A-Level Physics

Refraction

Question Paper

Time available: 55 minutes
Marks available: 40 marks

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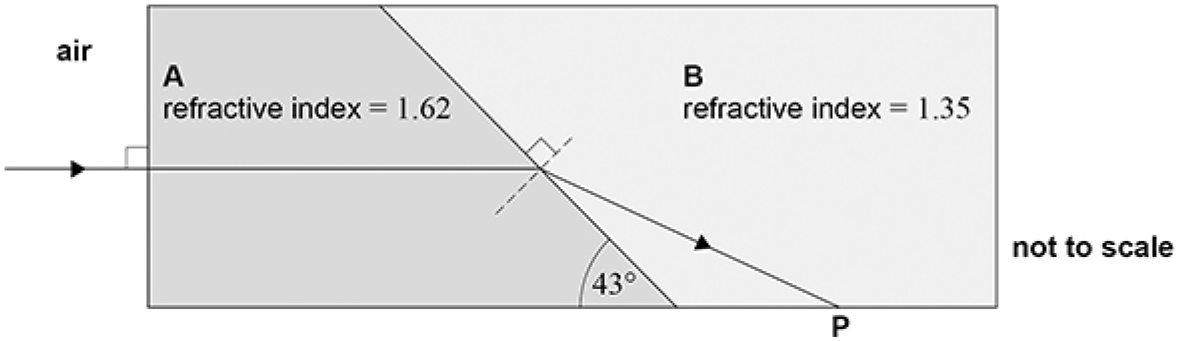
1. Two transparent prisms **A** and **B** of different refractive indices are placed in contact to produce a rectangular block.
The figure below shows the path of a ray, incident normally on **A**, refracting as it crosses the boundary between the prisms.



(a) Explain how the path of the ray shows that the refractive index of **A** is greater than the refractive index of **B**.

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(1)

(b) Show that the angle of refraction of the ray in **B** is about $60°$.

(2)

(c) Draw, on the figure above, the path of the ray immediately after it reaches **P**.
Justify your answer with calculations.

(3)
(Total 6 marks)

2. Optical fibres are used to carry pulses of light.

(a) Explain what is meant by modal dispersion in an optical fibre.

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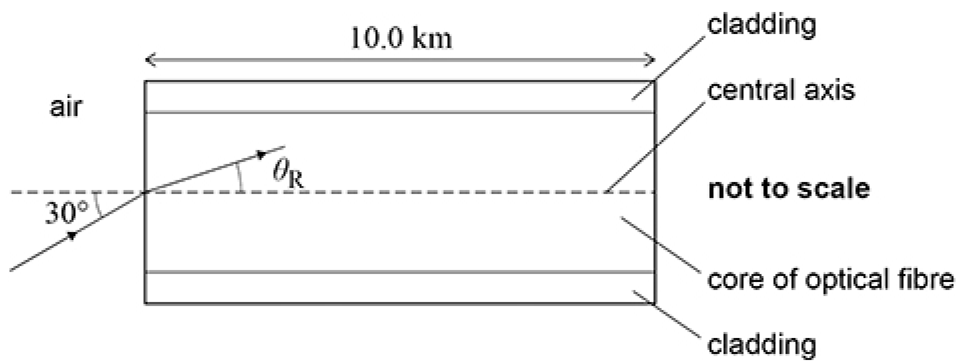
(2)

Figure 1 shows a ray of light incident on the central axis of an optical fibre at an angle of incidence of 30°. The optical fibre is straight and horizontal and has a length of 10.0 km.

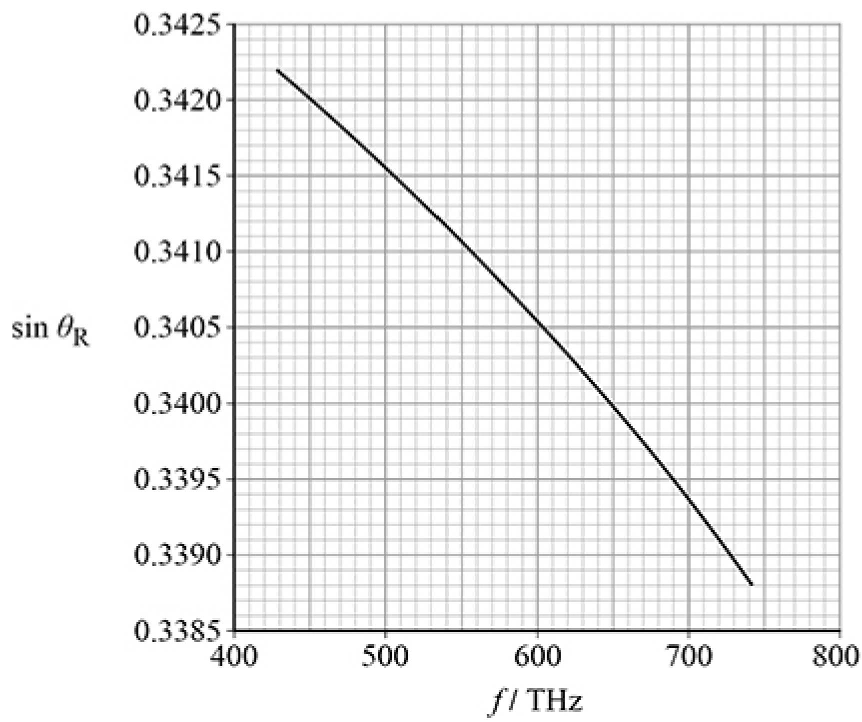
Figure 1



For light incident on the core at a given angle of incidence, the angle of refraction θ_R varies with the frequency f of the light.

Figure 2 shows how sin θ_R varies with f when the angle of incidence is 30°.

Figure 2



The transit time is the time between a pulse of light entering and leaving the optical fibre.
A single pulse of blue light is incident on the air−core boundary at an angle of incidence of 30°.

The transit time of this pulse along the 10 km length of the optical fibre is 5.225×10^{-5} s.

(b) Show that the horizontal component of the velocity of the pulse is approximately 1.9×10^8 m s^{-1}.

(1)

(c) The frequency of the blue light in the pulse is 720 THz.

Calculate the speed of the blue light in the core of the optical fibre.

speed = ________________ m s^{-1}

(3)

(d) Two pulses of monochromatic light are incident normally on the air−core boundary. They then travel along the central axis of the core.
One pulse consists of blue light; the other consists of red light.

Explain, with reference to refractive index, why the pulse of red light has a shorter transit time than the pulse of blue light.

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(2)

(e) Another two pulses, identical to the pulses in part (d), are incident on the central axis of the optical fibre and travel along its length.
However, the pulse of red light and pulse of blue light are now incident on the air−core boundary at an angle of incidence of 30°.

Suggest **one** reason why the difference in their transit times may **not** be the same as in part (d).

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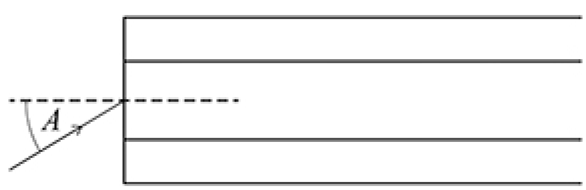
(1)
(Total 9 marks)

3. **Figure 1** shows a ray of monochromatic light incident at angle A from air onto the end of a straight optical fibre.

This ray undergoes total internal reflection at the core−cladding boundary. A ray that enters the optical fibre at an angle greater than A will only be partially reflected at the core−cladding boundary.

Figure 1



The table below shows some properties of the optical fibre.

	Refractive index
cladding	1.41
core	1.47

(a) Calculate the speed of the light ray in the optical fibre.

speed = ________________ $m\ s^{-1}$

(1)

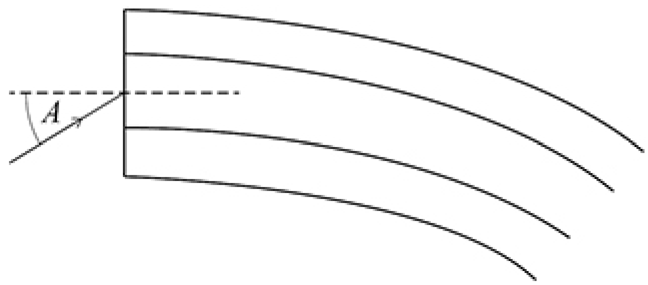
(b) Calculate A, in degrees, for the optical fibre shown in **Figure 1**.

A = ________________ degrees

(3)

(c) A ray is incident on the optical fibre at angle A. The optical fibre is now bent, as shown in **Figure 2**.

Figure 2



Draw, on **Figure 2**, what happens to the ray within the optical fibre. Explain your answer.

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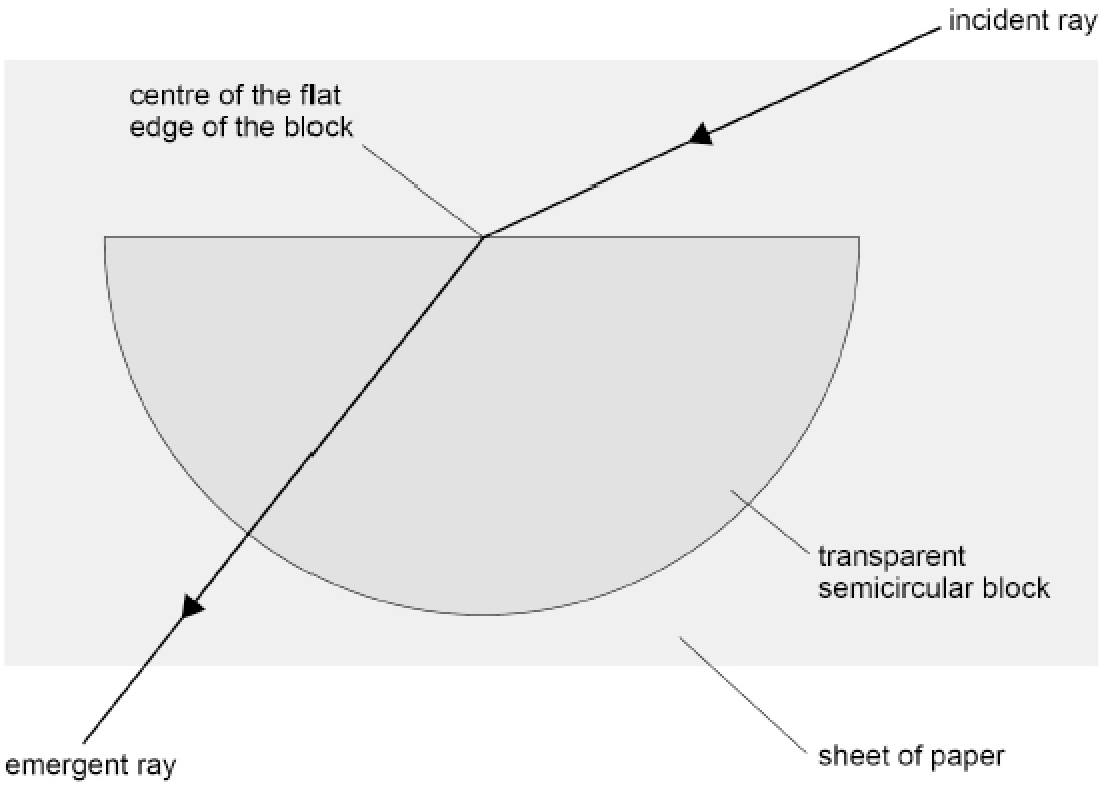
(3)

(Total 7 marks)

4. A student places a transparent semicircular block on a sheet of paper and draws around the block. She directs a ray of light at the centre of the flat edge of the block.

Figure 1 shows the path of the ray through the block.

Figure 1



(a) State why the emergent ray does not change direction as it leaves the block.

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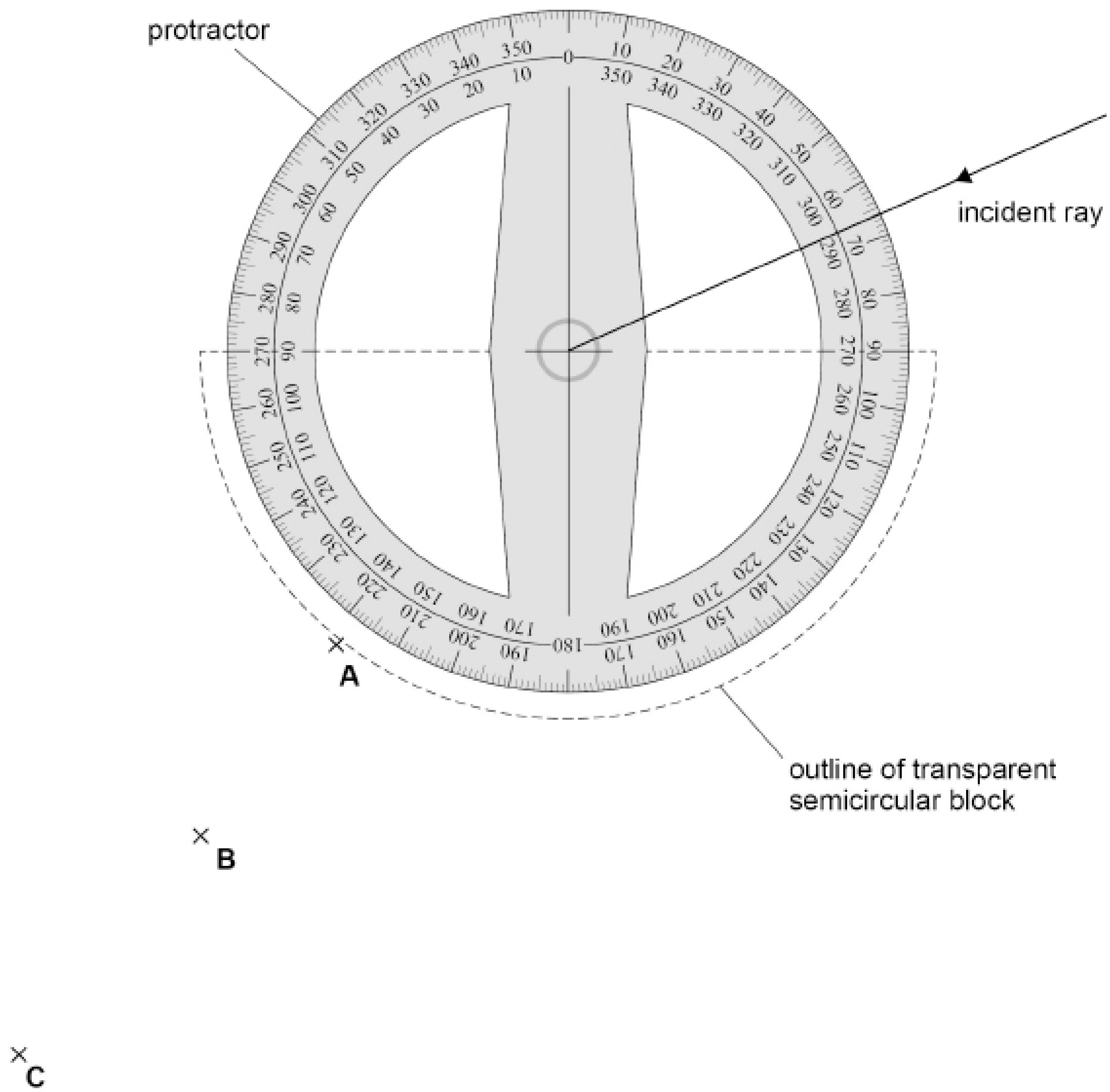
(1)

(b) The student draws an arrow on the paper to mark the incident ray. She marks the path of the emergent ray with crosses **A**, **B** and **C**.

She removes the block from the paper and places a protractor over the outline of the block, as shown in **Figure 2**.

Figure 2



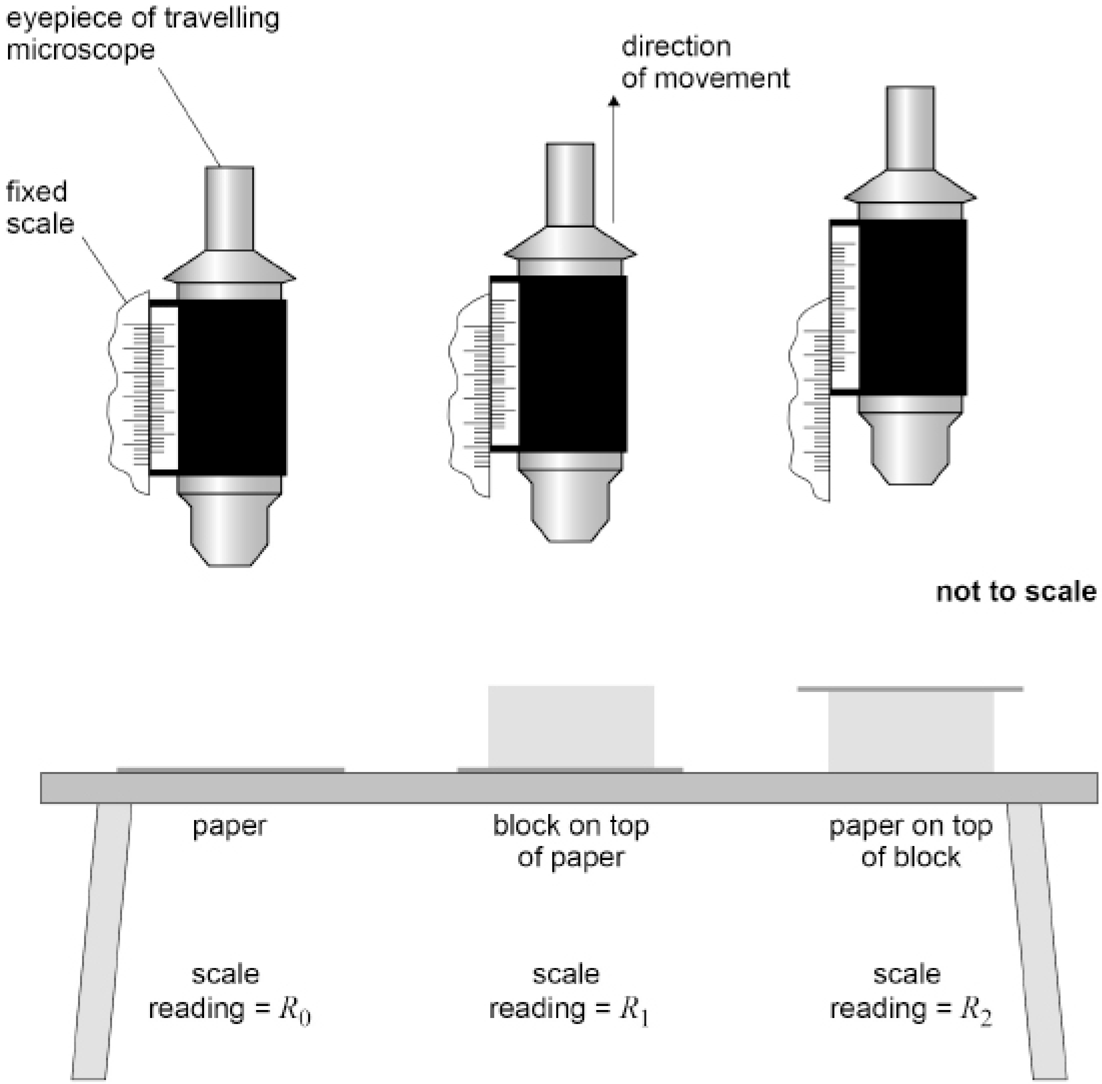
Determine, using **Figure 2**, the refractive index of the block.

refractive index = ________________

(4)

The student uses a different method to determine the refractive index of the block. She focuses a travelling microscope on some dots on a sheet of paper for each of the three situations shown in **Figure 3**.

Figure 3



The table shows the readings made by the student.

R_0 / mm	R_1 / mm	R_2 / mm
5.74	10.31	20.02

(c) The refractive index n of the block is given by

$$n = \frac{R_2 - R_0}{R_2 - R_1}$$

Determine n.

n = ________________

(1)

(d) The absolute uncertainty in each of the readings R_0, R_1 and R_2 is 0.04 mm.

State the absolute uncertainty in $R_2 - R_0$.

absolute uncertainty in $R_2 - R_0$ = ________________ mm

(1)

(e) The absolute uncertainty in $R_2 - R_1$ is the same as the absolute uncertainty in $R_2 - R_0$.

Calculate the percentage uncertainty in n.

percentage uncertainty in n = _______________%

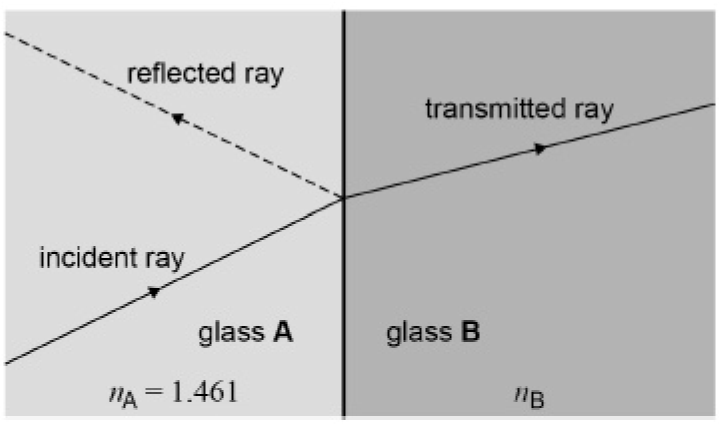
(3)

(Total 10 marks)

5. (a) **Figure 1** shows an incident ray of light being partially reflected at the boundary between glass **A** and glass **B**. The refractive index n_A of glass **A** is 1.461

The speed of light in glass **B** is 3.252% less than the speed of light in glass **A**.

Figure 1



Calculate the refractive index n_B of glass **B**.

Give your answer to an appropriate number of significant figures.

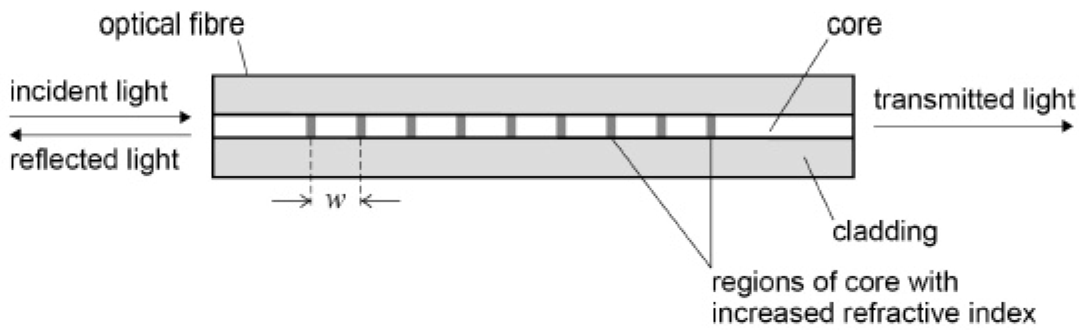
speed of light in a vacuum = 2.998×10^8 m s^{-1}

n_B = ______________________

(3)

(b) **Figure 2** shows a cross-sectional view of an optical fibre strain gauge.

Figure 2

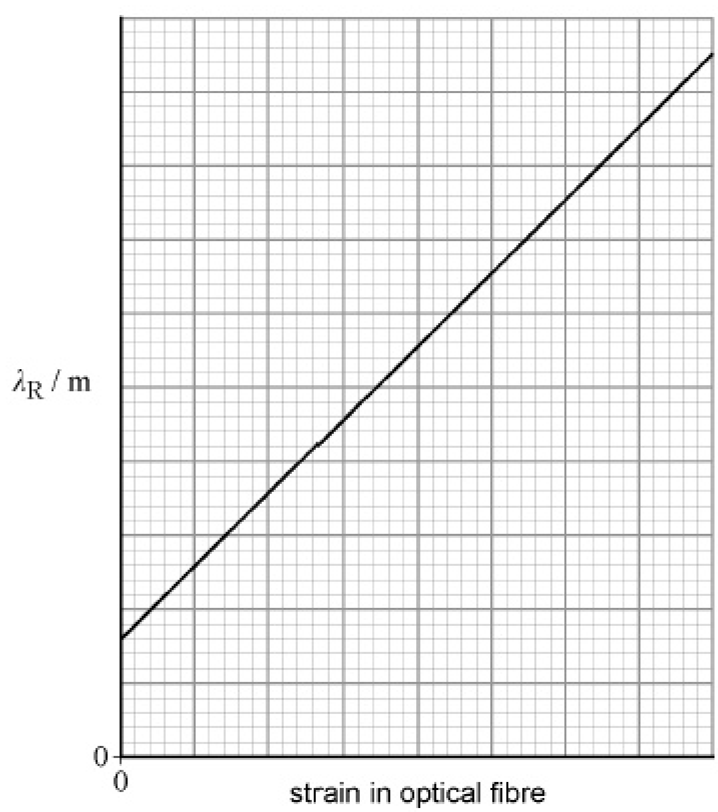


A maximum intensity of the reflected light is produced due to superposition of the light reflected from each of the regions with increased refractive index in the core.

This maximum intensity occurs at a particular wavelength λ_R.

Figure 3 shows the relationship between λ_R and the strain in the optical fibre.

Figure 3



A cable is used to raise and lower a lift. An engineer fixes the optical fibre strain gauge to the cable to monitor changes of the strain in the cable.

The lift is initially at rest and then accelerates downwards for a short time before reaching a constant velocity.

Discuss how the value of λ_R changes.

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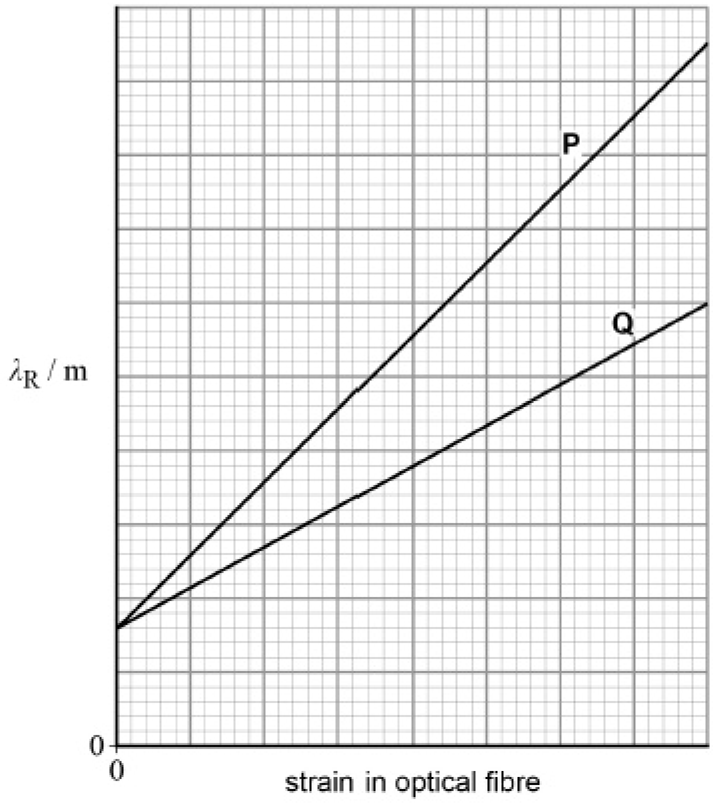
(3)

(c) **Figure 4** shows the relationship between λ_R and the strain in two optical fibre strain gauges **P** and **Q**. The engineer wishes to measure small accelerations in another lift. She can choose to fix either optical fibre strain gauge **P** or optical fibre strain gauge **Q** to the lift's cable.

Figure 4



Explain which gauge the engineer should select.

(2)

(Total 8 marks)