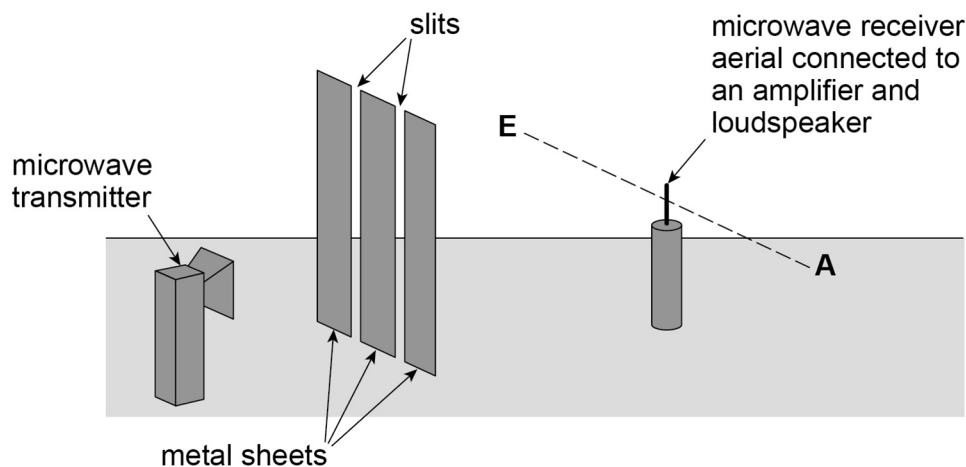
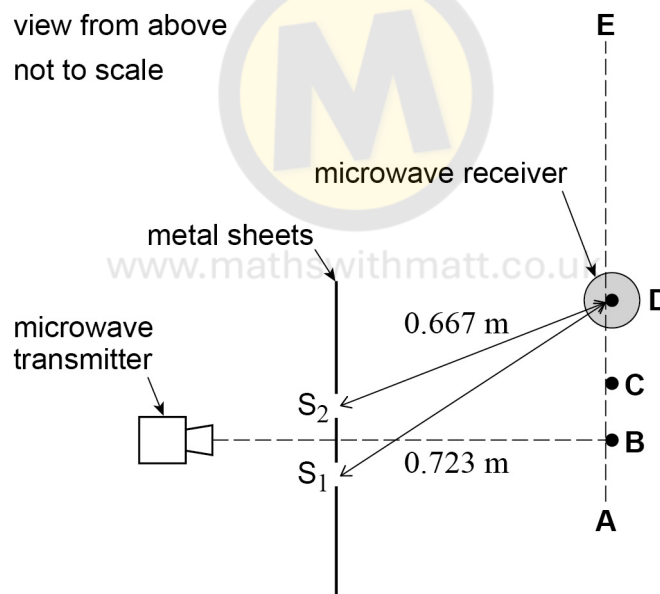


0 4

Figure 4 shows an arrangement used to investigate double slit interference using microwaves. **Figure 5** shows the view from above.

Figure 4**Figure 5**

view from above
not to scale



The microwaves from the transmitter are polarised. These waves are detected by the aerial in the microwave receiver (probe). The aerial is a vertical metal rod.

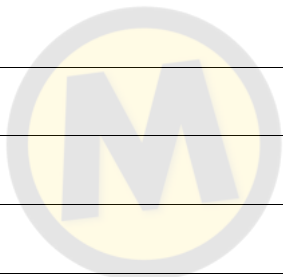
The receiver is moved along the dotted line **AE**. As it is moved, maximum and minimum signals are detected. Maximum signals are first detected at points **B** and **C**. The next maximum signal is detected at the position **D** shown in **Figure 5**.

Figure 5 shows the distances between each of the two slits, S_1 and S_2 , and the microwave receiver when the aerial is in position **D**.

S_1D is 0.723 m and S_2D is 0.667 m.



[3 marks]



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0	4	.	2
---	---	---	---

[3 marks]

frequency = Hz

Question 4 continues on the next page

Turn over ►



0 4 . 3

The intensity of the waves passing through each slit is the same.

Explain why the minimum intensity between **C** and **D** is not zero.

[2 marks]

0 4 . 4

The vertical aerial is placed at position **B** and is rotated slowly through 90° until it lies along the direction **AE**.

State and explain the effect on the signal strength as it is rotated.

[3 marks]

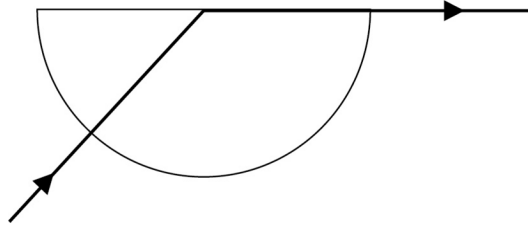


Question	Answer	Comments/ Guidance	Mark
04.1	path difference for two waves ✓ gives rise to a phase difference ✓ Destructive interference occurs ✓	Allow 'waves travel different distances' Condone out of phase if phase and path confused only give 1 for first 2 marks allow explanation of interference	3
04.2	(Path difference =) 0.056 m ✓ Path difference = 2λ or wavelength = 0.028 m ✓ e Use of $f=c/\lambda$ so $f= 11(10.7) \times 10^9$ Hz ✓	Allow 2 max for 5.4×10^9 Hz or 2.7×10^9 Hz Allow ecf	3
04.3	Intensity decreases with distance ✓ One wave travels further than the other ✓ Amplitudes/intensities of the waves at the minimum points are not equal ✓	Or "do not cancel out"	max 2
04.4	The signal decreases/becomes zero ✓ The waves transmitted are polarised ✓ zero when detector at 90° to the transmitting aerial/direction of polarisation of wave ✓		max 3

0	3
---	---

Figure 2 shows a ray of monochromatic green light incident normally on the curved surface of a semicircular glass block.

Figure 2



0	3	.	1
---	---	---	---

The angle of refraction of the ray at the plane surface is 90° .

Refractive index of the glass used = 1.6

Calculate the angle of incidence of the ray on the flat surface of the block.

[1 mark]



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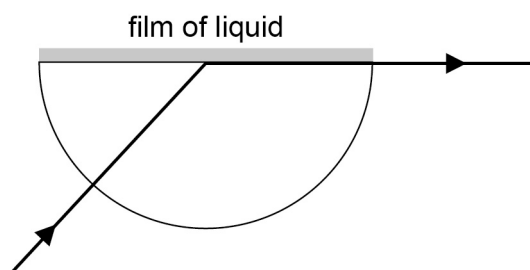
angle of incidence = _____ degrees



0 3 . 2

A thin film of liquid is placed on the flat surface of the glass block as shown in Figure 3.

Figure 3



The angle of incidence is changed so that the angle of refraction of the green light ray at the glass–liquid interface is again 90° . The angle of incidence is now 58° .

Calculate the refractive index of the liquid.

[2 marks]



refractive index = _____

0 3 . 3

The source of green light is changed for one that contains only red and blue light. For any material red light has a lower refractive index than green light, and blue light has a higher refractive index than green light. The angle of incidence at the glass–liquid interface remains at 58° .

Describe and explain the paths followed by the red and blue rays immediately after the light is incident on the glass–liquid interface.

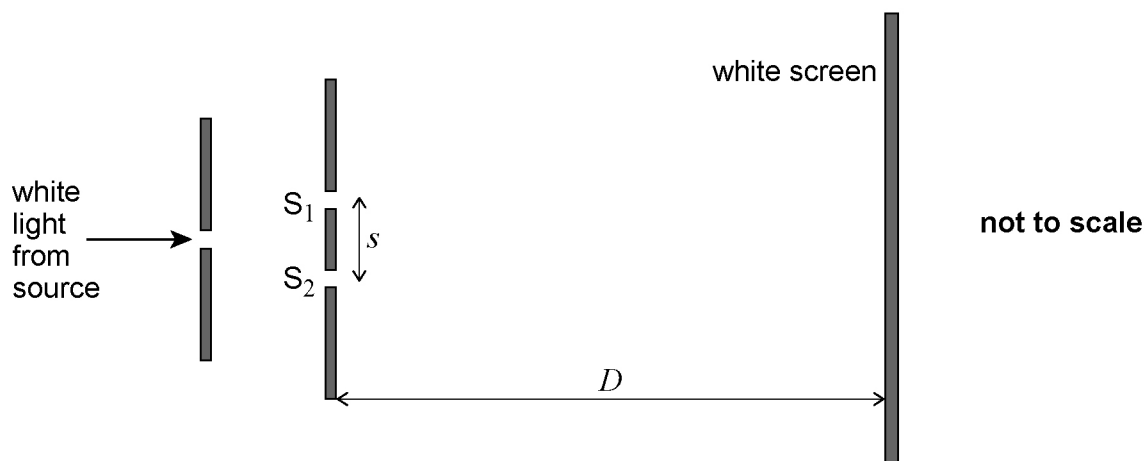
[3 marks]



Question	Answers	Additional Comments/Guidelines	Mark
03.1	$i = \sin^{-1}(1/1.6) = 39^\circ$ ✓		1
03.2	$\sin 58 = n/1.6$ ✓ $n = 1.4$ (1.36) ✓		1 1
03.3	blue light undergoes TIR ✓ red light refracted ✓ reason i.e. critical angle for red light is more OR critical angle for blue light is less ✓ OR if refractive indices change by same factor ✓ critical angle stays constant ✓ so path followed by red and blue light is the same ✓ OR don't know if refractive indices change by same factor ✓ so can't predict the effect on critical angle ✓ so can't predict paths of red and blue light ✓	Allow correct description of refraction. Ignore statements about towards/away from normal For second two alternatives third mark (i.e. about paths of red and blue) dependent on first mark (i.e. factor of refractive index change)	1 1 1
Total	www.mathswithmatt.co.uk		6

0 7

Figure 8 shows a diagram of apparatus used to demonstrate the formation of interference fringes using a white light source in a darkened room. Light from the source passes through a single slit and then through two narrow slits S_1 and S_2 .

Figure 8

0 7 . 1

Describe the interference pattern that is seen on the white screen.

[2 marks]



0 7 . 2

A filter transmits only green light of wavelength λ and red light of wavelength 1.2λ . This filter is placed between the light source and the single slit.

Describe the interference pattern now seen on the white screen.

Use a calculation to support your answer.

[4 marks]



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Question 7 continues on the next page

Turn over ►



0 7 . 3

A student decides to use the apparatus shown in **Figure 8** to determine the wavelength of red light using a filter that transmits only red light.

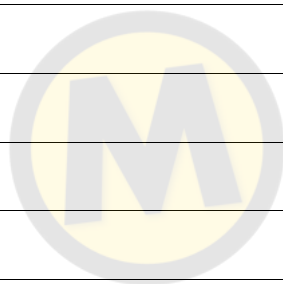
The student suggests the following changes:

- decrease slit separation s
- decrease D , the distance between the slits and the screen.

The student decides to make each change independently.

Discuss the effects each independent change has on the interference pattern, and whether this change is likely to reduce uncertainty in the determination of the wavelength.

[6 marks]



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Question	Answers	Additional Comments/Guidelines	Mark
07.1	TWO FROM: central white fringe✓ (fringes either side) showing range of colours/spectrum✓ with red furthest and blue/violet closest to centre✓	Allow rainbow for spectrum Reject different colour fringes If colours mentioned for last mark must be in right order i.e. red last	1 1 (MAX 2)
07.2	FOUR FROM: central fringe is a mixture of red and green light/two wavelengths ✓ EITHER (1 marks) (separate) red and green fringes are seen (on either side) ✓ OR (for 2 marks) spacing of green fringes is less than spacing of red fringe / green fringes closer to middle than red✓✓ OR (for 3 marks) spacing of red fringes is 20% (or 1.2 times) greater than green fringes✓✓✓ 6 th green fringe overlaps with 5 th red fringe ✓	allow orange/yellow for central fringe if w used must be identified as fringe spacing for third alternative	1 1 1 1 (MAX 4)

07.3

The mark scheme gives some guidance as to what statements are expected to be seen in a 1 or 2 mark (L1), 3 or 4 mark (L2) and 5 or 6 mark (L3) answer. Guidance provided in section 3.10 of the 'Mark Scheme Instructions' document should be used to assist in marking this question.

Mark	Criteria	QoWC
6	Explains how (%) uncertainties combine to determine uncertainty in wavelength OR identify % uncertainty s as being the largest	The student presents relevant information coherently, employing structure, style and sp&g to render meaning clear. The text is legible.
5	Explain how wavelength is determined using $\lambda = \frac{ws}{D}$	
4	Explains how second change affects fringe spacing AND Comments on how change in fringe spacing affects (%)uncertainty / change in s OR D affects (%)uncertainty	The student presents relevant information and in a way which assists communication of meaning. The text is legible. Sp&g are sufficiently accurate not to obscure meaning.

The following statements may be present for decreasing slit separation s :

Fringe separation increases
Uncertainty in measuring fringe separation will decrease
and as this is needed to measure wavelength, uncertainty in wavelength measurement will decrease

The following statements may be present for smaller D :

Uncertainty in measuring D would increase
Fringe separation would also decrease
so uncertainty in measuring fringe separation would increase
Both are required to find wavelength so uncertainty in finding wavelength would increase

FOR Middle Band **one** of these considered:

Decrease s
Larger fringe separation so smaller (%) uncertainty (in w)
Smaller s so higher (%) uncertainty in s
Decrease D
Smaller fringe separation so larger (%) uncertainty (in w)
Smaller D so higher (%) uncertainty in D

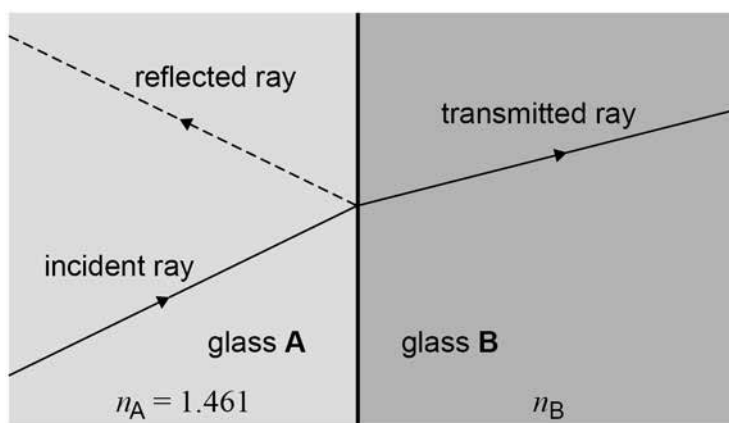
6

0 4 . 1

Figure 9 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 9

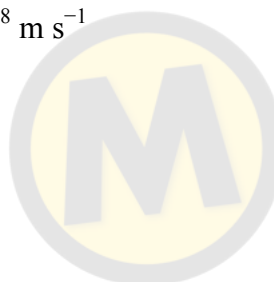


Calculate the refractive index n_B of glass **B**.

Give your answer to an appropriate number of significant figures.

speed of light in a vacuum = $2.998 \times 10^8 \text{ m s}^{-1}$

[3 marks]



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$n_B =$ _____

Question 4 continues on the next page

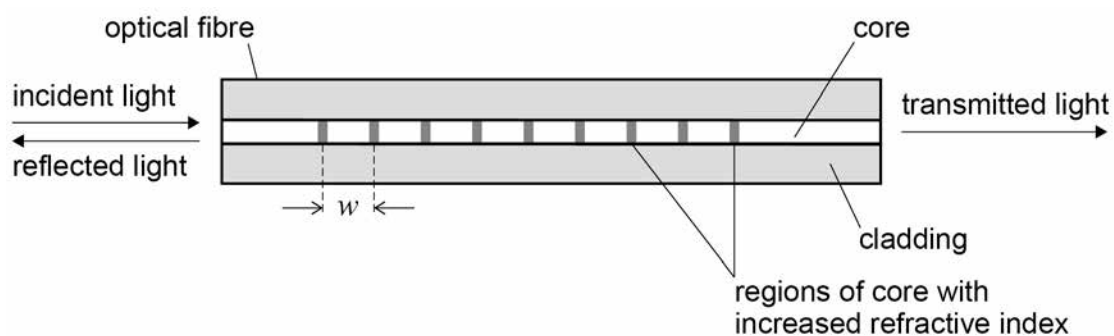
Turn over ►



0 4 . 2

Figure 10 shows a cross-sectional view of an optical fibre strain gauge.

Figure 10

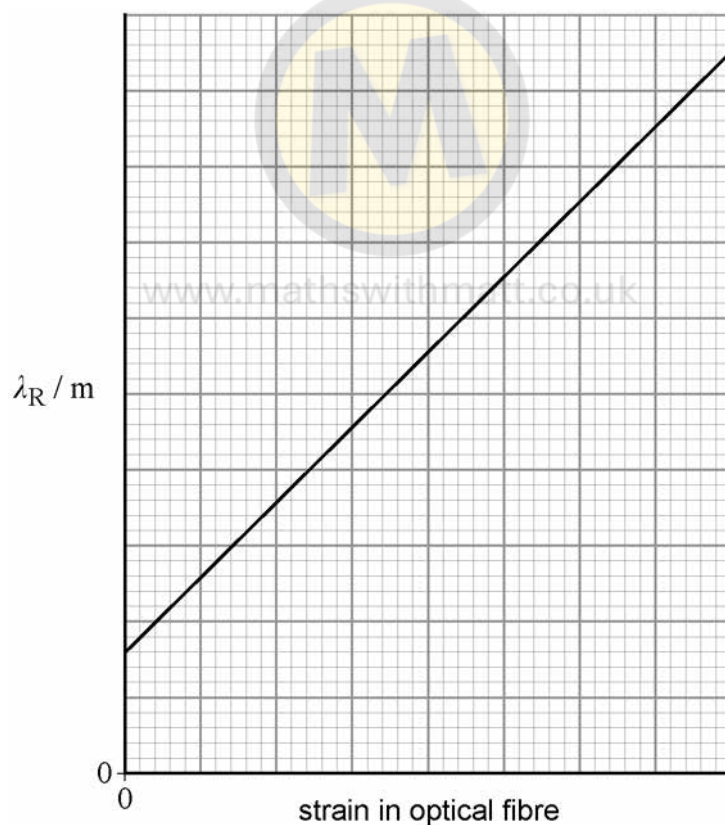


A maximum intensity of the reflected light is produced due to superposition of the light reflected from each of the regions with increased refractive index in the core.

This maximum intensity occurs at a particular wavelength λ_R .

Figure 11 shows the relationship between λ_R and the strain in the optical fibre.

Figure 11

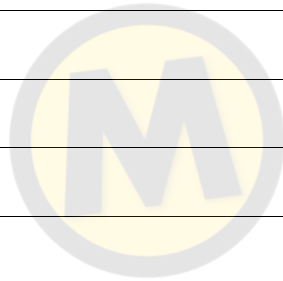


A cable is used to raise and lower a lift. An engineer fixes the optical fibre strain gauge to the cable to monitor changes of the strain in the cable.

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.

[3 marks]



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Question 4 continues on the next page

Turn over ►

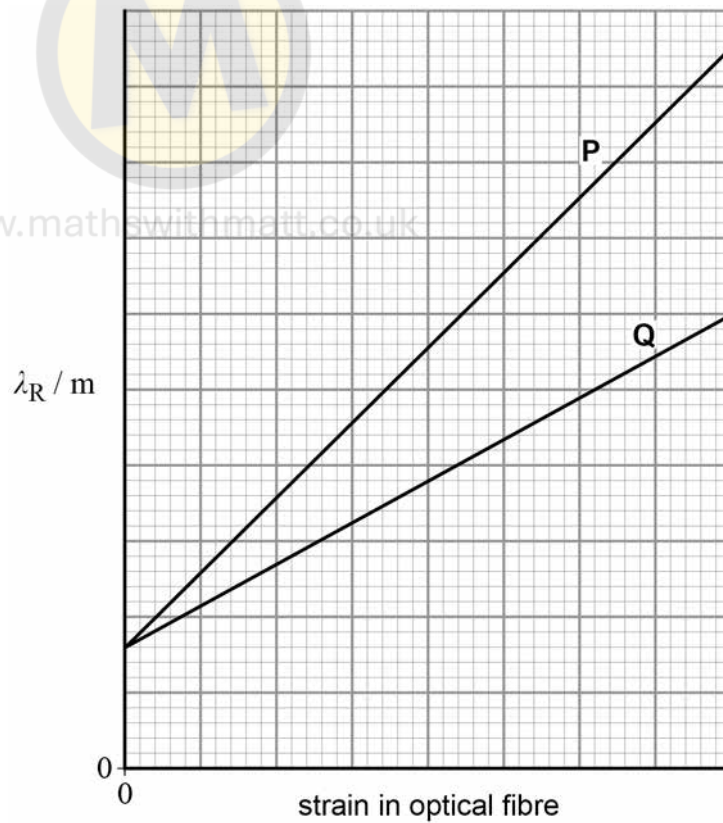


0 4 . 3

Figure 12 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.

Do not write
outside the
box

Figure 12



Explain which gauge the engineer should select.

[2 marks]



Question	Answers	Additional Comments/Guidance	Mark
04.1	<p>Use of $n_A = \frac{c}{c_A}$ to make c_A the subject of the equation</p> <p>or</p> <p>speed in glass A = $2.05(2) \times 10^8 \text{ ms}^{-1}$ _{1✓}</p> <p>Speed in glass B = $1.985(3) \times 10^8$</p> <p>or</p> <p>their speed in glass A $\times 0.96748$ (or equivalent) _{2✓}</p> <p>or</p> <p>Alternative 1st and 2nd marks</p> <p>Use of $n_A/n_B = c_B/c_A$ by substitution for n_A _{1✓}</p> <p>Use of $n_A/n_B = c_B/c_A$ by substitution for n_A and $c_B = c_A \times 0.96748$ _{2✓}</p> <p>Or</p> <p>$n_B = 1.461 / 0.96748$ _{1✓2✓}</p>	<p>Condone truncation without appropriate rounding mid-calculation.</p> <p>Condone use of $c = 3 \times 10^8$ But must see answer to 4 sf answer</p> <p>Values obtained using $c = 3 \times 10^8$:</p> <ul style="list-style-type: none"> • speed in glass A = $2.05(3) \times 10^8 \text{ ms}^{-1}$ • speed in glass B = $1.98(7) \times 10^8$ • $n = 1.510$ <p>watch for maths errors: dividing by 1.03252 $\neq$ multiplying by 0.96748</p>	3

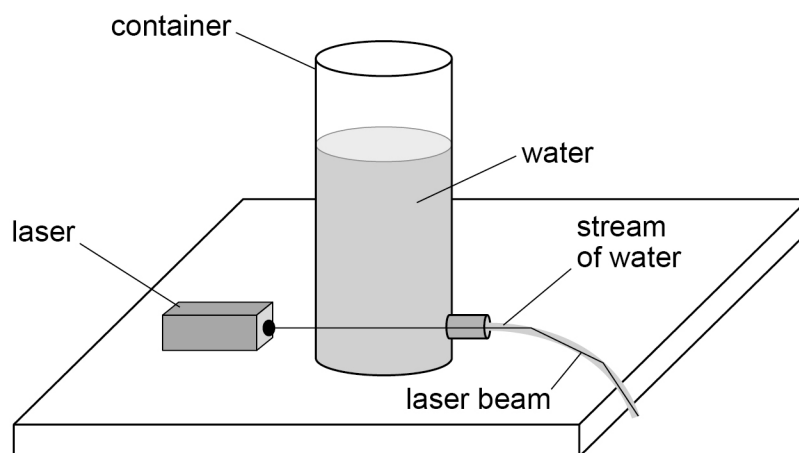
	1.510 cao to 4 sf only 3✓	<p>multiplying by 1.03252 ≠ dividing by 0.96748</p> <p>Correct answer to 4 sf obtains all 3 marks. Penalise any unit on final answer.</p>	
04.2	<p>Relationship:</p> <p>Increase in tension (or stress) in cable produces increase in strain resulting in increase in λ_R</p> <p>Or</p> <p>Decrease in tension (or stress) causes decrease in strain resulting in decrease in λ_R. 1✓</p> <p>Variation due to motion:</p> <p>As the lift accelerates downwards, (the tension is less than the weight in the cable, a decrease in tension results) in λ_R decreasing 2✓</p> <p>At constant velocity (the tension again equals the weight and) λ_R returns to the initial, at rest value 3✓</p>	<p>Allow a correct comment on the directional relationship between tension, strain and λ_R independent of the motion of the lift for first mark</p>	3
04.3	<p>P because it will produce a larger increase in λ_R for the (same) <u>increase</u> in strain</p> <p>Or</p> <p>P because it has a larger gradient (must be a sense of larger increase in λ_R for the (same) <u>increase</u> in strain) ✓</p> <p>Hence <u>smaller accelerations</u> (which produce small changes in strain) can produce <u>measurable changes</u> in λ_R</p> <p>Or</p> <p>Hence gauge P will have a higher resolution ✓</p>	<p>Selecting Q gains zero marks</p> <p>Linking steeper gradient to being able to withstand a larger force negates this mark.</p> <p>Allow more accurate measurement of <u>acceleration</u> Allow more readings of <u>acceleration</u> can be taken (over the range) More sensitive treat as neutral</p>	2
Total			8

0	4
---	---

In 1870 John Tyndall sent a beam of light along a stream of water.

Figure 4 shows a modern version of Tyndall's experiment using a laser beam. Water has a refractive index of 1.33

Figure 4



0	4	1
---	---	---

Explain why the laser beam stays inside the stream of water.

[2 marks]



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0 4 . 2

Calculate the speed of the laser light in the water.
Give your answer to an appropriate number of significant figures.

[3 marks]

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speed = _____ m s^{-1}

0 4 . 3

Calculate the critical angle for the water–air boundary.

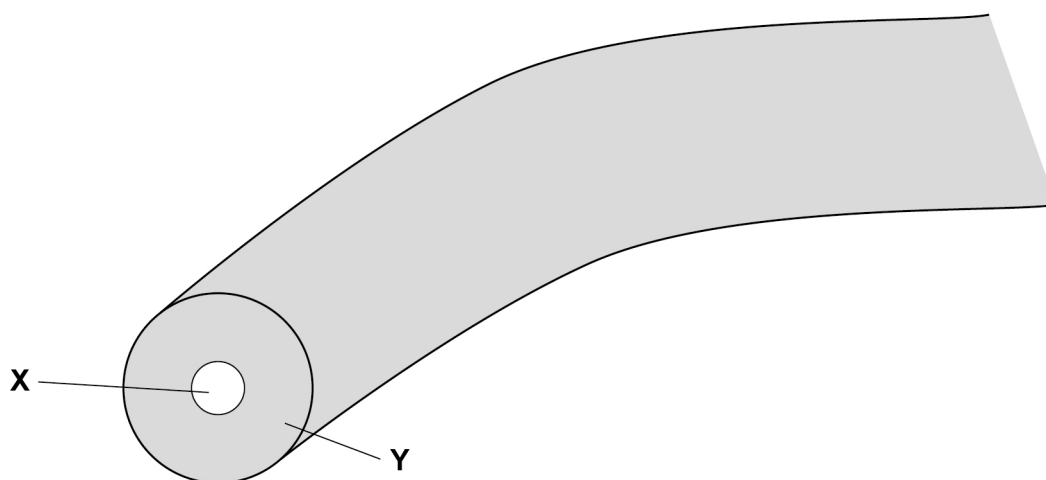
[1 mark]

critical angle = _____ degrees

0 4 . 4

Tyndall's experiment led to the development of optical fibres.
Figure 5 shows a step-index optical fibre.

Figure 5



Discuss the properties of a step-index optical fibre.

Your answer should include:

- the names of part **X** and part **Y**
- a description of the functions of **X** and **Y**
- a discussion of the problems caused by material dispersion and modal dispersion and how these problems can be overcome.

[6 marks]

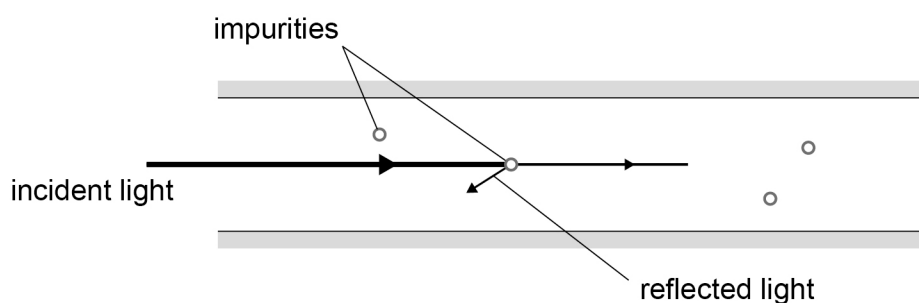


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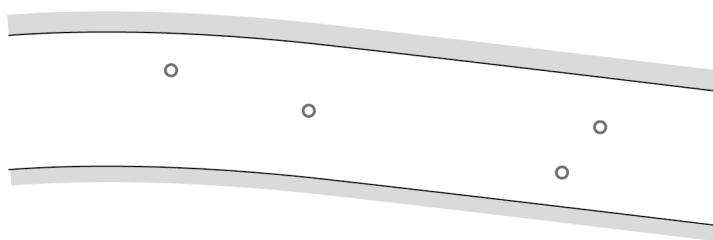


0 4 . 5

Scientists use optical fibres to monitor earthquakes. Light travelling through an optical fibre can be reflected by impurities in the fibre, as shown in **Figure 6**.

Figure 6

Earthquakes bend the optical fibre slightly, as shown in **Figure 7**. This changes the amount of reflected light.

Figure 7

Suggest why the amount of reflected light changes as the fibre bends. You may draw on **Figure 7** as part of your answer.

[2 marks]



0	4	.	6
---	---	---	---

The waves caused by earthquakes can be longitudinal or transverse.

Describe the difference between longitudinal waves and transverse waves.

[2 marks]

*Do not write
outside the
box*

Question	Answers	Additional Comments/Guidance	Mark	ID details
04.1	<p>Max 2 from: ✓ ✓</p> <p>(Because) the refractive index of water is greater than air</p> <p>(and) the angle of incidence is greater than the critical angle</p> <p><u>total internal reflection</u> (of laser beam) occurs</p>	<p>Allow optical density for refractive index.</p> <p>Allow answer given as a diagram.</p>	2	2 × AO1.1a
04.2	<p>Use of $n = \frac{c}{c_s}$ eg $c_s = \frac{3.00 \times 10^8}{1.33}$ ✓</p> <p>$2.26 \times 10^8 \text{ (m s}^{-1}\text{)}$ ✓</p> <p>3 sf answer from some relevant working ✓</p>		3	AO1.1b
04.3	49 (°) ✓	Do not allow 1 sf answer.	1	AO1.1b

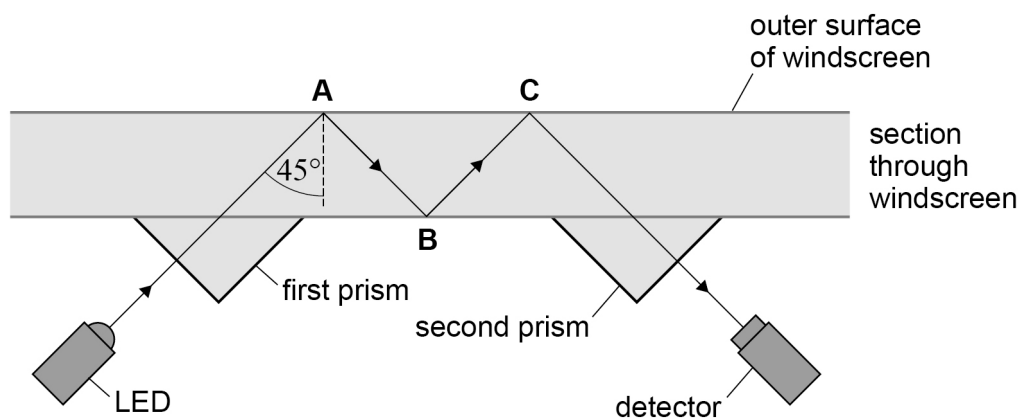
Question	Answers	Additional Comments/Guidance	Mark	ID details																
04.4	<p>The mark scheme gives some guidance as to what statements are expected to be seen in a 1 or 2 mark (L1), 3 or 4 mark (L2) and 5 or 6 mark (L3) answer. Guidance provided in section 3.10 of the ‘Mark Scheme Instructions’ document should be used to assist in marking this question</p> <table><tr><th>Mark</th><th>Criteria</th></tr><tr><td>6</td><td>Both functions and dispersion problems discussed. No significant error or inconsistency.</td></tr><tr><td>5</td><td>Both functions and dispersion problems discussed. There may be some significant error or inconsistency.</td></tr><tr><td>4</td><td>Functions or dispersion problems described. No significant error or inconsistency.</td></tr><tr><td>3</td><td>Functions or dispersion problems described. There may be some significant error or inconsistency.</td></tr><tr><td>2</td><td>Both X and Y named and a function of one given; or A function of X and Y given, but only one named</td></tr><tr><td>1</td><td>X and Y identified by name or function</td></tr><tr><td>0</td><td>No relevant analysis</td></tr></table> <p>Level 2 max if dispersion modes confused in descriptions.</p>	Mark	Criteria	6	Both functions and dispersion problems discussed. No significant error or inconsistency.	5	Both functions and dispersion problems discussed. There may be some significant error or inconsistency.	4	Functions or dispersion problems described. No significant error or inconsistency.	3	Functions or dispersion problems described. There may be some significant error or inconsistency.	2	Both X and Y named and a function of one given; or A function of X and Y given, but only one named	1	X and Y identified by name or function	0	No relevant analysis	<p>The following statements are likely to be present.</p> <p>Names X is Core Y is Cladding</p> <p>Functions X: Propagates/Guides the wave/light By TIR (with) low attenuation/absorption Refractive index of core > cladding</p> <p>Y: Protects core from damage Prevents cross talk between touching fibres Provides ‘clean’ boundary for TIR</p> <p>Dispersion problems Both: Cause pulse broadening/limited bandwidth Material: different wavelengths have different speeds due to different refractive indices within the core – use monochromatic beam Modal: different paths have different lengths so effective time along fibre differs – use single-mode fibre (narrow core/small Δn between core and cladding)</p>	6	3 × AO1.1a 3 × AO2.1a
Mark	Criteria																			
6	Both functions and dispersion problems discussed. No significant error or inconsistency.																			
5	Both functions and dispersion problems discussed. There may be some significant error or inconsistency.																			
4	Functions or dispersion problems described. No significant error or inconsistency.																			
3	Functions or dispersion problems described. There may be some significant error or inconsistency.																			
2	Both X and Y named and a function of one given; or A function of X and Y given, but only one named																			
1	X and Y identified by name or function																			
0	No relevant analysis																			

Question	Answers	Additional Comments/Guidance	Mark	ID details
04.5	<p>Max 2 from: ✓ ✓</p> <p>Light may encounter impurities at different positions/angles</p> <p>Light may encounter different number of impurities</p> <p>Light may encounter different sizes of impurities</p> <p>Angle of incidence may become less than critical angle</p> <p>Bending may cause cracks in the core/cladding</p> <p>Light may be refracted (more/differently)</p>	<p>Allow responses shown on diagram.</p> <p>Allow “different impurities”.</p> <p>Don’t accept “critical angle changes”</p>	2	AO3
04.6	<p>Transverse – displacement/oscillations/vibrations at right angles/(perpendicular) to direction of energy transfer ✓</p> <p>Longitudinal – displacement/oscillations/vibrations along/(parallel to) direction of energy transfer ✓</p>	<p>Condone “direction of wave” once.</p> <p>1 mark for correct reference to difference in polarisation.</p> <p>Treat references to P and S wave as neutral.</p>	2	AO1.1a
Total			16	

0 2

Some cars are fitted with a water sensor designed to switch on windscreen wipers automatically when it rains. **Figure 1** shows a simplified diagram of the sensor.

Figure 1



A light ray travels from the light-emitting diode (LED) through the first prism and into the windscreen. The ray reflects off the surfaces of the windscreen at **A**, **B** and **C** and then passes through the second prism into the detector.

0 2 . 1

Suggest how the design ensures that there is no deviation of the ray as it enters the first prism.

[1 mark]

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0 2 . 2

Suggest **two** features of the design that ensure that there is no deviation of the ray as it leaves the first prism and enters the windscreen glass.

[2 marks]

1

2



0**2****.****3**

The refractive index of the windscreen glass is 1.52

Explain why the ray follows the path shown inside the windscreen glass in **Figure 1**.
Support your answer with a suitable calculation.

[2 marks]

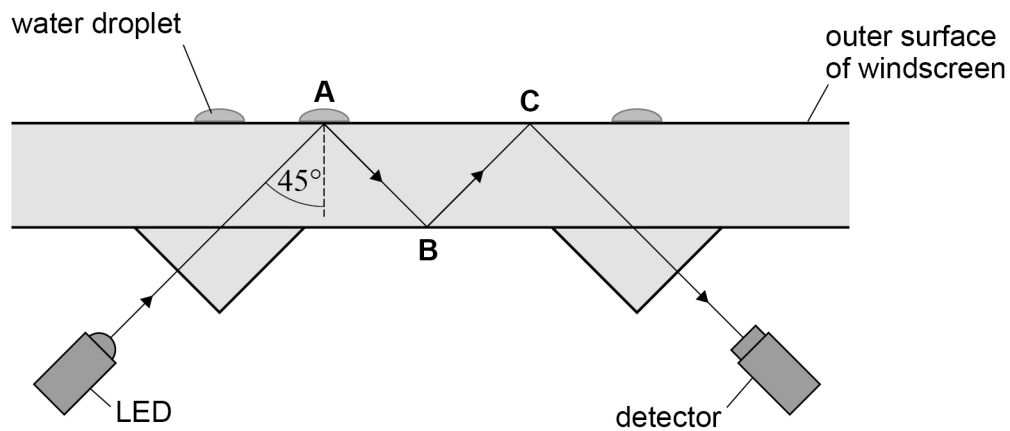


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0 2 . 4

When it starts to rain, water droplets form on the outside of the windscreen as shown in **Figure 2**.

Figure 2

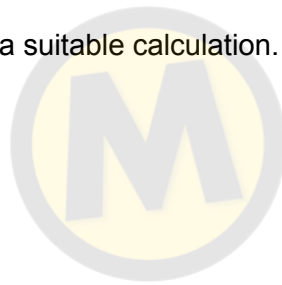


The refractive index of water is 1.33

Explain why the presence of water at **A** causes the intensity of the light at the detector to decrease.

Support your answer with a suitable calculation.

[2 marks]



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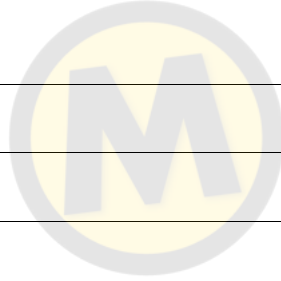


0 2 . 5

The refractive index of the windscreen glass can vary by a few per cent across the thickness of the glass.

Discuss how this variation may affect the path of the ray through the windscreen glass.

[2 marks]



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0 2 . 6

A different design has the LED and the detector further apart. The ray undergoes more reflections inside the windscreen glass before reaching the detector.

Discuss **two** ways in which this different design affects the sensitivity of the sensor to the presence of water droplets.

[2 marks]

1

2



Question	Answers	Additional Comments/Guidelines	Mark
02.1	Ray enters (prism) along normal ✓	Allow normal explained eg at right angles <u>to surface</u> Accept “angle of incidence is 0”.	1
02.2	Treat each point independently. Prism material/it has/they have same refractive index / <u>optical</u> density as windscreen ✓ Prism fitted to windscreen without gaps ✓	Condone ‘it has’ or ‘they have’ or just ‘same’ Allow “no change of speed between prism and windscreen” Allow “made from same material” Do not allow “same refractive index between them” Treat “monochromatic” as neutral Allow “contact between prism and windscreen is clean” etc. Allow “touching the windscreen” Condone suggestion that any bonding material has same refractive index (as prism and windscreen). Do not accept ‘no boundary’	2
02.3	$C = \arcsin(1/1.52) = \arcsin(0.66) = 41(.1)^\circ$ ✓ 45° > critical angle / 41.1° resulting in <u>total internal reflection / tir</u> (at each boundary) ✓	The first mark is for the calculation. The second is for the discussion but is contingent on obtaining a value for C. Ecf for any $C < 45^\circ$	2

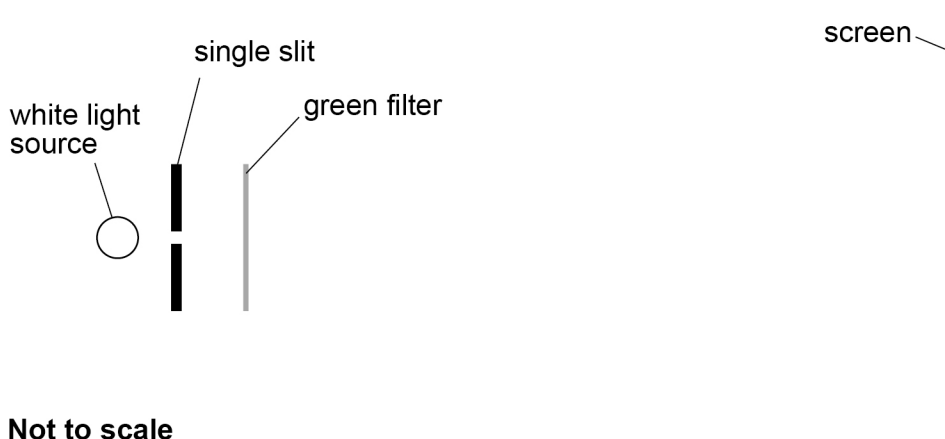
		Accept clear reference to angle at point A in place of 45° statement. Do not allow “angle of incidence > critical angle” on its own.	
02.4	<p>Calculation of critical angle at glass–water boundary (61.0°) OR Calculation of possible n from glass to water (0.707) or absolute n for glass (1.88) OR Calculation of angle of refraction in water (53.9°) ✓</p> <p>So total internal reflection no longer takes place OR some light escapes/refracts (into water) / less light reflects ✓ (Less light stays within windscreen so less light detected at sensor)</p>	<p>Do not allow suggestion that TIR occurs at critical angle/when angle of incidence=critical angle. Do not allow “ray/all the light escapes/refracts” or “no light reflects” or “less TIR”. Do not condone “total internal refraction/diffraction”</p>	2
02.5	<p>Statement of effect of change in n on the path direction ✓</p> <p>(Sensible reference to the variation of a few per cent) leads to the idea that change is unlikely to be significant ✓</p>	<p>Eg for MP1</p> <ul style="list-style-type: none"> • Light may change direction inside windscreen • Light may change direction at a windscreen boundary <p>Eg for MP2</p> <ul style="list-style-type: none"> • Variation too small to deviate significantly within windscreen – internal effect • Variation too small to affect tir at A without 	Max 2

02.6	<p>More sensitive because...</p> <p>more likely to encounter/detect water drop OR will encounter more water drops ✓</p> <p>bigger decrease in light intensity, so more sensitive to rain ✓</p> <p>Less sensitive because...</p> <p>more likely to encounter imperfections in glass/on surface of glass /dirt on surface of glass ✓</p> <p>any curvature effects will be greater so may not hit detector ✓</p> <p>light intensity reduced without presence of water / greater absorption in windscreen due to greater path length ✓</p>	<p>Allow any 2 comments taken from list .</p> <p>There must be a sense of whether the comment relates to an improvement or decrease in sensitivity.</p> <p>Treat as list; mark 1 and 2 independently.</p> <p>Allow idea of larger area</p> <p>Do not allow a response that discusses travel time of ray.</p>	Max 2
Total			11

0 3

Figure 3 shows an arrangement to investigate diffraction. White light is incident on a single slit. After leaving the slit, the diffracted light passes through a green filter to reach the screen.

Figure 3



Not to scale

0 3 . 1

Describe the pattern produced on the screen.

[2 marks]

0 3 . 2

The green filter is replaced with a red filter.

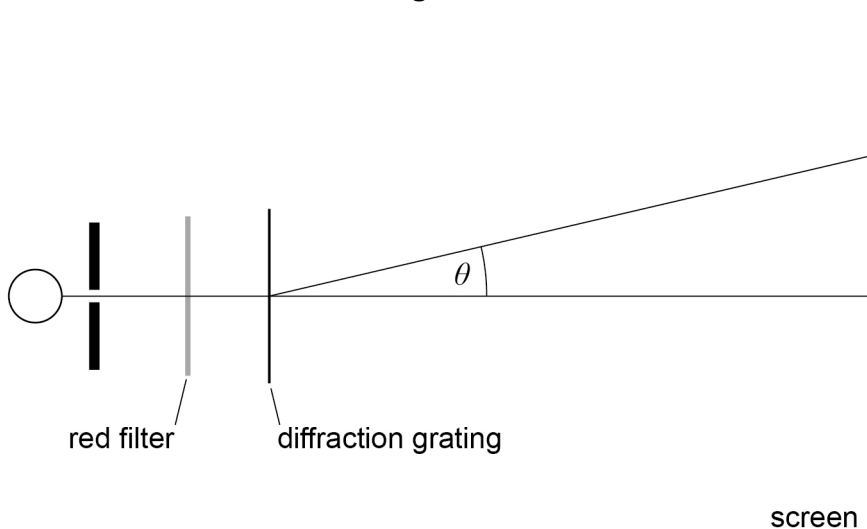
Describe the change in the pattern produced on the screen.

[2 marks]



0 3 . 3

A diffraction grating is placed between the red filter and the screen. The diffraction grating has 500 lines per millimetre. Light is incident normally on the grating. **Figure 4** shows the arrangement.

Figure 4**Not to scale**

The wavelength of the red light is 650 nm.

Calculate the angle θ between a first-order maximum and the central maximum.

[2 marks]

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$\theta =$ _____ degrees

Question 3 continues on the next page

Turn over ►

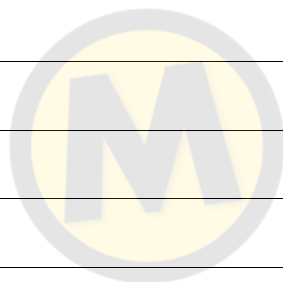


0	3	.	4
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In practice, the filter transmits red light with wavelengths in the range 600 nm to 700 nm.

Suggest how this affects the appearance of the maxima.

[2 marks]



Question	Answers	Additional Comments/Guidelines	Mark
03.1	<p>Central maximum with lower intensity maxima (either side) ✓</p> <p>Central maximum is twice as wide/wider than other maxima ✓</p>	<p>MP1 is for comparison of intensity. Condone references to brightness/dimness. MP2 is for comparison of width</p> <p>Award credit for a drawn answer eg on Fig 3.</p> <p>Suggestion that pattern due to white light = max 1</p> <p>Reference to Young's slit or equation = max 1</p> <p>If only a single maximum is referred to MP2=0 but MP1 can score for description of intensity variation.</p>	2
03.2	<p>Wider (central) maxima (maximum) ✓</p> <p>(Subsequent) maxima further apart ✓</p>	<p>'The pattern is wider/more spread out' gets 1 mark if no other marks given.</p> <p>Not "larger pattern".</p> <p>Condone "larger" distances between maxima.</p> <p>Condone 'maxima more spaced out'</p> <p>Reference to Young's slit or equation = max 1</p> <p>Ignore comments related to change in wavelength</p>	2
03.3	<p>$d = 1 \times 10^{-3}/500 (= 2 \times 10^{-6})$ ✓</p> <p>$(\sin \theta = n\lambda/d = 6.5 \times 10^{-7} / 2 \times 10^{-6} = 0.33)$</p>	<p>Allow POT error for d for MP1</p> <p>May be seen in diffraction grating equation.</p>	2

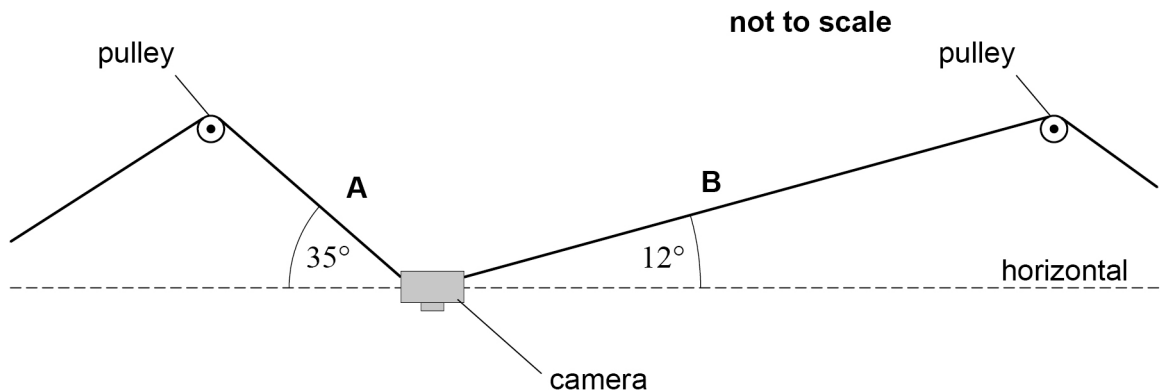
	$\theta = 19^\circ$ ✓	Allow max 1 for use of grating constant rather than d to give $7.45 \times 10^{-11} \text{ m}$ if no other credit available.	
03.4	<p>Any two from: ✓ ✓</p> <p>(Range of wavelengths results in):</p> <p>Central maximum unchanged in width</p> <p>Broader maxima/range of angles for each maximum/order</p> <p>Gradually getting broader/more spread out for greater order maxima</p> <p>Part of third order maximum suppressed at long wavelengths (for $\theta > 90^\circ$)</p>	<p>Give credit for answer shown in diagram</p> <p>Evidence for these marks may be seen in calculations</p> <p>Treat intensity variation as neutral.</p>	Max 2
Total			8

Section B

Answer **all** questions in this section.

0 3

Figure 6 shows a camera filming a sports event from above. The position of the camera is controlled by two steel cables, **A** and **B**, that pass over fixed, smooth pulleys.

Figure 6

0 3 . 1

In **Figure 6** the camera is stationary. The tension in **A** is 430 N and **A** makes an angle of 35° to the horizontal. **B** makes an angle of 12° to the horizontal.

Calculate the tension in **B**.

[2 marks]

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tension in **B** = _____ N

0 3 . 2

The cross-sectional area of **A** is $7.0 \times 10^{-6} \text{ m}^2$. The unstretched length of **A** is 150 m.

Calculate the extension of **A** when the tension in it is 430 N.

Young modulus of steel = 210 GPa

[2 marks]



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extension = _____ m

0 3 . 3

The camera is moved horizontally to the right to a new stationary position. The tension in **A** is now different from that in **Figure 6**.

Deduce whether the tension in **A** has increased or decreased.

[3 marks]

Question 3 continues on the next page

Turn over ►



0 3 . 4

The camera's signal is transmitted as a series of pulses through an optical fibre. **Table 2** shows data for two optical fibres **X** and **Y**. Both optical fibres are identical except for their core diameter.

Table 2

Optical fibre	Core diameter / μm
X	8
Y	50

Deduce which fibre allows a greater pulse transmission rate.

[3 marks]

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10



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[illegible]

Question	Answers	Additional Comments/Guidance	Mark	AO details
03.4	<p>Greater rate occurs when pulses are shorter (in time)/less modal dispersion ✓</p> <p>Smaller diameter (leads to less modal dispersion) means smaller range of path lengths ✓</p> <p>X is more suitable because narrower core leads to lower modal dispersion or reduced pulse broadening ✓</p>	<p>Allow reverse arguments</p> <p>Accept idea of fewer reflections</p>	3	<p>1.1b</p> <p>1.1b</p> <p>1.1b</p>
Total	www.mathswithmatt.co.uk		10	

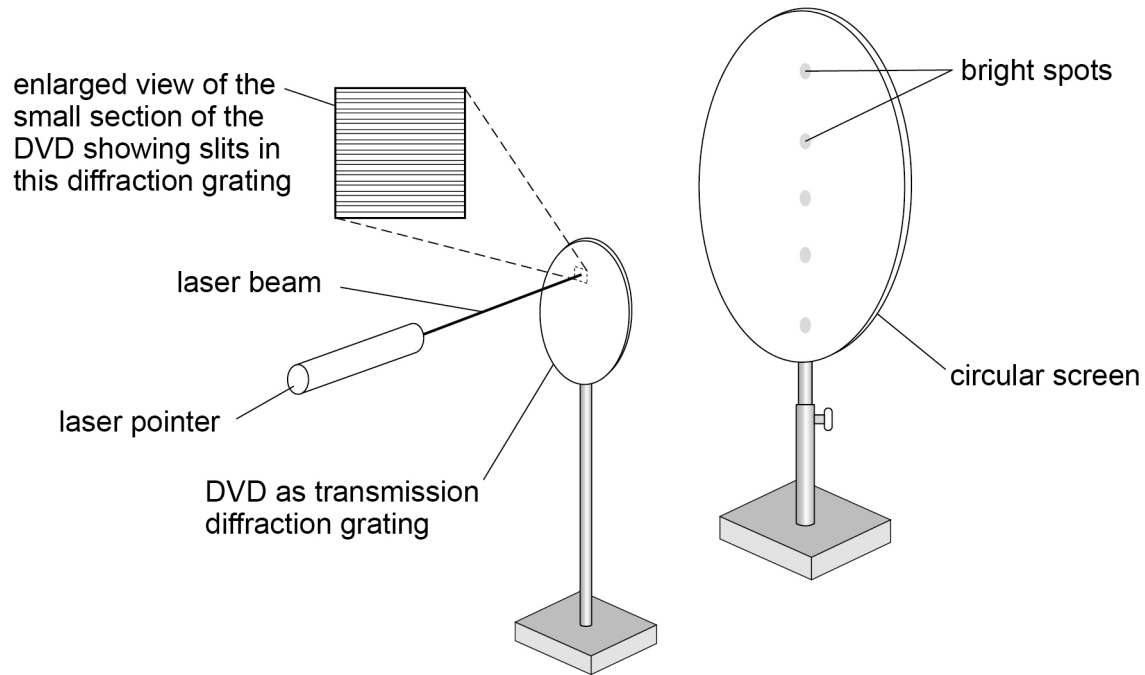
0 2

A student removes the reflective layer from a DVD. She uses the DVD as a transmission diffraction grating.

Figure 3 shows light from a laser pointer incident normally on a small section of this diffraction grating. The grooves on this section act as adjacent slits of the transmission diffraction grating.

A vertical pattern of bright spots (maxima) is observed on a circular screen behind the disc.

Figure 3

**0 2 . 1**

Light of wavelength λ travels from each illuminated slit, producing maxima on the screen.

State the path difference between light from adjacent slits when this light produces a first-order maximum on the screen.

[1 mark]



0 2 . 2

Explain how light from the diffraction grating forms a maximum on the screen.

[3 marks]

*Do not write
outside the
box*

The student has three discs: a Blu-ray disc, a DVD and a CD. She removes the reflective coating from the discs so that they act as transmission diffraction gratings. These diffraction gratings have different slit spacings.

The student also has two laser pointers **A** and **B** that emit different colours of visible light.

Table 2 and **Table 3** show information about the discs and the laser pointers.

Table 2

Disc	Slit spacing / μm
Blu-ray disc	0.32
DVD	0.74
CD	1.60

Table 3

Laser pointer	Wavelength of light emitted / 10^{-7} m
A	4.45
B	6.36

0 2 . 3

Deduce the combination of disc and laser pointer that will produce the **greatest** possible number of interference maxima.

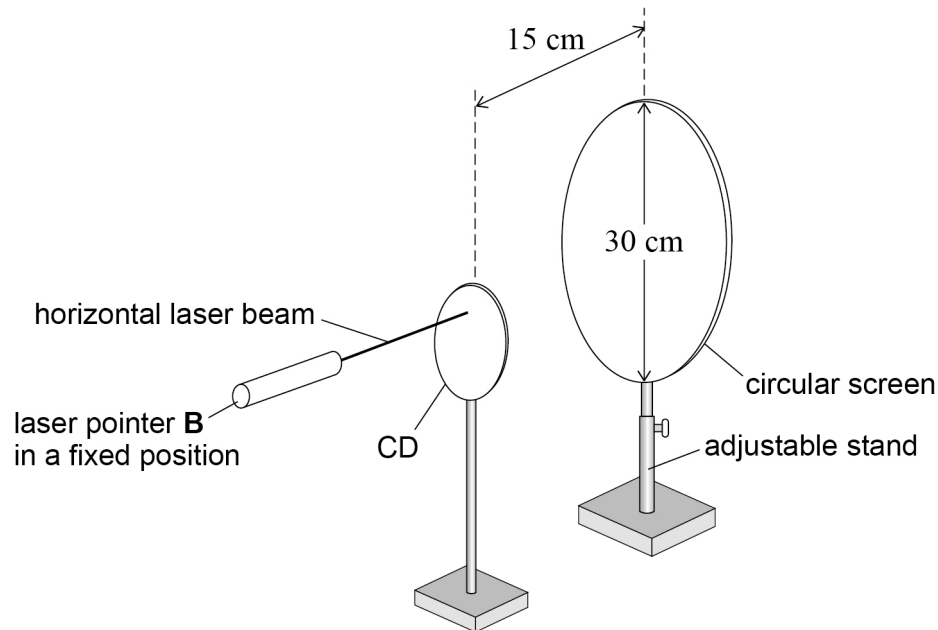
[2 marks]

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0 2 . 4

The student uses the CD and laser pointer **B** as shown in **Figure 4**. A diffraction pattern is produced on the screen. Laser pointer **B** and the CD are in fixed positions. The laser beam is horizontal and incident normally on the CD. The height of the screen can be adjusted.

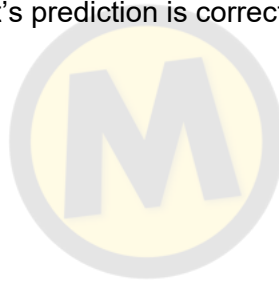
Figure 4

The screen has a diameter of 30 cm and is positioned behind the CD at a fixed horizontal distance of 15 cm.

The student plans to adjust the height of the screen until she observes the greatest number of spots.

The student predicts that, using this arrangement, the greatest number of spots on the screen will be 3.

Determine whether the student's prediction is correct.

[3 marks]

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Question	Answers	Additional Comments/Guidance	Mark	AO
02.1	One wavelength✓	Accept λ	1	AO1.1a

Question	Answers	Additional Comments/Guidance	Mark	AO
02.2	<p>Light from slits overlap / undergo diffraction✓</p> <p>Path difference is a whole number of wavelengths</p> <p>Or</p> <p>Arrive at screen in phase / zero phase difference ✓</p> <p>(Meet and) undergo superposition / waves superpose✓</p>	<p>If no other mark awarded allow one mark for:</p> <p>interfere constructively / Produces reinforcement / produces constructive interference</p>	3	<p>AO2.1c</p> <p>AO2.1c</p> <p>AO2.1c</p>

Question	Answers	Additional Comments/Guidance	Mark	AO
02.3	<p>Pointer A and CD ✓</p> <p>(Smallest) angular spread for each order ($\theta_{\min}$) is given by</p> $\sin \theta_{(\min)} = \frac{n \lambda}{d}$ <p>OR</p> <p>Greatest number of maxima is given by $n_{\max} = \frac{d}{\lambda}$ ✓</p>	<p>Condone:</p> <p>smallest wavelength and greatest slit spacing</p> <p>Max 1 mark for:</p> <p>An argument that links spacing to slit width and its effect on diffraction.</p>	2	<p>AO3.1b</p> <p>AO3.1b</p>

Question	Answers	Additional Comments/Guidance	Mark	AO
02.4	<p>use of $n \lambda = d \sin \theta$ ✓</p> <p>use of $\tan \theta = r / 15$ or adds θ_2 and θ_1 and compares to 90° or adds θ_2 and θ_2 and compares to 90° or adds θ_1 and θ_1 and compares to 90° ✓</p> <p>No, can see 4 (bright spots) ✓</p>	<p>For example, where: $n = 1, \lambda = 6.36 \times 10^{-7} \text{ m}$ and $d = 1.6 \times 10^{-6} \text{ m}$ $(\theta = 23^\circ)$ or $n = 2, \lambda = 6.36 \times 10^{-7} \text{ m}$ and $d = 1.6 \times 10^{-6} \text{ m}$ $(\theta = 53^\circ)$</p> <p>Allow use of $\tan \theta = r / 15$ for any combination of θ, r and 15 where unknown has been made subject.</p> <p>$\theta = 45^\circ$ and 3 bright spots therefore yes is a maximum of max 2 marks</p> <p>Allow use of $n = \frac{d}{\lambda}$ where they have reached a conclusion for 1 mark maximum.</p>	3	AO3.1b AO3.1b AO3.1b

Total			9	
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box*

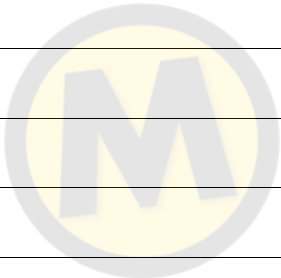
0 7

Optical fibres are used to carry pulses of light.

0 7 . 1

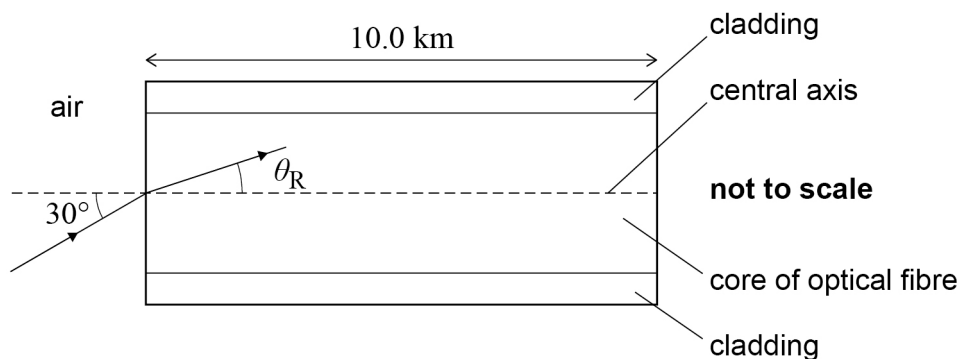
Explain what is meant by modal dispersion in an optical fibre.

[2 marks]



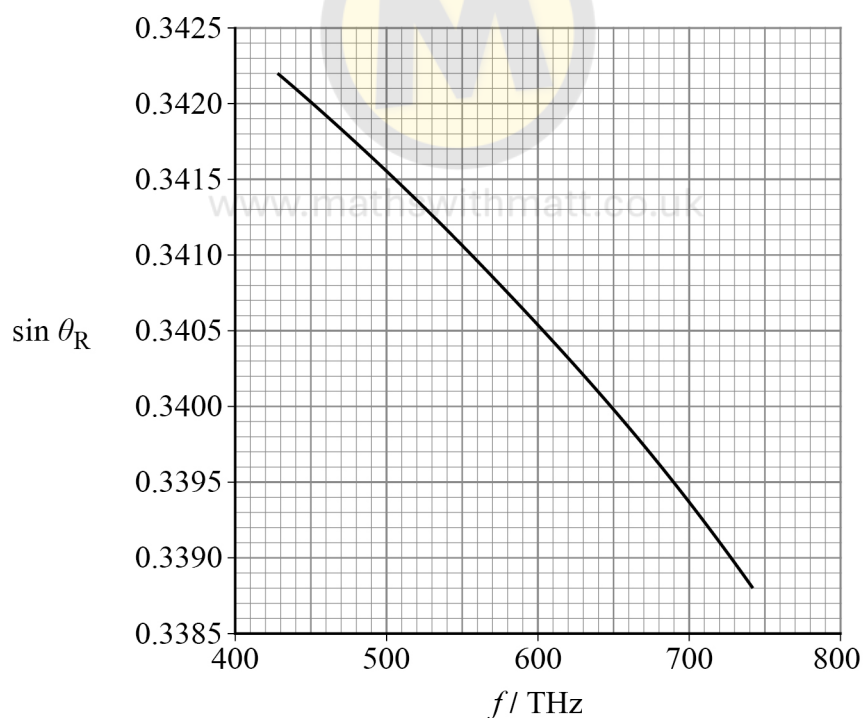
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Figure 15 shows a ray of light incident on the central axis of an optical fibre at an angle of incidence of 30° . The optical fibre is straight and horizontal and has a length of 10.0 km.

Figure 15

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 16 shows how $\sin \theta_R$ varies with f when the angle of incidence is 30° .

Figure 16

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.

0 7 . 2

Show that the horizontal component of the velocity of the pulse is approximately $1.9 \times 10^8 \text{ m s}^{-1}$.

[1 mark]

0 7 . 3

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.

[3 marks]



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speed = _____ m s^{-1}

Question 7 continues on the next page

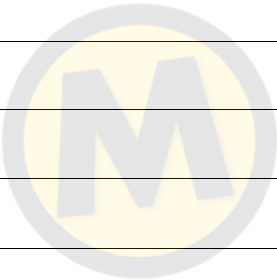
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0 7 . 4

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.

[2 marks]

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0 7 . 5

Another two pulses, identical to the pulses in Question **07.4**, 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 Question **07.4**.

[1 mark]

Question	Answers	Additional Comments/Guidance	Mark	AO
07.1	<p>Spreading of pulse / parts of a pulse take different times to travel through the fibre / pulse broadening✓</p> <p>Due to different paths through the optical fibre / due to entering the optical fibre at different angles ✓</p>	<p>Do not credit material dispersion. owtte</p> <p>Accept a diagram showing different paths.</p>	2	<p>AO1.1a</p> <p>AO1.1a</p>

Question	Answers	Additional Comments/Guidance	Mark	AO
07.2	<p>speed ($= \frac{\text{distance}}{\text{time}}$) = $\frac{10 \times 10^3}{5.225 \times 10^{-5}}$ ✓ (= 1.91×10^8)</p>		1	AO1.1a

Question	Answers	Additional Comments/Guidance	Mark	AO
07.3	<p>Reads off $\sin \theta_R = 0.3391$ or</p> <p>use of $n_1 \sin \theta_1 = n_2 \sin \theta_2$ ✓</p> <p>Use of $n = \frac{c}{c_s}$ seen ✓</p> <p>$c_s = 2.03 \times 10^8$ ✓</p> <p>Alternative:</p> <p>Reads off $\sin \theta_R = 0.3391$ or</p> <p>$\theta = 19.8^\circ$ ✓</p> <p>$c_s \cos 19.8 = 1.9 \times 10^8$ ✓</p> <p>$c_s = 2.03 \times 10^8$ ✓</p>	<p>With their $\sin \theta_R$</p> <p>(Refractive index of core = 1.47)</p> <p>Allow use of their refractive index where c_s is the subject of the formula</p> <p>Allow finding θ_R for their read off</p> <p>Allow use of their θ_R</p>	3	<p>AO1.1a AO2.1b AO2.1b</p>

Question	Answers	Additional Comments/Guidance	Mark	AO
07.4	<p>The refractive index of core for blue light is greater than the refractive index for red / The refractive index of core for red light is less than the refractive index for blue✓</p> <p>The speed of the blue light is less than the speed of the red light and travel the same distance / The speed of the red light is greater than the speed of the blue light and travel the same distance✓</p>	<p>Max 1 mark for stating that the refractive indices are different because their speeds are different</p> <p>MP1 can come from graph or prior knowledge</p>	2	<p>AO1.1b</p> <p>AO2.1a</p>

Question	Answers	Additional Comments/Guidance	Mark	AO
07.5	<p>the blue now travels a shorter distance than the red light (compared to 07.4).✓</p> <p>or</p> <p>the red light now travels a greater distance than the blue light (compared to 07.4).✓</p> <p>or</p> <p>the difference between the blue's velocity parallel to the central axis and the red's velocity (parallel to the central axis) has decreased (compared to 07.4).✓</p> <p>or</p> <p>the difference between the horizontal velocity of the red light and the horizontal velocity of the blue light has decreased (compared to 07.4).✓</p>	<p>Allow: now travel different distances whereas previously travelled the same distance.</p>	1	AO2.1a

Total			9	
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0 3

Figure 4 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 the core–cladding boundary.

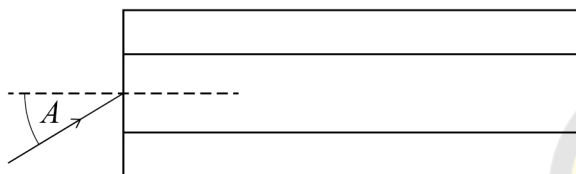
Figure 4

Table 2 shows some properties of the optical fibre.

Table 2

	Refractive index
cladding	1.41
core	1.47

0 3

1

Calculate the speed of the light ray in the optical fibre.

[1 mark]

speed = _____ m s^{-1}

0 3 . 2

Calculate A , in degrees, for the optical fibre shown in **Figure 4**.

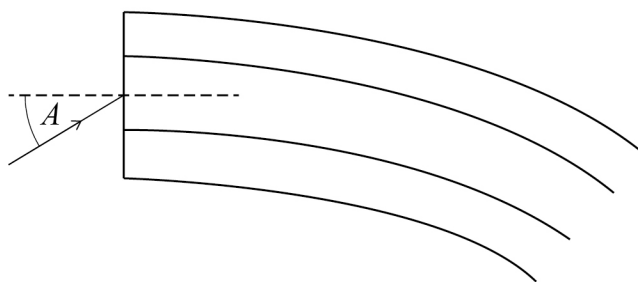
[3 marks]

$A =$ _____ degrees

0 3 . 3

A ray is incident on the optical fibre at angle A . The optical fibre is now bent, as shown in **Figure 5**.

Figure 5



Draw, on **Figure 5**, what happens to the ray within the optical fibre. Explain your answer.

[3 marks]

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Turn over ►



Question	Answers	Additional comments/Guidelines	Mark	AO
03.1	$\text{Speed} = 3.0 \times 10^8 / 1.47$ $= 2.0(4) \times 10^8 \text{ m s}^{-1} \checkmark$	Do not accept 1 sf answer	1	AO1.1b

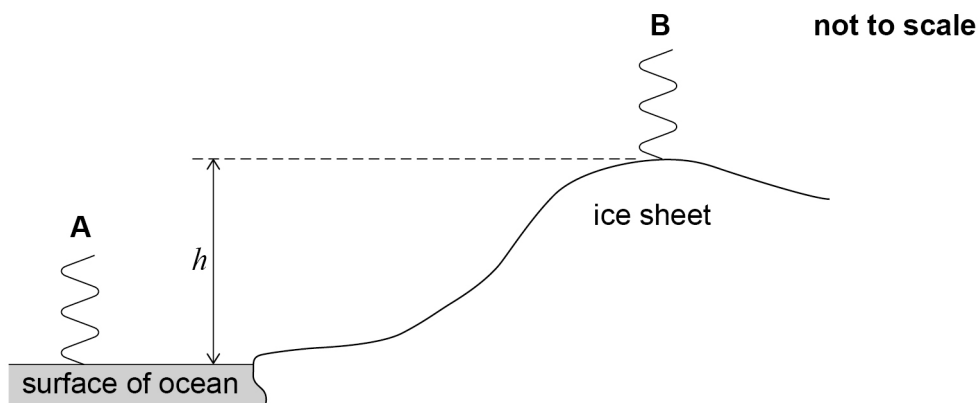
Question	Answers	Additional comments/Guidelines	Mark	AO
03.2	<p>Critical angle calculation $\checkmark$</p> $\sin C = n_{\text{clad}}/n_{\text{core}} = 1.41/1.47 = 0.96$ critical angle = 73.6° <p>Angle of refraction calculation $\checkmark$</p> $r = 90 - C = 16.4^\circ$ <p>Angle of incidence calculation $\checkmark$</p> $\sin(i) = 1.47 \sin(r)$ $i = 24.5^\circ$	<p>Do not give MP2 if calculated answer is given as A</p> <p>Allow 2 sf answer; allow 24.6°</p>	3	AO2.1d

Question	Answers	Additional comments/Guidelines	Mark	AO
03.3	<p>Correct path of light drawn showing partial reflection and transmission of ray when it encounters the boundary ✓</p> <p>Angle of incidence on core–cladding boundary decreases✓</p> <p>And will now be less than critical angle ✓</p> <p>(Some light will escape/be refracted into cladding</p> <p>Some light will continue)</p>	<p>If the diagram is not annotated and no other mark is given, 1 mark can be given for correct description of partial reflection.</p>	3	AO3.1b
Total			7	

0 3

A satellite system is used to measure the height h of the top of an ice sheet above the surface of the ocean.

The satellite emits two pulses **A** and **B** of infrared radiation. **A** is incident on the surface of the ocean and **B** is incident on the top of the ice sheet as shown in **Figure 2**.

Figure 2

0 3 . 1

The frequency of the infrared radiation is 3.8×10^{14} Hz.
Each pulse has a duration of 6.0 ns.

Calculate the number of cycles in each pulse.

[2 marks]

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number of cycles = _____

0 3 . 2

A and **B** reflect and return to the satellite. The travel time is the time between the emission of a pulse and its return to the satellite.

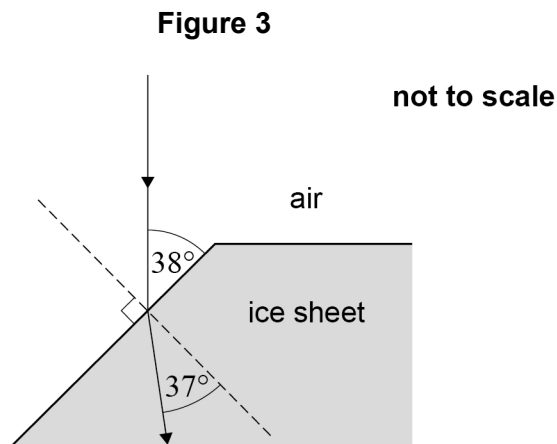
The difference in the travel times of **A** and **B** is $10.7 \mu\text{s}$.

Calculate h .

[2 marks] $h =$ _____ m

Some of the infrared radiation enters the ice sheet.

Figure 3 shows the path of infrared radiation that refracts at a sloping part of the ice sheet.



0 3 . 3 Calculate the refractive index of the ice.

[2 marks]



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refractive index = _____

0 3 . 4 Calculate the wavelength of the infrared radiation when it is inside the ice sheet.

[2 marks]

wavelength = _____ m

8

Turn over ►



Question	Answers	Additional Comments/Guidance	Mark	AO
03.1	<p>Use of $f = \frac{1}{T}$ or (T =) 2.63×10^{-15} (s) seen</p> <p>or</p> <p>number of waves = $\frac{6 \times 10^{-9}}{\text{their } T}$</p> <p>or</p> <p>$6 \times 10^{-9} \times 3.8 \times 10^{14} \checkmark$</p> <p>$2.3 \times 10^6 \checkmark$</p>	<p>Condone POT error in MP1</p> <p>Use of $f = \frac{1}{T}$ is f substituted and formula rearranged to make T the subject.</p> <p>$\frac{1}{6 \times 10^{-9}}$ is not sufficient for use of $f = \frac{1}{T}$</p> <p>Alternative for MP1:</p> <p>calculates the length of a pulse ($6 \times 10^{-9} \times 3 \times 10^8 = 1.8$ m) and calculates the wavelength = $\frac{3 \times 10^8}{3.8 \times 10^{14}} = 7.9 \times 10^{-7}$</p> <p>OR</p> <p>Determines maximum number of pulses per second $\frac{1}{6 \times 10^{-9}}$ and divides number of cycles per second by the number of pulses per second. That is:</p> <p>$\frac{3.8 \times 10^{14}}{\frac{1}{6 \times 10^{-9}}}$ or $\frac{3.8 \times 10^{14}}{1.67 \times 10^8}$ seen</p> <p>Calculator display 2280000</p> <p>Unsupported answers with POT error 1 mark</p>	2	<p>1 x AO1</p> <p>1 x AO2</p>

Question	Answers	Additional Comments/Guidance	Mark	AO
03.2	<p>Use of speed = $\frac{\text{distance}}{\text{time}}$</p> <p>by substituting for speed ($3 \times 10^8 \text{ ms}^{-1}$) and time ($10.7 \times 10^{-6} \text{ s}$) and making distance the subject</p> <p>OR</p> <p>Use of speed = $\frac{\text{distance}}{\text{time}}$ and divides their distance by 2</p> <p>OR</p> <p>(time =) $\frac{10.7 \times 10^{-6}}{2}$ / (time =) $5.35 \times 10^{-6} \text{ s}$ ✓</p> <p>$1.6 \times 10^3 \text{ (m)}$ ✓</p>	<p>Condone POT error on MP1</p> <p>An answer = $3.2(1) \times 10^3 \text{ (m)}$ obtains 1 mark with working (allow POT on this compensatory mark)</p> <p>Alternative calculation for total distance: Multiplies the wavelength ($7.9 \times 10^{-7} \text{ m}$) by the number of waves in $10.7 \mu\text{s}$ ($\frac{10.7 \times 10^{-6}}{2.63 \times 10^{-15}}$):</p> <p>That is $\frac{3 \times 10^8}{3.8 \times 10^{14}} \times \frac{10.7 \times 10^{-6}}{2.63 \times 10^{-15}}$ /</p> <p>$\frac{3 \times 10^8}{3.8 \times 10^{14}} \times \frac{10.7 \times 10^{-6}}{\frac{1}{3.8 \times 10^{14}}} / 7.9 \times 10^{-7} \times \frac{10.7 \times 10^{-6}}{2.63 \times 10^{-15}}$</p> <p>/ $7.9 \times 10^{-7} \times 4.066 \times 10^9$ seen</p> <p>OR</p> <p>Multiplies the wavelength ($7.9 \times 10^{-7} \text{ m}$) by the number of waves in $10.7 \mu\text{s}$. ($10.7 \times 10^{-6} \times f$) where $f = 3.8 \times 10^{14}$</p> <p>That is:</p> <p>$7.9 \times 10^{-7} \times 10.7 \times 10^{-6} \times 3.8 \times 10^{14}$ /</p> <p>$\frac{3 \times 10^8}{3.8 \times 10^{14}} \times 10.7 \times 10^{-6} \times 3.8 \times 10^{14}$ seen</p> <p>(Calculator displays 1605)</p>	2	2 x AO2

Question	Answers	Additional Comments/Guidance	Mark	AO
03.3	<p>Use of $n_1 \sin \theta_1 = n_2 \sin \theta_2$ ✓ by substitution</p> <p>($n_2 =$) 1.3(1) ✓</p>	<p>Condone use of $\theta_1 = 38^\circ$ provided $n_{\text{air}} = 1$: need to see an explicit statement $1 \times \sin \theta_1$ and answer = 1.0(2).</p> <p>Allow their θ_1 from an attempt to find $90 - 38$ in use of</p> <p>Allow 62 or 42 for θ_1 without supporting evidence in use of</p> <p>Do not allow $\theta_1 = 90^\circ$ in use of</p> <p>Allow use of $n_2 = \frac{\sin i}{\sin r}$ or $\frac{n_2}{n_1} = \frac{\sin i}{\sin r}$</p> <p>or $n = \frac{\sin i}{\sin r}$</p> <p>must see $i =$ their θ_1 and $r = 37^\circ$ for use of any of these</p> <p>Do not allow this method for $i = \theta_1 = 38^\circ$ unless answer = 1.0(2) and</p> <p>either</p> <p>$n_2 / \frac{n_2}{n_1}$ is seen as subject</p> <p>or</p> <p>n is subject and there is an explicit statement that $n_{\text{air}} = 1$</p>	2	<p>1 x AO1</p> <p>1 x AO2</p>

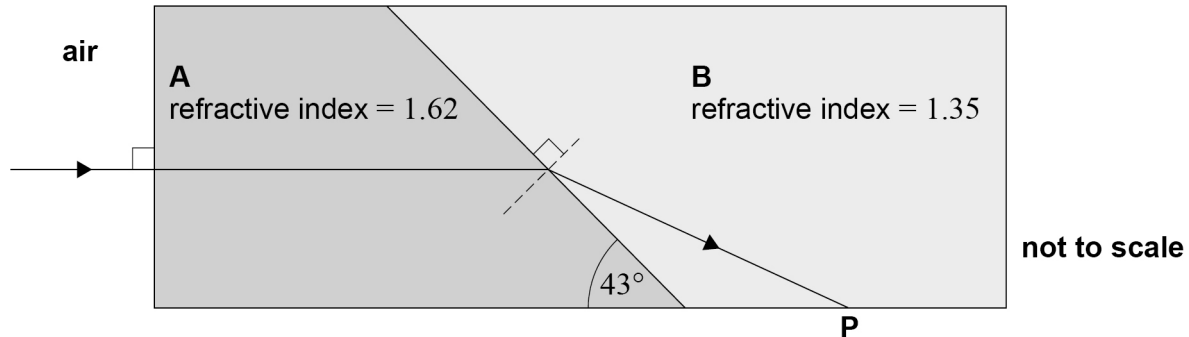
Question	Answers	Additional Comments/Guidance	Mark	AO
03.4	<p>Attempted use of $n = \frac{c}{c_s}$</p> <p>Or</p> <p>use of their $c_s = f\lambda$ ✓</p> <p>6.0×10^{-7} (m) or 6.1×10^{-7} (m) ✓</p> <p>Alternative</p> <p>Divides wavelength in air by the refractive index ✓</p> <p>6.0×10^{-7} (m) or 6.1×10^{-7} (m) ✓</p>	<p>Expect to see $c_s = 2.3 \times 10^8$ (m s⁻¹)</p> <p>Ecf from 03.3 in use of $n = \frac{c}{c_s}$</p> <p>Condone their c_s in use of $c = f\lambda$</p> <p>Ecf from 03.3</p> <p>Answer = $7.7(4) \times 10^{-7}$ (m) for $n = 1.02$</p> <p>Or $7.7(2) \times 10^{-7}$ (m) for $n=1.02$ where no rounding on ecf</p> <p>Answer = 7.89×10^{-7} (m) for $n = 1.0$ (only condone this answer where $n=1$ or $n=1.0$ seen as ecf from 03.3)</p> <p>Expect to see 6.03×10^{-7} or 6.07×10^{-7}</p> <p>Maximum of 1 mark where speed in ice sheet is more than speed of light in a vacuum is seen.</p> <p>Penalise 1 significant figure</p>	2	<p>1 x AO1</p> <p>1 x AO2</p>
Total			8	

0 6

Two transparent prisms **A** and **B** of different refractive indices are placed in contact to produce a rectangular block.

Figure 12 shows the path of a ray, incident normally on **A**, refracting as it crosses the boundary between the prisms.

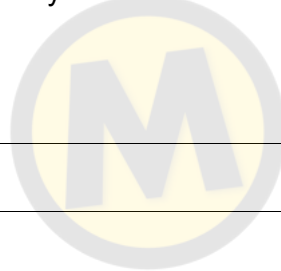
Figure 12



0 6 . 1

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

[1 mark]



0 6 . 2

Show that the angle of refraction of the ray in **B** is about 60° .

[2 marks]



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0 6 . 3

Draw, on **Figure 12**, the path of the ray immediately after it reaches **P**.
Justify your answer with calculations.

[3 marks]

6

END OF SECTION A

Turn over ►



Question	Answers	Additional comments/Guidelines	Mark	AO
06.1	<p>As angle of refraction greater than angle of incidence with reference to Snell's law / $n = \sin i \div \sin r$</p> <p>OR</p> <p>light bends away from normal when it speeds up ✓</p> <p>(Therefore $n_A > n_B$)</p>		1	AO1

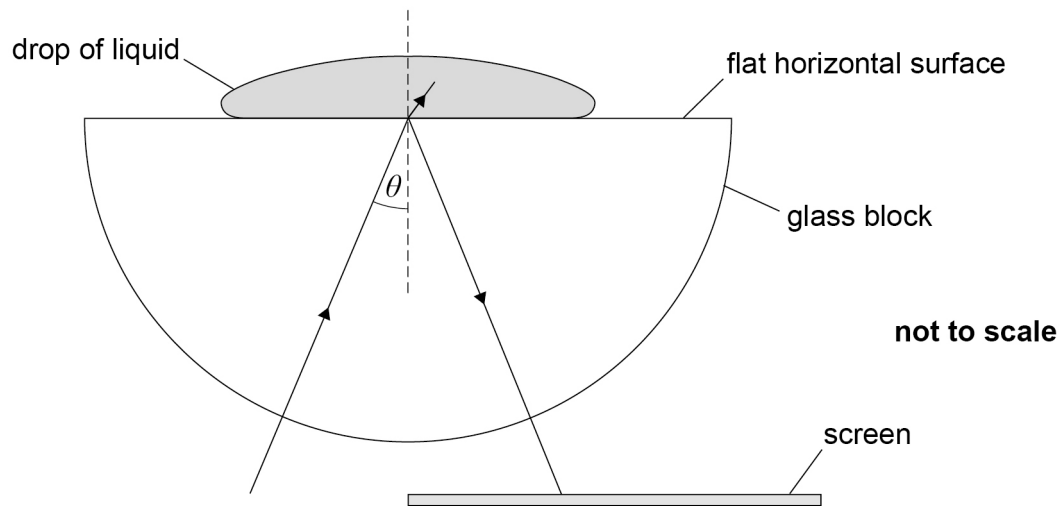
Question	Answers	Additional comments/Guidelines	Mark	AO
06.2	<p>Calculation of angle of incidence = $90^\circ - 43^\circ = 47^\circ$ ✓</p> <p>Use of Snell's law to give angle of refraction</p> <p>= $61(.4)^\circ$ cao ✓</p>	<p>MP1 may be seen on diagram</p> <p>Calculator value: 61.357 115 7</p>	2	2 x AO2

Question	Answers	Additional comments/Guidelines	Mark	AO
06.3	<p>Use of $\sin c = 1/n$ to get $c = 48^\circ$</p> <p>OR</p> <p>$i = (180^\circ - 43^\circ - 61.4^\circ) = 76^\circ$ ✓</p> <p>Other calculation and i greater than c therefore tir ✓</p> <p>Ray reflecting off P to land where the top of the n of 'not to scale' label meets the glass surface ✓</p>	<p>Condone 77° but not 75°</p> <p>No ecf from MP1 to MP2</p> <p>Allow a range:</p> 	3	3 x AO3
Total			6	

0 4

Figure 12 shows a type of refractometer.

A semi-circular glass block is arranged so that its semi-circular faces are vertical. A drop of liquid is placed at the centre of the flat horizontal surface of the block.

Figure 12

Light enters the block through the curved surface and is incident on the midpoint of the horizontal surface at angle of incidence θ .

Light that reflects at the glass–liquid boundary is detected on a screen that lies parallel to the horizontal surface.

0 4 . 1

Explain why the light ray in **Figure 12** does not change direction as it enters the block. [1 mark]

0 4 . 2

The refractometer is calibrated using a drop of liquid. When $\theta = 15^\circ$, light is partially refracted at the glass–liquid boundary.

Calculate the angle of refraction at this boundary.

refractive index of glass block = 1.84

refractive index of liquid = 1.33

[2 marks]

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angle of refraction = _____ °

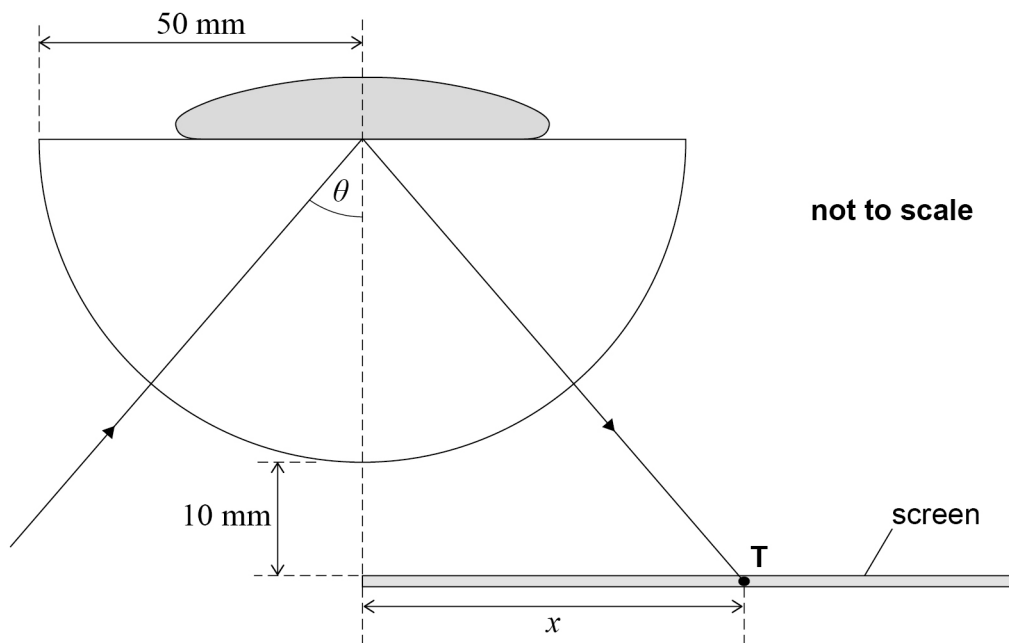
Turn over ►



The refractometer is used to determine the critical angle θ_c at the glass–liquid boundary.

Figure 13 shows dimensions of the arrangement.

Figure 13



The intensity of the light ray on the screen is observed as θ is increased from 15° . When $\theta = \theta_c$ the intensity of the light ray is seen to increase sharply at a point **T** on the screen.

The distance between the left-hand edge of the screen and **T** is x .

0 4 . 3

Explain why the intensity of the light ray on the screen increases at **T**.

[2 marks]



0	4	.	4
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The liquid is replaced with a drop of sugar solution.
The refractive index of the sugar solution is greater than 1.33

Deduce how this change affects the position at which the sharp increase in intensity is observed on the screen.

[2 marks]

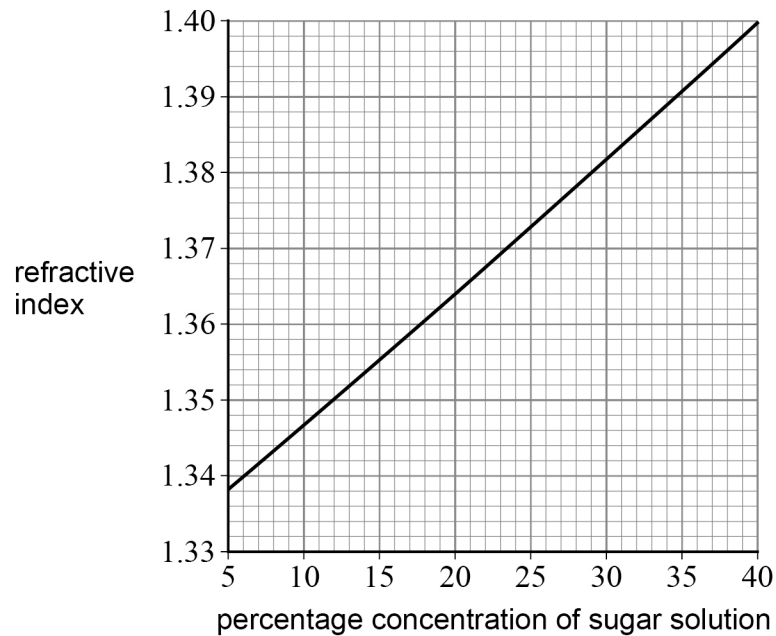
*Do not write
outside the
box*

0 4 . 5

The refractometer in **Figure 13** is used to determine the concentration of a sugar solution.

Figure 14 shows the variation of refractive index with concentration of sugar solution.

Figure 14



For a drop of a particular sugar solution, $x = 69$ mm.

Determine the percentage concentration of the sugar solution.

refractive index of glass block = 1.84

[3 marks]



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percentage concentration = _____

10

END OF SECTION B



Question	Answers	Additional Comments/Guidance	Mark	AO
04.1	ray is incident along/at the normal owtte ✓	Allow perpendicular/90° to the surface/block. Allow 'angle of incidence is 0°'. Reject 'towards the normal'.	1	AO1

Question	Answers	Additional Comments/Guidance	Mark	AO
04.2	correct use of Snell's law ✓ 21° ✓	Expect to see $1.84 \sin 15 = 1.33 \sin \theta$ Calculator value for θ is 20.9814°	2	AO2

Question	Answers	Additional Comments/Guidance	Mark	AO
04.3	(intensity increases because) total internal reflection occurs owtte ✓ idea that the lower intensity to left of T is due to partial reflection ✓	Reject 'more total internal reflection occurs'. 'There is more reflection' is insufficient. MP2 must be in terms of reflected, not refracted, light. Allow answers in terms of x .	2	AO2

Question	Answers	Additional Comments/Guidance	Mark	AO
04.4	T will move to right OR x will increase ✓ (because) critical angle will increase ✓	MP1 requires some relevant justification e.g. ratio $\frac{n_2}{n_1}$ will be closer to 1.	2	AO2

Question	Answers	Additional Comments/Guidance	Mark	AO
04.5	uses $\tan \theta = \frac{69}{60}$ to calculate correct θ_c to 2 sf min ✓ uses $\sin \theta_c = \frac{n}{1.84}$ to determine refractive index ✓ uses their refractive index to at least 4 sf to obtain the concentration ✓	MP1: Calculator value for θ_c is 48.99091° MP2: Allow ecf from MP1. Expect $n = 1.388$. MP3: Allow ecf from MP2. Expect 33.5%.	3	AO3

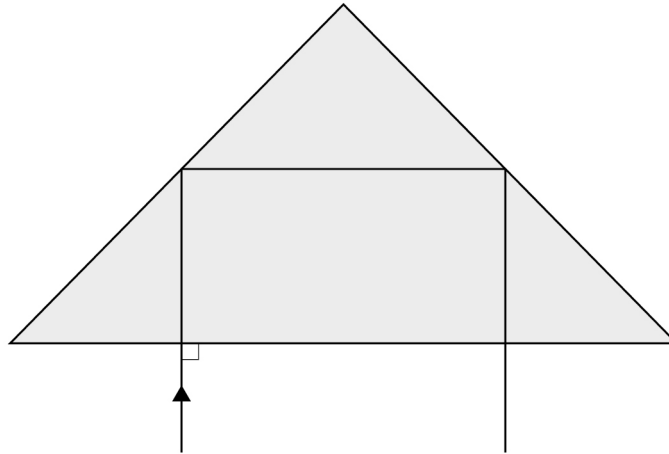
Total			10	
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0 4

Porro prisms are used in binoculars to reverse the path of the light. The prism is in the shape of a right-angled isosceles triangle.

Figure 7 shows a ray of light, at normal incidence on the longest side, passing through a glass Porro prism.

Figure 7



The critical angle for light in the prism is 41.5° .

0 4 . 1

Show that the glass used to make the prism has a refractive index of about 1.5

[1 mark]



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0 4 . 2

Explain why the ray emerges parallel to the incident ray.

[2 marks]

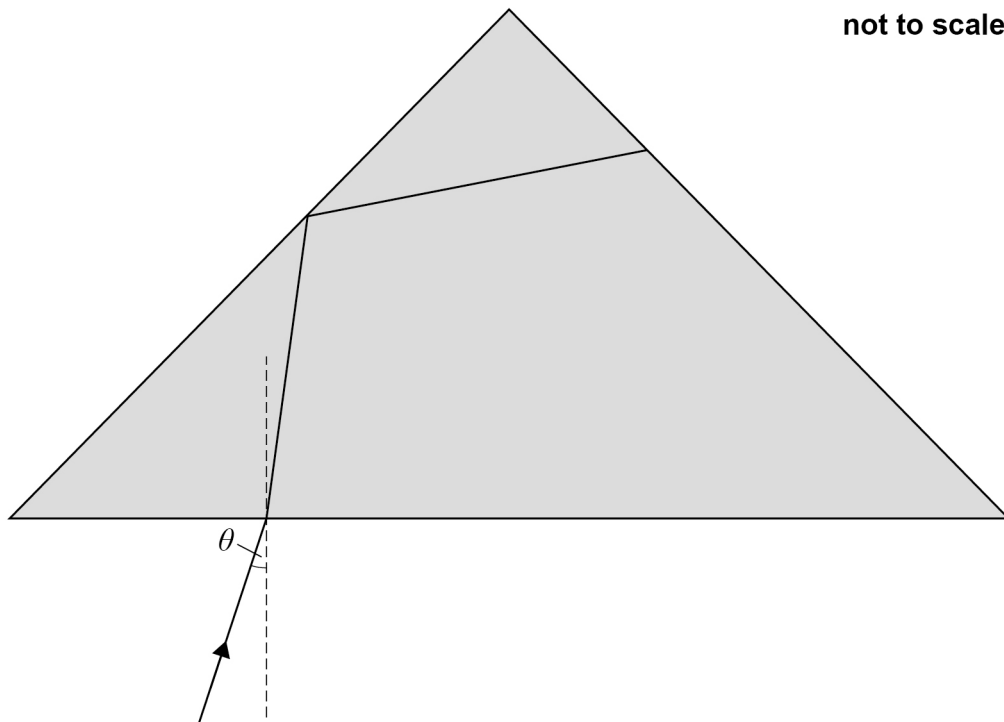
Question 4 continues on the next page

Turn over ►



Figure 8 shows a ray of light entering the prism at an angle of incidence θ and reflecting off one of the shorter sides.

Figure 8



θ is the largest angle of incidence for which all of the light leaves through the longest side.

0 4 . 3

Draw on **Figure 8** the path of the ray of light as it continues inside the prism and emerges from the longest side.

[3 marks]



0	4	.	4
---	---	---	---

When the angle of incidence is greater than θ , some of the light escapes the prism through one of the shorter sides.

Assume that the refractive index is 1.5 and the critical angle is 41.5° .

Show that θ is about 5° .

You can use **Figure 8** in your answer.

[4 marks]

*Do not write
outside the
box*

0 4 . 5

A manufacturer wants to make a prism with a larger value of θ .

Two alternative changes to the original design of the prism are suggested:

1. use a prism of the original glass in the shape of an equilateral triangle, as shown in **Figure 9**
2. use a prism of the original shape made from glass with a smaller refractive index, as shown in **Figure 10**.

Figure 9

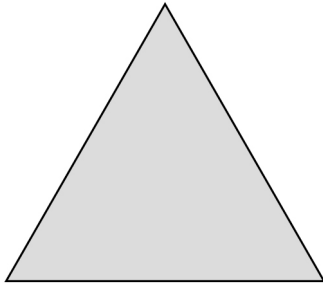
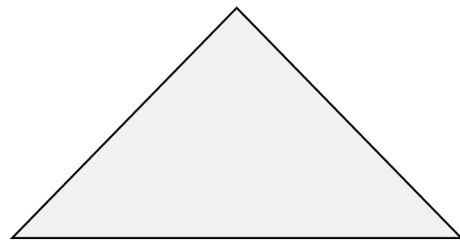


Figure 10



Discuss whether either of the two suggestions would work.

[4 marks]

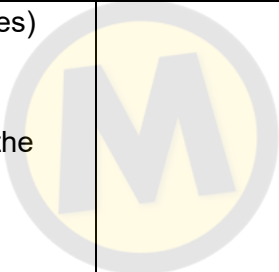
1

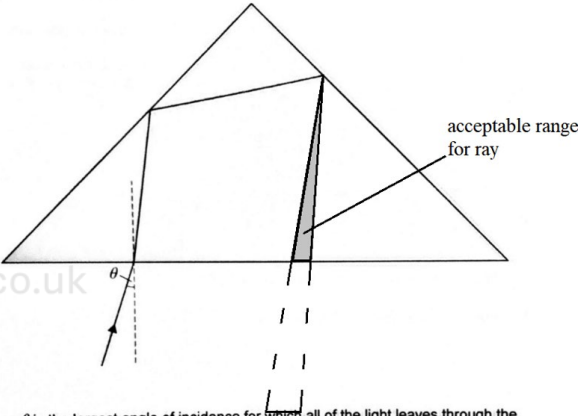
2



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Question	Answers	Additional comments/Guidelines	Mark	AO
04.1	Uses $\sin c = \frac{1}{n}$ to get 1.51 ✓	Must see relevant work to award the mark. Minimum 3 sf must be seen	1	AO1

Question	Answers	Additional comments/Guidelines	Mark	AO
04.2	(Each) angle of incidence is 45° (at 2 nd and 3 rd surfaces) AND total internal reflection occurs / which is greater than the critical angle. ✓ Angle of incidence as ray leaves block is 0° OR The ray leaves along the normal (and so the ray emerges parallel to the incident ray). ✓	 www.mathswithmatt.co.uk	2	AO1 AO2

Question	Answers	Additional comments/Guidelines	Mark	AO
04.3	<p>Only (totally internally) reflected ray seen at 2nd reflecting boundary ✓</p> <p>Reflected ray parallel to first refracted ray (by eye)✓</p> <p>Ray leaves parallel to initial ray (by eye) ✓</p>	<p>For MP2:</p>  <p>θ is the largest angle of incidence for which all of the light leaves through the</p>	3	AO2

Question	Answers	Additional comments/Guidelines	Mark	AO
04.4	<p>Angle of incidence at 2nd reflecting boundary = 41.5° ✓</p> <p>Angle of reflection at 1st reflecting boundary = 48.5° ✓</p> <p>Angle of refraction at entry = $(90^\circ - 45^\circ - 41.5^\circ) = 3.5^\circ$ ✓</p> <p>Use of $n = 1.5$ and Snell's law to give 5.3° to at least 2 sf ✓</p>	<p>MP1 is an identification of angle at 2nd reflecting boundary</p> <p>MP2 is <math>(90^\circ - \text{their angle at 2nd reflecting boundary})</math></p> <p>MP3 is <math>(45^\circ - \text{their angle at 2nd reflecting boundary})</math></p> <p>Accept answer that rounds to 5.3°</p> <p>The identification of their angles can be inferred from their working or diagram. Simply writing $90^\circ - 41.5^\circ = 48.5^\circ$ does not get a mark on its own.</p>	4	AO1



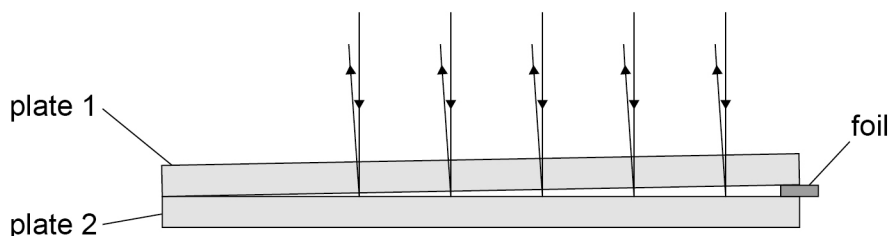
Question	Answers	Additional comments/Guidelines	Mark	AO
04.5	<p>Using 60° prism (Fig 9) does not work because:</p> <ul style="list-style-type: none"> • light would not leave the prism at the original angle ✓ • idea that light will escape from second reflection ✓ <p>A smaller n (Fig 10) does not work because:</p> <ul style="list-style-type: none"> • larger critical angle ✓ • which would reduce the value of θ ✓ 	<p>Suggestion that the design would work limits the mark to Max 1 for that design.</p> <p>Alternative for MP2</p> <p>Light would no longer be totally internally reflected at second reflection OR angle of incidence at second reflection is now less than the critical angle</p>	4	AO3
Total	www.mathswithmatt.co.uk		14	

0 4

Figure 13 shows an arrangement used to determine the thickness of metal foil using interference of light.

Figure 13

not to scale



Two thin glass plates are separated by the foil at one end. Monochromatic light is incident on the glass plates from above. A series of bright fringes is observed when viewed from above, as shown in **Figure 14**.

Figure 14

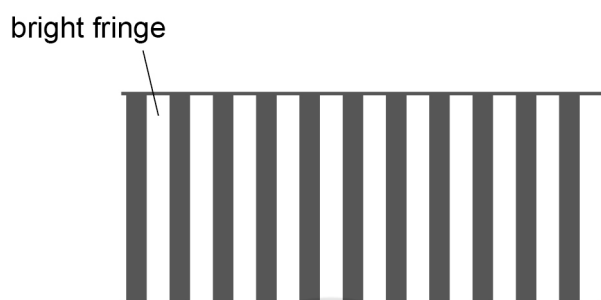
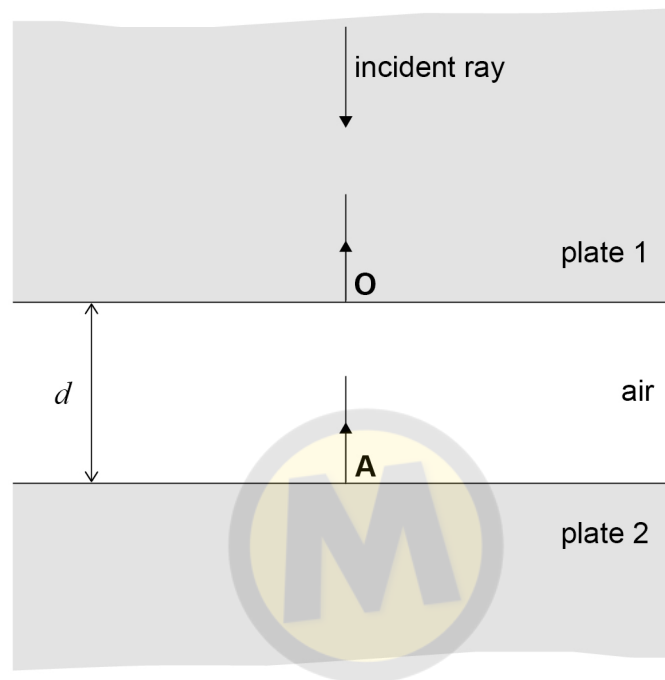


Figure 15 shows part of the arrangement where a bright fringe occurs.

The angle between the two plates caused by the foil in **Figure 13** is very small. This allows the following approximations to be made for **Figure 15**:

- the plates are parallel to each other
- the light rays travel perpendicular to both plates.

Figure 15



Some of the incident light is reflected at **O**. The remainder of the light is transmitted through the air gap and is reflected at **A**.

The reflected light from **A** combines at **O** with the reflected light from **O**.

At **O**, there is a phase difference between the reflected light from **A** and the reflected light from **O**.

This phase difference is caused by:

- the path difference due to the air gap
- the reflection at **A**.

At **A** the phase of the light that is reflected is changed by 180° .

At **O** there is no change to the phase of the light that is reflected or that is transmitted.

The thickness **OA** of the air gap is d .

Question 4 continues on the next page

Turn over ►



0 4 . 1

Deduce the relationship between d and the wavelength λ of light that produces a bright fringe.

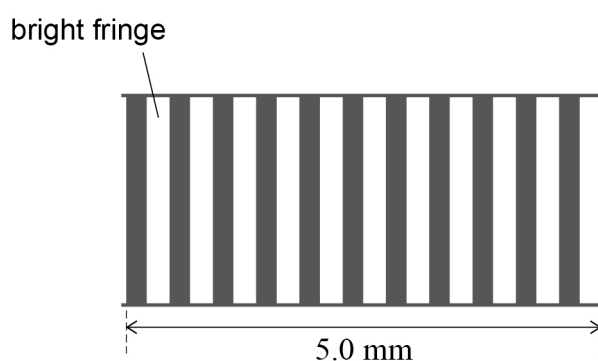
[3 marks]



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Figure 16 shows a small part of the fringe pattern as viewed from above.

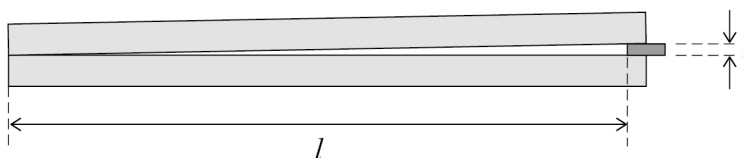
Figure 16



The distance between the centre of one bright fringe and the centre of the next bright fringe is s .

The thickness of the foil is t and the length of each glass plate up to the edge of the foil is l as shown in Figure 17.

Figure 17



It can be shown that

$$\frac{t}{l} = \frac{\lambda}{2s}$$



0 4 . 2

Determine t using **Figure 16**.

$$\lambda = 590 \text{ nm}$$

$$l = 6.0 \text{ cm}$$

[2 marks]

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 $t =$ _____ m

0 4 . 3

The space between the plates is now filled with water. The same light source is used, and t and l remain the same as before.

Deduce how the distance s will change when water fills the space between the plates.

refractive index of water = 1.3

[3 marks]

END OF SECTION B**Turn over ►**

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Question	Answers	Additional Comments/Guidance	Mark	AO
04.1	Max 2 from: $1\checkmark 2\checkmark$ links constructive interference as cause of bright fringe $a\checkmark$ correct reference to zero phase difference or 'in phase' $b\checkmark$ path difference = $2d$ OR $(n + 0.5)\lambda$ seen $c\checkmark$ $2d = (n \pm 0.5)\lambda$ $3\checkmark$	 www.mathswithmatt.co.uk	3	2 × AO2 1 × AO3

Question	Answers	Additional Comments/Guidance	Mark	AO
04.2	determines s from $\frac{5}{11}$ OR substitutes their s into $\frac{t}{l} = \frac{\lambda}{2s}$ with values for l and λ $1\checkmark$ $3.9 \times 10^{-5} \text{ (m)}$ $2\checkmark$	$1\checkmark$ Expect $s = 0.45 \text{ mm}$. Condone POT errors. $1\checkmark$ All substitutions must be in consistent units of length. $1\checkmark$ Must be some attempt to determine s . Reject use of 5.0 mm .	2	1 × AO2 1 × AO3

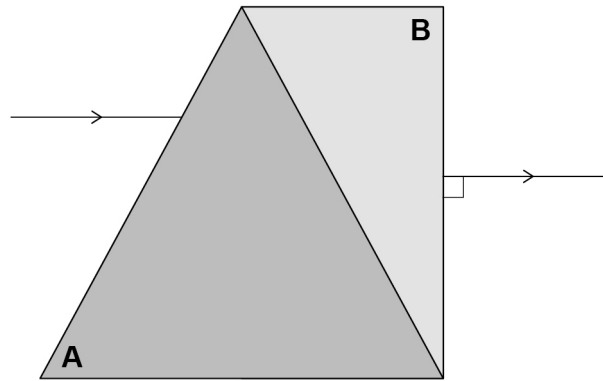
Question	Answers	Additional Comments/Guidance	Mark	AO
04.3	<p>Allow either $_1\checkmark$ or $_2\checkmark$ if there is no reference to frequency, but not both:</p> <p>wave speed decreases (and frequency is constant) $_1\checkmark$</p> <p>(frequency is constant so) wavelength decreases $_2\checkmark$</p> <p>s will decrease, with reference to $\frac{t}{l} = \frac{\lambda}{2s}$ $_3\checkmark$</p>	<p>If no other mark, credit use of 1.3 e.g. $c_{\text{water}} = 2.3 \times 10^8 \text{ m/s}$.</p> <p>$_2\checkmark$ May see calculated $\lambda_{\text{water}} = 454 \text{ nm}$</p> <p>$_3\checkmark$ Only awarded if values of both t and l are stated, or a clear reference to both of them being constant.</p> <p>$_3\checkmark$ Allow ecf from an incorrect $_2\checkmark$</p> <p>$_3\checkmark$ Reject references to e.g. double-slit equation.</p>	3	<p>1 × AO1</p> <p>1 × AO2</p> <p>1 × AO3</p>
Total			8	

0 3

Figure 1 shows two prisms **A** and **B** of different refractive indices joined to make a block.

A ray of monochromatic light is shown entering and then leaving the block.

Figure 1



0 3 . 1

Complete, on **Figure 1**, the path of the ray of light inside the block.

[1 mark]

0 3 . 2

Deduce which prism, **A** or **B**, has the greater refractive index.

[2 marks]

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The block is used with a telescope to investigate stars.
The block can be replaced with a diffraction grating.

0 3 . 3

Describe **one** non-astronomical application of a diffraction grating.

[1 mark]

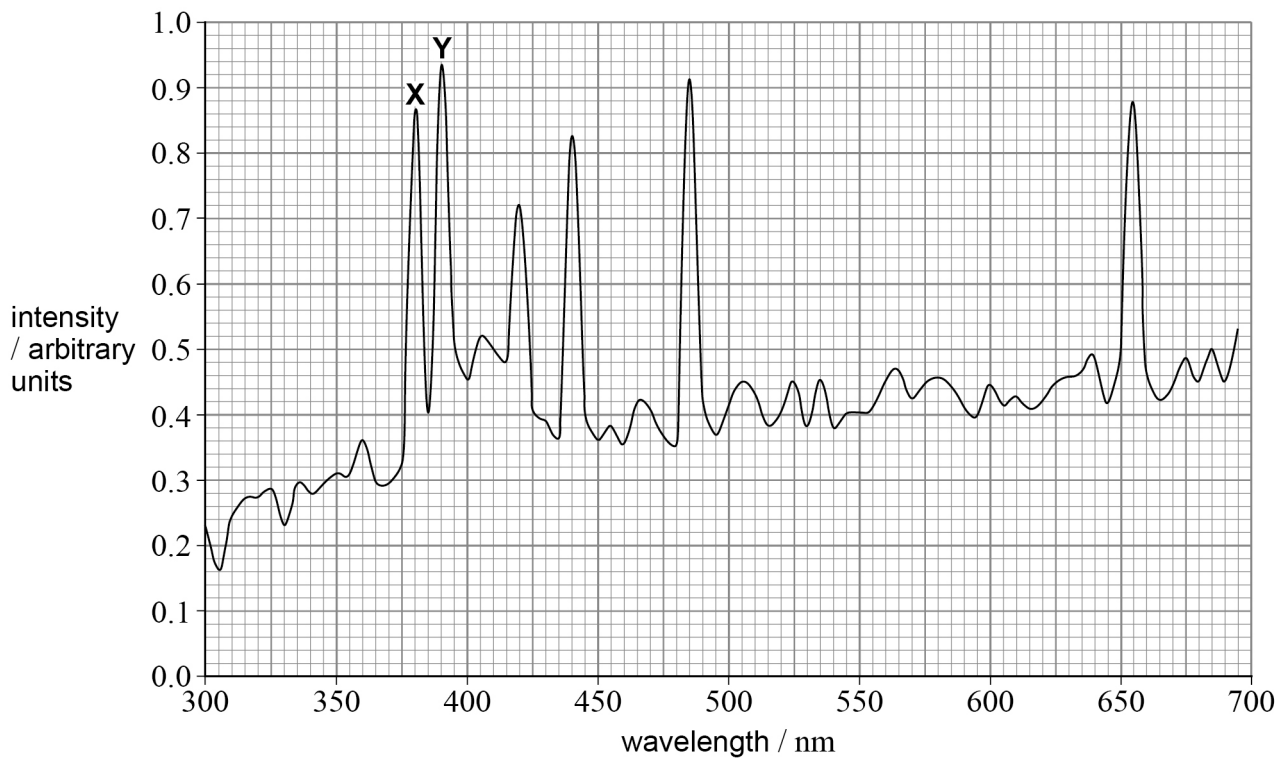
Question 3 continues on the next page

Turn over ►



0 3 . 4 Figure 2 shows a spectrum of light. Two lines in the spectrum are labelled **X** and **Y**.

Figure 2



The light passes at normal incidence through a diffraction grating. The number of lines per metre for the grating is G .

The first-order diffraction angle of **X** is at 28.2° to the normal.

Calculate G .

[3 marks]



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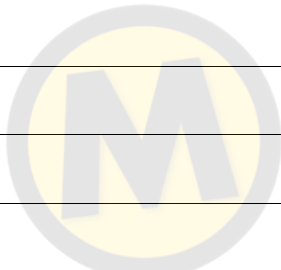
$G =$ _____ m^{-1}



A scientist wants to obtain an accurate value for the difference in wavelength between line **X** and line **Y**.

- option 1: to analyse the second-order spectrum from the original grating
- option 2: to analyse the first-order spectrum from a grating with $2G$ lines per metre.

[3 marks]



Question	Answers	Additional comments/Guidelines	Mark	AO
02.5	Idea that international collaboration/co-operation/verification is required OR (investment in) expensive equipment/hardware/infrastructure is required ✓	Accept idea that (people with) particular/specialist talents/technology/infrastructure must be in place. Ignore references to peer review or vague statements such as 'it takes a long time' or 'it/the research is expensive'.	1	AO1
Total			9	

Question	Answers	Additional comments/Guidelines	Mark	AO
03.1	ray through A links to ray in B AND ray in B horizontal by eye ✓	Ignore any arrow directions. www.mathswithmatt.co.uk	1	AO2

Question	Answers	Additional comments/Guidelines	Mark	AO
03.2	<p>Conclusion consistent with their Figure 1 ✓</p> <p>Supported by consideration of their angles of incidence and refraction at AB boundary ✓</p>	<p>Answer must be consistent with their Figure 1.</p> <p>For a correct diagram expect to see B has greater refractive index / A has lower refractive index'</p> <p>For a correct diagram expect to see 'at AB boundary angle of incidence > angle of refraction' OR 'at AB boundary the ray bends towards the normal'.</p>	2	AO3

Question	Answers	Additional comments/Guidelines	Mark	AO
03.3	appropriate application described ✓	<p>how the grating is used must be described e.g 'used to determine λ of named light source' or 'used to identify elements in a sample'</p> <p>Examples:</p> <p>To analyse chemical composition (of a sample)</p> <p>To stabilise/filter laser light</p> <p>To provide a monochromatic source/select a particular wavelength of light</p> <p>In optical encoders for high-precision motor control</p> <p>Spread evenly the light from e-readers</p> <p>Condone:</p> <p>to identify (some) authentic bank notes</p> <p>applications associated with entertainment eg light shows/diffraction glasses.</p> <p>application associated with analysis of the light from the Sun</p>	1	AO1

Question	Answers	Additional comments/Guidelines	Mark	AO
03.4	<p>MAX 2 from ✓✓</p> <ul style="list-style-type: none"> • λ read from spectrum = 380 nm • use of $d \sin \theta = n \times (\text{their } \lambda)$ • use of $G = \frac{1}{d}$ <p>to give $1.2 \times 10^6 \text{ (m}^{-1}\text{)} \checkmark$</p>	<p>Ignore POT error in MP1 & MP2.</p> <p>Accept answer in range 377.5 – 382.5 nm.</p> <p>'Use of' means clear substitution of n, θ and their λ or rearrangement of equation to give $d = \frac{n\lambda}{\sin \theta}$.</p> <p>If n not seen, assume that $n = 1$.</p> <p>Expect to see $8.04 \times 10^{-7} \text{ m}$ for d</p> <p>MP2 and MP3 may be seen together</p> <p>Calculator value range: $1.251790 \times 10^6 \text{ m}^{-1}$ to $1.2435547 \times 10^6 \text{ m}^{-1}$ to $1.235427 \times 10^6 \text{ m}^{-1}$</p>	3	<p>2 × AO2</p> <p>1 × AO3</p>

Question	Answers	Additional comments/Guidelines	Mark	AO
03.5	<p>Argument involving $\sin\theta = nG\lambda$ or equivalent comparing effect of $n = 2$ and $G' = 2G$ ✓</p> <p>Appreciation that angular separations would be the same for both options ✓</p> <p>Discussion suggesting option 2 / $2G$ should be used, as $n = 2$ spectrum could overlap with other orders obscuring absorption lines ✓</p>	<p>For MP3, allow maxima are better defined in option 2</p> <p>Alternative for MP3: idea that $2G$ should be used as the second-order spectrum would be dimmer – allow reverse argument that $2G$ first order would be brighter.</p>	3	3 × AO3
Total			10	

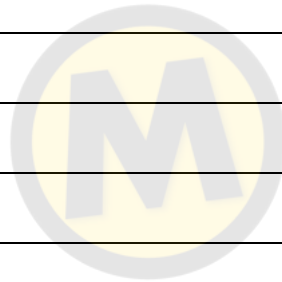
0 5

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1

Describe the structure of a step-index optical fibre outlining the purpose of the core and the cladding.

[3 marks]



- 0 5 . 2** A signal is to be transmitted along an optical fibre of length 1200 m. The signal consists of a square pulse of white light and this is transmitted along the centre of a fibre. The maximum and minimum wavelengths of the light are shown in **Table 1**.

Table 1

Colour	Refractive index of fibre	Wavelength / nm
Blue	1.467	425
Red	1.459	660

Explain how the difference in refractive index results in a change in the pulse of white light by the time it leaves the fibre.

[2 marks]

- 0 5 . 3** Discuss **two** changes that could be made to reduce the effect described in part 5.2.

[2 marks]

05.1	<p>Core is transmission medium for em waves to progress (by total internal reflection) ✓</p> <p>Cladding provides lower refractive index so that total internal reflection takes place ✓</p> <p>And offers protection of boundary from scratching which could lead to light leaving the core. ✓</p>	<p>Allow credit for points scored on a clear labelled diagram.</p>	<p>1</p> <p>1</p> <p>1</p>
05.2	<p>Blue travels slower than red due to the greater refractive index</p> <p>Red reaches end before blue, leading to material pulse broadening ✓</p> <p>Alternative calculations for first mark</p> <p>Time for blue = $d/v = d/(c/n)$</p> <p>$= 1200/(3 \times 10^8 / 1.467) = 5.87 \times 10^{-6} \text{ s}$</p> <p>Time for red = $d/v = d/(c/n)$</p> <p>$= 1200/(3 \times 10^8 / 1.459) = 5.84 \times 10^{-6} \text{ s}$</p> <p>Time difference = $5.87 \times 10^{-6} - 5.84 \times 10^{-6} = 3(.2) \times 10^{-8} \text{ s} \checkmark$</p>	<p>The first mark is for discussion of refractive index or for calculation of time difference.</p> <p>The second mark is for the link to material pulse broadening</p>	<p>1</p> <p>1</p>

05.3	<p>Discussions to include:</p> <p>Use of monochromatic source so speed of pulse constant</p> <p>Use of shorter repeaters so that the pulse is reformed before significant pulse broadening has taken place.</p> <p>Use of monomode fibre to reduce multipath dispersion ✓ ✓</p>	<p>Answer must make clear that candidate understands the distinction between modal and material broadening.</p>	2
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