Name	Date started	Target end date

GCE AS / A LEVEL — REFRACTION OF LIGHT QUESTION PACK

Legacy PH2 · New spec Unit 2 Topic 6 · AS unit, 20% of A-level

REVISE
.wales

PHYSICS — UNIT 2 · REFRACTION OF LIGHT

PH2.6 Refraction of light — Snell's law & total internal reflection

Applying Snell's law $n_1 \sin\theta_1 = n_2 \sin\theta_2$, deriving the critical angle $\sin\theta_C = 1/n$, and reasoning about total internal reflection in optical fibres and prisms.

NEW 2015 SPEC · UNIT 2 TOPIC 6

Estimated time for entire question pack: ~2 h 44 min

Derived from the legacy PH2 paper's pace of 80 marks in 1¼ hours.

*You are advised to **not** attempt to complete all of this in one sitting.*

ABOUT THIS QUESTION PACK

This is a **comprehensive practice question pack**, not a single mock paper. It contains every question from the legacy WJEC PH2 papers (2008 modular spec) that maps onto new-spec Unit 2 Topic 6 (2.6).

Questions are ordered chronologically within each section.

INSTRUCTIONS

Use black ink or black ball-point pen. Answer all questions in the spaces provided.

The number of marks is given in brackets at the end of each question or part-question. A calculator is required. The Data Booklet is allowed.

For Examiner's use only

Q	Source	Max	Mark
1	PH2 Jun 13 Q3	13	
2	PH2 Jun 14 Q4	14	
3	PH2 Jun 16 Q3	13	
4	PH2 Jun 10 Q3	12	
5	PH2 Jun 12 Q4	8	

Q	Source	Max	Mark
6	PH2 Jun 09 Q3	12	
7	PH2 Jan 11 Q4	10	
8	PH2 Jan 13 Q3	13	
9	PH2 Jun 15 Q4	14	
10	PH2 Jun 12 Q5	8	
Total		117	

Refraction of Light — what the new spec asks

WJEC GCE AS / A Level Physics (from 2015) · Unit 2: Electricity & Light · Topic 2.6.

Refractive index (A)

- Define n as speed of light in vacuum / speed of light in medium.
- Apply $n_1 \sin\theta_1 = n_2 \sin\theta_2$ (Snell's law).
- Wavelength change but constant frequency on crossing a boundary.

Critical angle (B)

- Derive $\sin\theta_c = 1/n$ (for light in medium going to vacuum).
- More generally $\sin\theta_c = n_2 / n_1$ for two media.
- Define total internal reflection.

Optical fibres (B)

- Step-index fibre: core and cladding refractive indices.
- Multimode vs monomode dispersion qualitatively.

Applications (B)

- Reasoning about prisms, periscopes and bicycle reflectors.
- TIR-based endoscopes.

Refraction of Light in one page

Quick-reference notes — revisit before each section.

Refractive index

$n = c/v$ (c = vacuum, v = in medium).

$n > 1$ in any material.

Frequency unchanged across boundary; λ changes.

Snell's law

θ measured from the normal, not the surface.

Bends towards normal entering denser medium.

Critical angle

From denser to less dense: $\sin\theta_c = n_2/n_1$.

Above θ_c: total internal reflection.

Useful: prism right-angle reflectors.

Optical fibres

Core n high, cladding n lower.

Light at $\theta > \theta_c$ stays in core.

Multimode: many paths ⇒ dispersion.

Watch out for

Refraction angle is always from the normal.

If θ from surface, take $90° - \theta$.

Strategy

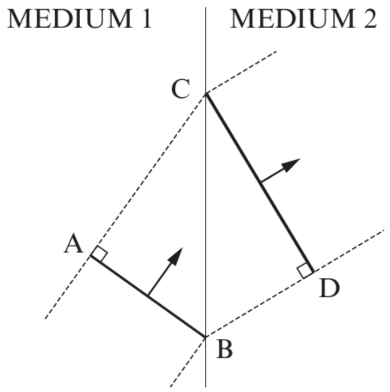
1. Sketch boundary + normal + ray.
2. Identify n on each side.
3. Apply Snell or critical angle as appropriate.

Section index

Use this index to jump straight to the section you need.

Section	Questions	Marks
A Snell's law & refractive index	Qs 1–5	60 marks
B Critical angle & total internal reflection	Qs 6–10	57 marks

3. *(a)* Explain, in terms of waves, why *refraction* occurs. **Refer to the diagram below in your answer.** [Mathematics is not needed.] [3]



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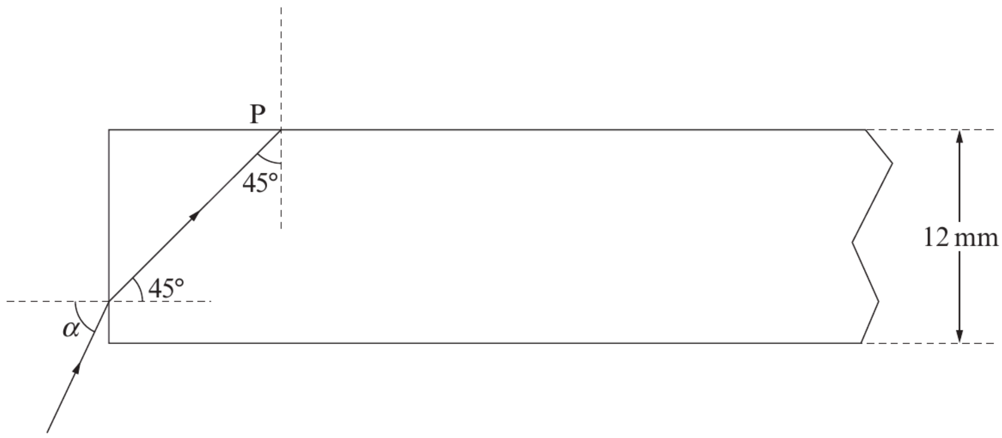
(b) A laser beam is directed on to the end-face of a rod of clear plastic of refractive index 1.33, surrounded by air (refractive index 1.00).



(i) Calculate the angle α. [2]

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(ii) At P, 90% of the light power is refracted out into the air, and 10% is reflected.

(I) **Draw** carefully on the diagram above the paths of the light refracted and reflected at P. The reflected ray need extend no further than the bottom of the rod. [2]

(II) Estimate how far the reflected light travels along the rod **from P** before the power drops to a millionth of the power of the beam incident on P. [Consider successive reflections.] [3]

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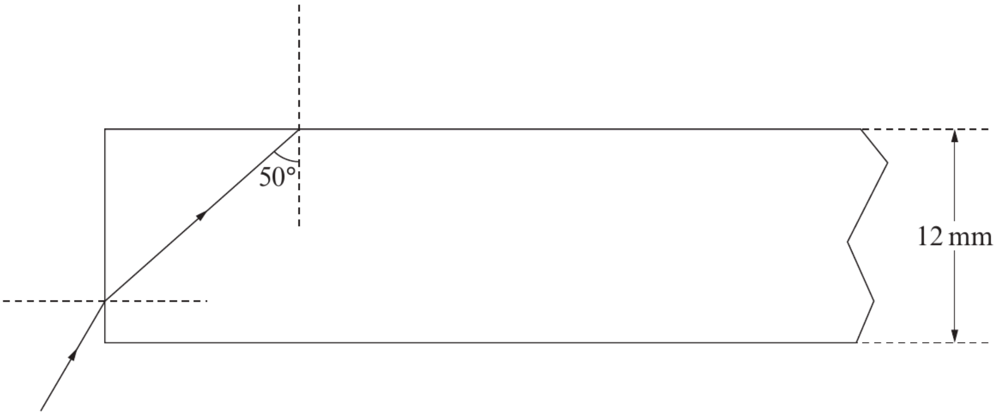
(c) The angle of the laser beam is changed as shown.



(i) By first calculating the critical angle, explain why the laser beam now travels along the rod with no loss of power at reflections. [2]

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(ii) Give the full name of the type of reflection occurring. [1]

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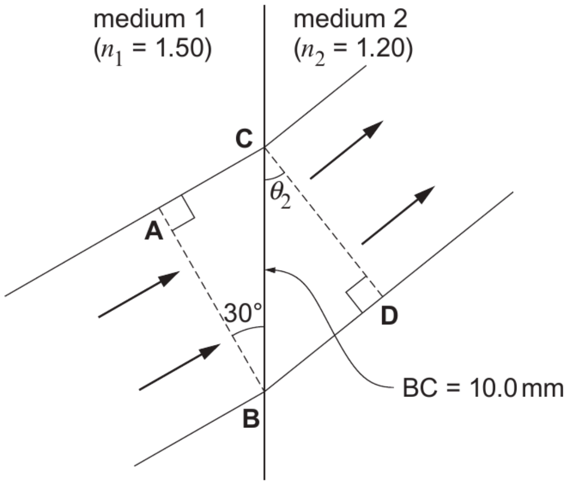
4. *(a)* A beam of light passes from medium 1, of refractive index n_1 = 1.50, into medium 2, of refractive index n_2 = 1.20.



(i) Calculate the speeds of light in the two media. [1]

medium 1 ....

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medium 2 ....

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(ii) Show clearly that the end, **A**, of wavefront **AB** will take 2.5×10^{-11} s to reach the boundary at **C**. [Note that distance BC = 10.0 mm.] [2]

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(iii) While **A** is travelling to **C**, the end, **B**, of wavefront **AB** travels to **D**, through medium **2**. Calculate the distance **BD** and hence the angle θ_2. [2]

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(iv) Check your value of θ_2 using a refraction equation involving n_1 and n_2. [2]

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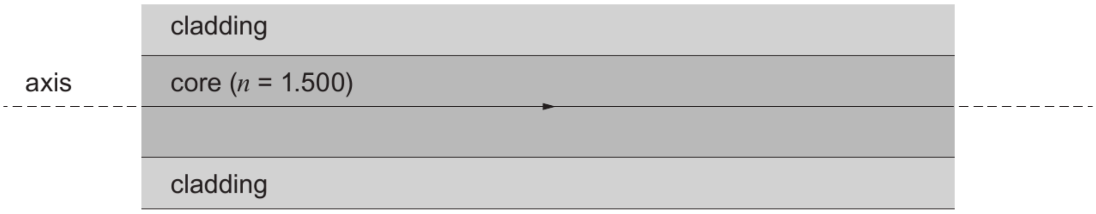
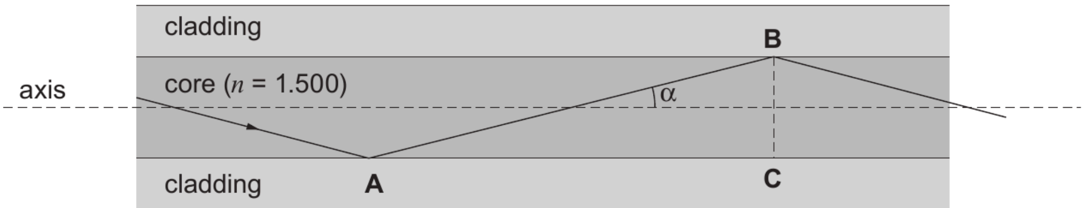
(b) A diagram of an optical fibre is given.



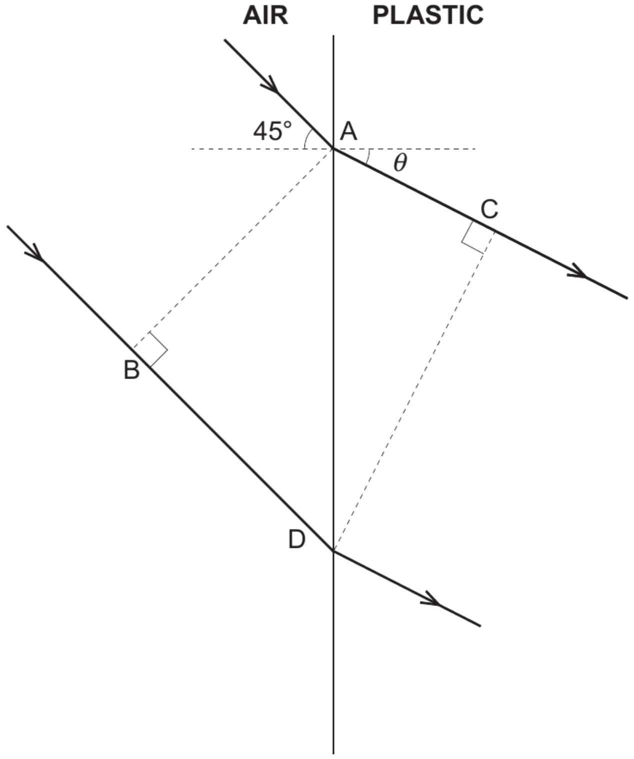
(i) Show clearly that a light pulse travelling along the axis of the fibre takes 8.0 μs to travel through 1.6 km of fibre. [2]

(ii) The greatest angle, α, **to the axis** at which light can travel through the core without escaping is 14°. Calculate the refractive index of the cladding. [3]



(iii) Calculate the **difference** in times taken for a pulse to travel through 1.6 km of fibre by the routes in *(b)*(i) and *(b)*(ii). [2]

3. *(a)* The diagram, which is **actual size**, shows a beam of light travelling through air and entering transparent plastic. A wavefront moves from AB to CD as it enters the plastic.



(i) By measuring **lengths** on the diagram show that the speed of light in the plastic is approximately $2 \times 10^8\,\text{m}\,\text{s}^{-1}$. [3]

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(ii) Calculate θ, the angle of refraction, giving your working. Assume $n_{air} = 1$. [2]

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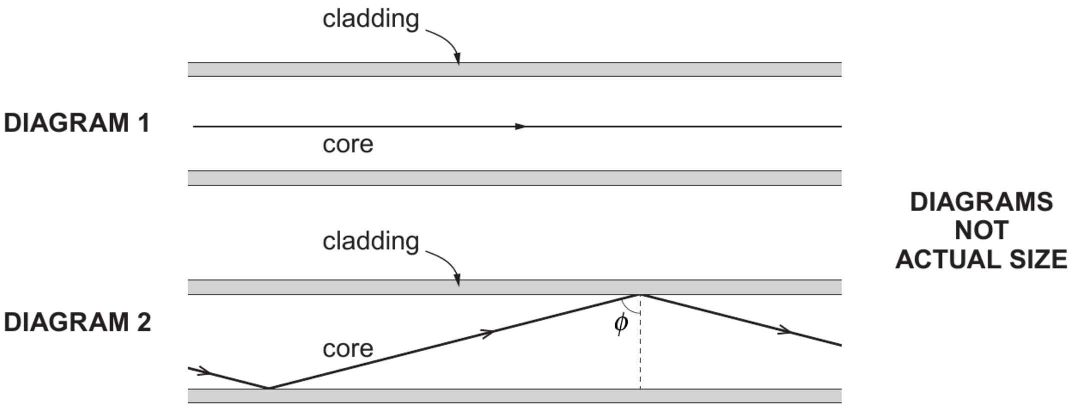
Examiner only

(b) Light takes 1.86 μs to travel through 360 m of multimode fibre by the **quickest** route, as shown in diagram **1**, and 1.91 μs to travel through the same fibre by the **slowest** route, as shown in diagram **2**.



(i) Calculate the refractive index of the core of the fibre. [2]

(ii) Calculate the angle ϕ. [2]

(iii) Explain why it is not possible to have slower routes than that shown in diagram **2**. [2]

(iv) Explain why multimode fibres are used for transmitting data over short distances only. [2]

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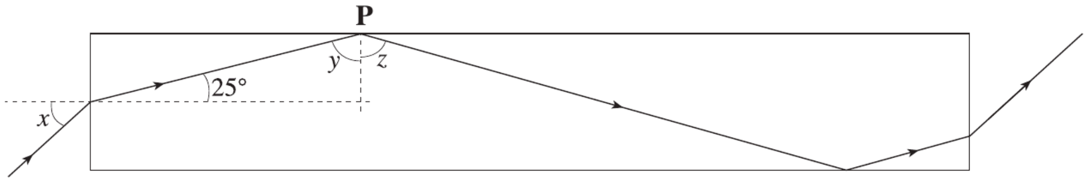
3. A student directs a narrow beam of light on to one end of a glass block, as shown.



(a) (i) Referring to the diagram, calculate the angle of incidence, *x*. [Refractive index of air = 1.00; refractive index of the glass = 1.52.] [3]

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(ii) Calculate the angle *y*. [1]

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(iii) Show that light does not refract into the air at point **P**. [2]

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(iv) (I) The light changes its direction of travel at point **P**. What is the full name for the process involved? [1]

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(II) How does the size of angle *z* compare with the size of angle *y*? [1]

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(b) (i) A glass fibre used for the transmission of data consists of a central glass *core* with a *cladding* of glass of lower refractive index. Suggest one advantage of having a glass cladding rather than simply an air surround. [1]

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(ii) What can be said about the diameter of a *monomode fibre*? [2]

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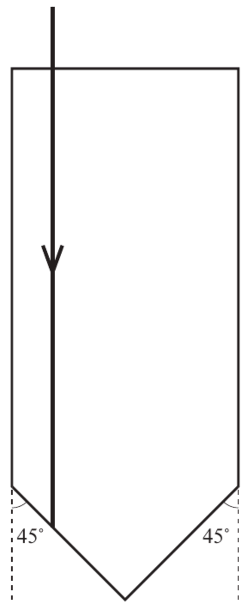
4. *(a)* A rod made of clear plastic of refractive index 1.55 is shaped as shown. The surrounding air has refractive index 1.00.



(i) Calculate the critical angle for light approaching a boundary between the plastic and the air. [2]

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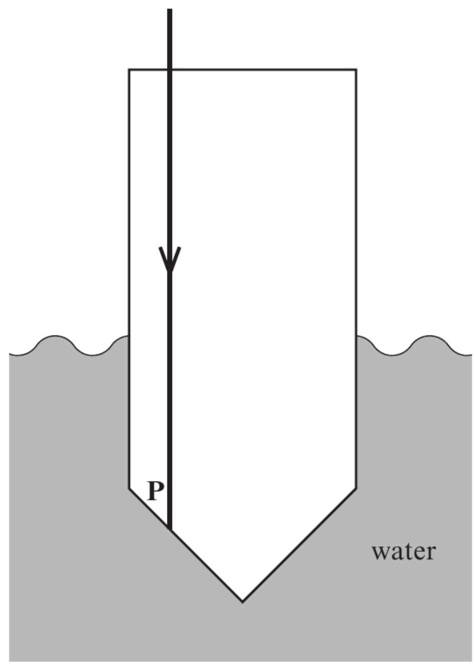
(ii) Hence complete the path of the beam in the diagram, showing its emergence into the air. [2]

(b) The bottom of the rod now dips into water, of refractive index 1.33.



(i) Calculate the angle of refraction of the beam into the water at **P**. [2]

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(ii) Sketch the refracted beam on the diagram. [1]

(iii) Suggest how this plastic rod might be used as part of a device to give a warning when the water level in a tank falls below a certain height. [1]

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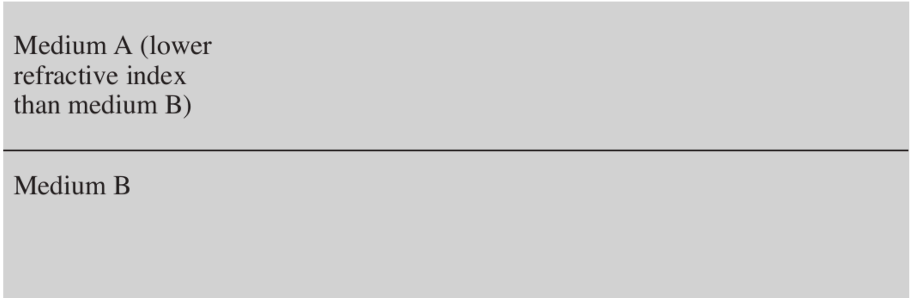
3. (a) Add to the diagram to show clearly what is meant by critical angle. [2]



(b) If A is glass of refractive index 1·520, and B is glass of refractive index 1·550, show clearly that the critical angle is approximately 80°. [3]

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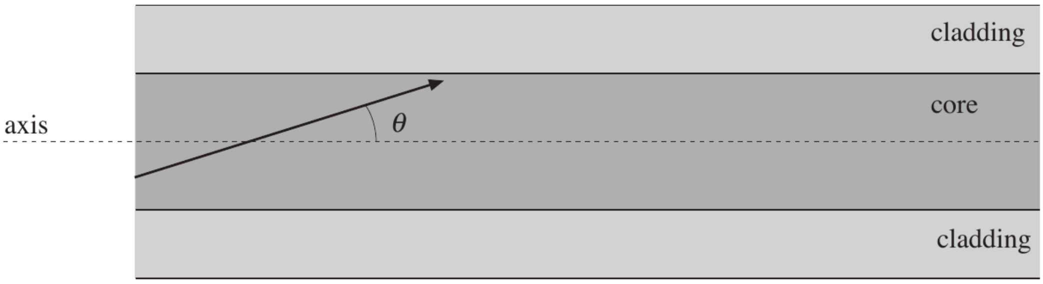
(c) A step-index optical fibre has a core of glass B, and cladding of glass A. [See part (b).]



(i) What is the largest angle, θ, to the axis, at which light can propagate along the fibre with successive total internal reflections? .... [1]

(ii) Explain why light initially travelling at an angle to the axis greater than θ will not reach the end of the fibre. [3]

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(d) Modern communications systems require very high data transmission rates, for which mono-mode optical fibres are needed. Explain why optical fibres with thick cores (multi-mode fibres) are not suitable. [3]

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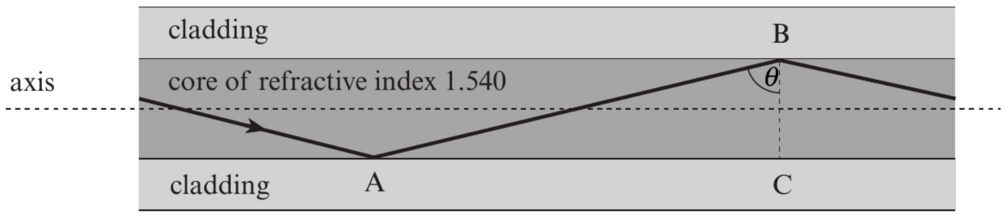
4. The diagram shows a path which light can take along a 'thick' (multimode) optical fibre.



(a) The smallest angle θ at which *total internal reflection* can take place is 77°. Calculate the *refractive index* of the cladding. [2]

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(b) (i) Calculate the time it takes light to travel along 2.0 km of the fibre if it travels through the core **in a straight line parallel to the axis of the fibre**. [3]

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(ii) (I) Show that for θ = 77°, the length of AB is 1.026 times greater than the length of AC (see diagram). [1]

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(II) Hence calculate the **extra** time it takes for light to travel 2.0 km along the fibre via the zigzag path (i.e. for θ = 77°). [2]

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(iii) Without further calculation explain how this difference in times limits the rate at which data (encoded in the light) can be sent through 2.0 km of the fibre. [2]

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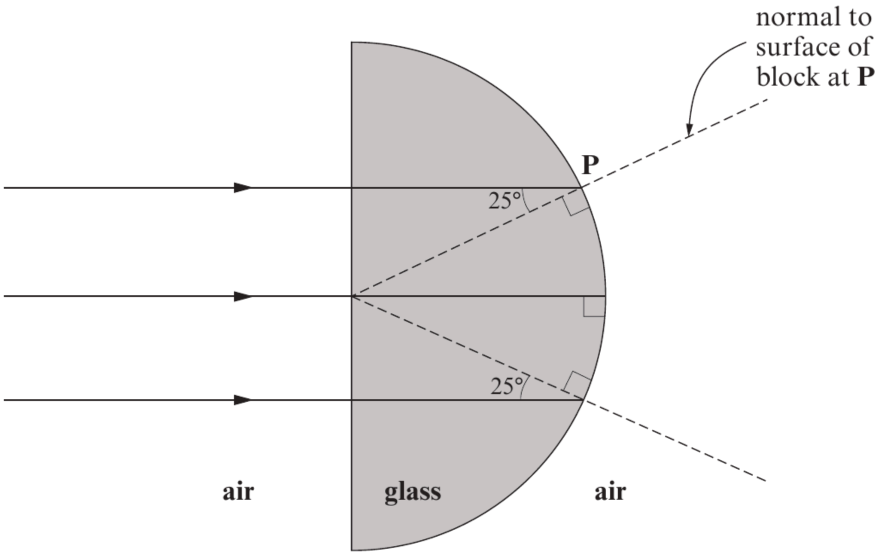
Examiner only

3. *(a)* (i) The diagram shows three beams of light travelling through a glass block of semicircular cross-section and refractive index, *n,* of 1.58. The block is surrounded by air (refractive index 1.00).



(I) **Sketch, on the diagram above, the paths** of all three beams when they emerge into the air from the curved surface of the block. [2]

(II) Calculate the angle to the normal at which the top beam emerges into the air at **P**. [2]

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(ii) (I) Show by calculation that a beam of light striking the curved surface at **Q** (see diagram alongside) will not re-enter the air at **Q**. [2]

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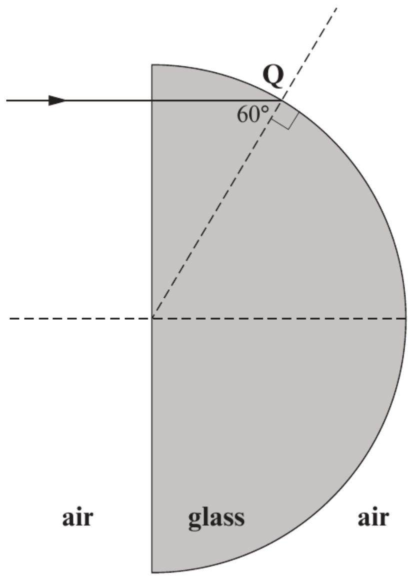

(II) **Continue** carefully on the diagram the path of the beam until it re-emerges into the air. [2]

(b) (i) State how the core of a *monomode* optical fibre differs from that in a multimode fibre. [1]

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(ii) How do the paths of light in monomode and multimode fibres differ? [1]

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(iii) Explain the advantage of monomode fibres over multimode fibres for communicating a rapid sequence of data encoded as light pulses. [3]

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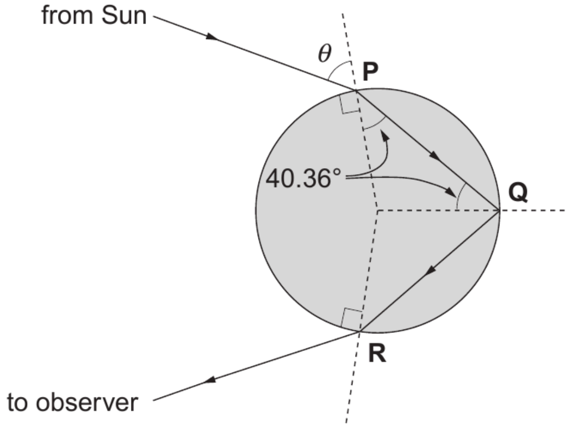
Examiner only

4. *(a)* Rainbows form when sunlight is refracted and reflected by raindrops. The diagram shows the path of red light (of wavelength 700 nm) through a raindrop when a rainbow is observed.



(i) The refractive index of water (for light of this wavelength) is 1.331. Calculate the angle of incidence, θ, at **P.** [Refractive index of air = 1.000.] [2]

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(ii) Is the internal reflection at **Q** a case of *total* internal reflection? Give your reasoning clearly. [2]

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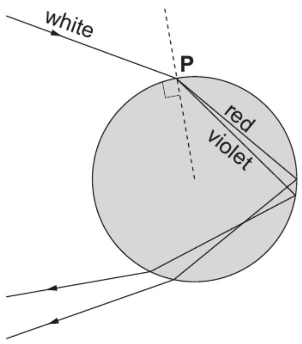
(iii) The diagram below shows the paths (difference exaggerated) of violet and red light through the raindrop. The paths are different because different wavelengths of light travel through water at slightly different speeds.



By comparing the refraction of the red and the violet light at **P**, explain which colour, violet or red, travels more slowly through water. [2]

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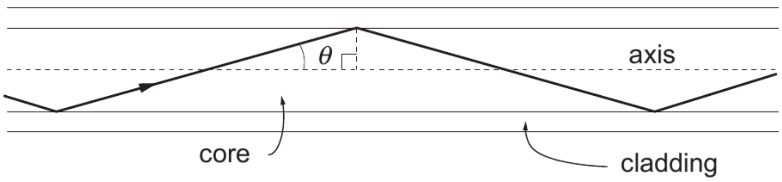
(b) Light takes 1.75 μs to travel through 360 m of multimode fibre by the quickest route through the core.

(i) Show that the refractive index of the core is approximately 1.5, giving your own answer to 3 significant figures. [2]

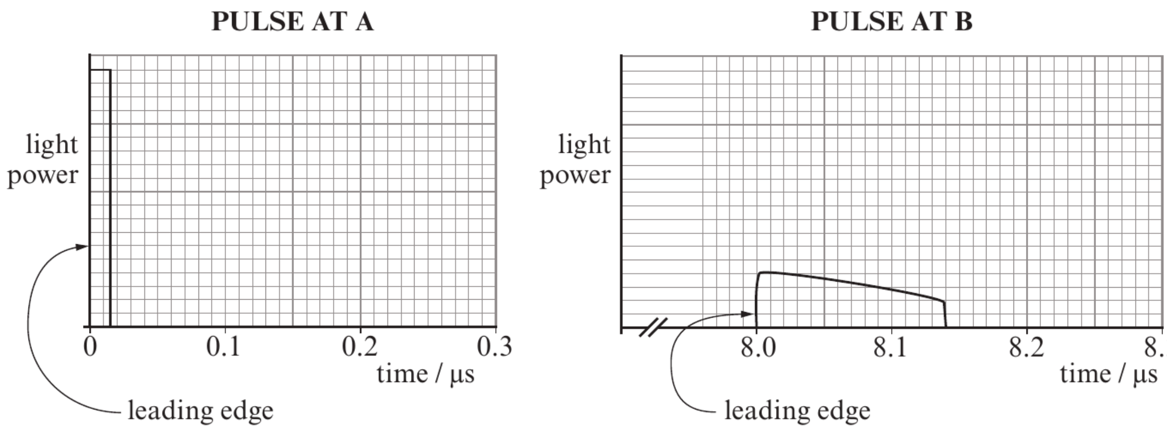
(ii) The greatest angle, θ, to the axis at which light can propagate with total internal reflection is 15°.



Calculate the refractive index of the **cladding**. [3]

(iii) Although total internal reflection occurs for any angle smaller than 15° to the axis, the accurate transmission of data encoded as a rapid stream of pulses is more likely if the paths are restricted to a maximum angle much lower than 15°. Explain why. [3]

5. *(a)* Pulses of monochromatic light are sent from **A** to **B** through a multimode optical fibre. The graphs show the pulse at **A** and when it arrives at **B**.



(i) By considering the leading edge (the start) of the pulse, calculate the distance from **A** to **B** along the axis of the fibre. The refractive index of the fibre's core is 1.50. [3]

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(ii) Explain why the pulse is spread out over time when it arrives at **B**. A sketched diagram may help your explanation. [2]

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(b) Suppose a second pulse is sent from **A** to **B**.

(i) State the minimum time interval t_{min}, between the leading edges of the first and second pulses at **A**, for them to arrive at **B** without overlapping. [1]

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(ii) Show the second pulse on both graphs opposite, if the time interval between pulses at **A** is t_{min}. [2]

END OF QUESTION PACK

10 questions · 117 marks · ~2 h 44 min

Source: WJEC PH2 (2008 modular spec)

Curated for WJEC Physics 2015 spec AS Unit 2 — Topic 6 (2.6)