

2.3 Intensity, refraction and polarisation

Name: _____ Class: _____ Date: _____

Total: 23 marks

KEY WORDS Intensity • Refraction • normal • refractive index • Total internal reflection
• critical angle • Plane polarisation

Objective

Build the methods for WPH12 statements 44–49: intensity, refraction and polarisation. These are original teaching questions, not copied past-paper items.

1 Key knowledge and worked examples

Intensity is power per unit area perpendicular to the energy flow:

$$I = \frac{P}{A}$$

Its unit is W m^{-2} . For a receiver, incident power is $P = IA$. Useful output is smaller if efficiency is below 100%. Convert area carefully: $1 \text{ cm}^2 = 10^{-4} \text{ m}^2$.

Worked example. Radiation intensity is 800 W m^{-2} over a 25 cm^2 solar cell. Efficiency is 20%. Can it supply 0.50 W ?

- Known: intensity, area, efficiency. First find incident power, then useful power.

$$P_{\text{in}} = IA = 800 \text{ W m}^{-2} \times 25 \times 10^{-4} \text{ m}^2 = 2.0 \text{ W}$$

$$P_{\text{out}} = \eta P_{\text{in}} = 0.20 \times 2.0 \text{ W} = 0.40 \text{ W}$$

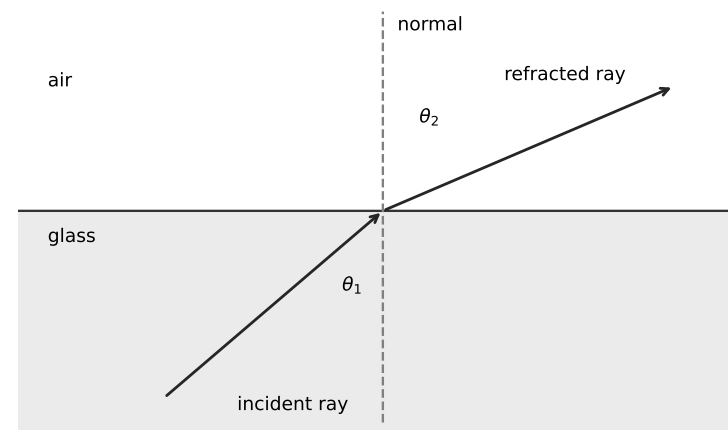
- $0.40 \text{ W} < 0.50 \text{ W}$, so it cannot supply the required useful power.

■ Refraction and total internal reflection

Refraction is a change in wave direction when speed changes at an interface. A ray entering along the normal changes speed without changing direction. The **normal** is perpendicular to the boundary. Measure all ray angles from it.

$$n = \frac{c}{v} \quad n_1 \sin \theta_1 = n_2 \sin \theta_2$$

The **refractive index** n compares vacuum light speed c with speed in the material. Frequency stays constant across the boundary, so wavelength changes with speed. Entering higher n bends the ray towards the normal; entering lower n bends it away.



The ray bends away from the normal when it enters the lower-index medium.

Total internal reflection requires travel from higher to lower refractive index and incidence greater than the **critical angle** C .

$$\sin C = \frac{n_2}{n_1} \quad \text{for material to air: } \sin C = \frac{1}{n}$$

At C the refracted angle is 90° ; call incidence greater than C total internal reflection. Below C , some energy is normally reflected and some transmitted. An optical fibre uses a higher-index core and lower-index cladding. Raising the cladding index raises the critical angle and can stop a previously reflected ray being trapped.

Worked example. Light travels from glass of index 1.50 into air. Does an incidence angle of 45° produce total internal reflection?

- Known: the two indices and incidence angle. Find the boundary angle before comparing.

$$C = \sin^{-1} \left(\frac{n_2}{n_1} \right) = \sin^{-1} \left(\frac{1.00}{1.50} \right) = 41.8^\circ$$

- The light travels towards lower index and $45^\circ > 41.8^\circ$. Both conditions hold, so total internal reflection occurs.

■ Measuring refractive index

Place a rectangular transparent block on paper and trace its outline. Use a narrow ray-box beam. Mark two points on the incident ray and two on the emerging ray. Remove the block and join the boundary points to reconstruct the ray inside. Draw the normal at entry and measure incidence i and refraction r with a protractor.

Repeat for several incidence angles, keeping the same material and light colour. Plot $\sin i$ vertically against $\sin r$ horizontally. For air into the block, the gradient is the

block's refractive index relative to air. Use a large triangle on a best-fit line. Narrow beams and widely separated ray marks reduce direction uncertainty. Very small angles give large percentage angle uncertainties.

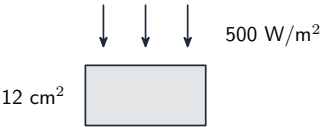
■ Plane polarisation

Plane polarisation restricts transverse vibrations to one plane containing the propagation direction. Unpolarised light has vibrations in many planes. A polariser transmits one vibration direction. Rotate a second polariser: parallel transmission directions give maximum brightness; perpendicular directions ideally give darkness. The ray still travels forward; its vibration direction changes selection.

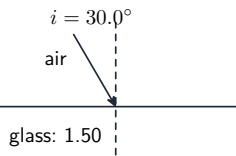
Longitudinal waves cannot be plane polarised because their vibration is already along propagation. Polarisation is therefore evidence that light is transverse.

2 Practice

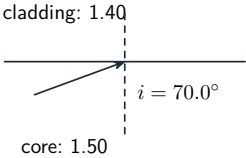
2.1 A receiver of area 12 cm^2 is perpendicular to radiation of intensity 500 W m^{-2} . Calculate incident power. If its efficiency is 15%, calculate useful power. [3]



2.2 Light enters glass of index 1.50 from air at 30.0° to the normal. Calculate refraction angle. State what happens to frequency. [3]

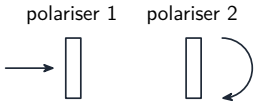


2.3 Light travels from a core of index 1.50 to cladding of index 1.40 at 70.0° incidence. Deduce whether total internal reflection occurs. [3]



3 Exam-style questions

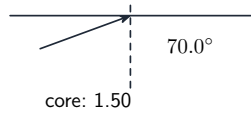
3.1 Unpolarised light passes through two ideal polarisers. Explain how brightness changes when the second rotates through 180° from parallel alignment. Explain what this shows about light. [4]



3.2 Plan a ray-box measurement of the refractive index of a rectangular block. Include ray reconstruction, angle definitions, a graph with its gradient meaning, and two measurement precautions. [6]

3.3 A fibre core has index 1.50. Its cladding index changes from 1.40 to 1.45. Calculate both critical angles. Deduce the effect on a core ray incident at 70.0° . [4]

cladding: 1.40 to 1.45



Solutions

These allocations are for the original questions on this sheet. B1 = one standalone point, M1 = one method point, A1 = one accuracy point.

2.1 $A = 12 \times 10^{-4} = 0.0012 \text{ m}^2$. $P = IA = 500 \times 0.0012 = 0.60 \text{ W}$. $P_{useful} = \eta P = 0.15 \times 0.60 = 0.090 \text{ W}$.

2.2 Snell's law: $n_1 \sin i = n_2 \sin r$. $r = \sin^{-1}(\sin 30.0^\circ / 1.50) = 19.5^\circ$. Frequency stays constant.

2.3 $\sin C = n_2 / n_1 = 1.40 / 1.50$, so $C = 69.0^\circ$. Travel is to lower index and $70.0^\circ > C$, so total internal reflection occurs.

3.1 The first polariser selects one transverse vibration direction. Brightness starts at maximum, reaches minimum at 90° , and returns to maximum at 180° . The second selects a direction perpendicular to the first at the minimum. This supports transverse vibration; longitudinal waves cannot be plane polarised.

3.2 Trace the block and mark separated points on incident/emerging rays, then remove the block and join entry/exit points to reconstruct the internal ray. Draw the entry normal and measure i, r from it. Repeat a range of incidence angles. Plot $\sin i$ against $\sin r$; the best-fit gradient is index relative to air. Narrow beam and widely separated marked points or avoiding very small angles reduce direction/percentage uncertainty.

3.3 $\sin C = n_{clad} / n_{core}$. Initially $C = 69.0^\circ$; finally $C = 75.2^\circ$. The ray initially undergoes total internal reflection, but afterwards $70.0^\circ < C$, so it is no longer totally internally reflected.