InkPhysics

ANSWER BOOK

Refraction and total internal reflection

Waves · Year 12

AQA 3.3.2.3 · OCR A 4.4.1(f)(i), 4.4.2(d)(i), 4.4.2(e)

18 questions · 52 marks

NAVY EDITION

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SECTION A · Warm-up

A1 Refractive index n = speed of light in a vacuum / speed of light in the material = c/v (1). It is always greater than or equal to 1 (1). [2]

A2 $n = c/v = (3.0 \times 10^8)/(2.0 \times 10^8)$ (1)
$n = 1.5$ (1) [2]

A3 The light must be travelling in the more optically dense medium (higher n) towards the boundary with a less dense one (1), and the angle of incidence must exceed the critical angle (1). [2]

A4 The speed decreases and the wavelength decreases in the same ratio (1). The frequency is unchanged (1). [2]

A5 Total internal reflection requires the light to be travelling towards a medium of lower refractive index (1). Air has a lower refractive index than glass, so this light is heading into the denser medium and no critical angle exists: $\sin \theta_c = n_2/n_1$ would be greater than 1 (1). [2]

SECTION B · Standard

B1 $n_1 \sin\theta_1 = n_2 \sin\theta_2$ (1)
$\sin\theta_2 = \sin 40°/1.5$ (1)
$\theta_2 = 25.4°$ (1) [3]

B2 $\sin\theta_c = 1/n = 1/1.5$ (1)
$\theta_c = 41.8°$ (1) [2]

B3 $\lambda_{glass} = \lambda/n = 600/1.5$ (1)
$= 400$ nm (1)
$v = c/n = (3.0 \times 10^8)/1.5 = 2.0 \times 10^8\ \text{m s}^{-1}$ (1) [3]

B4 $n_1 \sin\theta_1 = n_2 \sin\theta_2$ (1)
$1.33 \times \sin 30° = 1 \times \sin\theta_2$ (1)
$\theta_2 = 41.7°$ (1) [3]

B5 The angle of incidence is measured from the normal: $\theta_1 = 90° - 25° = 65°$ (1).
$\sin\theta_2 = \sin 65°/1.33$ (1), so $\theta_2 = 43.0°$ (1). [3]

B6 $n_1 \sin\theta_1 = n_2 \sin\theta_2$: $\sin\theta_2 = 1.52 \times \sin 50°/1.66$ (1), so $\theta_2 = 44.5°$ (1). The ray bends towards the normal because it enters the optically denser medium, where light travels more slowly (1). [3]

B7 Rays reflecting along the fibre at different angles travel different total distances, so parts of a pulse arrive at different times and the pulse broadens (1). A very narrow core reduces it by forcing all rays onto nearly the same path (1). [2]

SECTION C · Stretch

C1 $\sin\theta_c = n_{cladding}/n_{core}$ (1) [3]
$= 1.40/1.50$ (1)
$\theta_c = 69.0°$ (1)

C2 $\sin\theta_c = 1/n = 1/1.5$ (1) [3]
$\theta_c = 41.8°$ (1)
45° is greater than the critical angle, so the ray undergoes total internal reflection and does not leave the block (1)

C3 It has a central core of high refractive index surrounded by a cladding of slightly lower refractive index (1). The cladding gives a well-defined boundary for total internal reflection (1), protects the core, and reduces signal loss and crossover between fibres (1). [3]

C4 $\sin\theta_c = n_{cladding}/n_{core}$ (1). For P: $\theta_c = 65.2°$; for Q: $\theta_c = 72.5°$ (1); for R: $\theta_c = 80.7°$ (1). Only R gives a critical angle of at least 80°, so the manufacturer should choose cladding R (1). [4]

C5 $v = c/n = (3.0 \times 10^8)/1.48$ (1) $= 2.03 \times 10^8$ m s^{-1}, which is about 2×10^8 m s^{-1} (1). $t = d/v = (15 \times 10^3)/(2.03 \times 10^8)$ (1) $= 7.4 \times 10^{-5}$ s (1). [4]

C6 Modal dispersion: rays reflecting at different angles travel different total path lengths along the fibre (1), so parts of the same pulse arrive at different times and the pulse spreads out (1). A very narrow core reduces this by forcing every ray onto nearly the same path (1). Material dispersion: different wavelengths travel at slightly different speeds in the glass, so a pulse of non-monochromatic light spreads in time (1); using monochromatic light (a single wavelength, for example from a laser) removes this spread (1). Broadened pulses can overlap their neighbours so that individual pulses can no longer be distinguished; pulses must therefore be sent less often, limiting the data rate (1). [6]