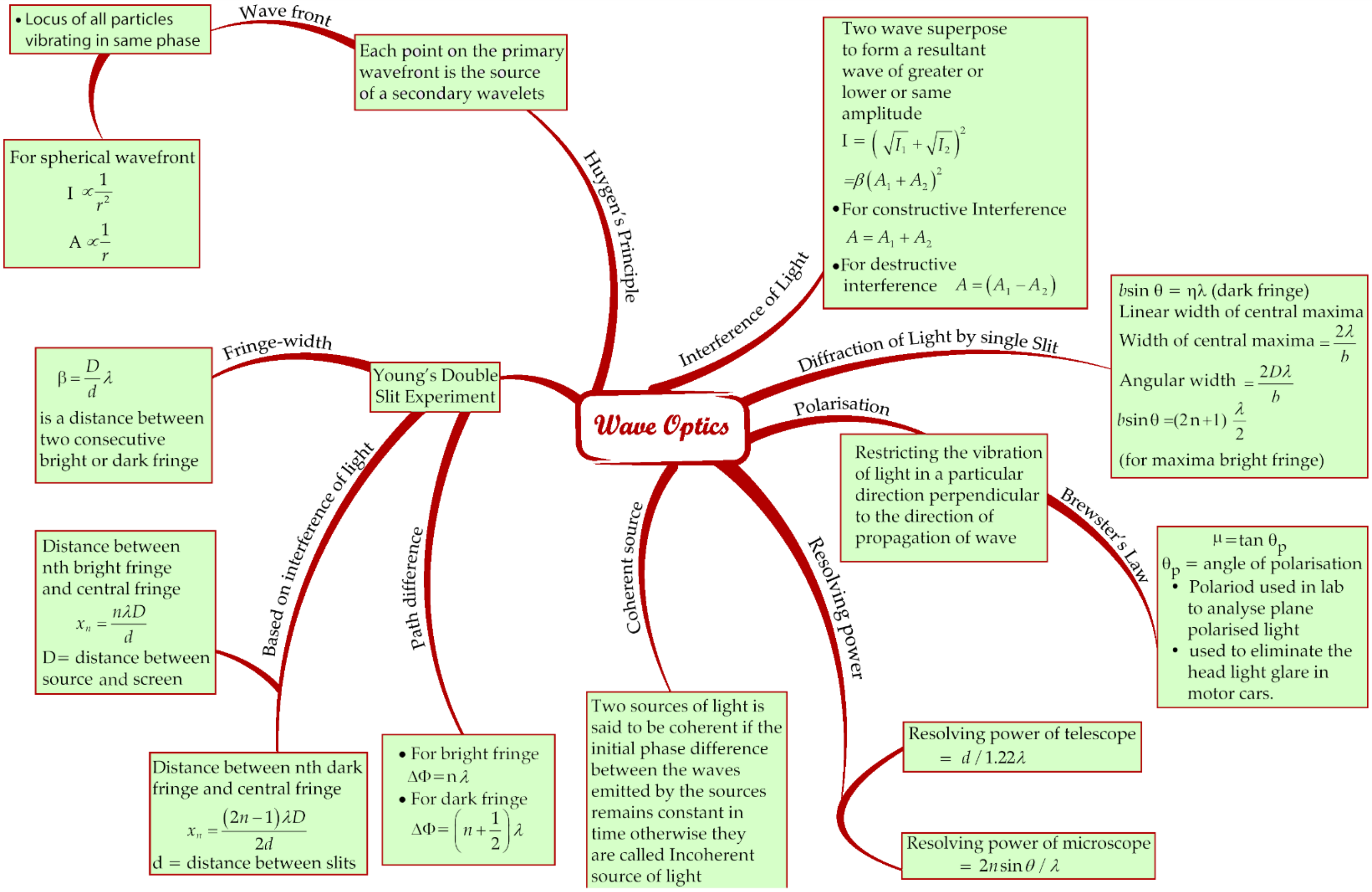
  where D is the distance between the slits & the screen d is the distance between the
  two slits
- **Constructive Interference:**
  (a) Phase difference: $\Delta\Phi = 2\pi n$ where n is an integer
  (b) Path difference: $\Delta X = n\lambda$ where n is an integer
- Destructive interference:
  (a) Phase difference: $\Delta\phi = \left(n + \frac{1}{2}\right) 2\pi$, where n is an integer
  (b) Path difference: $\Delta X = \left(n + \frac{1}{2}\right)\lambda$, where n is an integer
- **Diffraction due to Single Slit:**
  (a) Angular spread of the central maxima $= \frac{2\lambda}{d}$
  (b) Width of the central maxima: $\frac{2\lambda D}{d}$
  Where D is the distance of the slit from the screen d is the slit width
- **Condition for the Minima on the either side of the Central Maxima:**

  $d \sin\theta = n\lambda$, where n = 1,2,3,.....
- **Relation between phase difference & path difference:**

  $$\Delta\phi = \frac{2\pi}{\lambda}.\Delta X$$

  Where $\Delta\phi$ is the phase difference & ΔX is the path difference
- **Diffraction:**
  (a) It refers to light spreading out from narrow holes and slits, and bending around corners and obstacles.
  (b) The single-slit diffraction pattern shows the central maximum ($at\theta$= 0), zero intensity at angular separation

MIND MAP


Wave Optics
Wave front
• Locus of all particles vibrating in same phase
For spherical wavefront
$I \propto \frac{1}{r^2}$
$A \propto \frac{1}{r}$
Huygen's Principle
Each point on the primary wavefront is the source of a secondary wavelets
Interference of Light
Two wave superpose to form a resultant wave of greater or lower or same amplitude
$I = \left(\sqrt{I_1} + \sqrt{I_2}\right)^2$
$= \beta(A_1 + A_2)^2$
• For constructive Interference
$A = A_1 + A_2$
• For destructive interference $A = (A_1 - A_2)$
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)
Polarisation
Restricting the vibration of light in a particular direction perpendicular to the direction of propagation of wave
Brewster's Law
$\mu = \tan\theta_p$
θ_p = angle of polarisation
• Polariod used in lab to analyse plane polarised light
• used to eliminate the head light glare in motor cars.
Resolving power
Resolving power of telescope $= d / 1.22\lambda$
Resolving power of microscope $= 2n\sin\theta / \lambda$
Coherent source
Two sources of light is 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
Young's Double Slit Experiment
Fringe-width
$\beta = \frac{D}{d}\lambda$
is a distance between two consecutive bright or dark fringe
Based on interference of light
Distance between nth bright fringe and central fringe
$x_n = \frac{n\lambda D}{d}$
D= distance between source and screen
Distance between nth dark fringe and central fringe
$x_n = \frac{(2n-1)\lambda D}{2d}$
d = distance between slits
Path difference
• For bright fringe
$\Delta\Phi = n\lambda$
• For dark fringe
$\Delta\Phi = \left(n + \frac{1}{2}\right)\lambda$

PRACTICE EXERCISE

MCQ

Q1. The condition for obtaining secondary maxima in the diffraction pattern due to single slit is
(a) a sin $\theta = n\lambda$
(b) a sin $\theta = (2n-1)\frac{\lambda}{2}$
(c) a sin $\theta = (2n-1)\lambda$
(d) a sin $\theta = \frac{n\lambda}{2}$

Q2. In double slit experiment, the angular width of the fringes is 0.20^0 for the sodium light $(\lambda = 5890Å)$. in order to increase the angular width of the fringes by 10%, the necessary change in wavelength is
(a) zero
(b) increased by 6479 Å
(c) decreased by 589 Å
(d) increased by 589 Å

Q3. If two waves represented by $y_1 = 4 \sin \omega t$and $y_2 = \left(\omega t + \frac{\pi}{3}\right)$Interfere at a point, then the amplitude of the resulting wave will be about
(a) 7 (b) 6
(c) 5 (d) 3.5

Q4. In Young's double slit experiment, the separation between the slits is halved and the distance between the slits and screen is doubled. The fringe width will
(a) be halved
(b) be doubled
(c) be quadrupled
(d) remain unchanged

Q5. Sodium light $(\lambda = 6 \times 10^{-7}\, m)$ is used to produce interference pattern. The observed fringe width is 0.12 mm. The angle between two interfering wave trains, is
(a) $1 \times 10^{-3}\, rad$
(b) $1 \times 10^{2}\, rad$
(c) $5 \times 10^{-3}\, rad$
(d) $5 \times 10^{-2}\, rad$

Q6. The Young's double slit experiment is performed with blue and with green light of wavelengths 4360 Å and with green light of wavelength 4360 Å and 5460 Å respectively. If x is the distance of 4th maxima from the central one, then
(a) x (blue) = x (green)
(b) x (blue) > x (green)
(c) x (blue) < x (green)
(d) $\frac{x(blue)}{x(green)} = \frac{5460}{4360}$

Q7. If yellow light emitted by sodium lamp in young's double slit experiment is replaced by a monochromatic blue light of the same intensity
(a) fringe width will decrease
(b) fringe width will increase
(c) fringe width will remain unchanged
(d) fringes will become less intense

Q8. When unpolarized light is incident on a plane glass plate at Brewster's angle, then which of the following statements is correct?
(a) Reflected and refracted rays are completely polarized with their planes of polarization parallel to each other
(b) Reflected and refracted rays are completely polarized with their planes of polarization perpendicular to each other
(c) Reflected light is plane polarized but transmitted light is partially polarized
(d) Reflected light is partially polarized but refracted light is plane polarized

Q9. Spherical wavefronts, emanating from a point source, strike a plane reflecting surface. What will happen to these wave fronts, immediately after reflection?
(a) They will remain spherical with the same curvature, both in magnitude and sign.
(b) They will become plane wave fronts.
(c) They will remain spherical, with the same curvature, but sign of curvature reversed.
(d) they will remain spherical, but with different curvature, both in magnitude and sign.

Q10. In the phenomena of diffraction of light, when blue light is used in the experiment in spite of red light, then
(a) fringes will become narrower
(b) fringes will become broader
(c) no change in fringe width
(d) None of these

ASSERTION AND REASONING

Directions: These questions consist of two statements, each printed as Assertion and Reason. While answering these questions, you are required to choose any one of the following four responses.
(a) Both Assertion and Reason are correct and the Reason is a correct explanation of the Assertion.
(b) Both Assertion and Reason are correct but Reason is not a correct explanation of the Assertion.
(c) Assertion is correct, Reason is incorrect
(d) Both Assertion and Reason are correct.

Q1. Assertion: Electromagnetic waves do not require medium for their propagation
Reason: They can't travel in a medium.

Q2. Assertion: The phase difference between any two points on a wavefront is zero.
Reason: From the source light, reaches every point on the wave front in the same time.

Q3. Assertion: The maximum intensity in interference pattern is four times the intensity in interference pattern is four times the intensity due to each slit of equal width.
Reason: Intensity is proportional to the square of amplitude.

Q4. Assertion: Thin films such as soap bubble or a thin layer of oil on water show beautiful colors when illuminated by white light.
Reason: It is due to interference of sun's light reflected from upper and lower surfaces of the film.

Q5. Assertion: No interference pattern is detected when two coherent sources are infinitely close to each other.
Reason: The fringe width is inversely proportional to the distance between the two slits.

SHORT ANSWER QUESTIONS

Q1. When monochromatic light travels from one medium to another, its wavelength changes but frequency remains the same. Explain.

Q2. Why are coherent sources required to create interference of light?

Q3. Differentiate between a ray and a wavefront.

Q4. What type of wavefront will emerge from a (i) point source and (ii) distant light source?

Q5. Unpolarized light of intensity I is passed through a polaroid. What is the intensity of the light transmitted by the polaroid?

Q6. Can two different bulbs, similar in all respect act as coherent sources? Give reasons for your answer.

NUMERICAL TYPE QUESTIONS

Q1. the red shift of radiation from a distant nebula consists of the light known to have a wavelength 4340×10^{-8} cm when observed in laboratory, appearing to have a wavelength of 4362×10^{-8} cm. What is the speed of the nebula in the line of sight relative to the earth? Is it approaching or receding.

Q2. If two waves represented by $y_1 = 4 \sin \omega t$ and $y_2 = 3\sin\left(\omega t + \frac{\pi}{3}\right)$ interfere at a point. Find out the amplitude of the resulting wave.

Q3. The intensity variation in the interference pattern obtained with the help of two coherent sources is 5% of the average intensity. Find out the ratio of intensities of two sources.

Q4. In an interference pattern, the slit widths are in the ratio 1 : 9. Then find out the ratio of minimum and maximum intensity.

Q5. A double slit is illuminated by light of wavelength 6000 Å. The slits are 0.1 cm apart and the screen is placed one meter away. Calculate
(i) The angular position of the 10^{th} maximum is radians and
(ii) separation between the two adjacent minima

Q6. The path difference between two interfering waves at a point on screen is 171.5 times the wavelength. If the path difference is 0.21029 cm. Find the wavelength.

Q7. Light of wavelength 6000 Å is incident on a thin glass plate of refractive index 1.5 such that angle of refraction into the plate is 60°. Calculate the smallest thickness of plate which will make it appear dark by reflection.

Q8. A planet moves with respect to us, so that light of 475 nm is observed at 475.6 nm. Then determine the speed of the planet.

Q9. If the amplitude ratio of two sources producing interference is 3 : 5, then find the ratio of intensities produced by each.

Q10. Two slits are separated by a distance of 0.5 mm and illuminated with light of $\lambda = 6000$ Å. If the screen is placed 2.5 m from the slits, then determine distance of the third bright image from the centre.

HOMEWORK EXERCISE QUESTIONS

MCQ

Q1. Two waves having the intensities in the ratio of 9 : 1 produce interference. The ratio of maximum to minimum intensity is

(a) 10 : 8 (b) 9 : 1
(c) 4 : 1 (d) 2 : 1

Q2. Consider the diffraction pattern for a small pinhole. As the size of the hole is increased

(a) the size decreases
(b) the intensity decreases
(c) the size increases
(d) (b) and (c)

Q3. An astronomical refracting telescope will have large angular magnification and high angular resolution, when it has an objective lens of

(a) small focal length and large diameter
(b) large focal length and small diameter
(c) large focal length and large diameter
(d) small focal length and small diameter

Q4. In young's double-slit experiment, the intensity of light at a point on the screen where the path difference is λ is I, λ being the wavelength of light used. The intensity at a point where the path difference is $\frac{\lambda}{4}$ will be

(a) $\frac{1}{4}$ (b) $\frac{1}{2}$
(c) 1 (d) zero

Q5. A beam of light is incident on a glass slab $(\mu = 1.54)$ in a direction as shown in the figure. The reflected light is analysed by a polaroid prism. On rotating the polaroid, $(\tan 57^0 = 1.54)$

(a) the intensity remains unchanged
(b) the intensity is reduced to zero and remains at zero
(c) the intensity gradually reduces to zero and then again increase
(d) the intensity increases continuously

Q6. Two sources of light of wavelengths 2500 Å and 3500 Å are used in young's double slit expt. simultaneously. Which orders of fringes of two wavelength patterns coincide?

(a) 3rd order of 1st source and 5th of the 2nd
(b) 7th order of 1st and 5th order of 2nd
(c) 5th order of 1st and 3rd order of 2nd
(d) 5th order of 1st and 7th order of 2nd

Q7. When the angle of incidence is 60^0 on the surface of a glass slab, it is found that the reflected ray is completely polarised. The velocity of light in glass is

(a) $\sqrt{2} \times 10^8\ ms^{-1}$ (b) $\sqrt{3} \times 10^8\ ms^{-1}$
(c) $2 \times 10^8\ ms^{-1}$ (d) $3 \times 10^8\ ms^{-1}$

Q8. A beam of light of $\lambda = 600\ nm$ from a distant source fall on a single slit 1 mm wide and the resulting diffraction pattern is observed on a screen 2 m away. The distance between first dark fringes on either side of the central bright fringe is

(a) 1.2 cm (b) 1.2 mm
(c) 2.4 cm (d) 2.4 cm

Q9. A parallel beam of light of wavelength λ is incident normally on a narrow slit. A diffraction pattern is formed on a screen placed perpendicular to the direction of the incident beam. At the second minimum of the diffraction pattern, the phase difference between the rays coming from the two edges of slit is

(a) $\pi\lambda$ (b) 2π
(c) 3π (d) 4π

Q10. In a Young's double slit experiment, the intensity at a point where the path difference $\frac{\lambda}{6}$ ($\lambda -$ is wavelength of the light) is I. If I_0 denotes the maximum intensity, then $\frac{I}{I_0}$ is equal to

(a) $\frac{1}{2}$ (b) $\frac{\sqrt{3}}{2}$
(c) $\frac{1}{\sqrt{2}}$ (d) $\frac{3}{4}$

Q11. According to Huygens, the ether medium pervading the entire universe is

(a) Less elastic and denser.
(d) Highly elastic and less dense.
(d) Not elastic
(d) Much heavier.

Q12. Unpolarized light is incident on a dielectric of refractive index $\sqrt{3}$. What is the angle of incidence if the reflected beam is completely polarized?

(a) 30^0 (b) 45^0
(c) 60^0 (d) 75^0

Q13. With a monochromatic light, the fringe-width obtained in a young's double slit experiment is 0.133 cm. The whole set up is immersed in water of refractive index 1.33, then the new fringe width is

(a) 0.133 cm (b) $0.1\ cm$
(c) $1.33\ cm$ (d) $0.2\ cm$

Q14. Which of the following is correct for light diverging from a point source?

(a) The intensity decreases in proportion for the distance squared.
(b) The wavefront is parabolic.
(c) The intensity at the wavelength does depend of the distance.
(d) None of these

Q15. The phenomena which is not explained by Huygens's construction of wavefront

(a) reflection (b) diffraction
(c) refraction (d) origin of spectra

Q16. Huygens's concept of secondary wave

(a) allows us to find the focal length of a thick lens
(b) is a geometrical method to find a wavefront
(c) is used to determine the velocity of light
(d) is used to explain polarization

Q17. The energy in the phenomenon of interference
(a) is conserved, gets redistributed
(b) is equal a every point
(c) is destroyed in regions of dark fringes
(d) is created at the place of bright fringes

Q18. The resultant amplitude in interference with two coherent sources depends upon
(a) only amplitude
(b) only phase difference
(c) on both the above
(d) none of the above

Q19. Two sources of light are said to be coherent, when they give light waves of same
(a) amplitude and phase
(b) wavelength and constant phase difference
(c) intensity and wavelength
(d) phase and speed

Q20. In double slit experiment, for light of which color, the fringe width will be minimum?
(a) Violet (b) Red
(c) Green (d) Yellow

ASSERTION AND REASONING

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(c) Assertion is correct, Reason is incorrect
(d) Both Assertion and Reason are correct.

Q1. Assertion: Incoming light reflected by earth is partially polarized.
Reason: Atmospheric particle polarize the light.

Q2. Assertion: When light ray is incident at polarizing angle on glass, reflected light is completely polarized.
Reason: The intensity of light decreases in polarization.

Q3. Assertion: colored spectrum is seen when we look through a muslin cloth.
Reason: it is due to the diffraction of white light on passing through fine slits.

Q4. Assertion: when tiny circular obstacle is placed in the path of light from some distance, a bright spot is seen at the center of the shadow of the obstacle.
Reason: destructive interference occurs at the center of the shadow.

Q5. Assertion : It is necessary to have two waves of equal intensity to study interference pattern. Reason : There will be an effect on clarity if the waves are of unequal intensity.

SHORT ANSWER QUESTIONS

Q1. Which of the following waves can be polarized (i) Heat waves (ii) Sound waves? Give reason to support your answer.

Q2. In what way is the diffraction from each slit related to interference pattern in double slit experiment?

Q3. Explain the following, giving reasons:
(i) When monochromatic light is incident on a surface separating two media, the reflected and refracted light both have the same frequency as the incident frequency.
(ii) When light travels from a rarer to a denser medium, the speed decreases. Does this decrease in speed imply a reduction in the energy carried by the wave?
(iii) In the wave picture of light, intensity of light is determined by the square of the amplitude of the wave. What determines the intensity in the photon picture of light?

Q4. For a single slit of width a, the first minimum of the interference pattern of a monochromatic light of wavelength m occurs at an angle of $\frac{\lambda}{a}$. At the same angle of $\frac{\lambda}{a}$, we get a maximum for two narrow slits separated by a distance a. Explain.

Q5. Explain why the intensity of light coming out of a polaroid does not change irrespective of the orientation of the pass axis of the polaroid.

NUMERICAL TYPE QUESTIONS

Q1. A parallel beam of light of wavelength 6000 Å gets diffracted by a single slit width 0.3 mm. Then determine the angular position of the first minima of diffracted light.

Q2. In a diffraction pattern due to a single slit of width *a*, the first minimum is observed at an angle 30° when light of wavelength 5000 Å is incident on the slit. Then determine the angle that firstly secondary maximum is observed.

Q3. Light of wavelength 6328 Å is incident normally on a slit of width 0.2 mm. Calculate the angular width of central maximum on a screen distance 9 m ?

Q4. An unpolarized beam of light of intensity I_0 falls on a polaroid. Then find the intensity of the emergent beam.

Q5. Light of wavelength 5000Å is incident on a slit of width 0.1 mm. Find out the width of the central bright line on a screen distance 2m from the slit?

Q6. The Hale telescope of Mount Palomar has a diameter of 200 inch. What is its limiting angle of resolution for 600 nm light?

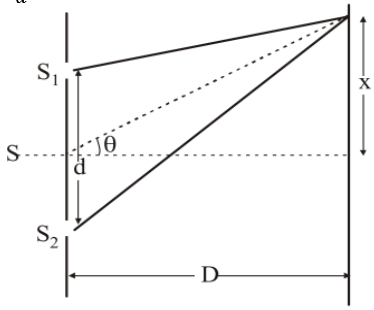
Q7. A ray of light is incident on the surface of glass plate of refractive index 1.5 at polarizing angle. What is the angle of refraction?

PRACTICE EXERCISE SOLUTIONS

MCQ

S1. **(b)** A sin θ = (2n−1) λ/2 is the condition for obtaining secondary maxima in the diffraction pattern due to single slit.

S2. **(d)** Let λ be wavelength of monochromatic light incident on slit S, then angular distance between two consecutive fringes, that is the angular fringe width is $\theta = \frac{\lambda}{d}$ where d is distance between coherent sources.



Given, $\frac{\Delta\theta}{\theta} = \frac{10}{100}$

So, from eq. (1),

$\frac{\Delta\lambda}{\lambda} = \frac{\Delta\theta}{\theta} = \frac{10}{100} = 0.1$

$\Rightarrow \Delta\lambda = 0.1\lambda = 0.1 \times 5890$ Å $= 589$Å (increase)

S3. **(b)** $\phi = \frac{\pi}{3}, a_1 = 4, a_2 = 3$

So, A = $\sqrt{a_1^2 + a_2^2 + 2a_1a_2\, cos\phi} \approx 6$

S4. **(c)** $\beta = \frac{D\lambda}{d}$, where D is the distance between the slits & screen and d is the separation between the slits.

$\beta' = \frac{2D\lambda}{d/2} = \frac{4D\lambda}{d} = 4\beta$

S5. **(c)** The fringe width is given by, $\beta = \frac{\lambda D}{d}$

The angular width of fringe is given by

$\frac{d}{D} = \frac{\lambda}{\beta} = \frac{6\times10^{-7}}{0.12\times10^{-3}} = 5 \times 10^{-3}\, rad.$

S6. **(c)** Distance of nth maxima, x = $n\lambda\frac{D}{d} \propto \lambda$

As $\lambda_b < \lambda_g$ $\quad \therefore X_{blue} < X_{green}$

S7. **(a)** As $\beta = \frac{\lambda D}{d}$ and $\lambda_b < \lambda_y$,

∴ Fringe width β will decrease

S8. **(c)** At Brewster's angle, only the reflected light is plane polarized, but transmitted light is partially polarized.

S9. **(c)** The wavefront will remain to be spherical after reflection from the surface but their direction of propagation will be revered.

S10. **(a)** Fringe width is directly proportional to wavelength of light used. Wavelength of blue is less than the wavelength of red light, therefore fringes will become narrower.

S11. **(a)** Wavefront is the locus of all points, where the particles of the medium vibrate with the same phase.

S12. **(b)** Huyghue's principle gives us a geometrical method of tracing a wavefront.

S13. **(c)** Converging spherical

S14. **(b)** For coherent sources O is same and phase is also same or phase diff. is constant.

S15. **(a)** According to wave theory, intensity of light is directly proportional to square of amplitude.

S16. **(a)** Polaroid glass polarizes light reducing the light intensity to half its original value.

S17. **(b)** Angle between plane of vibration and plane of polarization is 90º

S18. **(d)** When red light is replaced by blue light the diffraction bands become narrow and crowded.

S19. **(b)** At the center, all colors meet in phase, hence central fringe is white.

S20. **(d)** Interference pattern will be invisible, because red and green are complimentary colors.

ASSERTION AND REASONING

S1. **(c)** Electromagnetic wave which can travel with or without medium.

S2. **(a)** A wave front is the locus of points having the same phase. Thus, assertion is true because the phase difference is zero as all points have same phase. Reason is true because a wavefront is composed of all points where the light reaches from the source in the same time. As light takes the same time it has the same phase at all points on a wavefront and hence it correctly explains assertion.

S3. **(b)** Let a be the amplitude of waves from each slit. Intensity is directly proportional to square of amplitude i.e., $I \propto a^2$. Due to each slit $I_1 \propto a^2$ When destructive interference occurs, then resultant amplitude =a−a=0

∴ Minimum intensity, $I_{min}=0$

When constructive interference occurs, the resultant amplitude =a+a=2a

∴ Maximum intensity, $I_{max} \propto (2a)^2$

Hence, $I_{max} \propto 4a^2$

or I_{max}=4 times the intensity due to each slit.

S4. **(c)** Thin films show colors when illuminated by white light because the reflected rays from the upper and the lower surface of the film interfere constructively to give domination of some color for a particular value of thickness at a point.

S5. **(a)** When d is negligibly small, fringe width. β which is proportional to 1/d may become too large. Even a single fringe may occupy the whole screen. Hence the pattern cannot be detected.

SHORT ANSWER QUESTIONS

S1. Frequency is the fundamental characteristic of the source emitting waves and does not depend upon the medium. Light reflects and refracts due to the interaction of incident light with the atoms of the medium. These atoms always take up the frequency of the incident light which forces them to vibrate and emit light of same frequency. Hence, frequency remains same.

S2. Coherent sources are required for sustained interference. If sources are incoherent, the intensity at a point will go on changing with time.

S3. A wavefront is a surface of constant phase. A ray is a perpendicular line drawn at any point on wavefront and represents the direction of propagation of the wave.

S4. (i) Spherical wavefront (ii) Plane wavefront.

S5. Intensity of light transmitted through the polaroid =I/2.

S6. No, because the light waves emitted by two independent bulbs will not have stable constant phase difference

SOLUTION FOR HOMEWORK EXERCISE

S1. **(a)** we are given the ratio of intensities of two waves

$I_1 : I_2 = 9 : 1$

The ratio of maximum and minimum intensities

$\frac{I_{max}}{I_{min}} = \left(\frac{A_1 + A_2}{A_1 - A_2}\right)^2$

The amplitude, $A_1 = \sqrt{I_1}$ and $A_2 = \sqrt{I_2}$

$\Rightarrow \frac{I_{max}}{I_{min}} = \left(\frac{\sqrt{I_1}+\sqrt{I_2}}{\sqrt{I_1}-\sqrt{I_2}}\right)^2$

$\Rightarrow \frac{I_{max}}{I_{min}} = \left(\frac{\left(\frac{\sqrt{I_1}}{\sqrt{I_2}}+1\right)^2}{\frac{\sqrt{I_1}}{\sqrt{I_2}}-1}\right)^2$

$\Rightarrow \frac{I_{max}}{I_{min}} = \left(\frac{\sqrt{9}+1}{\sqrt{9}-1}\right)^2 = \left(\frac{3+1}{3-1}\right)^2$

$\Rightarrow \frac{I_{max}}{I_{min}} = \left(\frac{4}{2}\right) = 2 : 1$

S2. (d) We know that width β 0 of central maxima $\beta_0 = D\lambda/d$
Here D = distance between slit and screen
λ = wavelength of source, it does not change.
So, on increasing width of pinhole, d increases. Hence the size of central maxima decreases. The amount of light is now distributed over a small area, as intensity ∝ 1 / area, and the area is decreasing, so intensity increases. So, the intensity of pattern will increase.

S3. (c) For astronomical refracting telescope Angular magnification is more for large focal length of objective lens M. P = f_0 / f_e
Resolving power = $\frac{d}{1.22\,\lambda}$
Resolving power is high for large diameter.

S4. (b) For path difference λ, Phase difference = 2π $\left(Q = \frac{2\pi}{\lambda}x = \frac{2\pi}{\lambda}.\lambda = 2\pi\right)$

$\Rightarrow I = I_0 + I_0 + 2I_0 \cos 2\pi$

$\Rightarrow$ I = $4I_0$ $(\because \cos 2\pi = 1)$

For X = $\frac{\lambda}{4}$, phase difference = $\frac{\pi}{2}$

$\therefore$ I' = $I_1 + I_2 + 2\sqrt{I_1}\sqrt{I_2}\cos\frac{\pi}{2}$

If $I_1 = I_2 + 2\sqrt{I_1}\sqrt{I_2}\cos\frac{\pi}{2}$

If $I_1 = I_2 = I_0$ then $I' = 2I_0 = 2.\frac{I}{4} = \frac{I}{2}$

S5. **(c)**
Here Angle of incidence, I = 57
Tan $57^0 = 1.54$
u_{glass} = tan i
It means, Here Brewster's law is followed and the reflected ray is completely polarized.
Now, when reflected ray is analyzed through a polaroid then intensity of light is given by malus law.
i.e., $I = I_0 \cos^2\theta$
On rotating polaroid 'θ' changes. Due to which intensity first decreases and then increases.

Q6. (b) Let nth fringe of 2500 Å coincide with (n -2) the fringe of 3500 Å.
∴ 3500 (n-2) = 2500 × n
1000 n = 7000, n = 7
∴ 7th order fringe of 1st source will coincide with 5th order fringe of 2nd source.

Q7. **(b)** $a\mu_g = \tan\theta_p$ = polarising angle.
Or, $a\mu_g$ = tan 60^0
Or, $\frac{c}{v_g} = \sqrt{3}$
Or, $v_g = \frac{c}{\sqrt{3}} = \frac{3\times10^8}{\sqrt{3}} = \sqrt{3}\times10^8\ ms^{-1}$

Q8. **(d)** Given: D = 2m; d = 1 mm = 1×10^{-3} m
λ = 600 nm = 600×10^{-6} m
Width of central bright fringe $(= 2\beta)$
$= \frac{2\lambda D}{d} = \frac{2\times600\times10^{-6}\times2}{1\times10^{-3}}m = 2.4$ mm

Q9. **(d)** Conditions for diffraction minima are
path diff. $\Delta x = n\lambda$ and Phase diff. $\delta\phi = 2n\pi$
Path diff. = nλ = 2λ
Phase diff. = 2nπ = 4π (∴ n = 2)

Q10. **(d)** Phase difference, $\phi = \frac{2\pi}{\lambda}\times$ Path difference ϕ
$= \frac{2\pi}{\lambda}\times\frac{\lambda}{6} = \frac{\pi}{3} = 60^0$
As, I = $I_{max}\cos^2\frac{\phi}{2}$
$I = I_0\cos^2\frac{60^0}{2} = I_0\times\left(\frac{\sqrt{3}}{2}\right)^2 = \frac{3}{4}I_0\frac{I}{I_0} = \frac{3}{4}$

S11. (b) Huygens considered, light needs a medium to propagate called ether which is highly elastic and less dense.

S12. (c) $\mu = tan$ i

$\Rightarrow i = tan^{-1}(\mu) = tan^{-1}(\sqrt{3}) = 60^0$.

S13. (b) $\beta' = \frac{\beta}{\mu} = \frac{0.133}{1.33} = 0.1cm$

S14. (a) Wavefront is the locus of all points, where the particles of the medium vibrate with the same phase.

S15. (d) The Huygens's construction of wavefront does not explain the phenomena of origin of spectra.

S16. (b) Huyghue's principle gives us a geometrical method of tracing a wavefront

S17. (a) interference in light waves is just a re-distribution of energy, depending on exactly which parts of the light wave overlap at each point in space. The pattern of light you see is then determined by the geometry

S18. (c) $A = \sqrt{a_1^2 + a_2^2 + 2a_1a_2cos\varphi}$

ϕ − Angle between two waves or phase difference.

So, A depends on both amplitude & phase difference.

S19. (b) In physics, two wave sources are perfectly coherent if they have a constant phase difference and the same frequency (amplitude may be different). As c be the speed of light which is constant.

Using, c=νλ

Now same ν gives same λ. for the two light sources.

S20. (a) β∝λ

Correct answer is violet, as it has minimum wavelength. Fringe width is directly proportional to the wavelength. So, purple or violet has the minimum fringe width whereas red has maximum fringe width.

ASSERTION AND REASONING

S1. (a) As we know that earth's atmosphere has some particle which can scatter the light. Hence due to these particles the incoming light reflected by earth is partially polarized Hence, Both Assertion and Reason are correct and Reason is the correct explanation for Assertion

S2. (b) When light is incident at polarizing angle, a particular component of electric field vector (i.e., a particular polarization) completely passes to the other medium. Thus, the reflected light is completely polarized. Intensity decreases in polarization. When unpolarized light is passed through one polarizer, the intensity is reduced to half. So, assertion is correct and reason is also correct but reason is not the correct explanation of assertion

S3. (a) The colored spectrum is due to diffraction of white light on passing through fine slits made by fine treads in the muslin cloth.

S4. (c) The waves diffracted from the edges of circular obstacles placed in the path of light interfere constructively at the center of the shadow resulting in the formation of a bright spot.

S5. (d) For interference, the waves may be of unequal intensities.

SHORT ANSWER QUESTIONS

S1. Heat waves are transverse or electromagnetic in nature whereas sound wave are not. Polarization is possible only for transverse waves.

S2. The intensity of interference fringes in a double slit arrangement is modulated by the diffraction pattern of each slit. Alternatively, in double slit experiment the interference pattern on the screen is actually superposition of single slit diffraction for each slit.

S3. (i) Reflection and refraction arise through interaction of incident light with atomic constituents of matter which vibrate with the same frequency as that of the incident light. Hence frequency remains unchanged.

(ii) No; when light travels from a rarer to a denser media, its frequency remains unchanged. According to quantum theory of light, the energy of light photon depends on frequency and not on speed.

(iii) For a given frequency, intensity of light in the photon picture is determined by the number of photon incident normally on a crossing an unit area per unit time.

S4. Case I: The overlapping of the contributions of the wavelets from two halves of a single slit produces a minimum because corresponding wavelets from two halves have a path difference of λ/2.

Case II: The overlapping of the wavefronts from the two slits produces first maximum because these wavefronts have the path difference of λ.

S5. When unpolarized light passes through a polarizer, vibrations perpendicular to the axis of the polaroid are blocked. Unpolarized light have vibrations in all directions. Hence, if the polarizer is rotated, the unblocked vibrations remain same with reference to the axis of polarizer. Hence for all positions of polaroid, half of the incident light always get transmitted. Hence, the intensity of the light does not change.

NUMERICAL TYPE QUESTIONS

S1. Given, $\lambda = 6000$ Å = 6000×10^{-10} m, $d = 0.3$ mm $= 0.3 \times 10^{-3}$ m

For minima, $d \sin\theta = m\lambda$

First minima mean (m = 1) $\Rightarrow \sin\theta = \frac{\lambda}{d}$

Angular position of 1st minima,

$\sin\theta = \theta = \frac{\lambda}{d} = \frac{6000 \times 10^{-10}}{0.3 \times 10^{-3}} = 2 \times 10^{-3}$ rad

So, angular position of first minima is 2×10^{-3} rad.

S2. For minima, $a \sin\theta = n\lambda$

$\Rightarrow \quad a \sin 30° = (1)\lambda \quad (n = 1)$

$\Rightarrow \quad a = 2\lambda \quad \left(\because \sin 30° = \frac{1}{2}\right) \quad ...(i)$

For 1st secondary maxima

$\Rightarrow \quad a \sin\theta_1 = \frac{3\lambda}{2} \Rightarrow \theta_1 = \frac{3\lambda}{2a} \quad ...(ii)$

Substitute value of *a* from Eq. (i) to Eq. (ii), we get

$\sin\theta_1 = \frac{3\lambda}{4\lambda} \Rightarrow \sin\theta_1 = \frac{3}{4}$

$\theta_1 = \sin^{-1}\frac{3}{4}$

S3. Given, $\lambda = 6.328 \times 10^{-7}$ m, a = 0.2×10^{-3} m

$w_\theta = \frac{2\lambda}{a} = \frac{2\times6.328\times10^{-7}}{2\times10^{-4}} radian = \frac{6.328\times10^{-3}\times180}{3.14} = 0.36°$

S4. In unpolarized beam, vibrations are probable in all directions in a plane perpendicular to the direction of propagation. Therefore, θ can have any value from 0 to 2π.

$[\cos^2\theta]_{av} = \frac{1}{2\pi}\int_0^{2\pi} \cos^2\theta\, d\theta$

$= \frac{1}{2\pi}\int_0^{2\pi} \left(\frac{1+\cos 2\theta}{2}\right) d\theta$

$= \frac{1}{4\pi}\left([\theta]_0^{2\pi} + \left[\frac{\sin 2\theta}{2}\right]_0^{2\pi}\right) = \frac{1}{4\pi} \times 2\pi = \frac{1}{2}$

So, using law of Malus, $I = I_0 \cos^2\theta \Rightarrow I = I_0 \times \frac{1}{2} = \frac{I_0}{2}$

S5. $\boldsymbol{w_x = \frac{2f\lambda}{a} = \frac{2\times2\times5\times10^{-7}}{10^{-4}} = 20\ mm}$

S6. Here, a = 200 in = 200 × 2.54 cm = 508 cm = 5.08 m

λ = 600 nm = 600×10^{-9} m = 6.00×10^{-7} m

$\Delta\theta = 1.22\left(\frac{\lambda}{a}\right) = 1.22\left(\frac{6.00\times10^{-7} m}{5.08\, m}\right) = 1.44 \times 10^{-7} rad$

S7. As $\mu = \tan i_p$, $\tan i_p = 1.5$ or $i_p = \tan^{-1}(1.5)$ or $i_p = 56°19'$

As $r + i_p = 90°$, $r = 90° - i_p = 33°41'$