Class 12 Physics · Chapter 10: Wave Optics

Answer key and marking scheme · 20 marks · about 40 minutes · based on NCERT

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1. A beam of light passes from glass into air. The quantity that does not change is its [1]

(a) frequency
(b) wavelength
(c) speed
(d) direction of travel, for oblique incidence

Answer: (a) In the Huygens construction a crest from A reaches E as the crest from B reaches C, so $v_1/\lambda_1 = v_2/\lambda_2$: the frequency is unchanged, while speed and wavelength both increase in air and an oblique ray bends.

2. Light of frequency 6.0×10^{14} Hz has a wavelength of 400 nm inside a transparent plastic. Taking $c = 3.0 \times 10^8$ m s^{-1}, the refractive index of the plastic is [1]

(a) 0.80
(b) 1.33
(c) 1.25
(d) 2.40

Answer: (c) The frequency is the same in every medium, so the speed in the plastic is $v = v\lambda = 6.0 \times 10^{14} \times 400 \times 10^{-9} = 2.4 \times 10^8$ m s^{-1}, and $n = c/v = 3.0/2.4 = 1.25$. 0.80 is v/c, inverted; 1.33 is the index of water, assumed rather than worked out; 2.40 is the speed in units of 10^8 m s^{-1}.

3. According to the superposition principle, the resultant displacement at a point where several waves meet is [1]

(a) the vector sum of the displacements due to each wave
(b) the displacement due to the strongest wave alone
(c) the sum of the intensities of the waves
(d) the product of the individual displacements

Answer: (a) The resultant displacement is the vector sum of the displacements produced by each wave. Intensities add only for incoherent sources, and that is a time average, not a displacement.

4. A convex lens forms a real image of a point object. The ray through the centre of the lens covers a shorter geometrical path than a ray through the edge, yet both reach the image together because [1]

(a) the edge ray travels faster in glass than the central ray
(b) the central ray is delayed by reflection at the lens surfaces
(c) light takes no time to cross a thin lens
(d) the central ray spends more of its path in glass, where light travels more slowly

Answer: (d) The time from object point to image point is the same along every ray. The central ray's path is shorter, but more of it lies in glass, where light is slower; the two effects balance.

5. Light travels at 2.0×10^8 m s^{-1} in a certain glass. Taking $c = 3.0 \times 10^8$ m s^{-1}, the critical angle for light going from this glass into air is [1]

(a) 48.2°
(b) 41.8°
(c) 33.7°
(d) 19.5°

Answer: (b) $n = c/v = 1.5$, and $\sin i_c = n_2/n_1 = 1/1.5 = 2/3$, so $i_c \approx 41.8°$. 48.2° is the complement; 33.7° takes $\tan i_c = 2/3$; 19.5° takes $\sin i_c = 1/3$.

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6. Two coherent sources each produce an intensity I_0 at a point on a screen. Find the resultant intensity at points where the phase difference between the two waves is (i) $\pi/2$, (ii) $5\pi/3$. [2]

$I = 4I_0\cos^2(\phi/2)$. (i) $\phi = \pi/2$: $I = 4I_0\cos^2(\pi/4) = 4I_0 \times 1/2 = 2I_0$. (ii) $\phi = 5\pi/3$: $I = 4I_0\cos^2(5\pi/6) = 4I_0 \times 3/4 = 3I_0$.

- $I = 4I_0\cos^2(\phi/2)$; (i) $2I_0$ (1)
- (ii) $3I_0$ (1)

7. State Huygens' principle. Using it, describe how the position of a plane wavefront at a time τ later is obtained, and state the direction of the rays. [2]

Every point of a wavefront is a source of secondary wavelets, which spread out in all directions with the speed of the wave; the common tangent (forward envelope) of these wavelets at a later time gives the new wavefront. For a plane wavefront F_1F_2, draw spheres of radius $v\tau$ about several of its points; the plane G_1G_2 touching them is the wavefront at time τ, parallel to F_1F_2. The rays are the lines normal to both wavefronts.

- each point a source of secondary wavelets moving at the wave speed; their envelope is the new wavefront (1)
- spheres of radius $v\tau$ give the parallel plane G_1G_2; rays are normal to the wavefronts (1)

8. Using the Huygens construction for the refraction of a plane wavefront at a plane surface, show that $\lambda_1/\lambda_2 = v_1/v_2$, and hence that the frequency of the light does not change. State how the wavelength changes when light passes into a denser medium. [2]

In the construction, while the edge B of the incident wavefront AB travels $BC = v_1\tau$ to the surface at C, the wavelet from A spreads to radius $AE = v_2\tau$ in the second medium; CE is the refracted wavefront. Take τ as one period: then BC is one wavelength λ_1 and AE one wavelength λ_2, since the crest from A reaches E as the crest from B reaches C. So $\lambda_1/\lambda_2 = v_1/v_2$, that is $v_1/\lambda_1 = v_2/\lambda_2$: the frequency v/λ is the same in both media. In a denser medium $v_2 < v_1$, so $\lambda_2 < \lambda_1$: the wavelength becomes shorter in the same ratio as the speed.

- $BC = v_1\tau$, $AE = v_2\tau$; with τ one period, $BC = \lambda_1$ and $AE = \lambda_2$, so $\lambda_1/\lambda_2 = v_1/v_2$ and $v_1/\lambda_1 = v_2/\lambda_2$, frequency unchanged (1)
- denser medium: $v_2 < v_1$, so the wavelength decreases in proportion to the speed (1)

9. In a double-slit experiment the slits are 0.35 mm apart, the screen is 1.25 m away and the light has a wavelength of 560 nm. Find (i) the fringe width, (ii) the distance between the second bright fringe on one side of the centre and the third dark fringe on the other side, (iii) the fringe width when the screen is moved to 1.75 m. [3]

(i) $\beta = \lambda D/d = 560 \times 10^{-9} \times 1.25/(0.35 \times 10^{-3}) = 2.0 \times 10^{-3}$ m = 2.0 mm. (ii) Second bright fringe at 2β = 4.0 mm on one side; third dark fringe at $(2 + 1/2)\beta$ = 5.0 mm on the other; separation 9.0 mm. (iii) $\beta \propto D$: $\beta = 2.0 \times 1.75/1.25 = 2.8$ mm.

- $\beta = \lambda D/d$ = 2.0 mm (1)
- $2\beta + 2.5\beta$ = 9.0 mm (1)
- $\beta \propto D$ gives 2.8 mm (1)

10. Unpolarised light of intensity 32 W m^{-2} falls on a polaroid P_1, and the light from it on a second polaroid P_2. The light emerging from P_2 has intensity 4.0 W m^{-2}. Find (i) the intensity between P_1 and P_2, (ii) the angle between their pass-axes, (iii) the smallest angle through which P_2 must be turned to double the emerging intensity. [3]

(i) P_1 halves unpolarised light: 16 W m^{-2}. (ii) Malus' law: $4.0 = 16\cos^2\theta$, $\cos^2\theta = 1/4$, $\theta = 60°$. (iii) For 8.0 W m^{-2}, $\cos^2\theta' = 1/2$, $\theta' = 45°$: turn P_2 through 15°, bringing its pass-axis closer to that of P_1.

- 16 W m^{-2} after P_1 (1)
- $\cos^2\theta = 1/4$, $\theta = 60°$ (1)
- $\cos^2\theta' = 1/2$, $\theta' = 45°$, turn by 15° (1)

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11. Light travels at 2.25×10^8 m s^{-1} in a liquid. It meets the plane surface between the liquid and air from inside the liquid. Taking $c = 3.00 \times 10^8$ m s^{-1}, find (i) the refractive index of the liquid, (ii) the critical angle for the liquid–air surface. (iii) Using the Huygens construction, explain why there is no refracted wavefront when the angle of incidence exceeds the critical angle. [3]

(i) $n = c/v = 3.00/2.25 = 1.33$ (4/3). (ii) $\sin i_C = n_2/n_1 = 1/(4/3) = 0.75$, $i_C \approx 48.6°$. (iii) Going into the rarer medium, $v_2 > v_1$, so the wavelet from A in air has radius $v_2\tau$ greater than BC = $v_1\tau$. The refracted wavefront is the tangent from C to this wavelet, with $\sin r = (v_2/v_1) \sin i$. When $\sin i > v_1/v_2$, the wavelet's radius $v_2\tau$ exceeds AC, so C lies inside it and no tangent plane can be drawn from C ($\sin r$ would exceed 1): there is no refracted wave, and the light is totally reflected.

- $n = c/v = 4/3$ (1)
- $\sin i_C = 3/4$, $i_C \approx 48.6°$ (1)
- for $i > i_C$ the wavelet radius $v_2\tau$ exceeds AC; no tangent from C, so no refracted wavefront (1)

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