WAVE OPTICS

GUPTA CLASSES

For any help contact:
9953168795, 9268789880

Nishant Gupta, D-12[illegible] Vihar, Rohini, Delhi-85
Contact: 9953168795, 9268789880

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Wavefront:

1. The locus of all particles vibrating in the same phase is called a wavefront
2. For a point source of light, the wavefront is spherical in shape with source lying at its centre. When the source of light is linear, then the wavefront takes the cylindrical shape. For a parallel beam of light wave front is plane.

Huygen's Principle : It provides a geometrical method of finding the successive positions of the wavefront as follows:

(a) Every point on the wavefront acts as a fresh source of light giving out secondary wavelets. These secondary wavelets travel out in all directions with the same speed as that of light.

(b) The envelope of these wavelets in forward direction gives the position of the new wavefront at any subsequent time.

Interference of light:

1. When two light waves of same frequency with zero initial phase difference or constant phase difference superimpose over each other, then the resultant amplitude (or intensity) in the region of superimposition is different from the amplitude (or intensity) of individual waves. This modification in intensity in the region of superposition is called interference.
2. When resultant intensity is greater than the sum of two individual wave intensities [$I > (I_1 + I_2)$], then the interference is said to be constructive.
3. When the resultant intensity is less than the sum of two individual wave intensities [$I < (I_1 + I_2)$] then the interference is said to be destructive.
4. To obtain the stationary interference pattern, the following conditions must be fulfilled:

(a) The two sources should be coherent, i.e., they should vibrate in the same phase or there should be a constant phase difference between them.

(b) The two sources must emit continuously waves of same wavelength and frequency.

(c) The separation between two coherent sources should be small.

(d) The distance of the screen from the two sources should be large.

(e) For good contrast between maxima and minima, the amplitudes of the two interfering waves should be as nearly equal as possible and the background should be dark.

(f) For a large number of fringes in the field of view, the sources should be narrow and monochromatic.

Superposition of light waves of equal frequency and of constant phase difference:

1. When two light waves having same frequency, different amplitudes a_1 and a_2 with a constant phase difference superimpose each other, then the amplitude of the resultant wave can be expressed as: $a = \sqrt{a_1^2 + a_2^2 + 2a_1a_2\cos\phi}$

Amplitude is max. (a) If $\phi = 0, 2\pi, 4\pi, \ldots\ldots. 2n\pi$, and $a_{max.} = a_1 + a_2$.

Amplitude is min. (b) If $\phi = \pi, 3\pi, 5\pi, \ldots\ldots(2n-1)\pi$, and $a_{min.} = a_1 - a_2$.

2. The intensity of the resultant wave is: $I = I_1 + I_2 + 2\sqrt{I_1 I_2}\cos\phi$

Intensity is max. (a) When $\phi = 2n\pi$, and $I_{max.} = (\sqrt{I_1} + \sqrt{I_2})^2$

Intensity is min. (b) When $\phi = (2n-1)\pi$, and $I_{min.} = (\sqrt{I_1} - \sqrt{I_2})^2$

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3. If amplitudes of the two waves are equal, $a_1 = a_2 = a_0$ then resultant amplitude $a = \sqrt{2a_0^2 \cos\varphi} = 2a_0 \cos(\varphi/2)$

   and the resultant intensity $I = 4I_0 \cos^2(\phi/2)$

   Also, in this case, $a_{max.} = 2a_0$, $I_{max.} = 4I_0$

   And $a_{min.} = 0$, $I_{min.} = 0$

4. If phase difference is ϕ and path difference is Δx, then $\phi = \frac{2\pi}{\lambda}\Delta x$

5. **Condition of maxima in terms of path difference:** $\Delta x = n\lambda$ (n = 0,1,2,…)

6. **Condition of minima:** $\Delta x = (2n-1)\frac{\lambda}{2}$ (n = 1,2,…)

Young's interference (Double slit) experiment:

1. **Location of fringes on the screen w.r.t. centre:**

   (a) The location of nth bright fringe from center is: $x_n = \frac{n\lambda D}{d}$ (n = 0,1, 2,...)

   (b) The location of nth dark fringe from center is: $x_n = (2n-1)\frac{D\lambda}{2d}$ (n = 1,2,...)

2. **Fringe width:** In Young's double slit experiment, fringes of equal widths are formed. Fringe width of any bright or dark fringe is given by: $\beta = \frac{D\lambda}{d}$

3. **Angular width of the fringe:** It is given by $\alpha = \frac{\beta}{D} = \frac{\lambda}{d}$

4. Although the intensity at maximum is $4I_0$ (i.e., double of that expected on the basis of average value $2I_0$) and the intensity at minimum is zero, but $(I_{max.} + I_{min.})/2 = I_{average} = 2I_0$. This shows that energy is simply redistributed in interference. Some energy is transferred from the destructive interference region to the constructive interference region.

5. If the entire arrangement of Young's double slit experiment is immersed in water, then fringe width decreases.

   In water, $\beta_{water} = \frac{\lambda_{water} D}{d}$ and $\lambda_{water} = \frac{\lambda_{air}}{{}^a\mu_w}$

6. If a **monochromatic** light source is replaced by a white light source in Young's interference experiment, then the central fringe is white and some coloured fringes are formed around the central white fringe.

7. If a thin glass plate or mica sheet is placed in front of one of the slits, then the central fringe shifts towards the slit in front of which the glass plate is placed. If t is the thickness of glass or mica sheet and μ is the refractive index of the material of sheet, then extra path difference introduced by the sheet is $(\mu - 1)t$ and the whole pattern is shifted from center is $y = \frac{(\mu-1)tD}{d}$

Diffraction of light:

1. When light waves fall on a small aperture or a small sized obstacle whose linear dimension d is comparable to the wavelength λ, of the wave, then there is a departure from straight line propagation and wave energy flares out into the region of geometrical shadow of the obstacle or aperture. The spreading of wave energy beyond the limits prescribed by the straight line propagation of the rays is called diffraction. Diffraction effects become more prominent when (λ/d) increases.

Nishant Gupta, D-122, Prashant vihar, Rohini, Delhi-85
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2. As $\lambda_{sound} > \lambda_{light}$, diffraction is more easily observed in sound as compared to light.
3. Interference takes place when there is superposition of two separate wavefronts originating from two separate coherent sources. Diffraction takes place due to superposition of secondary wavelets starting from different points of the same wavefront.
4. **Condition of minima in terms of path difference:** $\Delta x = d\sin\theta = n\lambda$ (n = 1,2,…)
5. **Condition of maxima:** $\Delta x = d\sin\theta = (2n+1)\frac{\lambda}{2}$ (n = 1,2,…)
6. Width of maxima or minima $\beta = \frac{D\lambda}{d}$, Width of central maxima $\beta = \frac{2D\lambda}{d}$
7. Angular width of maxima or minima $\alpha = \frac{\beta}{D} = \frac{\lambda}{d}$, Angular width of central maxima $\alpha = \frac{2\lambda}{d}$

Polrisation

1. A light wave in which vibrations of electric component are present in all directions, perpendicular to the propagation of wave is called as unpolarised light
2. The phenomenon of restricting the oscillations of light wave (electric vector) to only one plane perpendicular to direction of wave motion is called ***polarization*** of light and light so obtained is called ***plane polarized light***.
3. The crystal, which polarises the light, is called polariser and the one which analysis the polarized light is called analyser. The same type of crystal may act as polariser as well as analyser
4. The plane within which the vibrations of the polarized beam are confined is called the plane of vibration and a plane normal to this is called plane of polarization
5. Polarisation confirms that light is a transverse wave because only transverse waves can be polarized.

Law of Malus

According to this law, when a beam of completely polarized light is incident on an analyzer, the resulatant intensity of light (I) transmitted from analyzer varies directly as cosine of angle (ϕ) between plane of transmission of panalyser and polariser.

i.e. $\mathbf{I \propto \cos^2 \phi}$

Polarisation by Reflection

1. When unpolarised light is reflected from a surface, the reflected light may be unpolarised, partially polarized or completely polarized depending on the angle of incidence.
2. The angle at which light is compeletly polarized is called ***polarizing angle*** or ***Brewster angle (I_p).***
3. ***Brewster Law :*** According to this law, when unpolarised light is incident on an interface separating air from medium of refractive index μ then the reflected light is fully polarized provided $\mu = \tan i_p$.
4. The reflected and refracted rays shall be perpendicular to each other if $\mu = \tan i_p$ and vice-versa. i.e. when a beam of light falls at the polarizing angle, the reflected and refracted beams are at right angle to each other.

Polarisation by Scattering

When a beam of white light is passed through a medium containing particles whose size is of the order of wavelength of light, then the beam gets scattered. When this scattered light is seen from a direction perpendicular to direction of incidence. It is found to be polarized. This phenomenon is called scattering of light.

Polaroids

A polaroid is a material which polarizes light. Tourmaline is a natural polarizing material. A small needle shaped crystal of quinine idosulphate has the property of polarizing the light. A number of these crystals with their axes parallel to one another are packed in between two sheets of plastic. Such a sheet serves as polariser.

Nishant Gupta, D-122, Prashant vihar, Rohini, Delhi-85
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Wave Optics Assignment

1. Identical waves (each of intensity I_o), from two incoherent sources of light superpose at a point in space; then the average intensity of the resultant wave will be:
(a) zero (b) I_0 (c) $2I_0$ (d) $\sqrt{2}I_0$
2. Identical waves (each of intensity I_o) from two coherent sources of light superpose at a point in space; then the resultant intensity of wave will be:
(a) zero
(b) $4I_0$
(c) $2I_0$
(d) any value between 0 and $4I_0$
3. Ratio of intensities of two waves is given by 4 : 1. The ratio of amplitudes of the waves is:
(a) 2 : 1 (b) 1 : 2 (c) 4 : 1 (d) 1 : 4
4. Two interfering waves have amplitudes in the ratio 5 : 1. The ratio of the maximum to the minimum intensity is:
(a) 25 : 1 (b) 4 : 9 (c) 6 : 4 (d) 9 : 4
5. Two coherent monochromatic light beams of intensities I and $4I$ are superposed; the maximum and minimum possible intensities in the resulting beam are:
(a) $5I$ and I (b) $5I$ and $3I$
(c) $9I$ and I (d) $9I$ and $3I$
6. If two waves, each of intensity I_0, having the same frequency but differing by a constant phase angle of 60°, superpose at a certain point in space, then the intensity of resultant wave is:
(a) $2\ I_0$ (b) $\sqrt{3}I_0$ (c) $3\ I_0$ (d) $4\ I_0$
7. Two monochromatic waves, each of amplitude a, have random phase difference between them. When these superpose, then the amplitude of resultant wave is given by:
(a) $\sqrt{2}$a (b) 2a (c) 4a (d) zero
8. In an interference pattern produced by two identical slits the intensity at the site of the central maximum is I. The intensity at the same spot when either of the two slits is closed is I_0. We must have:
(a) $I = I_0$
(b) $I = 2I_0$
(c) $I = 4I_0$
(d) I and I_0 are not related
9. For most distinct interference patterns to be observed the necessary condition is that the ratio of intensities of light waves from the two coherent sources should be:
(a) 1: 1 (b) 1 : 2 (c) 1: 3 (d) 1 : 4
10. In a certain double slit experimental arrangement, interference fringes of width 1.0 mm each are observed when light of wavelength 5000 Å is used. Keeping the setup unaltered if the source is replaced by another of wavelength 6000 Å, the fringe width will be:
(a) 0.5 mm (b) 1.0 mm (c) 1.2 mm (d) 1.5 mm
11. In a Young's double slit experiment, the fringe width is found to be 0.4 mm. If the whole apparatus is immersed in water of refractive index (4/3), without disturbing the geometrical arrangement, the new fringe width will be:
(a) 0.30 mm (b) 0.40 mm
(c) 0.53 mm (d) 450 microns
12. In Young's double slit experiment the angular width of a fringe formed on distant screen is 1°. The wavelength of light used is 6000 Å. The spacing between the slits is approximately:
(a) 1 mm (b) 0.05 mm
(c) 0.03 mm (d) 0.01 mm
13. The path difference equivalent to a phase difference of 270° (given wavelength of wave = λ) is:
(a) zero (b) $\lambda/2$ (c) $3\lambda/4$ (d) λ
14. Four independent waves are represented by the equations:
$y_1 = a_1 \sin \omega t$, $y_2 = a_2 \sin \omega t$,
$y_3 = y_3 \cos \omega t$, $y_4 = a_4 \sin (\omega t + \pi/3)$
Then the waves for which the phenomenon of interference will be observed are:
(a) 1 and 3 (b) 1 and 4
(c) all 1, 2. 3 and 4 (d) none of these
15. In the phenomenon of interference, the energy:
(a) conservation does not hold good as energy is redistributed from destructive interference regions to constructive interference regions
(b) conservation is valid, only redistribution of energy takes place
(c) conservation is not valid but amplitude addition holds good
(d) conservation is not valid but intensity addition holds good
16. In Young's double slit experiment, if width (aperture) of the slit S is increased keeping other parameters constant, then the interference fringes will:
(a) remain unchanged
(b) form closer
(c) form further away
(d) gradually disappear
17. Two sources (monochromatic, coherent) S_1 and S_2 are at a distance $\lambda/2$ apart. Then a point lying on the line bisecting the line joining two sources will have:
(a) maximum intensity
(b) minimum intensity
(c) average intensity

Nishant Gupta, D-122, Prashant vihar, Rohini, Delhi-85
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(d) none of the above

18. In double slit experiment, the phase difference between the two waves reaching at the location of the third dark fringe is:
(a) π (b) 6π (c) 5π (d) 7π

19. In Young's double slit experiment carried out with light of wavelength λ = 5000 Å, the distance between the slits is 0.2 mm and the screen is at 200 cm from the plane of slits. The central maximum is at x = 0. The third maximum will be at x equal to:
(a) 1.67cm (b) 1.5cm (c) 0.5 cm (d) 5.0 cm

20. In Young's experiment, two coherent sources are placed 0.90 mm apart and the fringes are observed one metre away. If it produces the second order dark fringe at a distance of 1 mm from the central fringe the wavelength of monochromatic light used would be:
(a) 60×10^{-4} cm (b) 10×10^{-4} cm
(c) 10×10^{-5} cm (d) 6×10^{-5} cm

21. The central fringe of the interference pattern produced by light of wavelength 6000 Å is found to shift to the position of 4th bright fringe after a glass plate of refractive index 1.5 is introduced. The thickness of the glass plate would be:
(a) 4.8 μm (b) 8.23μm
(c) 14.98 μm (d) 3.78 μm

22. In Young's experiment when sodium light of wavelength 5893 Å is used, then 62 fringes are seen in the field of view. Instead, if violet light of wavelength 4358 Å is used then the number of fringes that will be seen in the field of view will be:
(a) 54 (b) 64 (c) 74 (d) 84

23. In Young's experiment monochromatic light through a single slit S is used to illuminate the two slits S_1 and S_2. Interference fringes are obtained on the screen. The fringe width is found to be β. Now a thin sheet of mica (thickness t and refractive index μ,) is placed near and in front of one of the two slits. Now the fringe width is found to be β'. Then:
(a) $\beta' = \beta/\mu$ (b) $\beta' = \beta\mu$
(c) $\beta' = (\mu - 1)\beta$ (d) $\beta' = \beta$

24. In Young's experiment the wavelength of red light is 7.8×10^{-5} cm and that of blue light 5.2×10^{-5} cm. The value of n for which (n + l)th blue bright band coincides with nth red band is:
(a) 4 (b) 3 (c) 2 (d) 1

25. A slit 5.0 cm wide is irradiated normally with microwaves of wavelength 1.0 cm. Then the angular spread of the central maximum on either side of the incident light is nearly:
(a) (1/5) radian (b) 4 radian
(c) 5 radian (d) 6 radian

26. In the Young's double slit experiment, the intensity on the screen at a point where path difference is λ is K. What will be the intensity at the point where path difference is (λ/4)?
(a) K/4 (b) K/2 (c) K (d) Zero

27. Microwaves from a transmitter are directed normally towards a plane reflector. A detector moves along the normal to the reflector. Between positions of 14 successive maxima the detector travels a distance of 0.14 m. The frequency of transmitter is (c = 3×10^8m/s):
(a) 1.5×10^{10} Hz (b) 10^{10} Hz
(c) 3×10^{10} Hz (d) 6×10^{10} Hz

28. Diffraction effects are easily observable for:
(a) microwaves (b) sound waves
(c) radio waves (d) all of the above

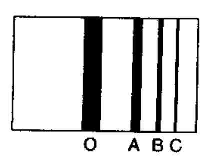
29. In Young's double slit experiment:
(a) only interference and no diffraction occurs
(b) only diffraction and no interference occurs
(c) both interference and diffraction occur
(d) nothing specific can be predicted

30. The phenomenon of diffraction may be thought of as interference, where the number of coherent sources are:
(a) zero (b) two
(c) infinite (d) none of these

31. The phenomenon of diffraction can be exhibited by:
(a) polarised waves only
(b) unpolarised waves only
(c) longitudinal waves only
(d) all, polarised or unpolarised, longitudinal or transverse waves

32. The first diffraction minimum due to a single slit diffraction is at $\theta = 30°$ for a light of wavelength 5000 Å. The width of the slit is:
(a) 5×10^{-5} cm (b) 1.0×10^{-4} cm
(c) 2.5×10^{-5} cm (d) 1.25×10^{-5} cm

33. The position of the direct image obtained at O, when a monochromatic beam of light is passed through a plane transmission grating at normal incidence is shown in figure. The diffracted images A, B and C correspond to the first, second and third order diffraction when the source is replaced by another source of shorter wavelength:



(a) all the four will shift in the direction C to O
(b) all the four will shift in the direction O to C
(c) the images C, B and A will shift towards O
(d) the images C, B and A will shift away to O

34. Light of wavelength 6328 Å is incident normally on a slit having a width of 0.2 mm. The width of the central maximum measured from minimum to minimum of diffraction pattern on a screen 9.0 metres away will be about:
(a) 0.36 degrees (b) 0.18 degrees

(c) 0.72 degrees (d) 0.09 degrees

35. A beam of light of wavelength 600 nm from a distant source falls on a single slit 1.00 mm wide and the resulting diffraction pattern is observed on a screen 2 m away. The distance between the 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 mm
36. If light is polarised by reflection, then the angle between reflected and refracted light is:
(a) π (b) $\pi/2$ (c) 2π (d) $\pi/4$
37. Polaroid glass is used in sun glasses because;
(a) it reduces the light intensity to half on account of polarisation
(b) it is fashionable
(c) it has good colour
(d) it is cheaper
38. A beam of light strikes a piece of glass at an angle of incidence of 60° and the reflected beam is completely plane polarised. The refractive index of the glass is:
(a) 1.5 (b) $\sqrt{3}$ (c) $\sqrt{2}$ (d) (3/2)
39. A polaroid is place at 45° to an incoming light of intensity I_0. Now the intensity of light passing through the polaroid after polarization would be:
(a) I_0 (b) $I_0/2$ (c) $I_0/4$ (d) zero
40. Two Nichol prisms are first crossed and then one of them is rotated through 60°. The percentage of incident light transmitted is:
(a) 1.25 (b) 25.0 (c) 37.5 (d) 50
41. Two beams of light having intensities I and $4I$ interfere to produce a fringe pattern on a screen. The phase difference between the beams is $\pi/2$ at point A and π at point B. Then the difference between the resultant intensities at A and B is:
(a) 2I (b) 4I (c) 5I (d) 7I
42. Which of these waves can be polarised?
(a) sound-waves
(b) longitudinal waves on a string
(c) transverse waves on a string
(d) light waves

ANSWERS

1c ,2d ,3a ,4d ,5c ,6c ,7a ,8c ,9a ,10c ,11a ,12c ,13c ,14d ,15b ,16d ,17a ,18c ,19b ,20d ,21a ,22d ,23d ,24c ,25a ,26b ,27a ,28b ,29c ,30c ,31d ,32b ,33c ,34a ,35d ,36b ,37a ,38b ,39b ,40c ,41b ,42d

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