13.2 Wave phenomena (full C.3, HL)

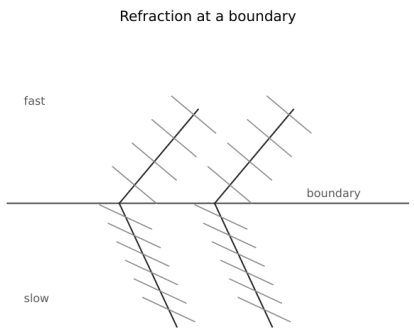
Name: _____ Class: _____ Date: _____ **Total: 31 marks**

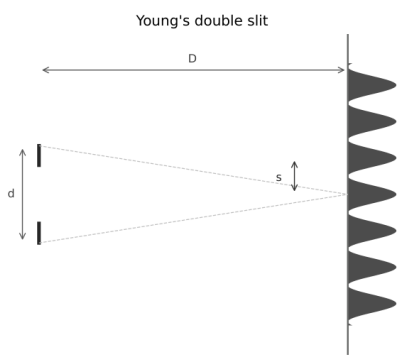
KEY WORDS wavefront • refractive index • total internal reflection • coherent sources • diffraction grating

Objective

Practise the full guide C.3 toolkit including AHL: wavefronts and rays, reflection, refraction and transmission at boundaries, Snell's law $n_1 \sin\theta_1 = n_2 \sin\theta_2$, critical angle and total internal reflection, diffraction, superposition with path differences $n\lambda$ and $(n+\frac{1}{2})\lambda$, coherence, and Young's double-slit relation $s = \lambda D/d$; at higher level also single-slit diffraction $\sin\theta = \lambda/b$, the modulation of double-slit fringes by the single-slit envelope, and the grating relation $n\lambda = d\sin\theta$. Original practice; not an official IB paper.

1 Key knowledge and worked examples





■ The C.3 equation set (HL)

$$n_1 \sin\theta_1 = n_2 \sin\theta_2 \qquad \sin\theta_c = \frac{n_2}{n_1} \qquad s = \frac{\lambda D}{d}$$

Path difference from two coherent sources: $n\lambda$ builds a maximum, $(n+\frac{1}{2})\lambda$ gives a minimum. Refraction bends a ray toward the normal entering a slower (higher-n) medium; frequency stays fixed, wavelength shortens with speed.

■ Worked example: reading the double-slit set-up

Slits $d = 0.20$ mm apart, screen $D = 2.4$ m away, 12 bright fringes across 55 mm – that is 11 gaps, so $s = 5.0$ mm. Then $\lambda = sd/D = (5.0 \times 10^{-3} \times 0.20 \times 10^{-3})/2.4 = 4.2 \times 10^{-7}$ m. Two habits: count fringe gaps, not fringes, and check the wavelength lands where the colour says it should.

2 Practice

2.1 State what a wavefront is, and state the geometric relationship between a wavefront and a ray. [2]

2.2 A ray travels from air ($n = 1.0$) into water ($n = 1.3$) at 50° to the normal. Calculate the angle of refraction. [3]

2.3 State the two conditions required for total internal reflection. [2]

2.4 Two coherent sources emit in phase with wavelength 0.60 m. A point is 2.00 m from one source and 2.30 m from the other. Determine whether the interference there is constructive or destructive. [2]

2.5 Light of wavelength 5.0×10^{-7} m passes through a single slit of width 0.050 mm. Calculate the angular position of the first minimum, and state the effect of widening the slit. [2]

3 Exam-style questions

3.1 A glass block has refractive index 1.5 and sits in air. Calculate the critical angle for the glass–air boundary, and calculate the refraction angle for a ray inside the glass hitting that boundary at 30° to the normal. [4]

3.2 Explain why sound heard through a doorway spreads around the frame while light through the same doorway appears to travel in straight lines. [3]

3.3 In a double-slit experiment, green light of wavelength 5.2×10^{-7} m gives fringes 4.0 mm apart with the screen 2.0 m from the slits. Calculate the slit separation, and state the effect on the fringe separation of moving the screen to 4.0 m. [4]

3.4 Light of wavelength 6.0×10^{-7} m passes through two slits 0.30 mm apart onto a screen 1.5 m away. Calculate the fringe separation, and explain why the two slits must be coherent for fringes to appear. [4]

3.5 A diffraction grating has 500 lines per millimetre. Light of wavelength 6.0×10^{-7} m strikes it at normal incidence. Calculate the angles of the first three orders, determine how many orders are visible in total, and explain one reason the grating maxima are brighter and sharper than a two-slit pattern. [5]

Solutions

Original-task marking: M1 method, A1 accuracy, B1 reasoning.

2.1 A line joining points that are in phase (one wavelength apart); a ray shows the direction of energy travel and is perpendicular to the wavefronts.

2.2 $\sin\theta_2 = (n_1/n_2)\sin\theta_1 = (1.0/1.3)\sin 50° = 0.589$; $\theta_2 = 36°$.

2.3 The wave must travel from a slower (higher refractive index) medium toward a faster one, and the angle of incidence must exceed the critical angle.

2.4 Path difference $= 2.30 - 2.00 = 0.30$ m $= \frac{1}{2}\lambda$ – half a wavelength out of step, so destructive: a minimum.

2.5 $\sin\theta = \lambda/b = (5.0 \times 10^{-7})/(5.0 \times 10^{-5}) = 1.0 \times 10^{-2}$, so $\theta = 0.57°$; widening the slit narrows the pattern – $\theta \propto 1/b$.

3.1 $\sin\theta_c = n_2/n_1 = 1.0/1.5 = 0.667$, so $\theta_c = 42°$; $30° < 42°$, so the ray escapes: $\sin\theta_2 = 1.5\sin 30° = 0.75$, $\theta_2 = 49°$.

3.2 Diffraction spread depends on the ratio of wavelength to aperture; sound has metre-scale wavelengths comparable with a doorway, so it diffracts strongly around the frame; light's wavelength (hundreds of nanometres) is tiny beside the opening, so its spreading is negligible.

3.3 $d = \lambda D/s = (5.2 \times 10^{-7} \times 2.0)/4.0 \times 10^{-3} = 2.6 \times 10^{-4}$ m $= 0.26$ mm; $s \propto D$ at fixed λ and d, so the fringes double to 8.0 mm.

3.4 $s = \lambda D/d = (6.0 \times 10^{-7} \times 1.5)/3.0 \times 10^{-4} = 3.0 \times 10^{-3}$ m $= 3.0$ mm; coherence – a constant phase difference and equal frequencies – keeps the same points of the screen always receiving crest-with-crest or crest-with-trough, so the pattern is steady rather than washing out.

3.5 $d = 1.0 \times 10^{-3}/500 = 2.0 \times 10^{-6}$ m; orders at $\sin\theta = 0.30, 0.60, 0.90$ – 17°, 37°, 64°; order 4 needs $\sin\theta = 1.2$, impossible, so exactly three orders are visible; many slits contribute to each maximum, making grating maxima brighter and far narrower than two-slit fringes.