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AQA A LEVEL PHYSICS (7408): QUESTIONS BY TOPIC

Waves (3.3)

A Level Physics (7408) · Section 3.3

77 questions · 263 marks · Mark schemes included

AQA A Level Physics (7408), June 2017 – June 2025

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HOW TO USE THIS BOOKLET

Questions are grouped by specification sub-topic and run from the lowest mark tariff to the highest within each one.

Click any row below to jump straight to that sub-topic or question.

On every question page, click ANSWER in the top-right corner to jump to its mark scheme.

Diagrams, graphs, tables and data are printed exactly as they appeared in the original papers.

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QUESTIONS

77 questions · 263 marks · 7 sub-topics



SUB-TOPIC 3.3.1.1

PROGRESSIVE WAVES

Sub-topic 3.3.1.1 · 6 questions · 6 marks · lowest tariff first



07

Water waves of wavelength λ and wave speed v are related by $v = \sqrt{k\lambda}$ where k is a constant.

What is a possible SI unit for k ?

[1 mark]

A m s^{-2}

☐

B m s^{-1}

☐

C $\text{m}^{\frac{3}{2}} \text{s}^{-1}$

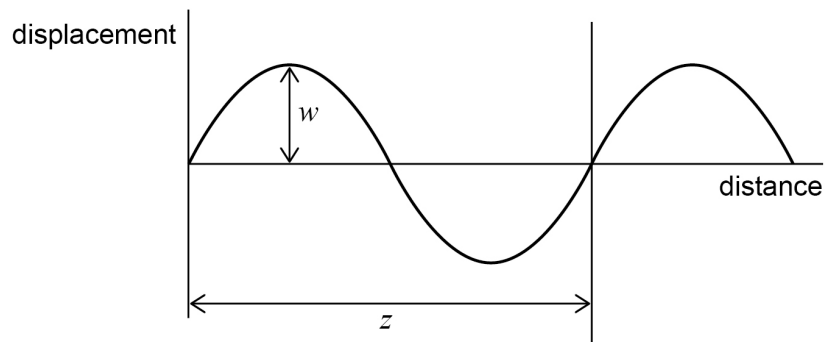
☐

D $\text{m}^{\frac{1}{2}} \text{s}^{-1}$

☐

1 5

A wave travels across the surface of water.
The diagram shows how the displacement of water particles at the surface varies with distance.



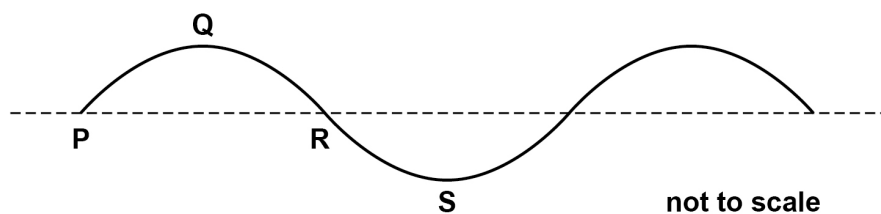
Which row correctly describes both w and z ?

[1 mark]

	w	z	
A	amplitude	wavelength	☐
B	half-amplitude	period	☐
C	half-amplitude	wavelength	☐
D	amplitude	period	☐

1 6

The diagram shows the cross-section of a progressive transverse wave travelling at 24 cm s^{-1} on water. The amplitude of the wave is 2.0 cm and the frequency is 4.0 Hz .



Which statement is correct?

[1 mark]

A The phase difference between particles at **P** and **S** is $\frac{\pi}{2}$ rad.

☐

B The distance between **P** and **R** is 6.0 cm .

☐

C The particle velocity at **Q** is a maximum.

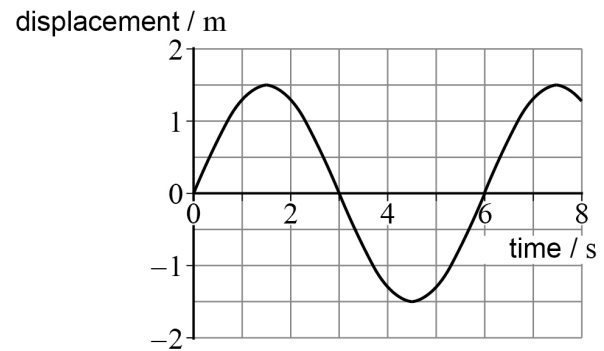
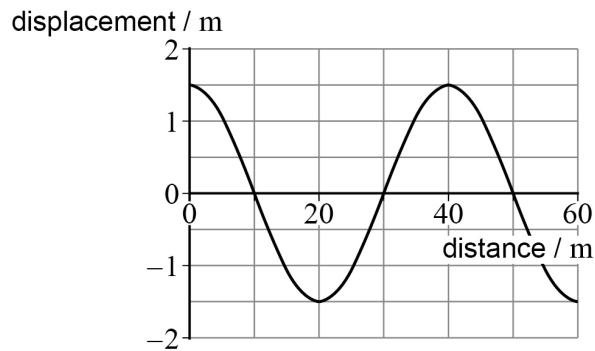
☐

D Particles at **P** and **R** are in phase.

☐

1 7

The diagrams show the displacement–distance graph for a wave and the displacement–time graph for a point in the wave.



Which is correct for this wave?

[1 mark]

A The amplitude is 3.0 m.

☐

B The wavelength is 6 m.

☐

C The speed is 8.3 m s^{-1} .

☐

D The frequency is 0.17 Hz.

☐

1 3

A laser emits light of wavelength 600 nm for 10 ns.

What is the number of complete waves emitted by the laser?

[1 mark]

A 5×10^{17}

☐

B 5×10^{12}

☐

C 5×10^8

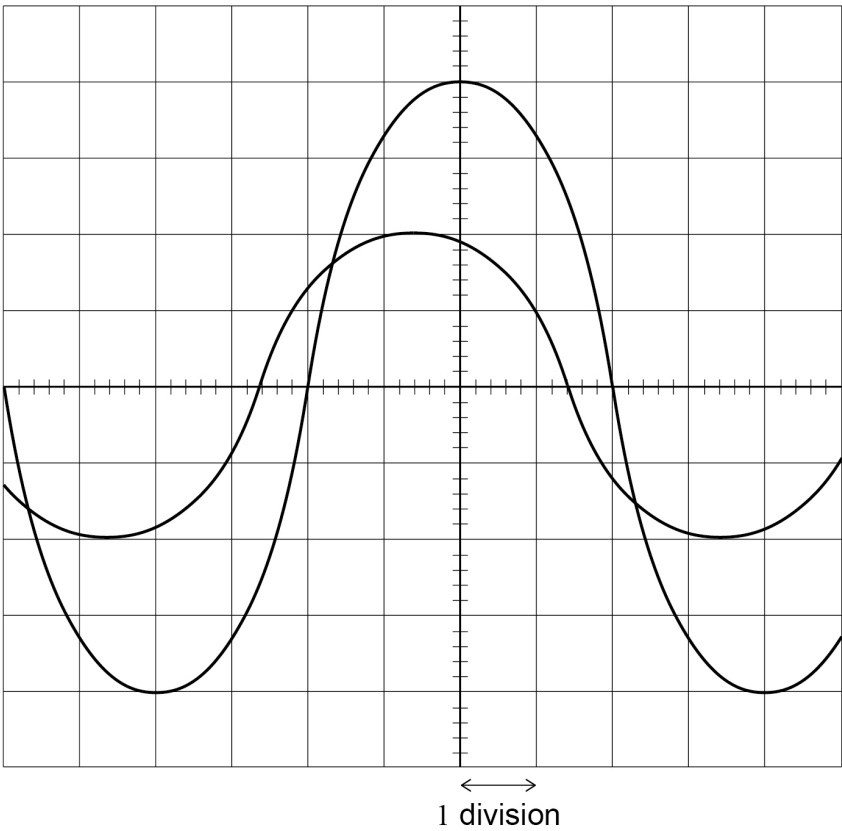
☐

D 5×10^6

☐

14

Two signals that have the same frequency are displayed simultaneously on an oscilloscope.
The display is shown with the time-base set to 5 ms div^{-1} .



Which row shows the frequency of both signals and the phase difference between them?
[1 mark]

	Frequency of both signals / Hz	Phase difference / rad	
A	50	0.30π	☐
B	50	0.15π	☐
C	25	0.30π	☐
D	25	0.15π	☐

SUB-TOPIC 3.3.1.2

LONGITUDINAL AND TRANSVERSE WAVES, POLARISATION

Sub-topic 3.3.1.2 · 5 questions · 15 marks · lowest tariff first



1	4
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Which statement is **not** correct for ultrasound and X-rays?

[1 mark]

A Both can be refracted

☐

B Both can be diffracted

☐

C Both can be polarised

☐

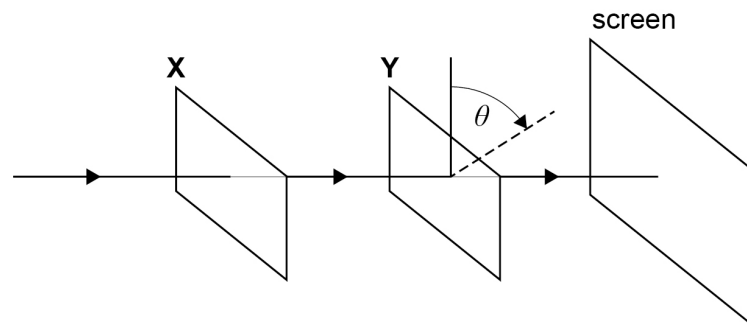
D Both can be reflected

☐

1 7

Unpolarised light travels through two polarising filters **X** and **Y** and is then incident on a screen. When **X** and **Y** are arranged as shown, there is a maximum intensity on the screen.

X is held stationary but **Y** is rotated in a plane at right angles to the beam so that θ increases.



What are the next three values of θ , in rad, for which the beam hits the screen with maximum intensity?

[1 mark]

A $\frac{\pi}{2}, \frac{2\pi}{2}, \frac{3\pi}{2}$ ☐

B $\frac{\pi}{2}, \frac{3\pi}{2}, \frac{5\pi}{2}$ ☐

C $\pi, 2\pi, 3\pi$ ☐

D $2\pi, 4\pi, 6\pi$ ☐

1 8

A longitudinal wave of frequency 660 Hz travels through a medium.
The wave speed is 330 m s^{-1} .

Which statement describes the motion of a particle in the wave?

[1 mark]

A It is travelling at a speed of 330 m s^{-1} .

☐

B It moves in phase with a particle in the wave 25 cm away.

☐

C It oscillates with a time period of 1.5 ms.

☐

D It changes direction 660 times every second.

☐

14

A detector measures the intensity of light from a source S_1 . Polaroid material is placed between source S_1 and the detector. When the material is rotated through a small angle, the detected intensity does not change. When this procedure is repeated for a source S_2 , the detected intensity decreases.

Which is correct?

[1 mark]

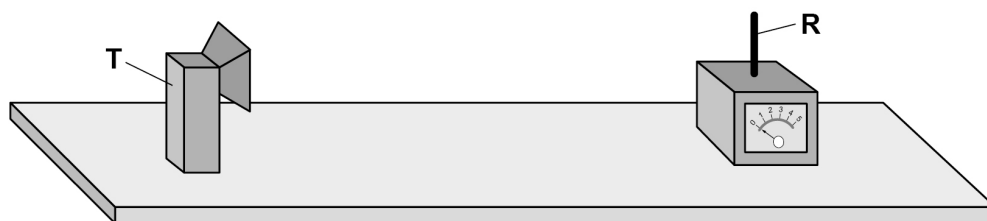
	Light waves from S_1	Light waves from S_2
A	unpolarised	polarised
B	unpolarised	unpolarised
C	polarised	polarised
D	polarised	unpolarised

☐☐☐☐

0	2
---	---

Figure 1 shows apparatus used to investigate the properties of microwaves. The microwaves from the transmitter **T** are vertically polarised and have a wavelength of about 3 cm. The microwaves are detected at the receiver by a vertical metal rod **R**.

Figure 1



0	2
---	---

1

Explain how the apparatus can be used to demonstrate that the waves from **T** are vertically polarised.

[3 marks]

Figures 2a and **2b** show **T** and **R** and two different positions of a metal plate **M** that reflects microwaves. **M** is vertical and parallel to the direct transmission from **T** to **R**.

Figure 2a

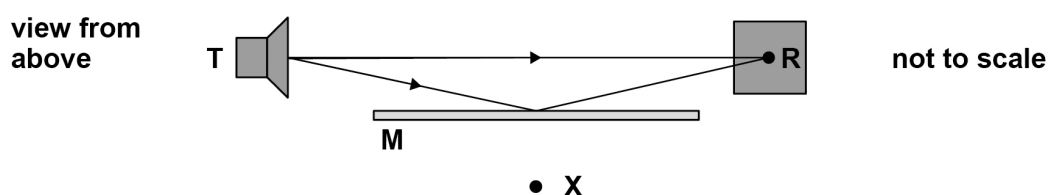
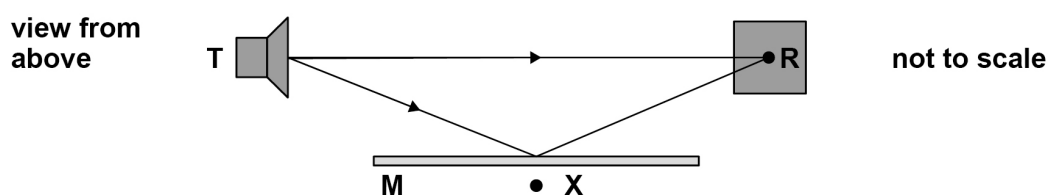


Figure 2b



In an experiment, **T** and **R** are about two metres apart. **M** is moved slowly towards **X**. **Figure 2a** shows the initial position of **M**.

Figure 2b shows **M** when it has been moved a few centimetres.

The arrowed lines show the path of waves that reach **R** directly and the path of waves that reach **R** by reflection from **M**.

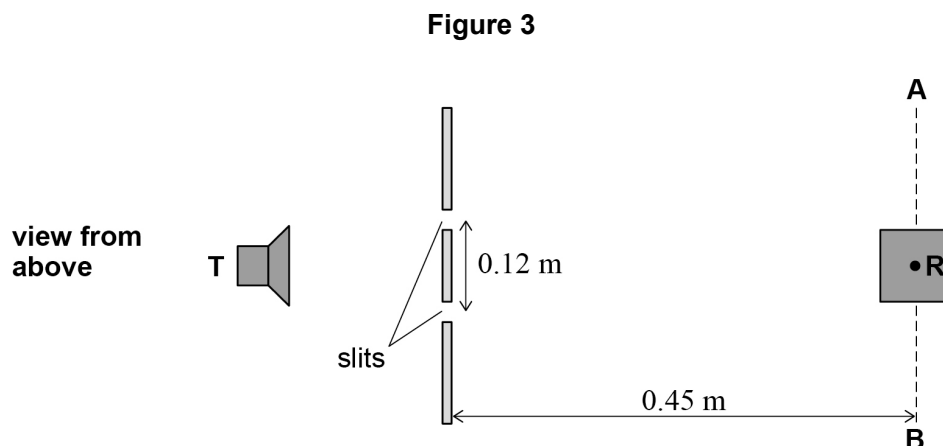
0 2 . 2

Explain what happens to the signal detected by **R** as **M** is moved slowly towards **X**.

[4 marks]

Question 2 continues on the next page

Figure 3 shows an arrangement used in a different experiment to try to determine the wavelength of the microwaves.



A double-slit arrangement is placed between **T** and **R**.

The initial position of **R** is the same distance from each slit and is 0.45 m from the midpoint of the two slits.

AB is a line perpendicular to the line between **T** and the initial position of **R**.

R can be moved 0.25 m towards **A** and 0.25 m towards **B** along **AB**.

The two slits act as two coherent sources with a separation of 0.12 m .

0 2 . 3 Suggest why Young's double-slit equation should **not** be used to determine the wavelength.

[1 mark]

0 2 . 4 The wavelength is known to be about 3 cm .

Deduce whether this practical arrangement is suitable for a determination of a value for the wavelength.

[3 marks]

SUB-TOPIC 3.3.1.3

SUPERPOSITION AND STATIONARY WAVES

Sub-topic 3.3.1.3 · 13 questions · 56 marks · lowest tariff first



1 5

A stationary wave is set up on a stretched string of length l and diameter d . Another stationary wave is also set up on a second string made from the same material and with the same tension as the first.

What length and diameter are required for the second string so that both strings have the same first-harmonic frequency?

[1 mark]

	Length of second string	Diameter of second string	
A	$2l$	$2d$	☐
B	l	$2d$	☐
C	$\frac{l}{2}$	$2d$	☐
D	l	$\frac{d}{2}$	☐



1 8

Stationary waves are set up on a rope of length 1.0 m fixed at both ends.

Which statement is **not** correct?

[1 mark]

A The first harmonic has a wavelength of 2.0 m.

☐

B The midpoint of the rope is always stationary for even-numbered harmonics.

☐

C A harmonic of wavelength 0.4 m can be set up on the rope.

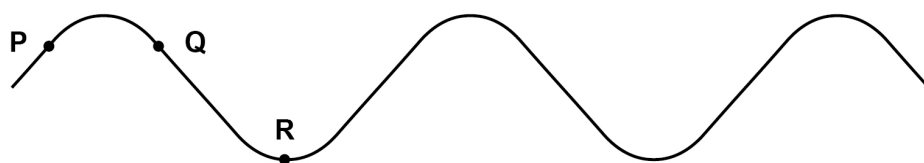
☐

D There are five nodes on the rope for the fifth harmonic.

☐

1 8

The diagram shows a stationary wave on a string at one instant in time. **P**, **Q** and **R** are three points on the string.



Which row is correct?

[1 mark]

A	P is in antiphase with R	P has the same amplitude as Q	☐
B	P is out of phase with R	P has the same amplitude as R	☐
C	P is in phase with Q	P has the same amplitude as R	☐
D	P is out of phase with Q	P has a smaller amplitude than R	☐

1 9

The frequency of the first harmonic of a standing wave on a string is f .

The tension in the string is T .

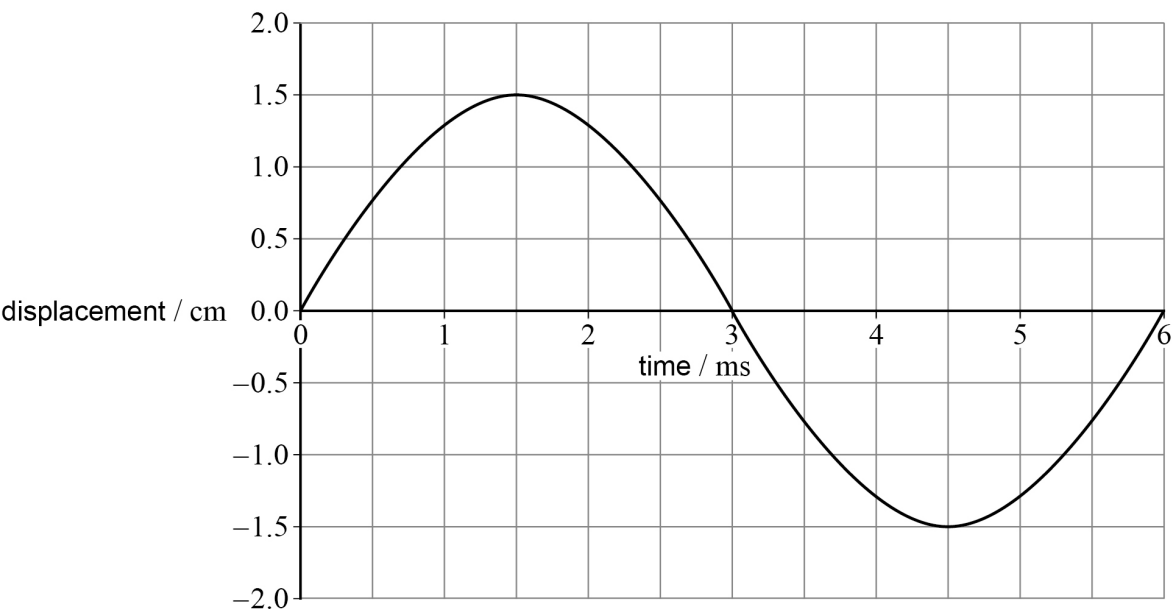
The tension is increased to $4T$ without changing the length or mass of the string.

Which harmonic has a frequency $2f$ after this change?

[1 mark]**A** first☐**B** second☐**C** third☐**D** fourth☐

14

A string with a length of 1.2 m vibrates at its second harmonic.
The diagram shows the displacement–time graph for a point on the string.



What are the wavelength and frequency of the wave on the string?

[1 mark]

	Wavelength / m	Frequency / kHz	
A	0.6	0.17	☐
B	0.6	0.34	☐
C	1.2	0.17	☐
D	1.2	0.34	☐

1 5

A standing wave is created on a string.

Which statement about the two waves that create the standing wave is **not** correct?

[1 mark]

A They have the same frequency.

☐

B They have a constant phase relationship.

☐

C They travel in opposite directions.

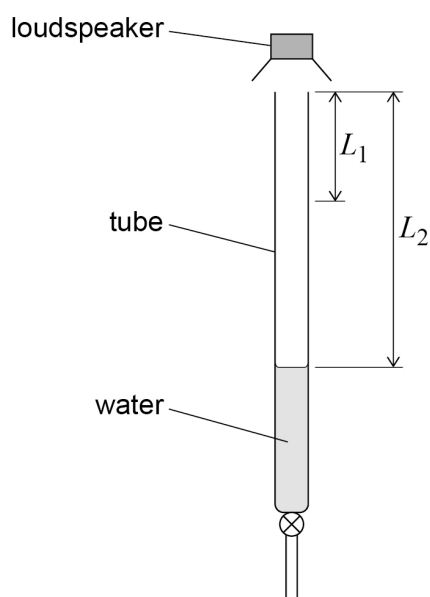
☐

D They have the same speed.

☐

1 5

A loudspeaker producing a single-frequency sound is mounted above a tube filled with water. A tap at the bottom of the tube is opened to allow the water to run out.



A student observes the change in loudness of the sound emitted by the tube as the water runs out.

When the length of the column of air in the tube reaches L_1 , the loudness is at its first maximum.

The next maximum is reached when the length of the column of air is L_2 .

What is the wavelength of the sound emitted by the loudspeaker?

[1 mark]

- A** L_2 ☐
- B** $2L_1$ ☐
- C** $L_2 - L_1$ ☐
- D** $2(L_2 - L_1)$ ☐

1 4

In an investigation of stationary waves on different wires, the frequency f of the first harmonic is measured.

Which quantity produces a straight-line graph through the origin when plotted against f ?
In each case all other variables are kept constant.

[1 mark]

- A** $\frac{1}{\text{diameter of the wire}}$ ☐
- B** $(\text{mass per unit length of the wire})^2$ ☐
- C** length of the wire ☐
- D** $(\text{tension in the wire})^2$ ☐

0 7

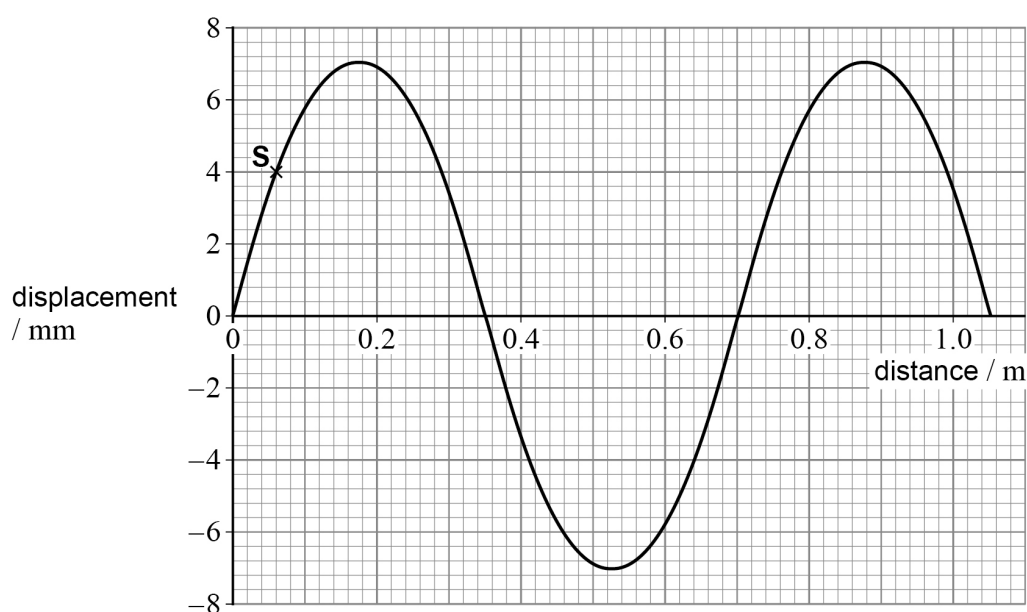
An experiment is done to investigate stationary waves on a string. A string of length 1.05 m is attached between a clamp stand and a vibration generator. A stationary wave is formed on the string when the vibration generator frequency is 625 Hz.

Figure 6 shows the variation of displacement with distance from one end of the string at time $t = 0$

At this time all points on the string have their maximum displacement.

S is one point on the string.

Figure 6



The stationary wave is produced by two progressive waves travelling in opposite directions on the string.

0 7 . 1

Deduce the amplitude of one of the progressive waves.

[1 mark]

amplitude = _____ mm

0 7 . 2 Determine, in m s^{-1} , the speed of one of the progressive waves.

[2 marks]

speed = _____ m s^{-1}

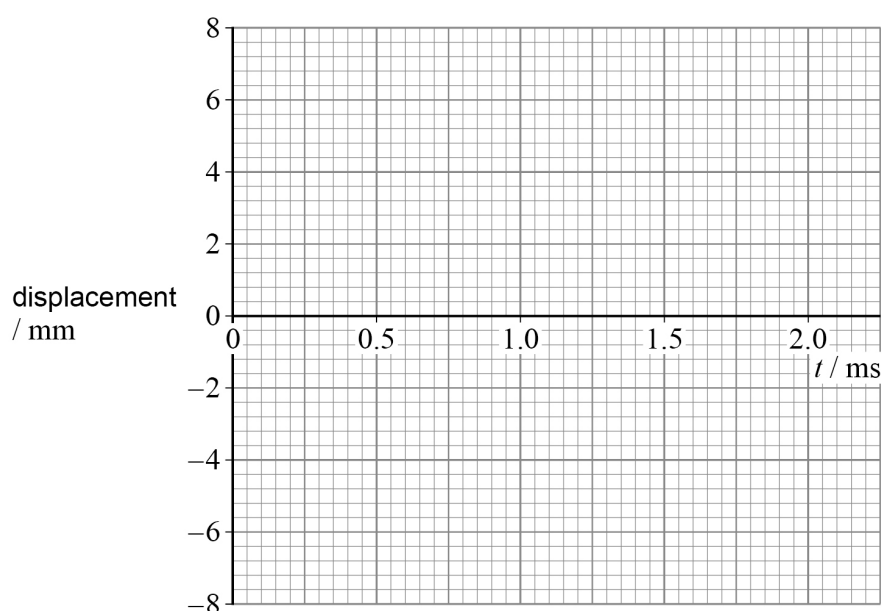
0 7 . 3 State the phase relationship between the two waves when $t = 0$

[1 mark]

0 7 . 4 Sketch, on **Figure 7**, a graph to show how the displacement of **S** varies with t .

[3 marks]

Figure 7



END OF SECTION A



Section B

Each of Questions **08** to **32** is followed by four responses, **A**, **B**, **C** and **D**.

For each question select the best response.

Only **one** answer per question is allowed.

For each question, completely fill in the circle alongside the appropriate answer.

CORRECT METHOD



WRONG METHODS



If you want to change your answer you must cross out your original answer as shown.



If you wish to return to an answer previously crossed out, ring the answer you now wish to select as shown.



You may do your working in the blank space around each question but this will not be marked.
Do **not** use additional sheets for this working.

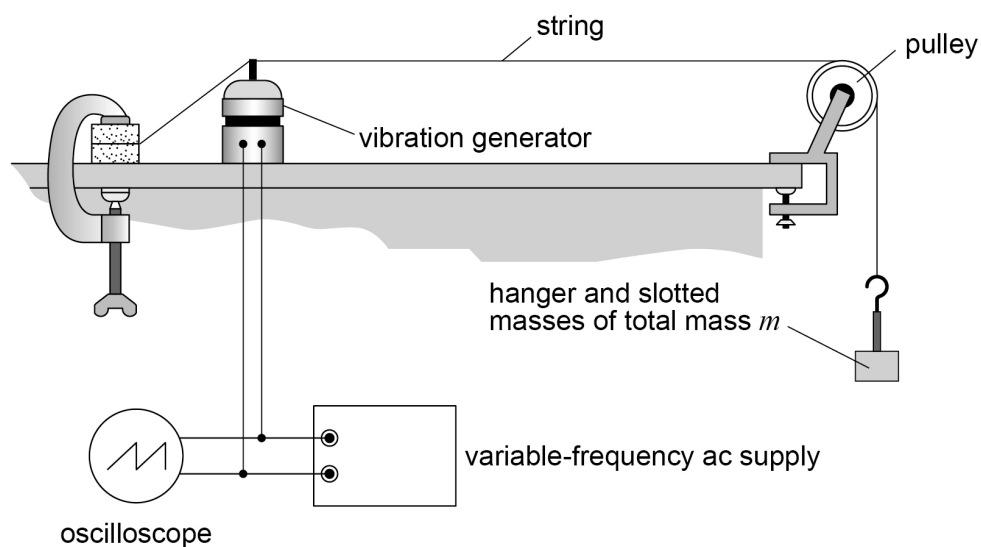


0 1

This question is based on an investigation into how the frequency of the first-harmonic stationary wave on a string varies with tension (required practical activity 1).

Figure 1 shows the arrangement for this investigation.

Figure 1



The tension in the string is equal to the weight mg of the total mass m tied to the string.

The frequency is changed until the first-harmonic stationary wave appears on the string. This frequency f is determined using the oscilloscope.

The process is repeated for different values of m .

0 1 . 1 Identify **two** control variables for the arrangement shown in **Figure 1**.

You may annotate **Figure 1** as part of your answer.

[2 marks]

1 _____

2 _____

0 1 . 2 The total mass m is made from a mass hanger and up to three slotted masses.

One 20 g, one 50 g and one 100 g slotted mass are provided.
The hanger has a mass of 100 g.

The hanger must not be removed from the string.

Which statement is correct?

Tick (✓) **one** box.

[1 mark]

m has a maximum range of 170 g.

☐

m has a maximum of 7 different values.

☐

m values are evenly distributed across the range.

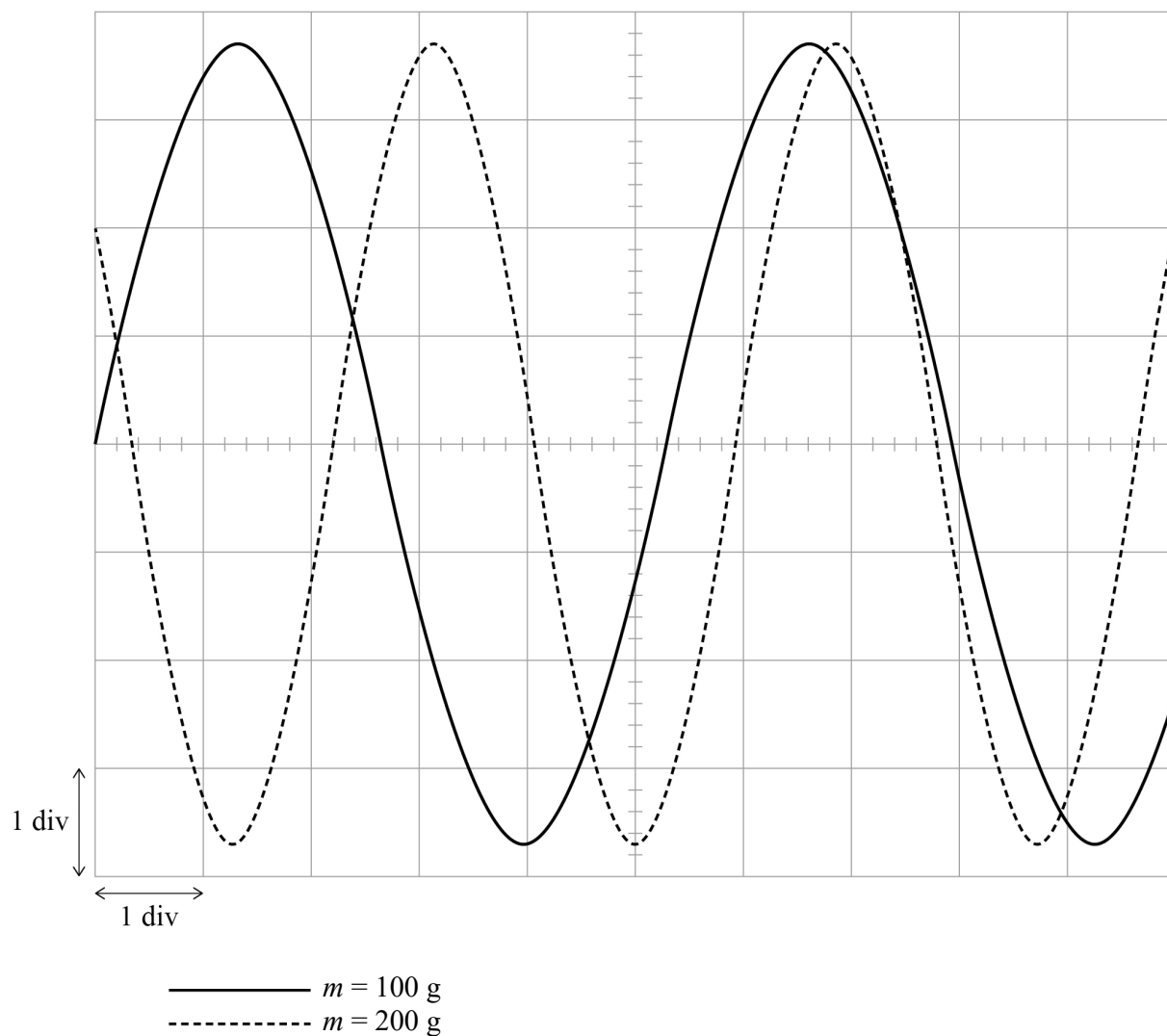
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Question 1 continues on the next page



The frequency f is calculated using the waveform displayed on the oscilloscope. **Figure 2** shows the waveforms displayed on the oscilloscope when $m = 100\text{ g}$ and when $m = 200\text{ g}$.

Figure 2



The y -voltage gain setting is 5 V div^{-1} .
The time-base setting is 20 ms div^{-1} .

0 1 . 3 Determine V_{rms} , the root mean square voltage of the ac supply.

[2 marks]

$V_{\text{rms}} =$ _____ V

0 1 . 4 Determine the period of the waveform on **Figure 2** when $m = 100$ g.

[1 mark]

period = _____ ms

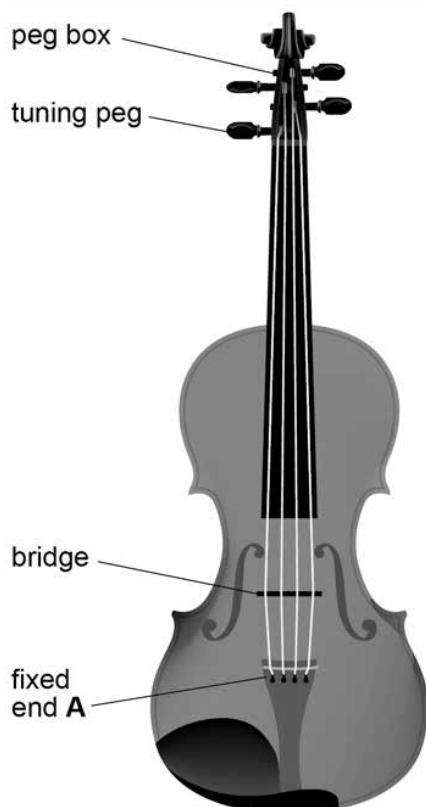
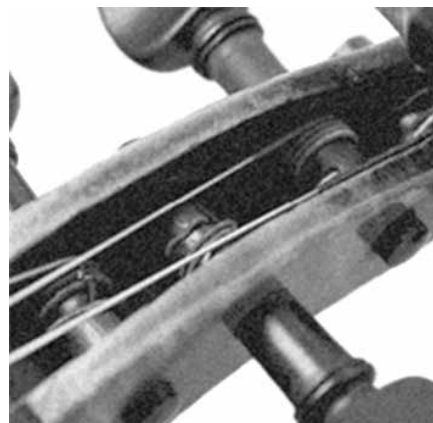
0 1 . 5 Deduce whether **Figure 2** shows the expected result of doubling m from 100 g to 200 g.

[2 marks]



0 3

Figure 4 shows the structure of a violin and **Figure 5** shows a close-up image of the tuning pegs.

Figure 4**Figure 5**

The strings are fixed at end **A**. The strings pass over a bridge and the other ends of the strings are wound around tuning pegs that have a circular cross-section. The tension in the strings can be increased or decreased by rotating the tuning pegs.

0 3 . 1 Explain how a stationary wave is produced when a stretched string is plucked. **[3 marks]**

0 3 . 2 The vibrating length of one of the strings of a violin is 0.33 m
When the tension in the string is 25 N, the string vibrates with a first-harmonic frequency of 370 Hz
Show that the mass of a 1.0 m length of the string is about 4×10^{-4} kg **[2 marks]**

0 3 . 3 Determine the speed at which waves travel along the string in question **03.2** when it vibrates with a first-harmonic frequency of 370 Hz **[1 mark]**

speed of waves = _____ m s^{-1}

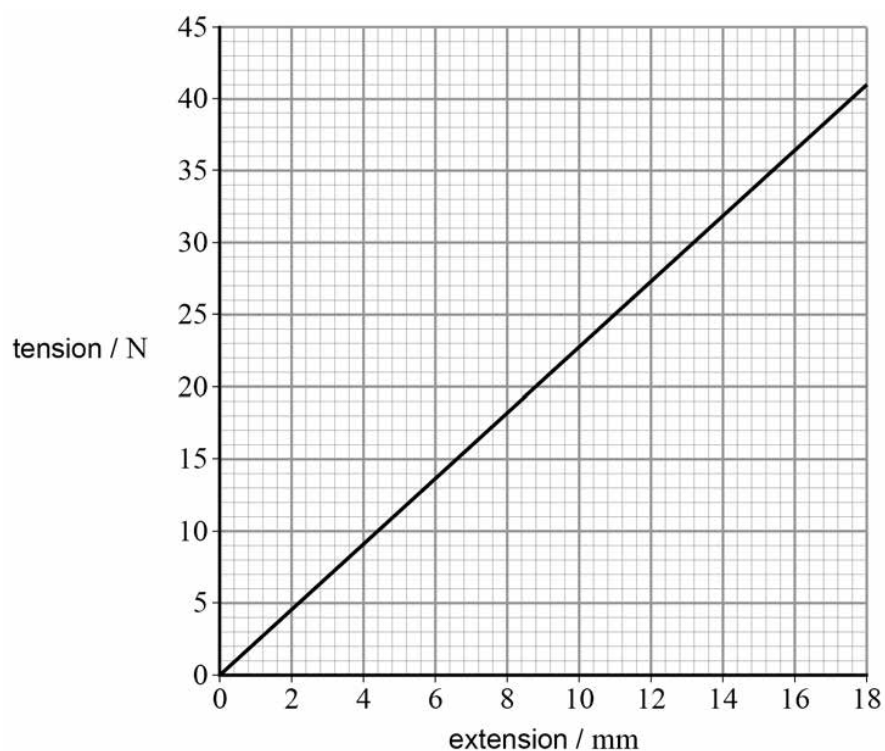
Question 3 continues on the next page



03.4

Figure 6 shows how the tension in the string in question **03.2** varies with the extension of the string.

Figure 6



The string with its initial tension of 25 N is vibrating at a frequency of 370 Hz
The diameter of the circular peg is 7.02 mm

Determine the higher frequency that is produced when the string is stretched by rotating the tuning peg through an angle of 75°

Assume that there is no change in the diameter of the string.

[4 marks]

frequency = _____ Hz

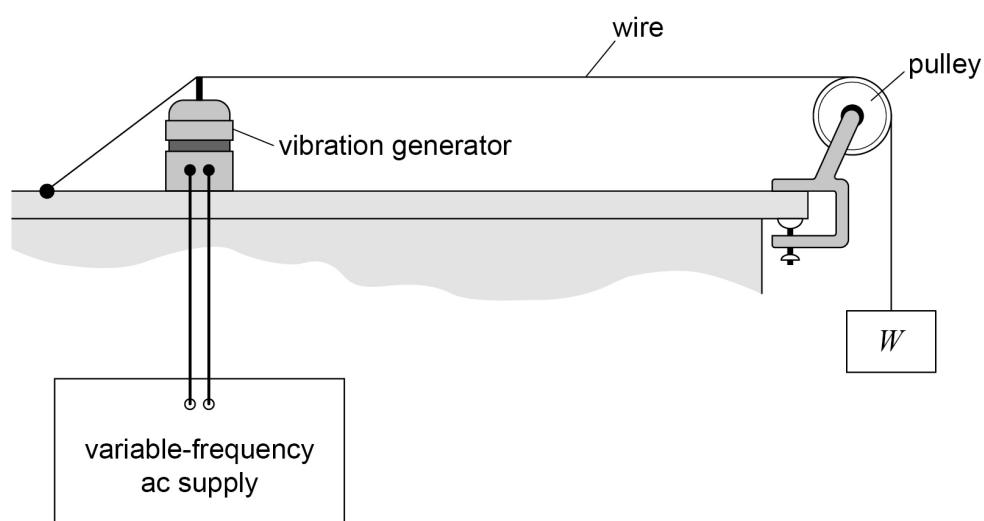


0 2 . 1 State what is meant by a transverse wave.

[2 marks]

Figure 2 shows apparatus that is used to investigate stationary waves on a stretched wire.

Figure 2



A block of weight W is used to keep the wire under tension.

The frequency of the ac supply is varied until a stationary wave is produced on the wire.

0 2 . 2 Explain how a stationary wave is produced on the wire.

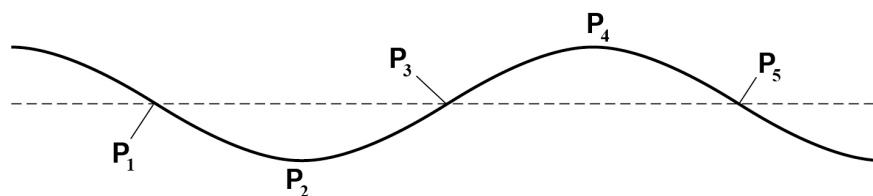
[1 mark]

0 2 . 3

Figure 3 shows a small section of the wire at one instant. Five points on the wire are labelled P_1 to P_5 .

The dashed line represents the position of the wire when the ac supply is turned off.

Figure 3



Describe how the phase of the oscillating particles varies along the wire between P_1 and P_5 .

[2 marks]

Question 2 continues on the next page

0 2 . 4

A student investigates stationary waves on a wire using the apparatus in **Figure 2**. The investigation requires the student to produce the first five harmonics on the wire.

The student needs to choose **one** of two wires, **A** or **B**, for the investigation.

The mass of a 2.00 m length of wire **A** is 1.32 g.

The mass of a 2.00 m length of wire **B** is 2.94 g.

The ac supply can produce signals in the range 1 Hz to 50 Hz.

The length of the wire that vibrates between the vibration generator and the pulley is 1.50 m.

The student needs to choose **one** value for weight W for the investigation.

W can be either 1.0 N or 5.0 N.

Determine, in kg m^{-1} , the mass per unit length of each wire.

Go on to suggest which wire and which value of W the student should use to produce the first five harmonics.

[5 marks]

mass per unit length of **A** = _____ kg m^{-1}

mass per unit length of **B** = _____ kg m^{-1}

wire = _____ W = _____ N

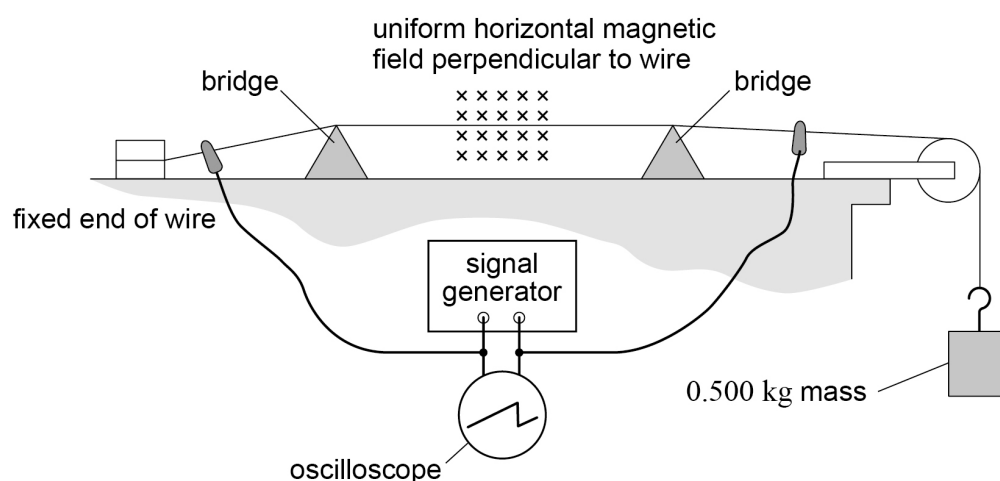


0 3

A stationary wave is formed on a stretched wire.

Figure 14 shows the wire, fixed at one end, supported by two bridges and passing over a pulley.

Figure 14



A 0.500 kg mass is attached to the free end of the wire.

A uniform horizontal magnetic field is applied perpendicular to the wire between the bridges.

A signal generator is connected to each end of the wire.

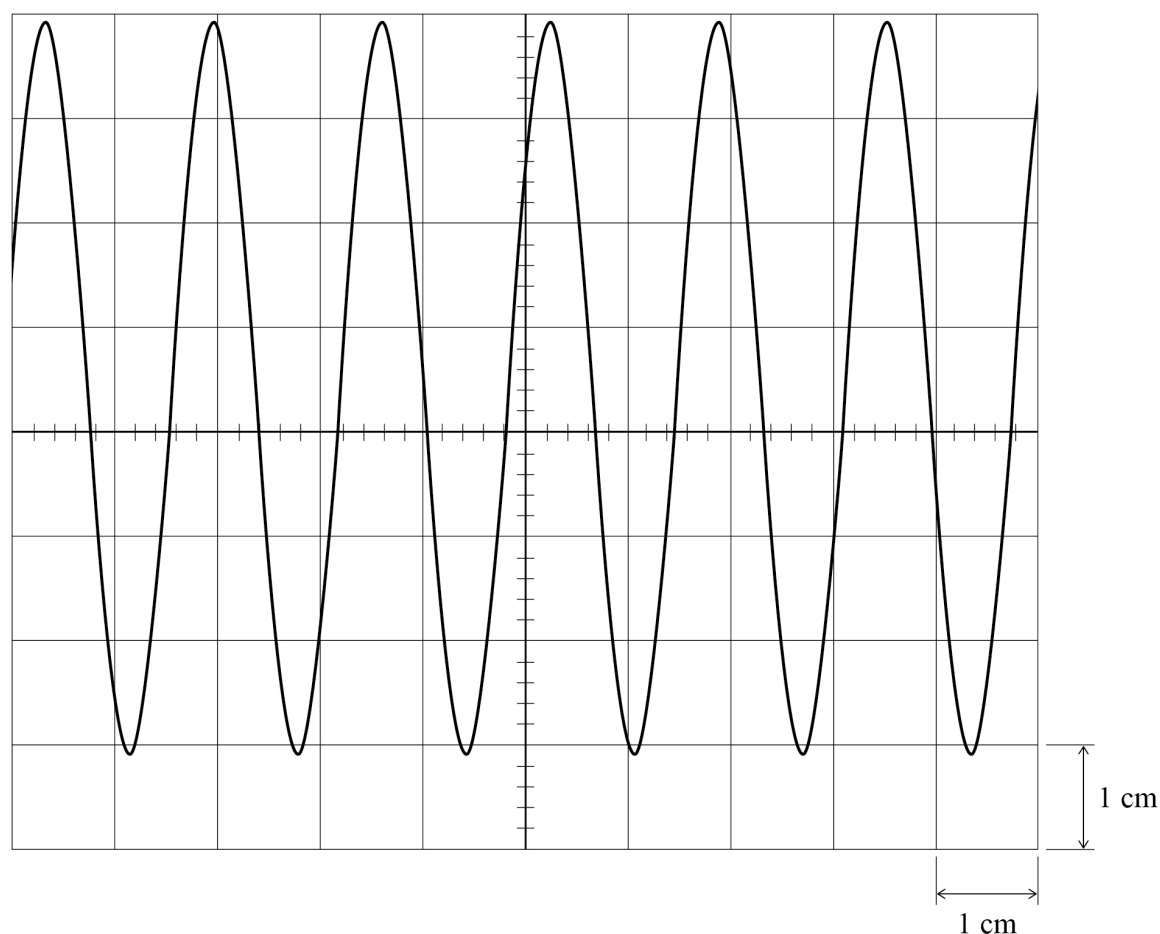
The oscilloscope shown is used to determine the frequency of the output of the signal generator. The wire oscillates because the alternating current in the wire interacts with the magnetic field.

Figure 15 shows the first harmonic stationary wave produced when the distance x between the bridges is adjusted.

Figure 15

- 0 3 . 1** The output potential difference (pd) of the signal generator is displayed on the oscilloscope, as shown in **Figure 16**.

Figure 16



The time-base setting of the oscilloscope is 10 ms cm^{-1} .

Determine f , the frequency of the alternating pd.

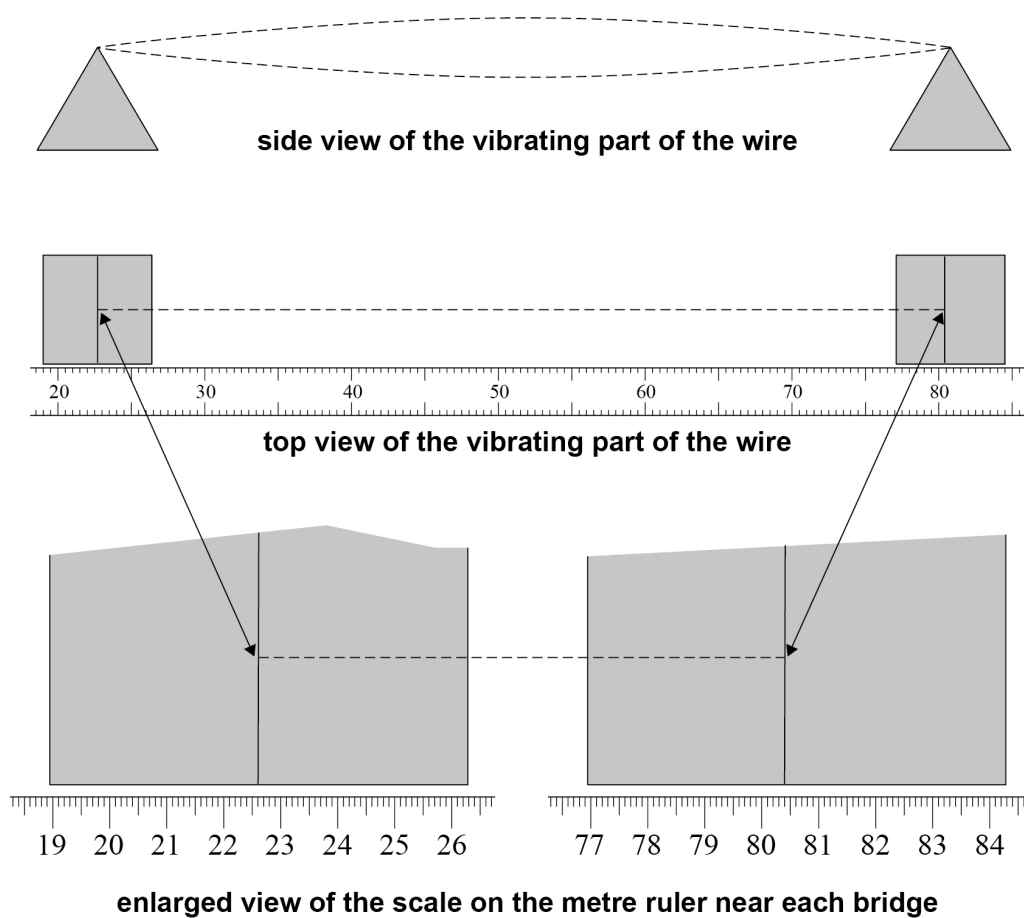
[2 marks]

$f =$ _____ Hz

Question 3 continues on the next page

0 3 . 2 A metre ruler is placed next to the bridges supporting the wire, as shown in **Figure 17**.

Figure 17



Determine the wavelength λ of the stationary wave shown in **Figure 17**.

[2 marks]

$\lambda =$ _____ m

0 3 . 3

The stationary wave is formed by two waves of frequency f and wavelength λ travelling with speed c in opposite directions.

Determine c .

[1 mark]

$c =$ _____ m s^{-1}

0 3 . 4

Determine, in kg m^{-1} , the mass per unit length of the wire.

[2 marks]

mass per unit length = _____ kg m^{-1}

Question 3 continues on the next page

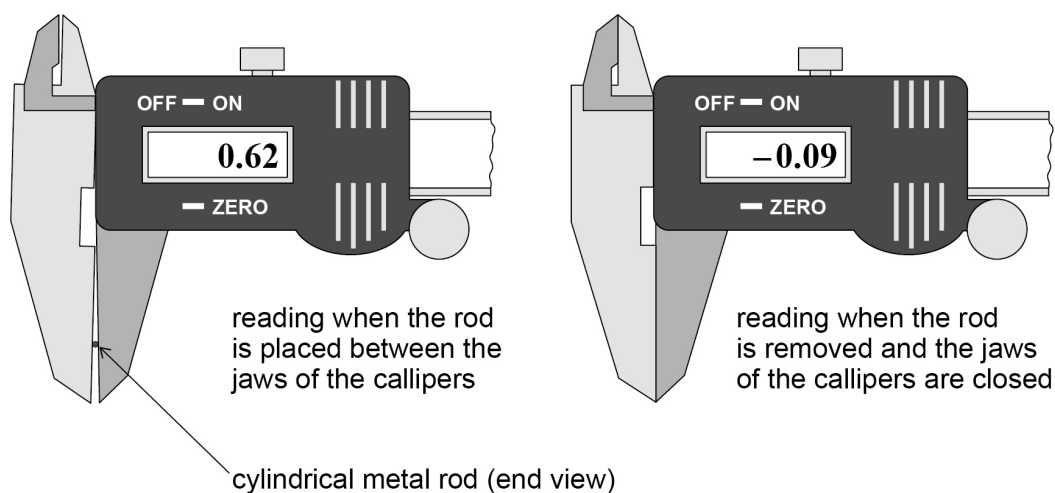


0 3 . 5

A student uses digital vernier callipers to measure the diameter of a cylindrical metal rod. The student places the rod between the jaws of the callipers and records the reading indicated. Without pressing the zero button, the student removes the rod and closes the jaws.

Figure 18 shows the calliper readings in millimetres, before and after the jaws are closed.

Figure 18



Calculate the diameter d of the rod.

[1 mark]

$d =$ _____ mm

0 3 . 6

Describe relevant procedures to limit the effect of random error in the result for d .

[2 marks]

0 3 . 7

Determine the density of the rod.

The mass per unit length of the rod is $3.54 \times 10^{-3} \text{ kg m}^{-1}$.**[3 marks]**density = _____ kg m^{-3} **END OF QUESTIONS**

SUB-TOPIC 3.3.2.1

INTERFERENCE

Sub-topic 3.3.2.1 · 10 questions · 38 marks · lowest tariff first



1	6
---	---

When a monochromatic light source is incident on two slits of the same width an interference pattern is produced.

One slit is then covered with opaque black paper.

What is the effect of covering one slit on the resulting interference pattern?

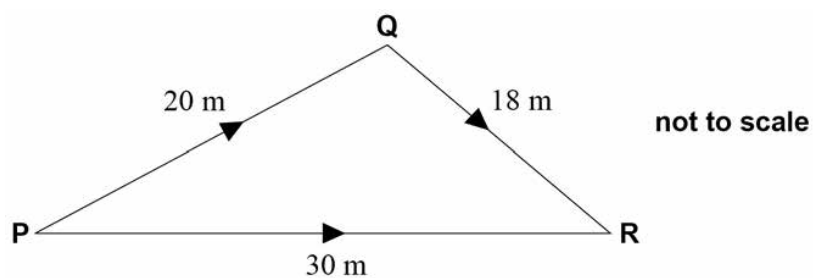
[1 mark]

- A The intensity of the central maximum will increase
- B The width of the central maximum decreases
- C Fewer maxima are observed
- D The outer maxima become wider

☐☐☐☐

1 5

In the diagram, **P** is the source of a wave of frequency 50 Hz



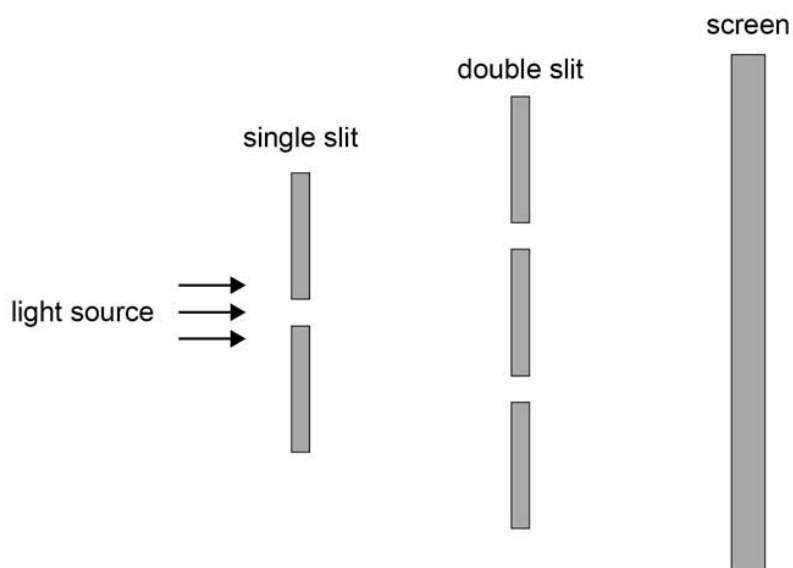
The wave travels to **R** by two routes, **P** → **Q** → **R** and **P** → **R**. The speed of the wave is 30 m s^{-1}

What is the path difference between the two waves at **R** in terms of the wavelength λ of the waves?

[1 mark]**A** 4.8λ ☐**B** 8.0λ ☐**C** 13.3λ ☐**D** 20.0λ ☐

1 6

Light from a point source passes through a single slit and is then incident on a double-slit arrangement. An interference pattern is observed on the screen.



What will increase the fringe spacing?

[1 mark]

- A** increasing the separation of the single slit and the double slit
- B** increasing the width of the single slit
- C** decreasing the distance between the double slits and the screen
- D** decreasing the separation of the double slits

☐☐☐☐

2 0

Light of wavelength 5.2×10^{-7} m is used in a Young's double-slit experiment.
The distance from the slits to the screen is 1.5 m.
The width of ten fringes is 3.5 cm.

What is the separation of the two slits?

[1 mark]

A 2.2×10^{-5} m

☐

B 9.9×10^{-5} m

☐

C 1.1×10^{-4} m

☐

D 2.2×10^{-4} m

☐

1 6

A double slit with a separation s is illuminated by light of wavelength λ . Fringes with spacing w are produced on a screen placed a distance D from the slits.

The distance from the slits to the screen is changed to $\frac{D}{2}$.

Which combination of slit separation and wavelength produces a fringe spacing of $1.5w$ on the screen?

[1 mark]

	Slit separation	Wavelength	
A	$0.22s$	0.66λ	☐
B	$0.50s$	0.75λ	☐
C	$0.60s$	1.20λ	☐
D	$1.20s$	0.40λ	☐

1 6 Point sources of sound of the same frequency are placed at S_1 and S_2 .



A sound detector is moved slowly along the line **PQ**. Consecutive maxima of sound intensity are detected at **W** and **Y** and consecutive minima are detected at **X** and **Z**.

What is the wavelength of the sound?

[1 mark]

A $(S_1Y - S_2Y) - (S_1W - S_2W)$

B $(S_1X - S_2X) - (S_1W - S_2W)$

C $(S_1Y - S_2Y) - (S_1X - S_2X)$

D $(S_1Z - S_2Z) - (S_1W - S_2W)$

1 7

Monochromatic light is used in a Young's double-slit interference experiment after passing through a single slit. The resulting fringe pattern is observed on a screen.

The separation of the fringes can be increased by

[1 mark]

A using monochromatic light of lower frequency.

☐

B decreasing the width of the single slit.

☐

C increasing the separation of the double slits.

☐

D decreasing the distance between the double slits and the screen.

☐

17

Monochromatic light of wavelength λ is used in a double-slit experiment. The slits are vertical and have a separation s . A narrow screen of width Y is placed a distance D from the slits.

Which gives the number of fringes observed on the screen?

[1 mark]

A $\frac{\lambda D}{sY}$ ☐

B $\frac{\lambda s}{DY}$ ☐

C $\frac{DY}{s\lambda}$ ☐

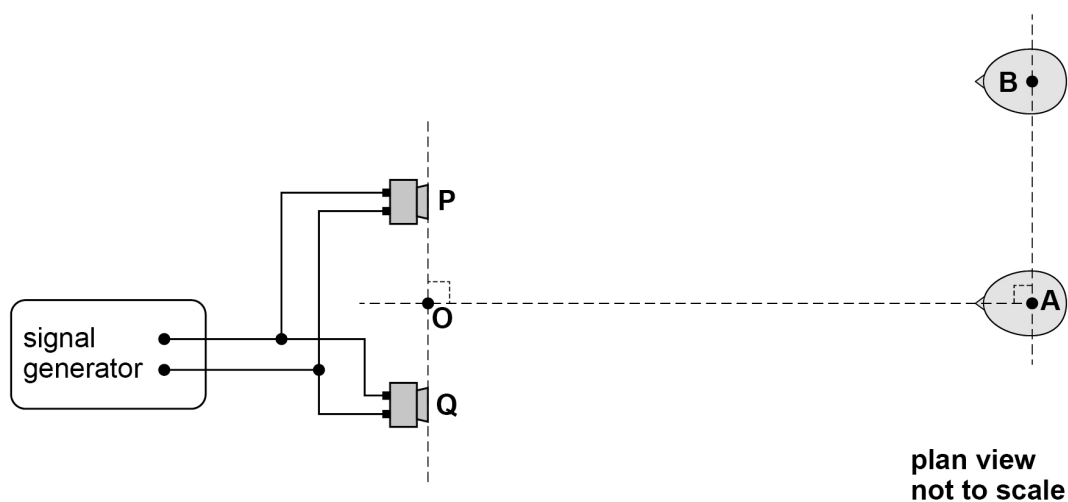
D $\frac{Ys}{\lambda D}$ ☐

0	3
---	---

A student investigates the interference of sound waves using two loudspeakers, **P** and **Q**, connected to a signal generator (oscillator). Each loudspeaker acts as a point source of sound.

Figure 3 shows the arrangement.

Figure 3



Point **O** is the midpoint between **P** and **Q**.

0	3
---	---

1

Explain why the two loudspeakers are coherent sources of sound waves.

[2 marks]

0 3 . 2

The student faces the two loudspeakers at point **A**. Point **A** is at equal distances from **P** and **Q**.

He then moves to point **B**, at right angles to the line **OA**, still facing the two loudspeakers.

As his head moves from **A** to **B** the amplitude of the sound wave he hears decreases and then increases. The amplitude starts to decrease again as he moves beyond **B**.

Explain why the variation in amplitude occurs as he moves from **A** to **B**.

[3 marks]

Question 3 continues on the next page



0 3 . 3

The student records the following data:

separation of the two loudspeakers	= 0.30 m
distance OA	= 2.25 m
distance from A to B	= 0.95 m

Show that the path difference for the sound waves from the two loudspeakers to point **B** is about 0.1 m.

[3 marks]**0 3 . 4**

The frequency of the sound wave is 2960 Hz.

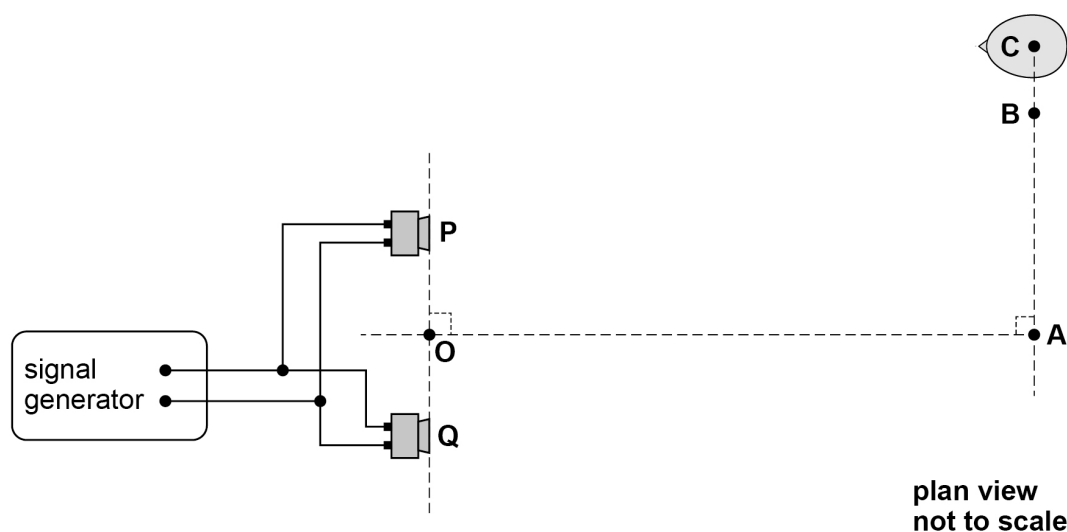
Calculate the speed of sound from the student's data.

[1 mark]speed of sound = _____ m s^{-1} 

0 3 . 5

The student moves his head to point **C** as shown in **Figure 4**. The emitted frequency of the sound from the loudspeakers is then gradually decreased.

Figure 4



Discuss the effect that this decrease in frequency has on the amplitude of the sound wave heard by the student.

[3 marks]

0 1

This question is about an experiment to measure the wavelength of microwaves.

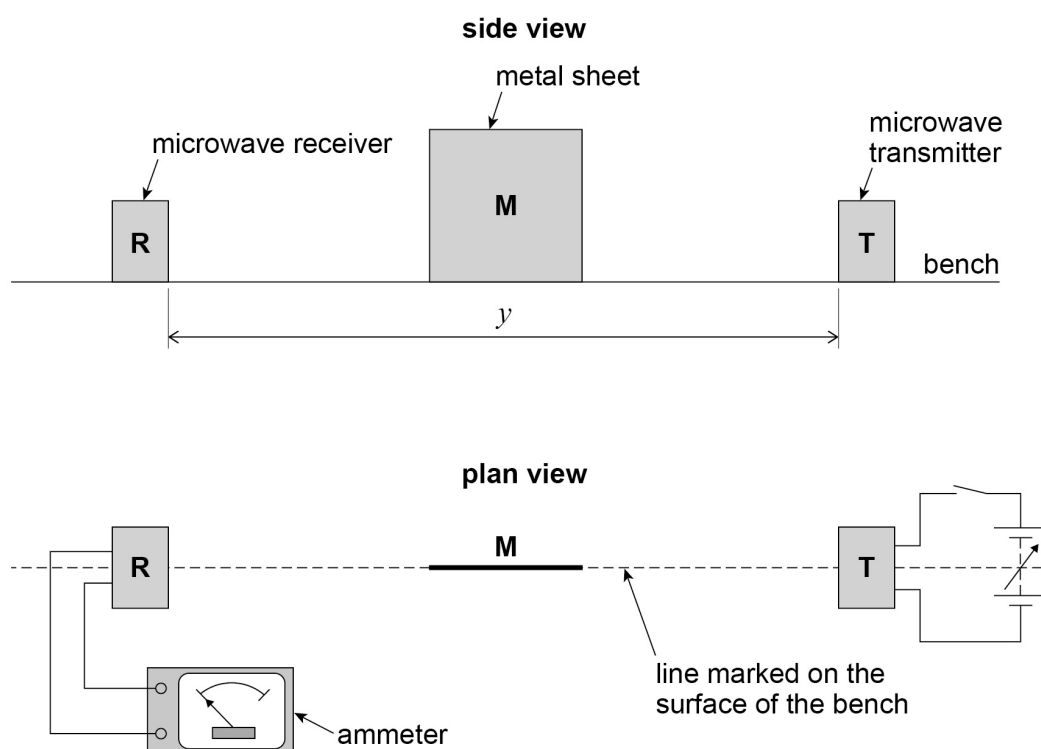
A microwave transmitter **T** and a receiver **R** are arranged on a line marked on the bench.

A metal sheet **M** is placed on the marked line perpendicular to the bench surface.

Figure 1 shows side and plan views of the arrangement.

The circuit connected to **T** and the ammeter connected to **R** are only shown in the plan view.

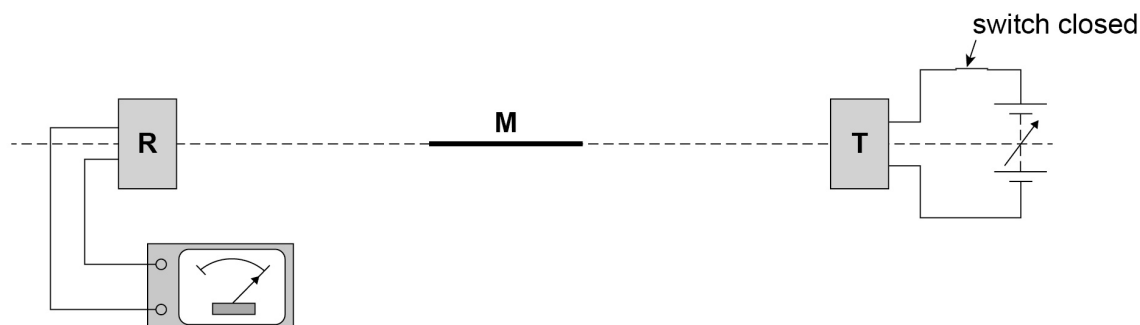
Figure 1



The distance y between **T** and **R** is recorded.

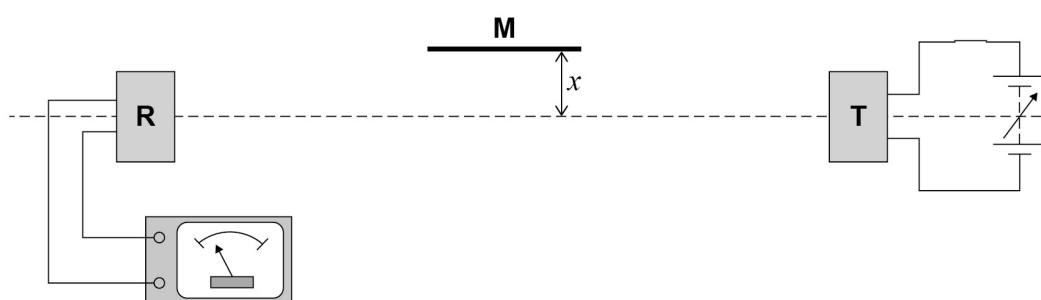
T is switched on and the output from **T** is adjusted so a reading is produced on the ammeter as shown in **Figure 2**.

Figure 2



M is kept parallel to the marked line and moved slowly away as shown in **Figure 3**.

Figure 3



The reading decreases to a minimum reading **which is not zero**.
The perpendicular distance x between the marked line and **M** is recorded.

0 1 . 1

The ammeter reading depends on the superposition of waves travelling directly to **R** and other waves that reach **R** after reflection from **M**.

State the phase difference between the sets of waves superposing at **R** when the ammeter reading is a **minimum**.
Give a suitable unit with your answer.

[1 mark]

Question 1 continues on the next page

0	1	.	2
---	---	---	---

Explain why the minimum reading is **not** zero when the distance x is measured.

[1 mark]

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

When **M** is moved further away the reading increases to a maximum then decreases to a minimum.

At the first minimum position, a student labels the minimum $n = 1$ and records the value of x .

The next minimum position is labelled $n = 2$ and the new value of x is recorded. Several positions of maxima and minima are produced.

Describe a procedure that the student could use to make sure that **M** is parallel to the marked line before measuring each value of x .

You may wish to include a sketch with your answer.

[2 marks]

Question 1 continues on the next page



0 1 . 4

It can be shown that

$$n\lambda = \sqrt{4x^2 + y^2} - y$$

where λ is the wavelength of the microwaves and y is the distance defined in **Figure 1**.

The student plots the graph shown in **Figure 4**.

The student estimates the uncertainty in each value of $\sqrt{4x^2 + y^2}$ to be 0.025 m and adds error bars to the graph.

Determine

- the maximum gradient $G_{\max}$ of a line that passes through all the error bars
- the minimum gradient $G_{\min}$ of a line that passes through all the error bars.

[3 marks]

$$G_{\max} = \underline{\hspace{10cm}}$$

$$G_{\min} = \underline{\hspace{10cm}}$$

0 1 . 5

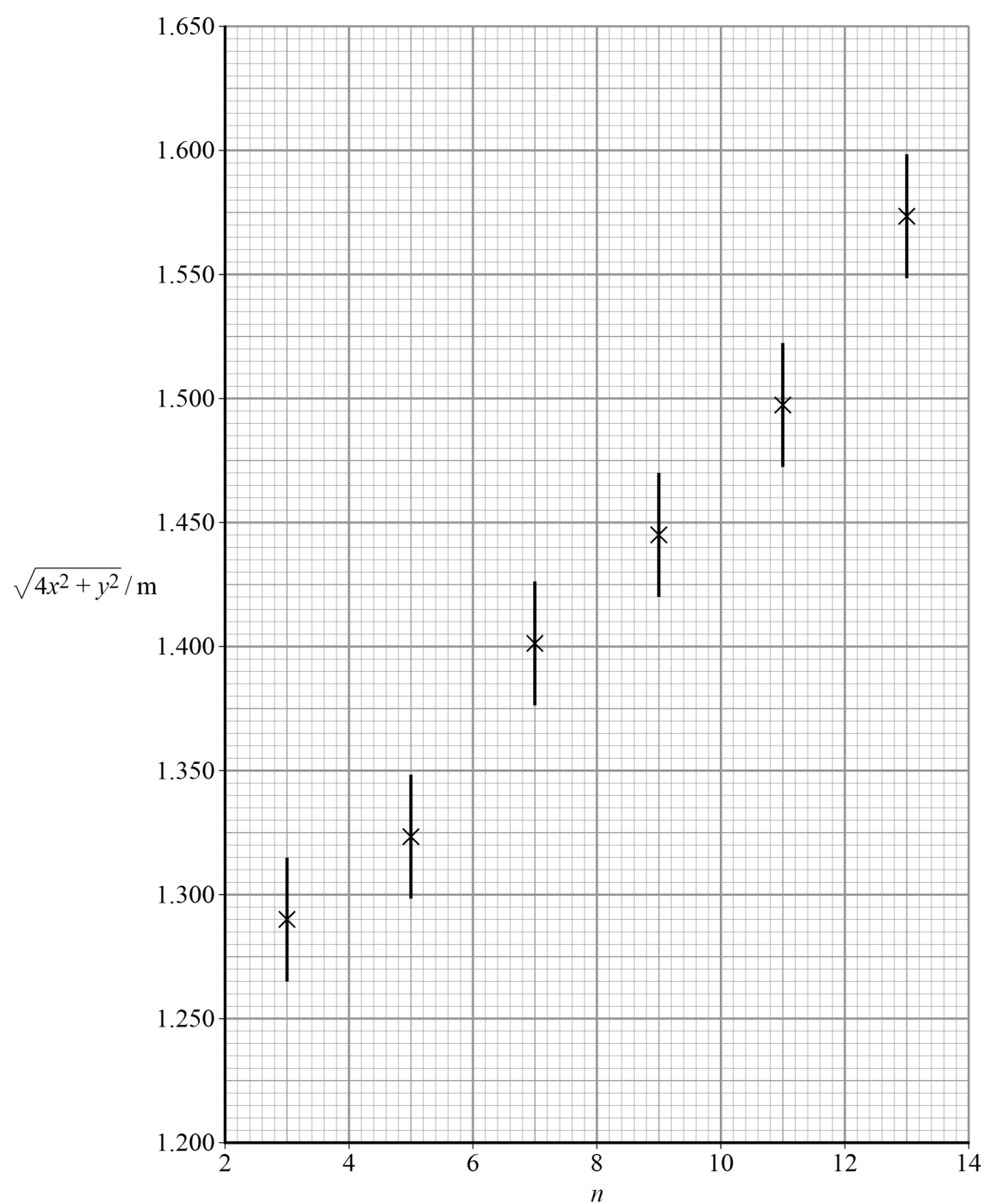
Determine λ using your results for $G_{\max}$ and $G_{\min}$.

[2 marks]

$$\lambda = \underline{\hspace{10cm}} \text{ m}$$



Figure 4



Question 1 continues on the next page

0 1 . 6

Determine the percentage uncertainty in your result for λ .

[3 marks]

percentage uncertainty in $\lambda =$ _____ %

0 1 . 7

Explain how the graph in **Figure 4** can be used to obtain the value of y .
You are **not** required to determine y .

[2 marks]

0 1 . 8

Suppose that the data for $n = 13$ had not been plotted on **Figure 4**.Add a tick (✓) in each row of **Table 1** to identify the effect, if any, on the results you would obtain for $G_{\max}$, $G_{\min}$, λ and y .

[4 marks]

Table 1

Result	Reduced	Not affected	Increased
$G_{\max}$			
$G_{\min}$			
λ			
y			



SUB-TOPIC 3.3.2.2

DIFFRACTION

Sub-topic 3.3.2.2 · 9 questions · 16 marks · lowest tariff first



1 7

When light of wavelength 5.0×10^{-7} m is incident normally on a diffraction grating the fourth-order maximum is observed at an angle of 30° .

What is the number of lines per mm on the diffraction grating?

[1 mark]

A 2.5×10^2

☐

B 2.5×10^5

☐

C 1.0×10^3

☐

D 1.0×10^6

☐

1 7

A diffraction grating has 500 lines per mm. When monochromatic light is incident normally on the grating the third-order spectral line is formed at an angle of 60° from the normal to the grating.

What is the wavelength of the monochromatic light?

[1 mark]

A 220 nm

☐

B 580 nm

☐

C 960 nm

☐

D 1700 nm

☐

1 9

Monochromatic light is incident normally on a diffraction grating that has $4.50 \times 10^5 \text{ lines m}^{-1}$.

The angle between the second-order diffraction maxima is 44° .

What is the wavelength of the light?

[1 mark]**A** 208 nm☐**B** 416 nm☐**C** 772 nm☐**D** 832 nm☐

1 9

A diffraction grating is illuminated normally.

The second-order maximum for light of wavelength 650 nm occurs at the same angle as the third-order maximum for light of wavelength λ .

What is λ ?

[1 mark]

A 217 nm

☐

B 325 nm

☐

C 433 nm

☐

D 975 nm

☐

2 1

Monochromatic light of wavelength $5.8 \times 10^{-7} \text{ m}$ is incident normally on a plane transmission diffraction grating that has a slit separation of $2.5 \times 10^{-6} \text{ m}$.

How many maxima are produced by the grating?

[1 mark]**A** 4☐**B** 5☐**C** 8☐**D** 9☐**2 1**

1 7

A single narrow slit is illuminated with monochromatic light and a diffraction pattern is produced.

The slit width is increased.

What happens to the width and brightness of the central maximum of the diffraction pattern?

[1 mark]

	Width of central maximum	Brightness of central maximum	
A	increases	increases	☐
B	increases	decreases	☐
C	decreases	increases	☐
D	decreases	decreases	☐

1 5

A student derives the equation $n\lambda = d\sin\theta$ for the production of a diffraction pattern on a screen.

This derivation requires that:

[1 mark]

A the diffraction angle θ is a small angle.

☐

B d is the number of slits per unit length.

☐

C light from adjacent slits arrives at the screen in phase.

☐

D $n\lambda$ is greater than or equal to d , where n is a whole number.

☐

2 0

Monochromatic light of wavelength 420 nm is incident normally on a plane transmission diffraction grating that has a slit separation of $3.6\text{ }\mu\text{m}$.

What is the total number of maxima produced by the grating?

[1 mark]

A 8 ☐

B 9 ☐

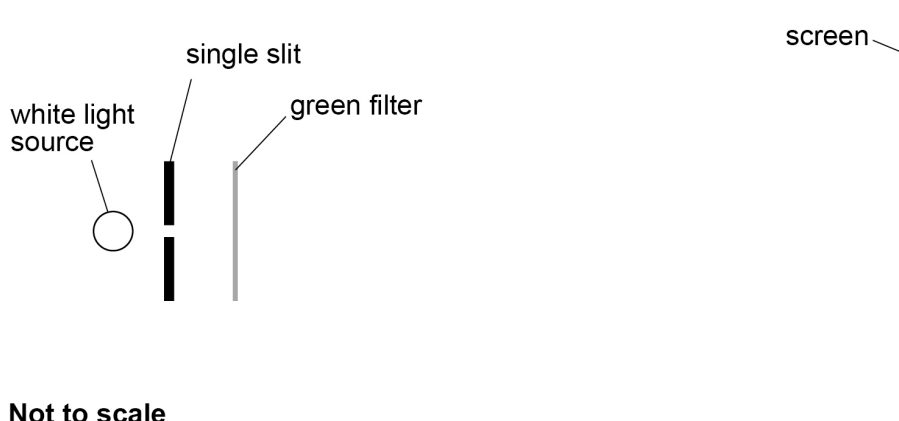
C 16 ☐

D 17 ☐

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**

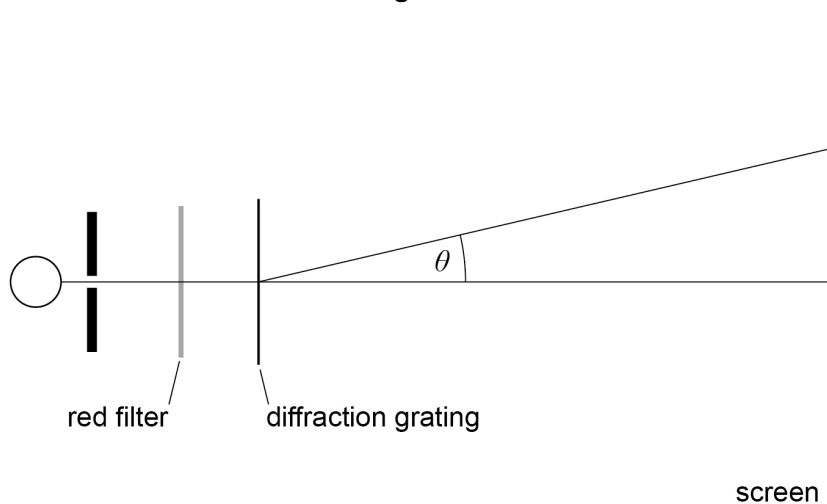
The green filter is replaced with a red filter.

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]

$\theta =$ _____ degrees

Question 3 continues on the next page

0	3	.	4
---	---	---	---

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]



SUB-TOPIC 3.3.2.3

REFRACTION AND TOTAL INTERNAL REFLECTION

Sub-topic 3.3.2.3 · 11 questions · 59 marks · lowest tariff first



1 8

An electromagnetic wave enters a fibre-optic cable from air. On entering the cable, the wave slows down to three-fifths of its original speed.

What is the refractive index of the core of the fibre-optic cable?

[1 mark]

A 0.67

☐

B 1.33

☐

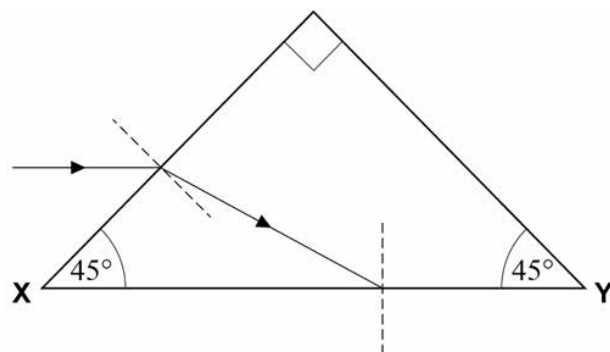
C 1.50

☐

D 1.67

☐

1 9 The diagram shows part of the path of a ray of light through a right-angled prism.

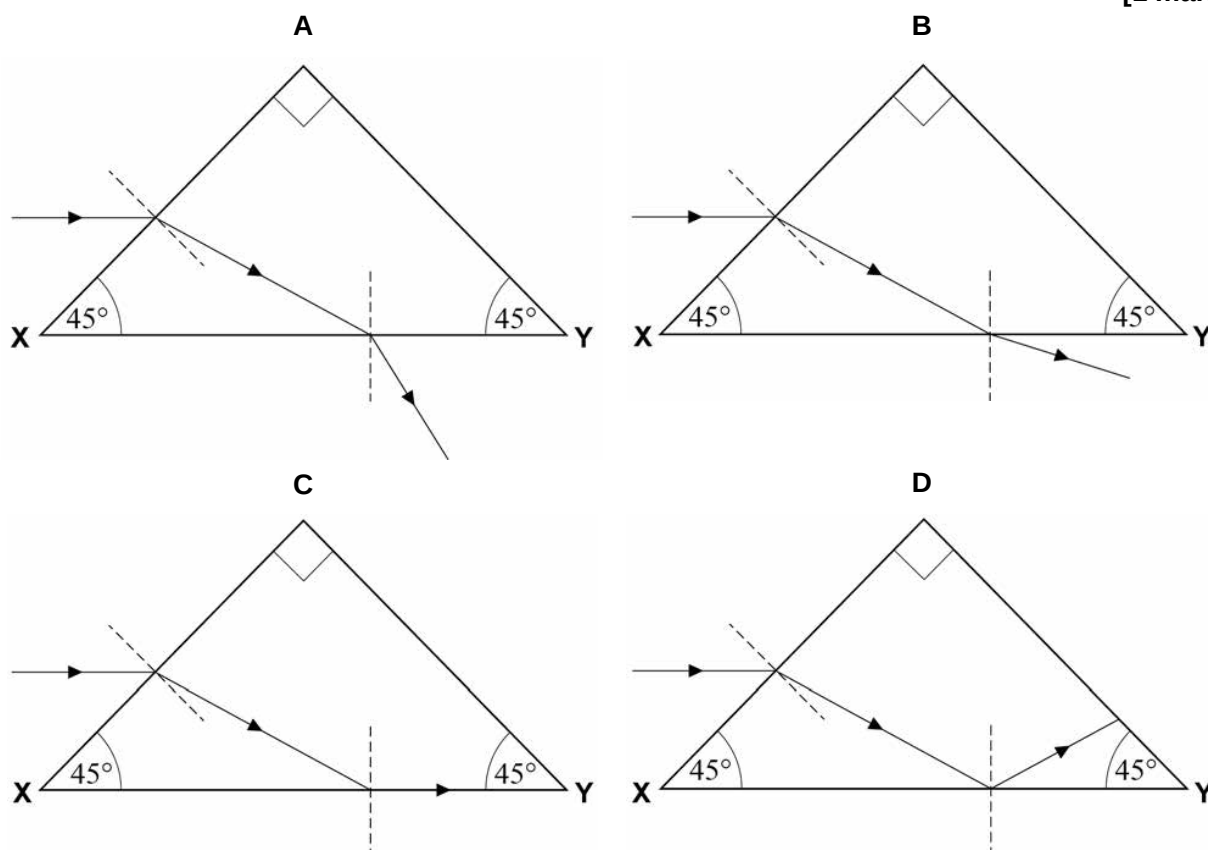


The prism is made of glass of refractive index 1.5

The incident light ray is parallel to the face XY . The ray is refracted towards the face XY .

What is the path of the ray after it is incident on face XY ?

[1 mark]



- A ☐
- B ☐
- C ☐
- D ☐

1 4

A monochromatic light wave travels from glass into air.

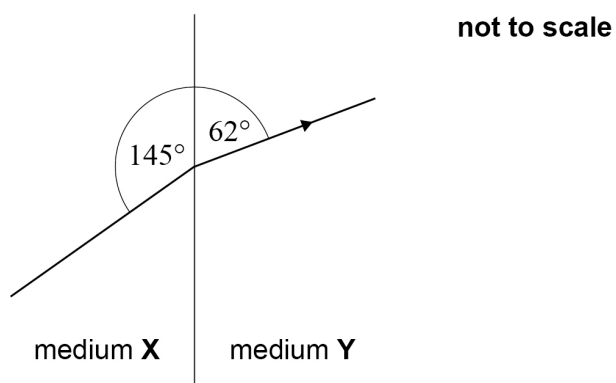
Which row shows what happens to the wavelength, speed and photon energy?

[1 mark]

	Wavelength	Speed	Photon energy	
A	increases	increases	increases	☐
B	does not change	decreases	does not change	☐
C	does not change	decreases	increases	☐
D	increases	increases	does not change	☐



1 **8** A light ray passes from medium **X** to medium **Y**.



The refractive index of **X** is 1.33

What is the refractive index of **Y**?

[1 mark]

A 0.86 ☐

B 1.22 ☐

C 1.74 ☐

D 2.32 ☐

1 9

The critical angle at a boundary between two media is 53° .
The speed of light in one medium is $2.6 \times 10^8 \text{ m s}^{-1}$.

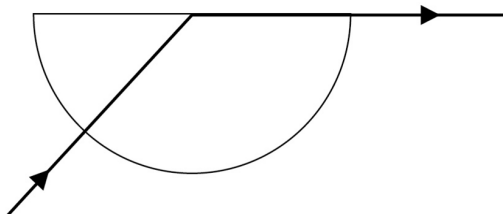
What is the speed of light in the other medium?

[1 mark]**A** $1.6 \times 10^8 \text{ m s}^{-1}$ ☐**B** $2.1 \times 10^8 \text{ m s}^{-1}$ ☐**C** $3.0 \times 10^8 \text{ m s}^{-1}$ ☐**D** $3.2 \times 10^8 \text{ m s}^{-1}$ ☐

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.

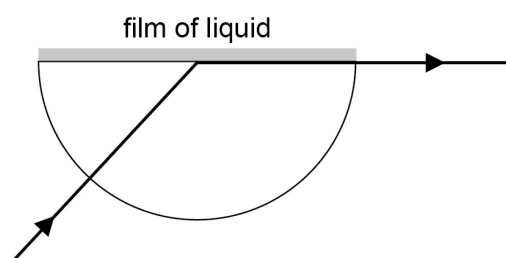
[1 mark]

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.

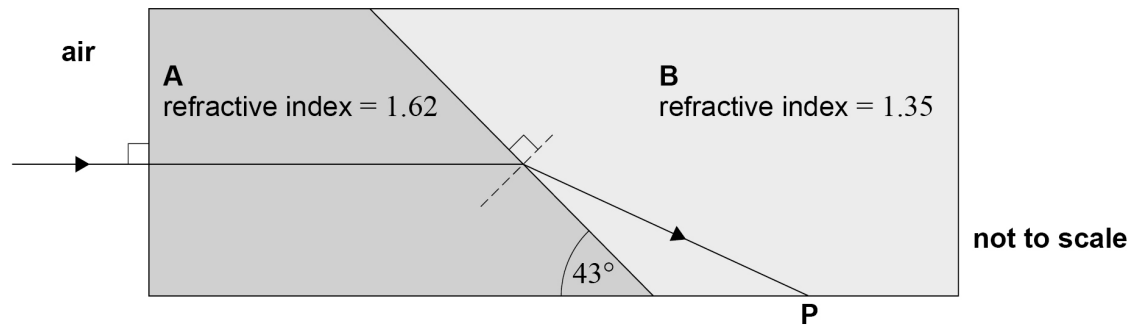
[3 marks]

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]

0 6 . 3 Draw, on **Figure 12**, the path of the ray immediately after it reaches **P**.
Justify your answer with calculations.

[3 marks]

END OF SECTION A



Section B

Each of Questions **07** to **31** is followed by four responses, **A**, **B**, **C** and **D**.

For each question select the best response.

Only **one** answer per question is allowed.

For each question, completely fill in the circle alongside the appropriate answer.

CORRECT METHOD



WRONG METHODS



If you want to change your answer you must cross out your original answer as shown.



If you wish to return to an answer previously crossed out, ring the answer you now wish to select as shown.



You may do your working in the blank space around each question but this will not be marked.
Do **not** use additional sheets for this working.



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

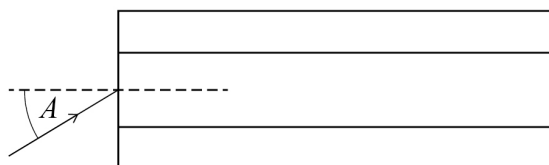


Table 2 shows some properties of the optical fibre.

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**.

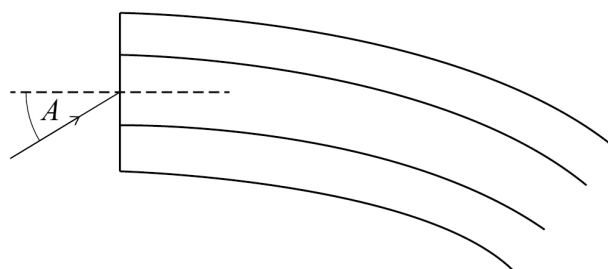
[3 marks]

$A =$ _____ 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.

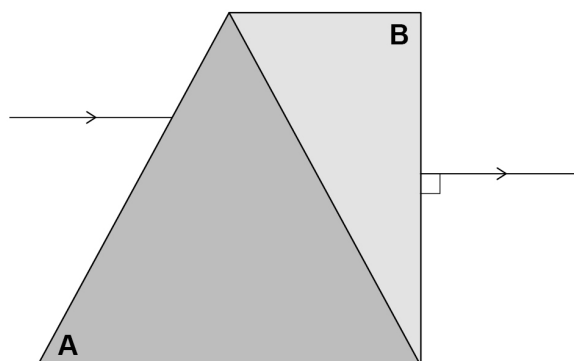
[3 marks]

03

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



03.1

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

[1 mark]

03.2

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

[2 marks]

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

03.3

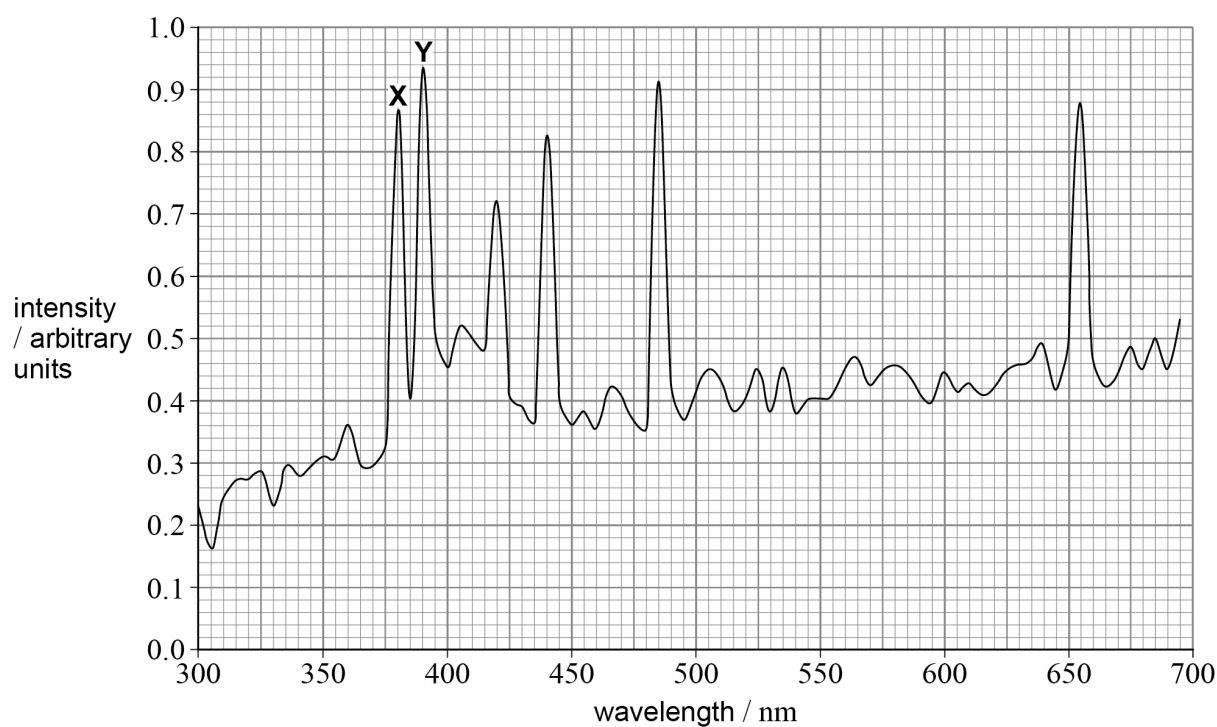
Describe **one** non-astronomical application of a diffraction grating.

[1 mark]

Question 3 continues on the next page

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]

$G =$ _____ m^{-1}



0	3	.	5
---	---	---	---

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

She has two options:

- 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.

Discuss which option she should choose.

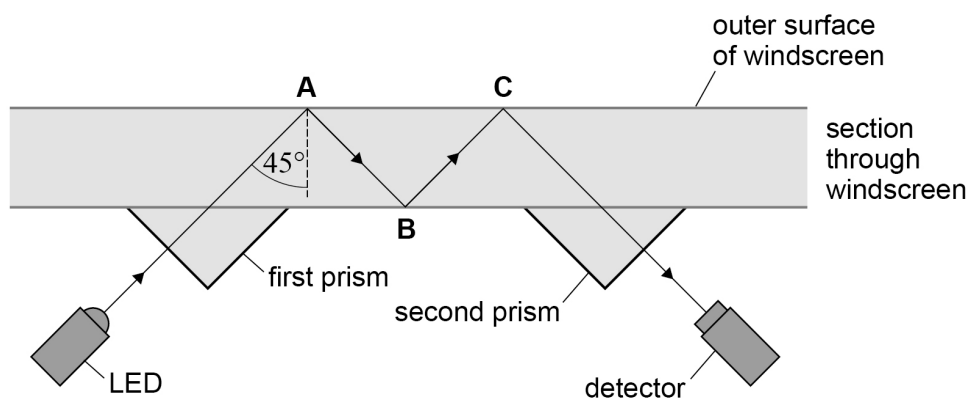
[3 marks]



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]

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

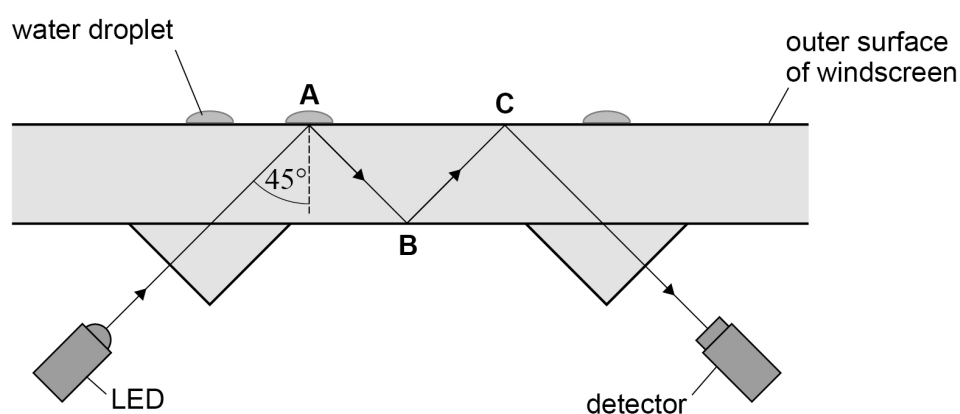
Explain why the ray follows the path shown inside the windscreen glass in **Figure 1**.
Support your answer with a suitable calculation.

[2 marks]

Question 2 continues on the next page

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]

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]

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

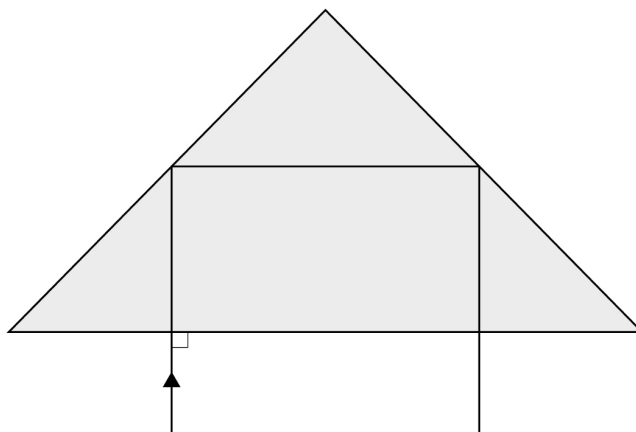


0 4

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]

0 4 . 2

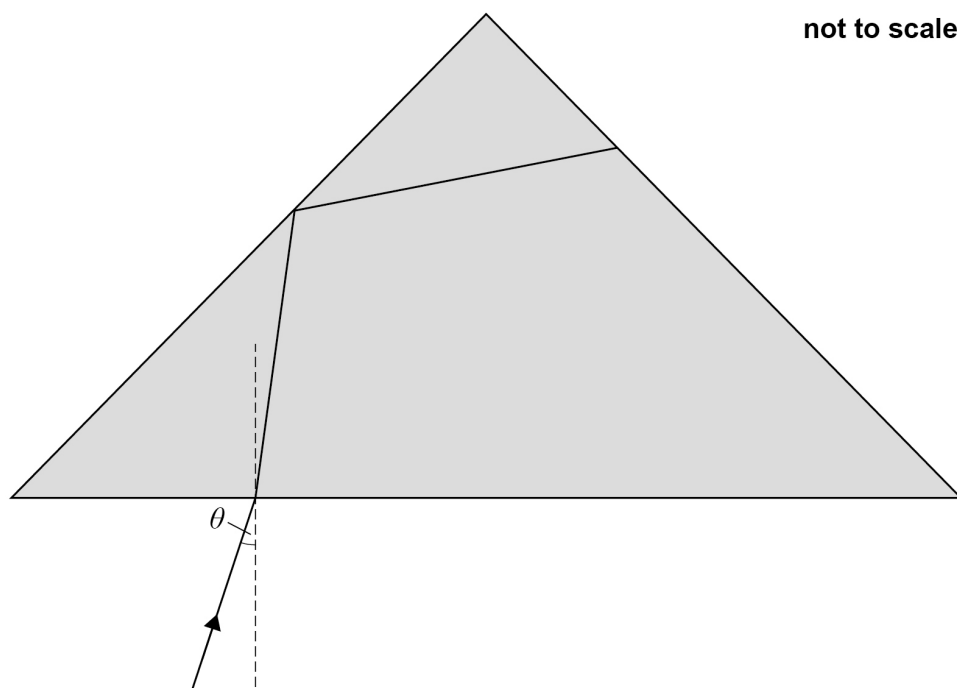
Explain why the ray emerges parallel to the incident ray.

[2 marks]

Question 4 continues on the next page

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]

Question 4 continues on the next page



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

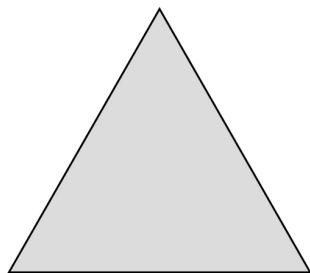
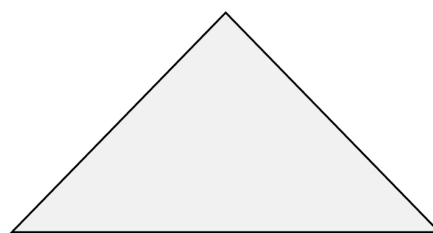


Figure 10



Discuss whether either of the two suggestions would work.

[4 marks]

- 1 _____

- 2 _____

SUB-TOPIC 3.3.S

SYNOPTIC: QUANTUM AND OTHER TOPICS

Sub-topic 3.3.S · 23 questions · 73 marks · lowest tariff first



1 0

A beam of light of wavelength λ is incident on a clean metal surface and photoelectrons are emitted. The wavelength of the light is halved but energy incident per second is kept the same.

Which row in the table is correct?

[1 mark]

	Maximum kinetic energy of the emitted photoelectrons	Number of photoelectrons emitted per second	
A	Increases	Unchanged	☐
B	Decreases	Increases	☐
C	Increases	Decreases	☐
D	Decreases	Unchanged	☐

1	1
---	---

Electrons moving in a beam have the same de Broglie wavelength as protons in a separate beam moving at a speed of $2.8 \times 10^4 \text{ m s}^{-1}$.

What is the speed of the electrons?

[1 mark]

A $1.5 \times 10^1 \text{ m s}^{-1}$

☐

B $2.8 \times 10^4 \text{ m s}^{-1}$

☐

C $1.2 \times 10^6 \text{ m s}^{-1}$

☐

D $5.1 \times 10^7 \text{ m s}^{-1}$

☐

1 4

Photons of wavelength 290 nm are incident on a metal plate. The work function of the metal is 4.1 eV

What is the maximum kinetic energy of the emitted electrons?

[1 mark]

A 0.19 eV

☐

B 4.3 eV

☐

C 6.9 eV

☐

D 8.4 eV

☐

2 9

A body performs simple harmonic motion.

What is the phase difference between the variation of displacement with time and the variation of acceleration with time for the body?

[1 mark]

A 0

☐

B $\frac{\pi}{4}$ rad

☐

C $\frac{\pi}{2}$ rad

☐

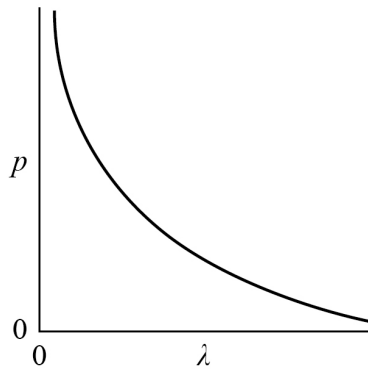
D π rad

☐

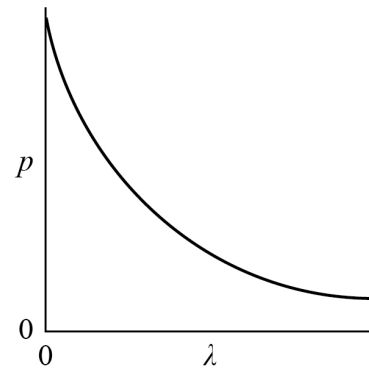
1 3 Which graph shows the variation of momentum p with wavelength λ of a photon?

[1 mark]

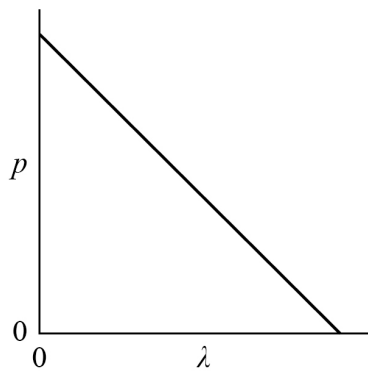
A



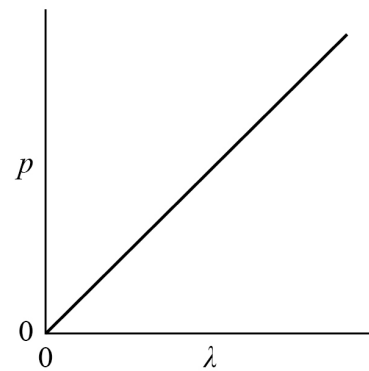
B



C



D



A ☐

B ☐

C ☐

D ☐

2 5

An alternating emf is induced in a coil rotating in a magnetic field.

What is the phase difference between the magnetic flux linkage through the coil and the emf?

[1 mark]**A** 0☐**B** $\frac{\pi}{3}$ rad☐**C** $\frac{\pi}{2}$ rad☐**D** π rad☐

1 6

A muon and an electron are travelling at the same speed.

Which row gives the particle with the greater kinetic energy and the particle with the longer de Broglie wavelength?

[1 mark]

	Greater kinetic energy	Longer de Broglie wavelength	
A	muon	muon	☐
B	muon	electron	☐
C	electron	muon	☐
D	electron	electron	☐

1 6

Which row gives evidence for the wave nature of electrons and evidence for the particulate nature of light?

[1 mark]

	Wave nature of electrons	Particulate nature of light	
A	electron diffraction	photoelectric effect	☐
B	electron diffraction	single-slit diffraction	☐
C	photoelectric effect	single-slit diffraction	☐
D	photoelectric effect	electron diffraction	☐

1 7

Which particle has the smallest de Broglie wavelength?

[1 mark]**A** an electron moving at $4 \times 10^3 \text{ m s}^{-1}$ ☐**B** a proton moving at $4 \times 10^3 \text{ m s}^{-1}$ ☐**C** an electron moving at $8 \times 10^5 \text{ m s}^{-1}$ ☐**D** a proton moving at $8 \times 10^5 \text{ m s}^{-1}$ ☐

2 9

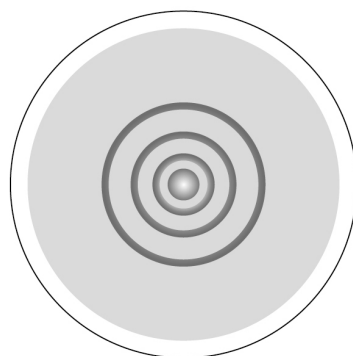
Which provides evidence for the existence of energy levels in nuclei?

[1 mark]**A** the Rutherford alpha particle scattering experiment☐**B** the existence of X-ray line spectra☐**C** the existence of gamma radiation☐**D** electron diffraction by crystals☐

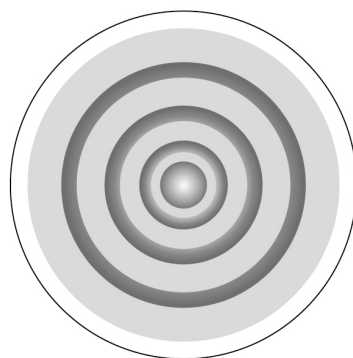
1 3

Electrons with a certain kinetic energy pass through a powdered crystalline sample and are incident on a fluorescent screen.

The diagram shows a sketch of the diffraction pattern produced.



A change is made and this second pattern is produced.



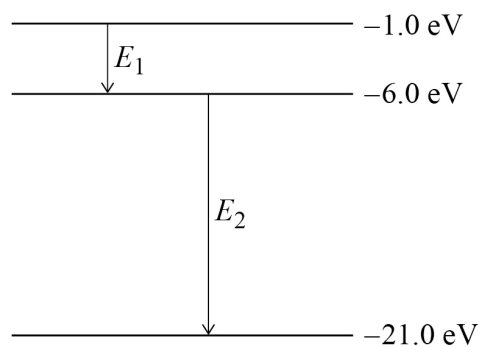
Which change could produce the second pattern?

[1 mark]

- A** decreasing the kinetic energy of the electrons
- B** replacing the electrons with protons with the same kinetic energy
- C** using a crystalline sample with a wider spacing between its atoms
- D** moving the screen closer to the crystalline sample

☐☐☐☐

1 1 Three energy levels for an atom are shown.



Energy change E_1 leads to the emission of a photon of wavelength λ_1 .

Energy change E_2 leads to the emission of a photon of wavelength λ_2 .

What is $\frac{\lambda_1}{\lambda_2}$?

[1 mark]

A $\frac{1}{4}$

B $\frac{1}{3}$

C 3

D 4

1 2

An electron and a proton move with the same speed.

What is $\frac{\text{de Broglie wavelength of electron}}{\text{de Broglie wavelength of proton}}$?**[1 mark]****A** 5.5×10^{-4} ☐**B** 2.3×10^{-2} ☐**C** 42 ☐**D** 1800 ☐

1 2

In a photoelectric effect experiment, monochromatic light is incident on a metal surface and the stopping potential is measured.

Which change results in a greater stopping potential?

[1 mark]

A using a metal that has a greater work function

☐

B using a light source that emits more photons per second

☐

C using a light source that emits light of a shorter wavelength

☐

D using a metal surface that has a positive charge

☐

1 3

Which row provides evidence for the particle nature of light and the wave nature of light?

[1 mark]

	Evidence for particle nature	Evidence for wave nature	
A	line spectra	photoelectric effect	☐
B	diffraction	line spectra	☐
C	photoelectric effect	diffraction	☐
D	photoelectric effect	line spectra	☐

2 7 An alpha particle has a speed of $4.5 \times 10^5 \text{ m s}^{-1}$.

What is the de Broglie wavelength of the alpha particle?

[1 mark]

A $2.2 \times 10^{-13} \text{ m}$ ☐

B $4.4 \times 10^{-13} \text{ m}$ ☐

C $8.8 \times 10^{-13} \text{ m}$ ☐

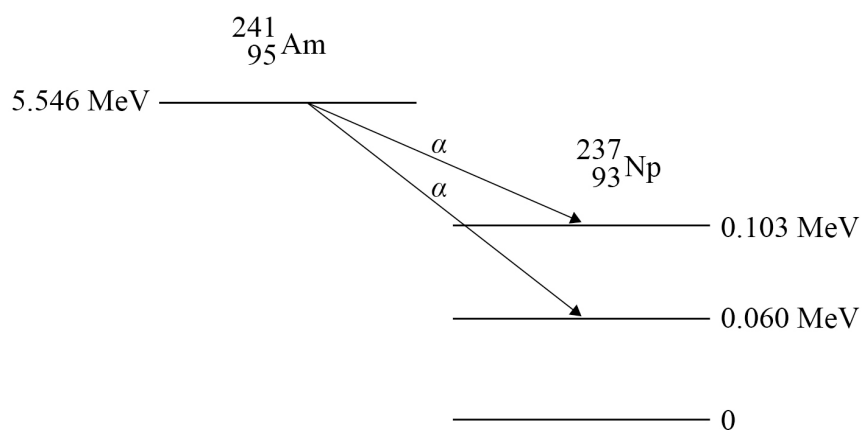
D $3.9 \times 10^{-12} \text{ m}$ ☐

2 6

$^{241}_{95}\text{Am}$ decays to one of two excited states of $^{237}_{93}\text{Np}$ by emitting an alpha particle.

The excited $^{237}_{93}\text{Np}$ nucleus then decays with the emission of a gamma photon.

The diagram shows the energy levels involved in the decay of $^{241}_{95}\text{Am}$.



What is the energy of the emitted gamma photon that has the shortest wavelength?

[1 mark]

A 5.546 MeV ☐

B 5.486 MeV ☐

C 0.103 MeV ☐

D 0.043 MeV ☐

08

Electrons in a fluorescent tube are accelerated from rest by a potential difference of 130 V.

08.1

Calculate the maximum speed of an electron that is accelerated from rest by this potential difference.

[2 marks]

maximum speed = _____ m s^{-1}

08.2

Explain why the average speed of the electrons in the tube is much less than the maximum speed you calculated in Question **08.1**.

[1 mark]

Question 8 continues on the next page

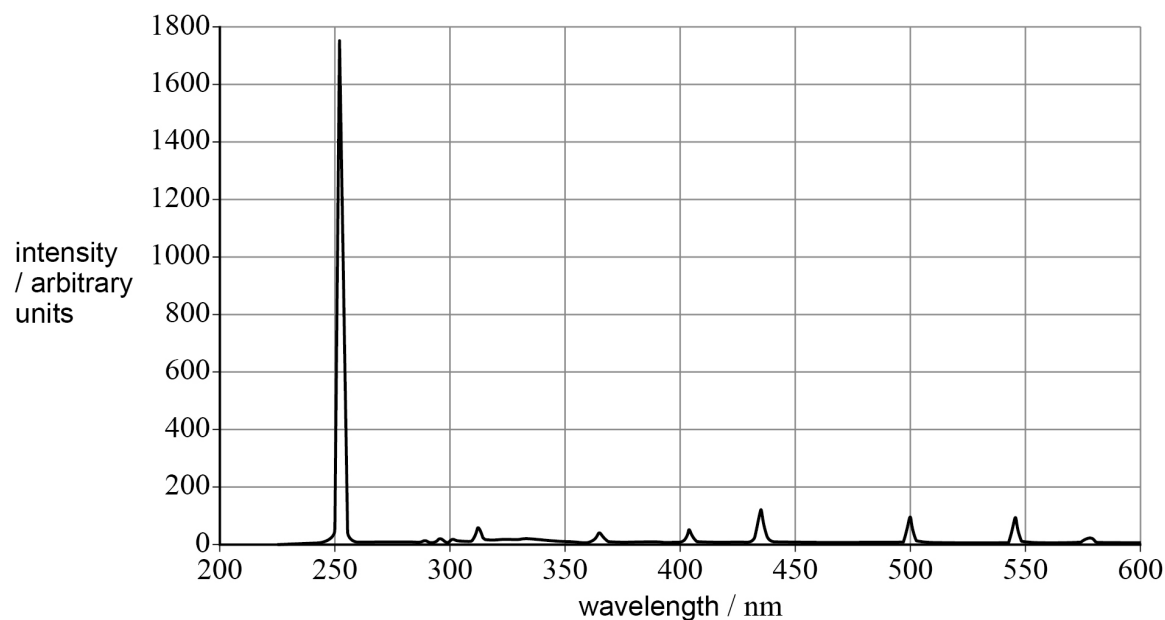


0 8 . 3

Scientists want to replace the mercury in fluorescent tubes with substance **X**.

Figure 12 is an emission spectrum for **X**.

Figure 12



White light consists of the whole range of visible wavelengths from 380 nm to 700 nm.

Explain, with reference to **Figure 12**, whether white light can be produced by a fluorescent tube that uses **X**.

[2 marks]

08.4

Figure 12 shows a maximum intensity peak that occurs at wavelength λ_{peak} .

Calculate, in eV, the energy change of an atom that produces a photon with a wavelength λ_{peak} .

[3 marks]

energy change = _____ eV

END OF SECTION A

Section B

Each of Questions **09** to **33** is followed by four responses, **A**, **B**, **C** and **D**.

For each question select the best response.

Only **one** answer per question is allowed.

For each question, completely fill in the circle alongside the appropriate answer.

CORRECT METHOD



WRONG METHODS



If you want to change your answer you must cross out your original answer as shown.



If you wish to return to an answer previously crossed out, ring the answer you now wish to select as shown.



You may do your working in the blank space around each question but this will not be marked. Do **not** use additional sheets for this working.

0	5	.	1
---	---	---	---

Calculate the binding energy, in MeV, of a nucleus of $^{59}_{27}\text{Co}$.

nuclear mass of $^{59}_{27}\text{Co} = 58.93320 \text{ u}$

[3 marks]

binding energy = _____ MeV

Question 5 continues on the next page



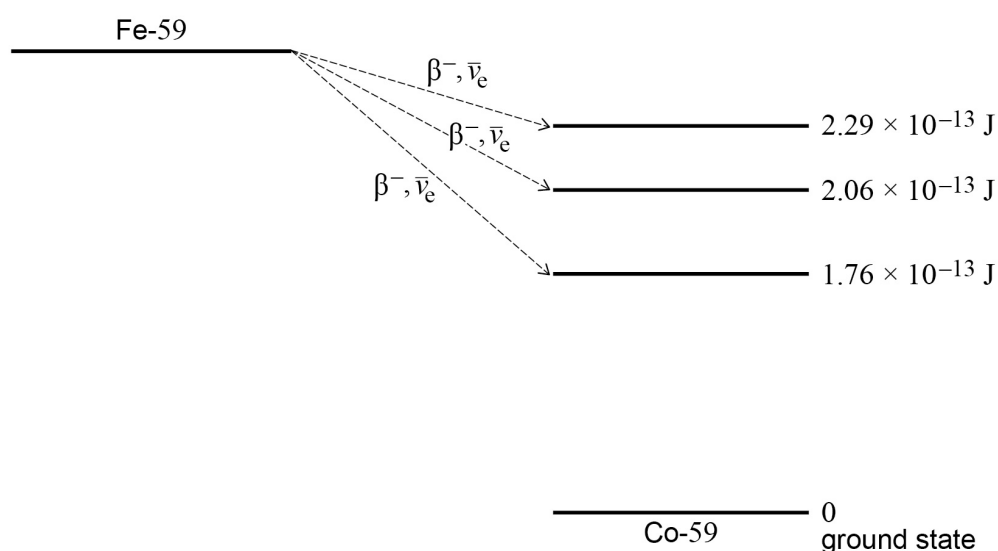
0 5 . 2

A nucleus of iron Fe-59 decays into a stable nucleus of cobalt Co-59. It decays by β^- emission followed by the emission of γ -radiation as the Co-59 nucleus de-excites into its ground state.

The total energy released when the Fe-59 nucleus decays is 2.52×10^{-13} J.

The Fe-59 nucleus can decay to one of three excited states of the cobalt-59 nucleus as shown in **Figure 5**. The energies of the excited states are shown relative to the ground state.

Figure 5



Calculate the maximum possible kinetic energy, in MeV, of the β^- particle emitted when the Fe-59 nucleus decays into an excited state that has energy above the ground state.

[2 marks]

maximum kinetic energy = _____ MeV



0	5	·	3
---	---	---	---

Following the production of excited states of ${}_{27}^{59}\text{Co}$, γ -radiation of discrete wavelengths is emitted.

State the maximum number of discrete wavelengths that could be emitted.

[1 mark]

maximum number = _____

0	5	·	4
---	---	---	---

Calculate the longest wavelength of the emitted γ -radiation.

[3 marks]

longest wavelength = _____ m



0 1

Information about the radius of a nucleus can be deduced from the closest approach of alpha particles and from electron diffraction.

0 1 . 1

Alpha particles, each with a kinetic energy of 5.59 MeV, are fired at a thin foil made of gold ($^{197}_{79}\text{Au}$) atoms.

Some of the alpha particles are scattered through an angle of 180° .

Estimate the radius of a $^{197}_{79}\text{Au}$ nucleus from this information.

[3 marks]

radius of nucleus = _____ m

0 1 . 2

Explain why your answer to Question **01.1** is an estimate.

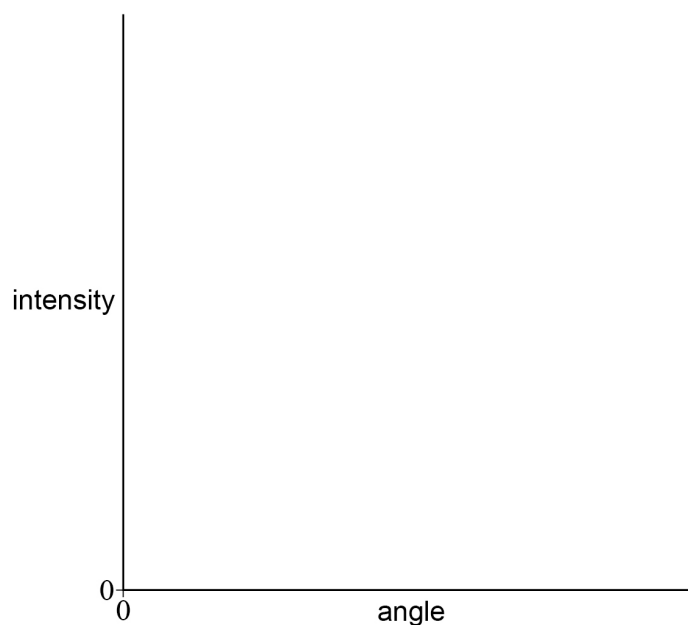
[2 marks]

0 1 . 3

Electron diffraction gives a more precise value for the radius of the nucleus.

Sketch, on **Figure 1**, a graph of intensity against angle for electron diffraction by a nucleus.

Go on to state the feature of this graph that is used to determine the radius of the nucleus.

[2 marks]**Figure 1**

Question 1 continues on the next page

0 1 . 4

Results from electron-diffraction experiments lead to the equation:

$$R = R_0 A^{\frac{1}{3}}$$

Show that the equation provides evidence for the constant density of nuclear material.

[2 marks]

|

1

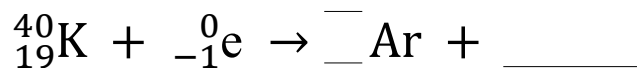


0 1

An isotope of potassium ${}^{40}_{19}\text{K}$ is used to date rocks. The isotope decays into an isotope of argon (Ar) mainly by electron capture.

0 1 . 1

The decay is represented by this equation:



Complete the equation to show the decay by filling in the gaps.

[2 marks]**0 1 . 2**

Explain which fundamental interaction is responsible for the decay in question **01.1**.

[2 marks]

0 1 . 3

One decay mechanism for the decay of ${}^{40}_{19}\text{K}$ results in the argon nucleus having an excess energy of 1.46 MeV. It loses this energy by emitting a single gamma photon.

Calculate the wavelength of the photon released by the argon nucleus.

[3 marks]

wavelength = _____ m

0 1 . 4

The potassium isotope can also decay by a second decay process to form a calcium-40 nuclide (${}^{40}_{20}\text{Ca}$).

Suggest how the emissions from a nucleus of decaying potassium can be used to confirm which decay process is occurring.

[3 marks]

0 2

Table 1 shows results of an experiment to investigate how the de Broglie wavelength λ of an electron varies with its velocity v .

Table 1

$v / 10^7 \text{ m s}^{-1}$	$\lambda / 10^{-11} \text{ m}$
1.5	4.9
2.5	2.9
3.5	2.1

0 2 · 1

Show that the data in **Table 1** are consistent with the relationship $\lambda \propto \frac{1}{v}$

[2 marks]

0 2 · 2

Calculate a value for the Planck constant suggested by the data in **Table 1**.

[2 marks]

Planck constant = _____ J s

Question 2 continues on the next page

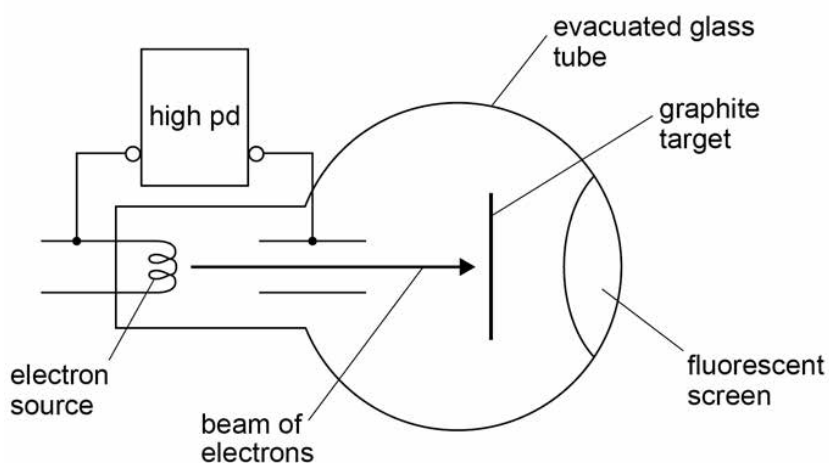


0 2 . 3

Figure 2 shows the side view of an electron diffraction tube used to demonstrate the wave properties of an electron.

Figure 2

Side view



An electron beam is incident on a thin graphite target that behaves like the slits in a diffraction grating experiment. After passing through the graphite target the electrons strike a fluorescent screen.

Figure 3 shows the appearance of the fluorescent screen when the electrons are incident on it.

Figure 3

Explain how the pattern produced on the screen supports the idea that the electron beam is behaving as a wave rather than as a stream of particles.

[3 marks]

0 2 . 4

Explain how the emission of light from the fluorescent screen shows that the electrons incident on it are behaving as particles.

[3 marks]



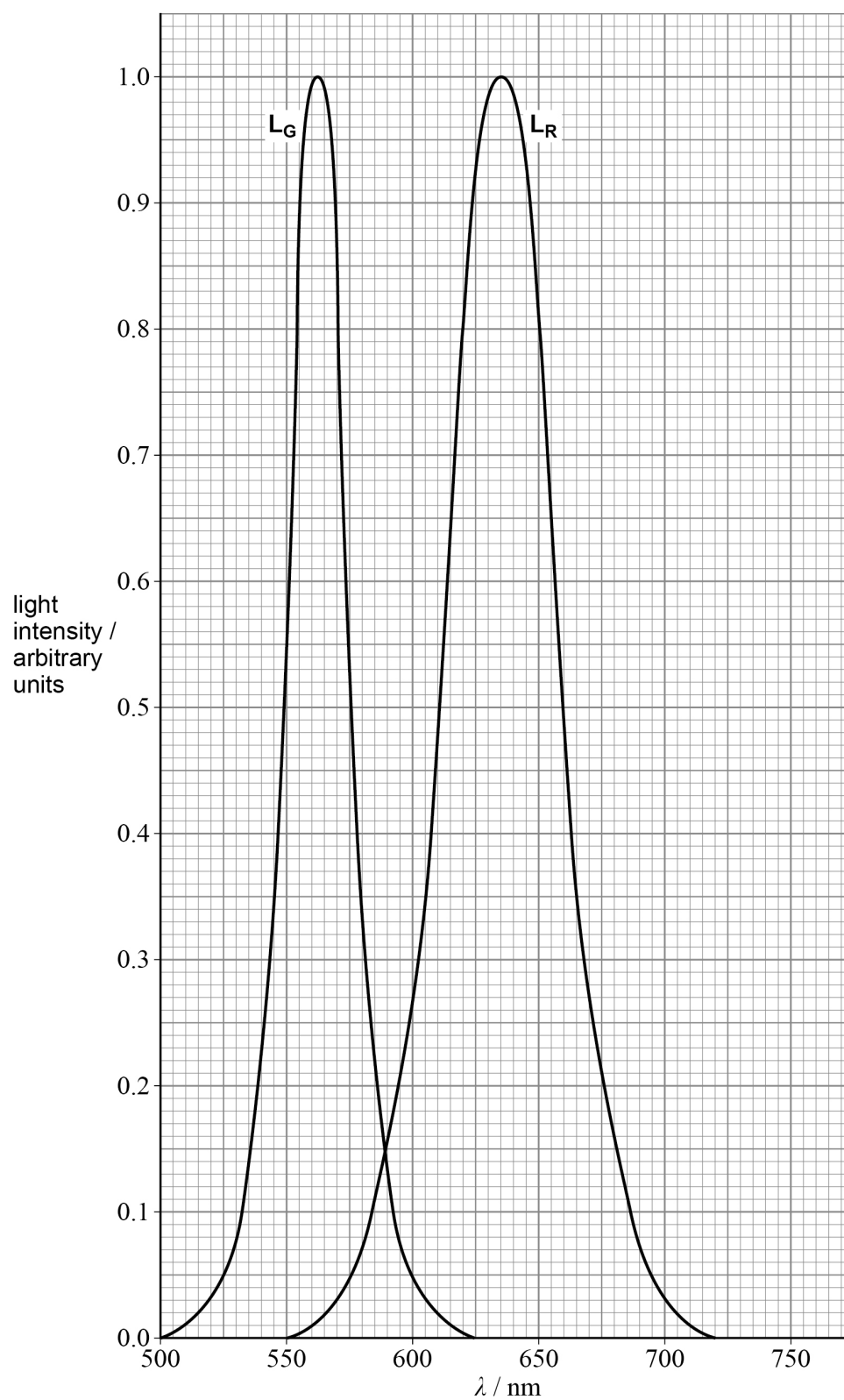
0	2
---	---

A light-emitting diode (LED) emits light over a narrow range of wavelengths. These wavelengths are distributed about a peak wavelength λ_p .

Two LEDs L_G and L_R are adjusted to give the same maximum light intensity. L_G emits green light and L_R emits red light.

Figure 3 shows how the light output of the LEDs varies with the wavelength λ .

Figure 3



Question 2 continues on the next page

0	2	.	1
---	---	---	---

Light from $\mathbf{L_R}$ is incident normally on a plane diffraction grating.
The fifth-order maximum for light of wavelength λ_p occurs at a diffraction angle of 76.3° .

Determine N , the number of lines per metre on the grating.

[3 marks]

$$N = \text{_____} \text{ m}^{-1}$$

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

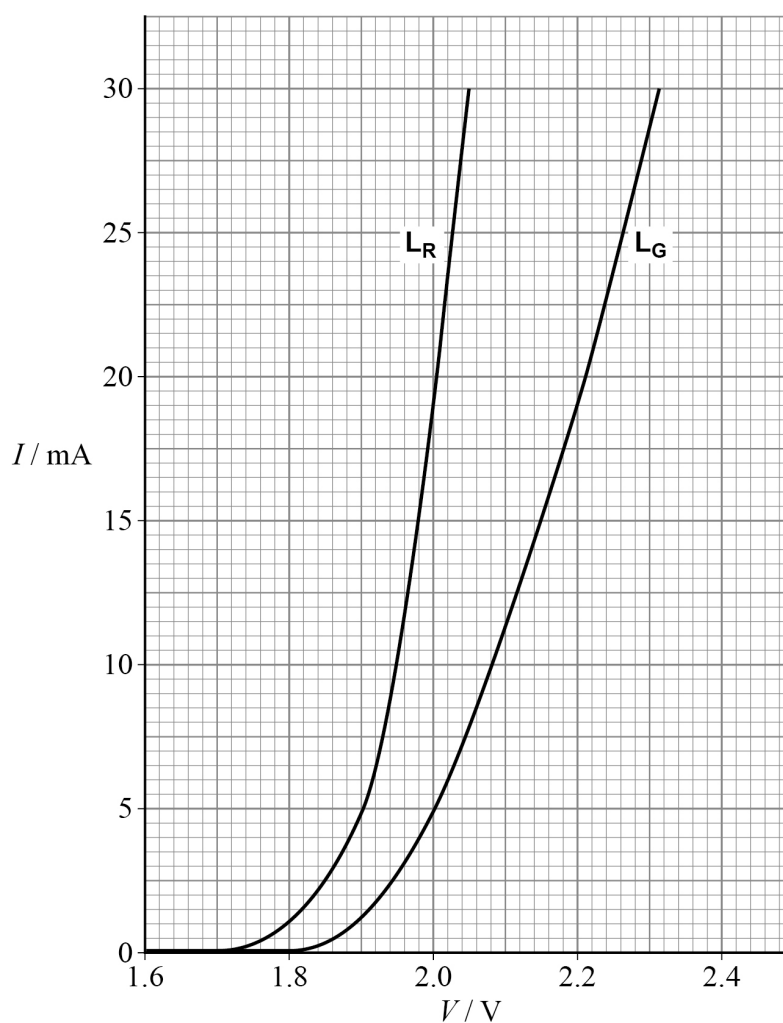
Suggest **one** possible disadvantage of using the fifth-order maximum to determine N .

[1 mark]



0 2 . 3 Figure 4 shows part of the current–voltage characteristics for L_R and L_G .

Figure 4



When the linear part of the characteristic is extrapolated, the point at which it meets the horizontal axis gives the activation voltage V_A for the LED.

V_A for L_G is 2.00 V.

Determine, using **Figure 4**, V_A for L_R .

[2 marks]

V_A for L_R = _____ V

Question 2 continues on the next page

0 2 . 4 It can be shown that:

$$V_A = \frac{hc}{e\lambda_p}$$

where h = the Planck constant.

Deduce a value for the Planck constant based on the data given about the LEDs.

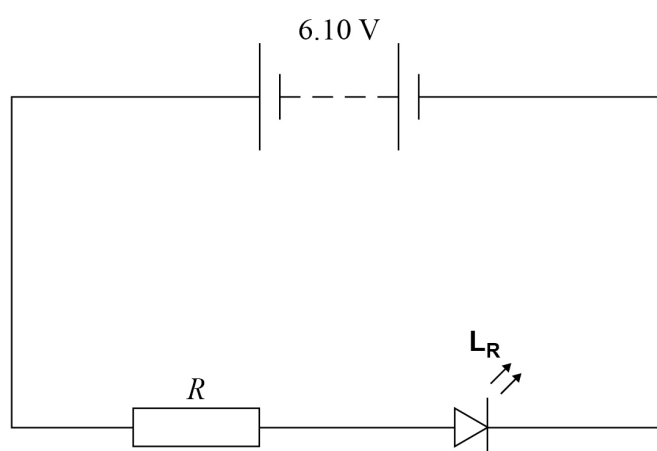
[2 marks]

$h =$ _____ J s



0 2 . 5 Figure 5 shows a circuit with L_R connected to a resistor of resistance R .

Figure 5



The power supply has emf 6.10 V and negligible internal resistance.
The current in L_R must not exceed 21.0 mA.

Deduce the minimum value of R .

[2 marks]

minimum value of $R =$ _____ Ω

MARK SCHEMES

official mark schemes



07	A
----	---



15	A
----	---



16	A
----	---



17	D	The frequency is 0.17 Hz.
----	---	---------------------------



| 13

| D

 5×10^6

| AO2



14

D

25

 0.15π 

C



17	C
----	---



18

C (AO2)

It oscillates with a time period of 1.5 ms.



14

A

unpolarised polarised

AO1



02.1	Rotate aerial in vertical plane ✓ When aerial vertical signal is a maximum When aerial horizontal signal is a minimum ✓ Max occurs when aerial aligned with plane of polarisation of microwave ✓	The first mark is for what needs to be done The second mark is for what is measured The third mark is for the link to polarisation	3	AO1.1b
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Question	Answers	Additional comments/Guidelines	Mark	AO
02.2	Received signal goes through series of max and min ✓ Reflected and direct microwaves interfere ✓ Path length of reflected wave/path difference increases as plate moved ✓ Phase difference between reflected and direct waves changes (so signal strength changes.) ✓	First mark is for what is observed Accept 'both' for 'reflected and direct' If no other mark given, 1 mark can be awarded for mention of interference/ superposition/ out of phase	4	AO3.1a

Question	Answers	Additional comments/Guidelines	Mark	AO
02.3	Equation only valid if slit-screen distance is a lot greater than slit separation✓	Allow arguments in terms of angles Allow 0.45 m for slit-screen distance Allow use of standard symbols	1	AO3.1a

Question	Answers	Additional comments/Guidelines	Mark	AO
02.4	Maximum path length for first slit $= \sqrt{(0.45^2 + (0.25 - 0.06)^2)}$ $= 0.49 \text{ m} \checkmark_1$ Max path length for second slit $= \sqrt{(0.45^2 + (0.25 + 0.06)^2)}$ $= 0.55 \text{ m} \checkmark_2$ Path difference $= 0.55 - 0.49 = 0.06 \text{ m}$ Which is greater than half a wavelength – so yes✓₃	MP1 is for one path length correct MP2 is for both path lengths correct MP3 is for determination of path difference and conclusion. Alternative for MAX2 Young equation used to determine fringe separation. ✓₁₂ Idea that fringe separation $< 0.25 \text{ m}$ so wavelength can be determined. ✓₃	3	AO3.1a L2 Ma
Total			11	

Question	Answers	Additional comments/Guidelines	Mark	AO
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C



18	D
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18	A	P is in antiphase with R P has the same amplitude as Q
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19	A (AO1)	first
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14

C

1.2

0.17



15

B

They have a constant phase relationship.



15

D

$$2(L_2 - L_1)$$

AO1



14

A

 $\frac{1}{\text{diameter of the wire}}$

AO1

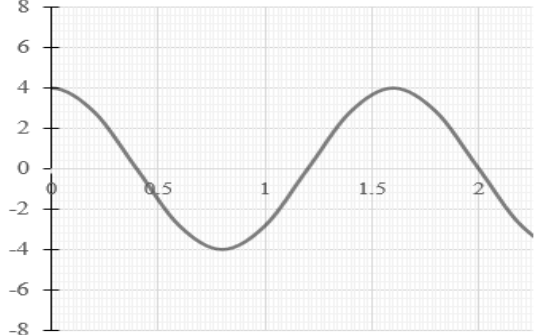


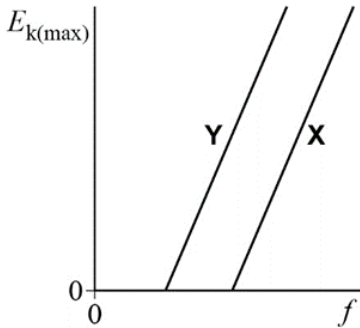
07.1	3.5 mm ✓	Accept 3.4 to 3.6	1	AO3
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Question	Answers	Additional comments/Guidelines	Mark	AO
07.2	Evidence of use of $v = f\lambda$ including 625 (Hz) ✓ Uses wavelength = 0.7 m to get 440 (m s ⁻¹) ✓	Allow range of 0.68 – 0.72 m in λ or 425-450 m s ⁻¹	2	AO3

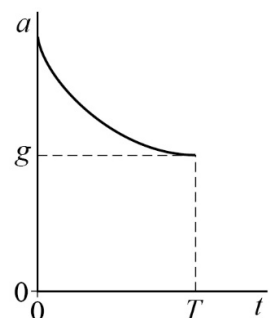
Question	Answers	Additional comments/Guidelines	Mark	AO
07.3	In phase OR 0 ✓	Accept 2π , 360° and multiples	1	AO1



Question	Answers	Additional comments/Guidelines	Mark	AO
07.4	Sinusoidal wave starting at displacement = 4 mm ✓ Amplitude = 4 mm ✓ Period ($= 625^{-1}$) = 1.6 ms ✓	Tolerance on drawing: half a square  Judge shape of wave on their first complete cycle. If there is no complete cycle, the line they have drawn must cover the width of the grid.	3	AO3
Total			7	

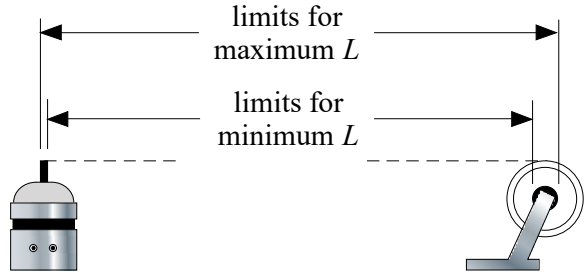
Question	Key	Answer	AO
08	C	the beta-plus decay of a ${}_{20}^{39}\text{Ca}$ nucleus	AO2
09	A		AO1
10	A	increases decreases	AO2
11	C	3	AO1
12	D	1800	AO2
13	D	5×10^6	AO2
14	A	unpolarised polarised	AO1
15	D	$2(L_2 - L_1)$	AO1
16	A	$(S_1 Y - S_2 Y) - (S_1 W - S_2 W)$	AO1
17	A	using monochromatic light of lower frequency.	AO1
18	B	$\frac{F}{m} \cos \beta - g \sin \alpha$	AO1



19	A	41°	AO2
20	D	$4d$	AO2
21	A	0.2 m	AO2
22	B		AO2
23	D	931 N	AO2
24	D	4700 kg	AO2
25	C	$3E$	AO2
26	C	$\frac{k(\Delta L)^2}{2t}$	AO2
27	D	1.50 V	AO2
28	A	from P to O	AO1
29	B	$2\pi^2 m f^2 r^2$	AO1

30	B	0.57 m s^{-1}	AO1
31	B	$\frac{T}{\sqrt{2}}$	AO2
32	C	$T \quad T\sqrt{2}$	AO2



01.1	mass per unit length of string OWTTE 1✓ length (of string) between vibration generator and pulley 2✓ acceptable limits for defining L in Figure 1: 	quantitative properties only answers may be in either order for 1✓ condone minor slip 'wire'; condone 'μ' of string; 'type of string' / 'same string' are neutral for 2✓ accept 'distance between vibration generator and pulley' / 'length of horizontal (part of) string'; allow clear annotation to Figure 1 to correctly identify dimension (correct by eye): allow use of a symbol, eg L condone 'amplitude of supply output voltage' / 'output voltage' or WTTE 'ac frequency' (or WTTE) / 'total (suspended) mass' / 'length of vibrating section (of string)' / 'diameter of string' (or WTTE) / 'amount of string between generator and pulley' / 'temperature of string' / 'positions of generator etc' are neutral	2	AO1
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Question	Answers	Additional comments/Guidance	Mark	AO
01.2	m has a maximum range of 170 g. ✓	CAO	1	AO3

Question	Answers	Additional comments/Guidance	Mark	AO
01.3	V_{peak} in range 18(.0) to 19(.0) (V) OR calculates V_{rms} using $\frac{\text{their } V_{\text{peak}}}{\sqrt{2}}$ 1✓ V_{rms} in range 13.0 to 13.2 (V) 2✓	for 1✓ allow $V_{\text{rms}} = 0.71 \times \text{their } V_{\text{peak}}$ etc; allow $V_{\text{peak to peak}}$ in range 36(.0) to 38(.0) (V) OR $V_{\text{rms}} = \frac{\text{their } V_{\text{peak to peak}}}{2\sqrt{2}}$ allow V_{rms} correct in cm, ie $\frac{3.7 \pm 0.1}{\sqrt{2}}$ OR $\frac{7.4 \pm 0.2}{2\sqrt{2}}$ for 2✓ max 4 sf; condone 4 sf rounding to 3 sf in range do not accept 2 sf 13 (V)	2	AO2

Question	Answers	Additional comments/Guidance	Mark	AO
01.4	T_{100} in range 104 to 107 (ms) ✓	period must be expressed in units of time; allow 0.104 to 0.107 s if answer line amended	1	AO3



Question	Answers	Additional comments/Guidance	Mark	AO						
01.5	determines T_{200} OR f_{200} AND attempts to compare T_{200} with T_{100} (their 01.4) OR attempts to compare f_{200} with f_{100} (based on their 01.4) $1\checkmark$ expected pairs of values: <table><tr><td>$T_{100} = 105.4 \text{ ms}$</td><td>$T_{200} = 74.5 \text{ ms}$</td></tr><tr><td>$f_{100} = 9.49 \text{ Hz}$</td><td>$f_{200} = 13.4 \text{ Hz}$</td></tr><tr><td>$T_{100} = 5.30 \text{ cm}$</td><td>$T_{200} = 3.73 \text{ cm}$</td></tr></table> compares $\frac{\text{their } T_{100}}{\text{their } T_{200}}$ OR $\frac{\text{their } f_{200}}{\text{their } f_{100}}$ to $\sqrt{2}$ OWTTE AND makes a reasoned judgement (to show if their evidence is consistent with doubling m) $2\checkmark$	$T_{100} = 105.4 \text{ ms}$	$T_{200} = 74.5 \text{ ms}$	$f_{100} = 9.49 \text{ Hz}$	$f_{200} = 13.4 \text{ Hz}$	$T_{100} = 5.30 \text{ cm}$	$T_{200} = 3.73 \text{ cm}$	for $1\checkmark$ their T_{200} in range 73.5 to 75.6 ms OR f_{200} in range 13.2 to 13.6 Hz; condone use of T_{100} and T_{200} in cm OR in div; ignore POT but must be consistent between values for $T_{100/200}$ or $f_{100/200}$; allow any quantitative comparison; condone a qualitative comparison award $2\checkmark$ as follows: states Figure 2 is the expected result with $\frac{\text{their } T_{100}}{\text{their } T_{200}} \geq 1.34 \text{ AND } \leq 1.48 \text{ (OR } 1.4) \text{ etc}$ OR states Figure 2 is not the expected result with $\frac{\text{their } T_{100}}{\text{their } T_{200}} < 1.13 \text{ OR } > 1.69$; otherwise accept either conclusion OR 'cannot tell'	2	AO3
$T_{100} = 105.4 \text{ ms}$	$T_{200} = 74.5 \text{ ms}$									
$f_{100} = 9.49 \text{ Hz}$	$f_{200} = 13.4 \text{ Hz}$									
$T_{100} = 5.30 \text{ cm}$	$T_{200} = 3.73 \text{ cm}$									
Total			8							

Question	Answers	Additional comments/Guidance	Mark	AO
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03.1	In some positions the waves always cancel /interfere destructively to give zero amplitude/no vibration/nodes) OR interfere constructively to produce positions of maximum amplitude/maximum vibration/antinodes ✓	Creates nodes and antinodes stationary ✓	1
03.2	Use of $f = \frac{1}{2l} \sqrt{\frac{T}{\mu}}$ ✓ 4.2 (4.19) × 10⁻⁴ (kg) ✓	Either rearranges for μ without substitution or substitutes correctly in the formula	1 1
03.3	240 (244) (m s ⁻¹)		1

03.4	1 rotation of the peg = 22 mm ✓	Or Reads increase in tension produced by the extra extension (about 10 N) from graph and adds to 25	1
	extra extension = $22 \times 75/360 = 4.6$ mm (ecf for incorrect circumference)✓	$\pi d \times 75/360$ not evaluated =1	1
	Total extension = 11 + 4.6 (15.6 mm) so tension 35 - 36N ✓	Inspect their length and their tension in the substitution	1
	Calculates frequency for their tension	T must <u>be greater than</u> the original 25N Condone adding or subtracting <u>extra</u> extension to 0.33 m If 4.0×10^{-4} kg used then answer will be in range 448 Hz to 455 Hz If 4.19×10^{-4} used 438 to 444 Hz	
Total			10
	Length of resistance wire = $50 \times 2 \times 3.14 \times 4 \times 10^{-3} = 1.26$ m✓	or $50 \times 3.14 \times 8 \times 10^{-3}$	1
	Substitution of data in resistance formula	ecf for incorrect length from attempt at a calculation	1



02.1	Idea that the oscillations (of particles in the wave) are at right angles $_1\checkmark$ to the direction of energy transfer $_2\checkmark$	Allow 'oscillates' for 'oscillations'. Do not accept 'vibrations'. Allow 'displacement' for 'oscillations' Credit a correctly labelled diagram Do not allow a contradiction in $_1\checkmark$ $_2\checkmark$ is contingent on $_1\checkmark$. Do not allow direction of (wave) motion/travel Treat any reference to polarisation as neutral. If no other mark given: award max 1 when answer suggests that <u>amplitude</u> is perpendicular to the direction of energy transfer.	2	AO1
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Question	Answers	Additional comments/Guidance	Mark	AO
02.2	Idea that waves (from vibration generator and reflected wave) travel in opposite directions (along the wire) and superpose $\checkmark$	If a reflected wave is referred to, the presence of an incident wave can be assumed. Do not accept 'interfere' for 'superpose' Do not accept reference to 'phase (difference)' unless correct, ie a valid comment would be 'phase difference is time dependent'.	1	AO1

Question	Answers	Additional comments/Guidance	Mark	AO
02.3	Idea that particles in wave between P_1 and P_3 are in phase OR between P_3 and P_5 are in phase $_1✓$ Idea that particles between P_1 and P_3 are in antiphase with particles between P_3 and P_5 OR idea that P_2 and P_4 are in antiphase $_2✓$	If no other mark given: award max 1 for 'P1 and P3 and P5 are nodes' and 'P2 and P4 are antinodes' provided that there is no reference to a phase relationship between the nodes. Reject: 'completely out of phase' or 'out of phase' for antiphase; allow 'π out of phase' or '180 degrees out of phase'.	2	AO2

Question	Answers	Additional comments/Guidance	Mark	AO															
02.4	Determines mass per unit length for either wire and answer seen on answer line $_1✓$ Determines frequency of first harmonic f_1 for one wire and value of W $_2✓$ Evidence of use of $5f_1$ to determine the frequency range OR evidence of required frequency ≤ 10 Hz $_3✓$ Comparison between the fifth-harmonic (frequency) and 50 Hz. $_4✓$ Wire B and $W = 1.0$ N $_5✓$	A $\mu = 6.60 \times 10^{-4} \text{ kg m}^{-1}$ B $\mu = 1.47 \times 10^{-3} \text{ kg m}^{-1}$ Allow incorrect values of mass per unit length to be carried forward from $_1✓$ to the rest of the answer except $_5✓$. Expect to see values from: <table border="1"> <thead> <tr> <th>W / N</th><th>A f_1 / Hz</th><th>A $5f_1 / \text{Hz}$</th><th>B f_1 / Hz</th><th>B $5f_1 / \text{Hz}$</th></tr> </thead> <tbody> <tr> <td>1.0</td><td>13.0</td><td>65.0</td><td>8.7</td><td>43.5</td></tr> <tr> <td>5.0</td><td>29.0</td><td>145</td><td>19.4</td><td>97.0</td></tr> </tbody> </table> For $_4✓$, look for some idea that their selected fifth-harmonic frequency is the greatest that does not exceed 50 Hz or that first-harmonic is greatest that does not exceed 10 Hz. Allow reference to 'range' for values of frequency. $_4✓$ does not require a value for the fifth harmonic. B can be identified by its mass or mass per unit length. MP5 is a standalone mark and can be awarded without further evidence.	W / N	A f_1 / Hz	A $5f_1 / \text{Hz}$	B f_1 / Hz	B $5f_1 / \text{Hz}$	1.0	13.0	65.0	8.7	43.5	5.0	29.0	145	19.4	97.0	5	1 × AO1 4 × AO3
W / N	A f_1 / Hz	A $5f_1 / \text{Hz}$	B f_1 / Hz	B $5f_1 / \text{Hz}$															
1.0	13.0	65.0	8.7	43.5															
5.0	29.0	145	19.4	97.0															

	Alternative $_2\checkmark$, $_3\checkmark$ and $_4\checkmark$ $_2\checkmark$ Calculates a wavelength (or half wavelength) for 50 Hz and any one combination of wire and weight. $_3\checkmark$ Evidence of maximum wavelength (or half wavelength) of fifth harmonic is 1.5/(5/2) or 0.6m (or 1.5/2 or 0.3 m). $_4\checkmark$ compares between their combination wavelength and their fifth harmonic maximum wavelength.	For alternative $_2\checkmark$ expect to see one from: <table><tr><th>W / N</th><th>A wavelength / m</th><th>B <i>wavelength</i> / m</th></tr><tr><td>1.0</td><td>0.78</td><td>0.52</td></tr><tr><td>5.0</td><td>1.74</td><td>1.17</td></tr></table> If alternative methods are used: $_2\checkmark$ is for using the frequency formula, $_3\checkmark$ is for a calculation that allows the comparison; $_4\checkmark$ is for the comparison.	W / N	A wavelength / m	B <i>wavelength</i> / m	1.0	0.78	0.52	5.0	1.74	1.17	
W / N	A wavelength / m	B <i>wavelength</i> / m										
1.0	0.78	0.52										
5.0	1.74	1.17										
Total			10									

Question	Answers	Additional comments/Guidance	Mark	AO
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03.1	no credit for 1 sf; treat 60 as 2 sf unless clearly rounded to 6×10^1	for $_{12}\checkmark$ require ≥ 2 sf that rounds to more than 62 but not more than 64 if incorrect rounding leads to 60 treat this as 1 sf and give no credit use of $\frac{1}{T}$ does not have to be seen; marks are for final answer seen	AO3-1a = 2
03.2	(figures) 804 and 226 seen in working $_1\checkmark$ λ = difference between their readings $\times 2$; given to nearest mm; expect 1.156 (m) OR to nearest cm; expect 1.16 (m) $_2\checkmark$	for $_1\checkmark$ 578 is not enough for $_2\checkmark$ range is based on $x = (804 - 226 =) 578 \pm 2$ mm; give no credit for POT errors eg 115.6 / 116 etc accept 1156 mm etc if unit on answer line is amended	AO3-1b = 2
03.3	c correctly evaluated to ≥ 2 sf from their $f \times$ their $\lambda \checkmark$	substituted data may be from 03.1/2 final answers or unrounded (intermediate) data from working expected answer = $61 \times 0.578 \times 2 = 70.5 \text{ m s}^{-1}$	AO2-1d = 1

03.4	μ correct to 2 sf based on their f and their λ earns both marks $_1\checkmark_2\checkmark$ for incorrect / missing μ EITHER use of $c = \sqrt{\frac{T}{\mu}}$ OR use of $f = \frac{1}{2l} \sqrt{\frac{T}{\mu}}$ $_{12}\checkmark$	for $_1\checkmark$ their value of μ can be given to ≥ 2 sf but must agree with $\frac{0.5 \times g}{(\text{their } f \times \lambda)^2}$ OR $\frac{0.5 \times g}{(\text{their } c)^2}$ when rounded to 2 sf; use of $g = 9.81$ or 9.8 only; no ecf for mixed units expected answer $\mu = 9.9 \times 10^{-4} \text{ (kg m}^{-1}\text{)}$: be wary of which approach has been taken by the candidate for $_{12}\checkmark$ 'use of' means allow either rearranges so that μ is the subject eg $\mu = \frac{T}{c^2}$ (accept $\mu = \frac{mg}{c^2}$, $\frac{T}{c^2} = \mu$ etc) or substitution of all relevant data including their c into a correct expression with μ as the only unknown for T allow $4.9 / 4.91 / 4.905$ (accept 0.5×9.81 or 0.5×9.8); allow mixed units; allow $0.5g$ OR 'use of' means allow either rearranges to $\mu = \frac{T}{(2 \times l \times f)^2}$ OR $\frac{T}{4 \times l^2 \times f^2}$ or substitution of all relevant data including their l and f leaving μ as the unknown; allow sub of λ for $2l$ watch for possible error $\lambda = L$	AO2-1d = 2
03.5	0.71 (mm) $\checkmark$	only answer that gets mark	AO3-1b = 1

03.6	ANY TWO FROM repeat readings at different points along the rod and calculate an average / mean ₁✓ repeat readings in different directions (perpendicular to the rod) and calculate an average / mean ₂✓ reject / discard anomalous readings before calculating an average / mean ₃✓ award ₁₂₃✓ = 1 MAX for checking at different points / in different directions to confirm that the rod is uniform / that there are no anomalies	allow 'cylinder' / 'wire' etc for rod for ₁✓ ₂✓ and ₃✓ averaging idea only needs to be seen once; if averaging idea missing then allow 'repeat at different points and in different directions, then remove anomalies' ₁₂₃✓ = 1 MAX if 'calculate' is not seen allow 'work out' / 'determine' / 'compute'; anything that sounds like a mathematical process is ok; 'find' / 'obtain' / 'take' / 'do an average' are just ok; 'get' is not ok for ₁✓ allow repeat at 'different positions' / 'down / along the rod' for ₂✓ allow (repeat in different directions) 'around the rod' / 'different orientations' / 'angles' / 'planes' / 'sides' for ₃✓ allow 'ignore anomalies'; 'outlier' = 'anomaly' reject 'calculate an average to eliminate effect of anomalies' treat as neutral: 'turn the wheel to close the callipers' / suggestions about calibration treat as neutral: 'zero callipers before use' this is a procedure to eliminate a source of systematic error	AO2-1g = MAX 2
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03.7	(for use of expected 0.71) $\rho = 8.9(41) \times 10^3 \text{ (kg m}^{-3}\text{)}$ OR (for use of 0.53) $\rho = 1.6(05) \times 10^4 \text{ (kg m}^{-3}\text{)}$ OR $\rho = \frac{4.51 \times 10^{-3}}{(\text{their } d \text{ from 03.5})^2} \text{ }_{123} \checkmark \checkmark \checkmark$ OR attempts to use μ OR $3.5(4) \times 10^{-3}$ divided by their (recognisable) cross-sectional area $_1 \checkmark$ AND/OR evidence showing cross-sectional area $= \frac{\pi d^2}{4}$ using their d from 03.5 (allow πr^2 using their d) $_2 \checkmark$	correct answer scores $_{123} \checkmark \checkmark \checkmark$ for $_{123} \checkmark \checkmark \checkmark$ allow an answer that rounds to the correct 2 sf value sample results for expected d <table><thead><tr><th>d/mm</th><th>A/m^2</th><th>$\rho/\text{kg m}^{-3}$</th></tr></thead><tbody><tr><td>0.71</td><td>3.96×10^{-7}</td><td>$8.9(41) \times 10^3$</td></tr><tr><td>0.53</td><td>2.21×10^{-7}</td><td>$1.6(05) \times 10^4$</td></tr></tbody></table> for $_1 \checkmark$ accept use of symbols, eg $\rho = \frac{\mu}{A} \text{ / } = \frac{3.54 \times 10^{-3}}{A(\times 1)} \text{ / } = \frac{4 \times \mu}{\pi \times d^2} \text{ / } = \frac{4 \times 3.54 \times 10^{-3}}{\pi \times d^2(\times 1)}$ $= \frac{3.54 \times 10^{-3}}{\pi \times r^2(\times 1)}$ for $_2 \checkmark$ expect correct value of A seen or correct values of A or d in working, eg $\rho = \frac{3.54 \times 10^{-3}}{3.96 \times 10^{-7}(\times 1)} \text{ / } = \frac{4 \times 3.54 \times 10^{-3}}{\pi \times (0.71 \times 10^{-3})^2 \times (1)}$ accept values ≥ 2 sf for A; allow ecf d and don't penalise POT error in A or d (eg missing 10^{-7}, 10^{-3})	d/mm	A/m^2	$\rho/\text{kg m}^{-3}$	0.71	3.96×10^{-7}	$8.9(41) \times 10^3$	0.53	2.21×10^{-7}	$1.6(05) \times 10^4$	AO3-1a = $\frac{1}{2}$ AO2-1h = $\frac{1}{2}$
	d/mm	A/m^2	$\rho/\text{kg m}^{-3}$									
0.71	3.96×10^{-7}	$8.9(41) \times 10^3$										
0.53	2.21×10^{-7}	$1.6(05) \times 10^4$										
Total			13									

C



C



D



20

D (AO2)

$$2.2 \times 10^{-4} \text{ m}$$



16

A

 $0.22s$ 0.66λ 

16

A

$$(S_1Y - S_2Y) - (S_1W - S_2W)$$

AO1



17	A	using monochromatic light of lower frequency.	AO1
...	...	F	...



17

D

$$\frac{rs}{\lambda D}$$

AO1



03.1	Understanding that for coherence sources must have same frequency/wavelength AND constant phase difference. ✓ And that this achieved by both speakers being connected to same signal (generator). ✓		2	AO1a AO1b
03.2	The sound waves from the two speakers <u>superpose</u> (at a point) ✓ At A (and B) the two waves are in phase/ have zero phase difference (and a maximum is produced)✓ Moving away from A introduces a path difference/phase difference/waves are out of phase (and amplitude decreases) ✓ (Moving on towards B the waves move back in phase)	Do not accept 'interfere' or 'superimpose' for 'superpose' Accept for MP1 waves adding together/combine at a point (e.g. point A) for 'superpose'. Do not accept diagram. Award MP3 for formation of minimum/destructive interference due to (odd number of) half wavelength path difference/ π/ 180° phase difference/ antiphase.	3	2 × AO2.1g 1 × AO2.1c
03.3	Clear evidence of use of Pythagoras ✓ Correct calculation of either length PB or QB ✓ $PB = (2.25^2 + (0.95 - 0.3/2)^2)^{1/2} = 2.39 \text{ m}$ $QB = (2.25^2 + (0.95 + 0.3/2)^2)^{1/2} = 2.50 \text{ m}$ (Path difference =) $QB - PB$ either numerically or algebraically✓ (= 0.11 (0.12) m)	If ws/D used to give 0.13 (m) reward with 1 mark	3	AO2.1h

Question	Answers	Additional comments/Guidelines	Mark	ID details
03.4	(Path difference = one wavelength) Use of speed = frequency $\times$ wavelength to give Speed = $2960 \times 0.12 = 360 \text{ m s}^{-1}$ ✓	Working or equation must be seen. Condone use of 0.10 m or 0.11 m or 0.127m or 0.13 m 0.10 gives 300 (296) m s^{-1} 0.11 gives 330 (325.6) m s^{-1} 0.127 gives 376 m s^{-1} 0.13 gives 380 (385) m s^{-1}	1	AO2.1h
03.5	Wavelength (gradually) increases. ✓ So that path difference at C gets closer to one wavelength✓ (Amplitude of) sound will get larger/louder as waves move in phase (then smaller/quieter).✓	Alternative for MP2: Separation of maxima (along line AB) increases✓ Alternatives for MP3: Maximum moves (from B) towards C so amplitude of sound gets larger/louder (then quieter). OR Maximum moves further along path/beyond C so amplitude of sound gets quieter✓	3	AO3.1a
Total			12	

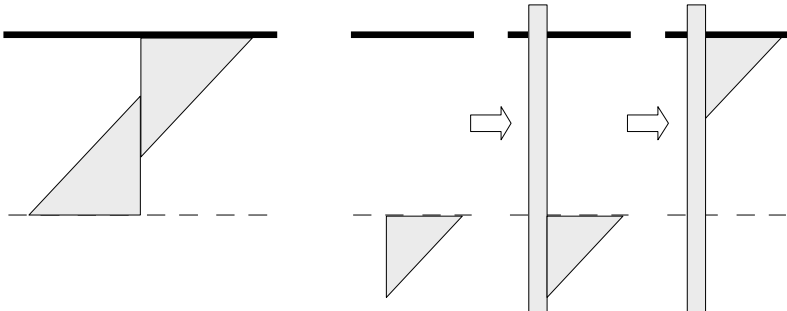


Question	Answers	Additional comments/Guidelines	Mark	ID details
	Evidence of distance travelled = area under graph			



01.1	π radians ✓	reject 'half a cycle' treat 'π radians in phase' as talk out	1
01.2	(idea that) sets of combining waves do not have the same amplitude ✓	condone 'waves do not have same intensity' or 'same energy' or 'some energy is absorbed on reflection' or 'same power' or 'same strength' or idea that non point source or non point receiver would lead to imperfect cancellation condone the idea that the waves may not be monochromatic ignore 'some waves travel further' or 'waves do not perfectly cancel out' reject 'waves may not be 180° out of phase'	1



01.3	valid use of a set square or protractor against TR (to ensure perpendicular) ₁✓ measure x at two <u>different</u> points [at each end of M] and adjust until [make sure] both <u>distances are the same</u> ₂✓ OR use of set square to align M with the perpendicular line earns ₂✓ if method used does not allow <u>continuous</u> variation in x then award maximum 1 mark OR align <u>graph paper</u> with TR ₁✓ align M with grid lines on graph paper ₂✓	both marks can be earned for suitable sketch showing a viable procedure involving one or more recognisable set squares or protractors; the sketch may also show a recognisable ruler, eg  allow use of scale on set square to measure the perpendicular distances don't penalise incorrect reference to the set square, eg as 'triangular ruler', as long as the sketch shows a recognisable set square	2
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01.4

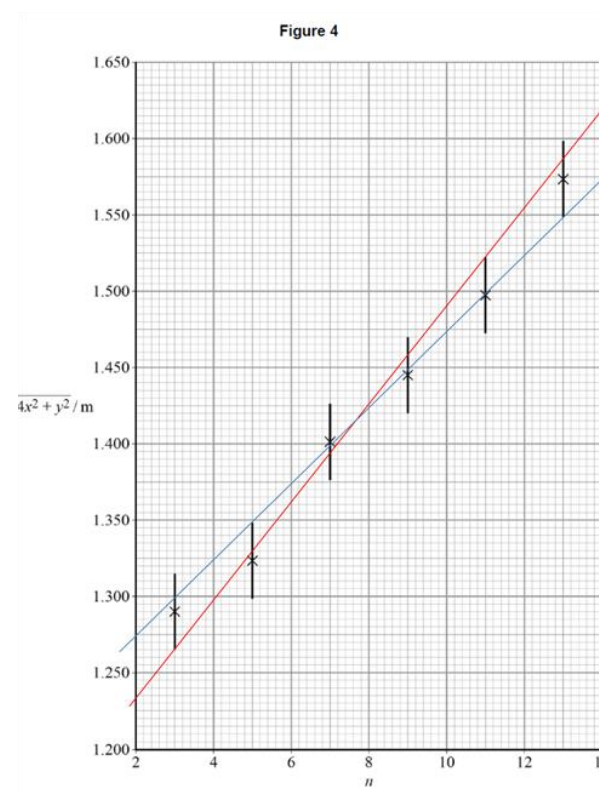
$G_{\max}$ line ruled through bottom of $n = 3$ error bar and through top of $n = 11$ error bar $_1$ ✓

$G_{\min}$ line ruled through top of $n = 5$ error bar and through bottom of $n = 13$ error bar $_2$ ✓

$G_{\max}$ and $G_{\min}$ calculated from valid y step divided by valid x step; both n steps ≥ 6 $_3$ ✓

allow 1 mm tolerance when judging intersection of gradient lines with error bars

ignore any unit given with $G_{\max}$ or $G_{\min}$; penalise power of ten error in 01.5



$_{12}$ ✓ = 1 MAX if (either) line is thicker than half a grid square or of variable width or not continuous;

expect $G_{\max} = 3.2(1) \times 10^{-2}$ and $G_{\min} = 2.5(2.49) \times 10^{-2}$

3

01.5	λ (from $\frac{G_{\max} + G_{\min}}{2}$) AND result in range 2.8(0) to 2.9(0) $\times 10^{-2}$ (m) $_1\checkmark_2\checkmark$ OR award one mark for 2.7(0) to 3.0(0) $\times 10^{-2}$ (m) $_{12}\checkmark$	penalise 1 mark for a power of ten error reject 1 sf 3 $\times 10^{-2}$ (m) if a best fit line is drawn between the $G_{\max}$ and $G_{\min}$ lines and the gradient of this is calculated award 1 mark for λ in range 2.8(0) to 3.0(0) $\times 10^{-2}$ (m)	2
01.6	uncertainty in $\lambda = G_{\max} - \lambda$ OR $\lambda - G_{\min}$ OR $\left(\frac{G_{\max} - G_{\min}}{2}\right) \quad _1\checkmark$ percentage uncertainty = (uncertainty/ λ) $\times 100$ $_2\checkmark$ result in range 11(.0) % to 14(.0) % $_3\checkmark$	$_1\checkmark$ can be earned by showing a valid uncertainty then dividing by λ ecf their λ , $G_{\max}$ and $G_{\min}$ for $_1\checkmark$ and $_2\checkmark$ allow λ found from best fit line accept $\left(\frac{G_{\max} - \lambda}{\lambda}\right) \times 100$ or $\left(\frac{G_{\max} - G_{\min}}{G_{\max} + G_{\min}}\right) \times 100$ etc for $_{12}\checkmark\checkmark$ allow $\left(\frac{\Delta\lambda}{\lambda}\right) \times 100$ where $\Delta\lambda$ is any plausible uncertainty for $_2\checkmark$ numerical answer without valid working can only earn $_3\checkmark$	3

01.7	(states) <u>calculate</u> the (vertical) intercept $_1$ ✓ OR outlines a valid calculation method to calculate y_1 ✓ determine the intercept for <u>both lines</u> and calculate average value $_2$ ✓ OR determine the (vertical) intercept of the line of best fit (between $G_{\max}$ and $G_{\min}$) $_2$ ✓	draw the line of best fit (between $G_{\max}$ and $G_{\min}$); perform calculation to find intercept earns $_{12}$ ✓✓	2																				
01.8	<table border="1"> <thead> <tr> <th>result</th><th>reduced</th><th>not affected</th><th>increased</th></tr> </thead> <tbody> <tr> <td>$G_{\max}$</td><td></td><td>✓</td><td></td></tr> <tr> <td>$G_{\min}$</td><td>✓</td><td></td><td></td></tr> <tr> <td>λ</td><td>✓</td><td></td><td></td></tr> <tr> <td>y</td><td></td><td></td><td>✓</td></tr> </tbody> </table>	result	reduced	not affected	increased	$G_{\max}$		✓		$G_{\min}$	✓			λ	✓			y			✓	general marker question allow any distinguishing mark as long as only one per row for ✓ and ✕ in same row ignore ✕ for ✓ and ✓ in same row give no mark ignore any crossed-out response	4
result	reduced	not affected	increased																				
$G_{\max}$		✓																					
$G_{\min}$	✓																						
λ	✓																						
y			✓																				



alternative approach: single best fit line drawn on Figure 4			
01.4	G calculated from y step divided by x step; $n \text{ step} \geq 6$ ✓		MAX 1
01.5	λ in range 2.8(0) to 2.9(0) $\times 10^{-2}$ ✓		MAX 1
01.6	percentage uncertainty in $\lambda = \frac{\Delta\lambda}{\lambda} \times 100$ AND result in range 11(.0) % to 14(.0) % ✓		MAX 1
01.7	<u>calculate</u> intercept OR outlines a valid calculation method to find y ✓		MAX 1
01.8	as main scheme	no ecf possible	4
alternative approach: non-crossing lines for G_{max} and G_{min} on Figure 4 : includes lines that meet but do not cross			
01.4	G_{max} and G_{min} calculated from y step divided by x step; both $n \text{ steps} \geq 6$ ✓		MAX 1
01.5 to 01.8	as main scheme		11

Question	Answer	Additional Comments/Guidance	Mark
	peak (to peak) voltage = 6.3(0) (V) ✓	accept any answer that rounds to 6.3 V	



A



B



19	B
----	---



19	C	433 nm
----	---	--------



21

D (AO2)

9



17

C

decreases

increases



15

C

light from adjacent slits arrives at the screen in phase.

AO1



20

D

17

AO2



03.1		Suggestion that pattern due to white light = max 1 Reference to Young's slit or equation = max 1 If only a single maximum is referred to MP2=0 but MP1 can score for description of intensity variation.	2
03.2	Wider (central) maxima (maximum) ✓ (Subsequent) maxima further apart ✓	'The pattern is wider/more spread out' gets 1 mark if no other marks given. Not "larger pattern". Condone "larger" distances between maxima. Condone 'maxima more spaced out' Reference to Young's slit or equation = max 1 Ignore comments related to change in wavelength	2
03.3	$d = 1 \times 10^{-3}/500 (= 2 \times 10^{-6})$ ✓ $(\sin \theta = n\lambda/d = 6.5 \times 10^{-7} / 2 \times 10^{-6} = 0.33)$	Allow POT error for d for MP1 May be seen in diffraction grating equation.	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	Any two from: ✓ ✓ (Range of wavelengths results in): Central maximum unchanged in width Broader maxima/range of angles for each maximum/order Gradually getting broader/more spread out for greater order maxima Part of third order maximum suppressed at long wavelengths (for $\theta > 90^\circ$)	Give credit for answer shown in diagram Evidence for these marks may be seen in calculations Treat intensity variation as neutral.	Max 2
Total			8

Question	Answers	Additional Comments/Guidelines	Mark
	The <u>centre of mass</u> of the beam and box is at the pivot ✓ Idea that moments balance / sum of the moments is zero at this position ✓ OR The anticlockwise moment (of weight of the beam) = clockwise moment (of weight of the box) ✓	Accept one route or the other, do not accept points from both. Allow max 1 for “the pivot is to the right of the centre (of mass) of the beam” ‘pivot’ on its own does not get the first mark	



D



D



14	D
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18

D

2.32

AO2

26

19

B

$$2.1 \times 10^8 \text{ m s}^{-1}$$

AO2



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			6

Question	Answers	Additional Comments/Guidelines	Mark
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06.1	As angle of refraction greater than angle of incidence with reference to Snell's law / $n = \sin i \div \sin r$ OR light bends away from normal when it speeds up ✓ (Therefore $n_A > n_B$)		1	AO1
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Question	Answers	Additional comments/Guidelines	Mark	AO
06.2	Calculation of angle of incidence = $90^\circ - 43^\circ = 47^\circ$ ✓ Use of Snell's law to give angle of refraction = $61(.4)^\circ$ ✓	MP1 may be seen on diagram Calculator value: 61.357 115 7	2	2 x AO2

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

Question	Key	Answer
07	C (AO1)	work done and the moment of a couple
08	D (AO3)	$m \mu p$
09	B (AO1)	10^6 J
10	A (AO2)	$4.4 \times 10^7 \text{ C kg}^{-1}$
11	C (AO1)	from 0.5 fm to 3 fm up to 0.5 fm
12	B (AO1)	Strange particles are always created in pairs.
13	B (AO2)	$s\bar{u}$
14	B (AO2)	maximum kinetic energy of a photoelectron
15	B (AO1)	absorbs photons of ultraviolet light from the gas and emits visible light.
16	A (AO1)	electron diffraction photoelectric effect
17	D (AO2)	a proton moving at $8 \times 10^5 \text{ m s}^{-1}$
18	C (AO2)	It oscillates with a time period of 1.5 ms.
19	A (AO1)	first
20	D (AO2)	$2.2 \times 10^{-4} \text{ m}$
21	D (AO2)	9
22	A (AO1)	270 km

23	C (AO2)	14 m
24	B (AO2)	4100 N
25	C (AO1)	the gravitational force of the parachutist on the Earth
26	D (AO2)	0.614 N s
27	D (AO1)	$9E$
28	C (AO3)	The strain of Q is double the strain of P.
29	A (AO2)	1.1×10^{18}
30	D (AO2)	25Ω
31	C (AO2)	54 mm s^{-1}

03.1	Speed = $3.0 \times 10^8 / 1.47$ = $2.0(4) \times 10^8 \text{ m s}^{-1}$ ✓	Do not accept 1 sf answer	1	AO1.1b
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Question	Answers	Additional comments/Guidelines	Mark	AO
03.2	Critical angle calculation ✓ $\sin C = n_{\text{clad}}/n_{\text{core}} = 1.41/1.47 = 0.96$ critical angle = 73.6° Angle of refraction calculation ✓ $r = 90 - C = 16.4^\circ$ Angle of incidence calculation ✓ $\sin(i) = 1.47 \sin(r)$ $i = 24.5^\circ$	Do not give MP2 if calculated answer is given as A Allow 2 sf answer; allow 24.6°	3	AO2.1d

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

Question	Answers	Additional comments/Guidelines	Mark	AO
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03.1	ray through A links to ray in B AND ray in B horizontal by eye ✓	Ignore any arrow directions.	1	AO2
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Question	Answers	Additional comments/Guidelines	Mark	AO
03.2	Conclusion consistent with their Figure 1 ✓ Supported by consideration of their angles of incidence and refraction at AB boundary ✓	Answer must be consistent with their Figure 1. For a correct diagram expect to see B has greater refractive index / A has lower refractive index' 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'.	2	AO3

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

Question	Answers	Additional comments/Guidelines	Mark	AO
03.4	MAX 2 from ✓✓ • λ read from spectrum = 380 nm • use of $d \sin \theta = n \times (\text{their } \lambda)$ • use of $G = \frac{1}{d}$ to give $1.2 \times 10^6 \text{ (m}^{-1}\text{)} \checkmark$	Ignore POT error in MP1 & MP2. Accept answer in range 377.5 – 382.5 nm. ‘Use of’ means clear substitution of n, θ and their λ or rearrangement of equation to give $d = \frac{n\lambda}{\sin \theta}$. If n not seen, assume that $n = 1$. Expect to see $8.04 \times 10^{-7} \text{ m}$ for d MP2 and MP3 may be seen together Calculator value range: $1.251790 \times 10^6 \text{ m}^{-1}$ to $1.2435547 \times 10^6 \text{ m}^{-1}$ to $1.235427 \times 10^6 \text{ m}^{-1}$	3	2 × AO2 1 × AO3

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

Question	Answers	Additional comments/Guidelines	Mark	AO
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02.1		<u>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	$C = \arcsin(1/1.52) = \arcsin(0.66) = 41(.1)^\circ$ ✓ $45^\circ > \text{critical angle} / 41.1^\circ$ 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	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°) ✓ 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)	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”	2
02.5	Statement of effect of change in n on the path direction ✓ (Sensible reference to the variation of a few per cent) leads to the idea that change is unlikely to be significant ✓	Eg for MP1 • Light may change direction inside windscreen • Light may change direction at a windscreen boundary Eg for MP2 • Variation too small to deviate significantly within windscreen – internal effect • Variation too small to affect tir at A without	Max 2

			droplet – boundary effect • Variation too small to significantly affect transmission at A with droplet – boundary effect Allow discussions that <i>may</i> cause a difference, eg there is a summative effect from multiple reflections etc	
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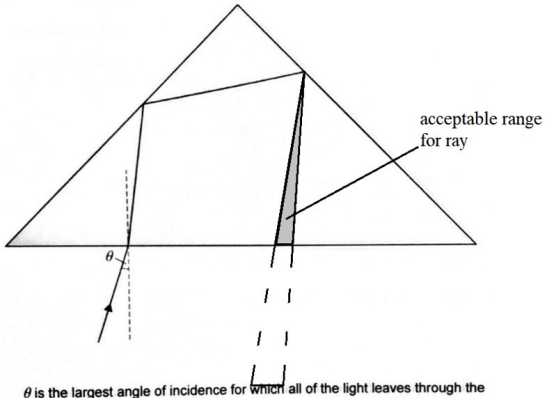
02.6	More sensitive because more likely to encounter/detect water drop OR will encounter more water drops ✓ bigger decrease in light intensity, so more sensitive to rain ✓ Less sensitive because more likely to encounter imperfections in glass/on surface of glass /dirt on surface of glass ✓ any curvature effects will be greater so may not hit detector ✓ light intensity reduced without presence of water / greater absorption in windscreen due to greater path length ✓	Allow any 2 comments taken from list . There must be a sense of whether the comment relates to an improvement or decrease in sensitivity. Treat as list; mark 1 and 2 independently. Allow idea of larger area Do not allow a response that discusses travel time of ray.	Max 2
Total			11

Question	Answers	Additional Comments/Guidelines	Mark
	Central maximum with lower intensity maxima (either side) ✓ Central maximum is twice as wide/wider than other maxima ✓	MP1 is for comparison of intensity. Condone references to brightness/dimness. MP2 is for comparison of width Award credit for a drawn answer eg on Fig 3.	



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
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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). ✓		2	AO1 AO2

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

Question	Answers	Additional comments/Guidelines	Mark	AO
04.4	Angle of incidence at 2nd reflecting boundary = 41.5° ✓ Angle of reflection at 1st reflecting boundary = 48.5° ✓ Angle of refraction at entry = $(90^\circ - 45^\circ - 41.5^\circ) = 3.5^\circ$ ✓ Use of $n = 1.5$ and Snell's law to give 5.3° to at least 2 sf ✓	MP1 is an identification of angle at 2nd reflecting boundary MP2 is <math>(90^\circ - \text{their angle at 2nd reflecting boundary})</math> MP3 is <math>(45^\circ - \text{their angle at 2nd reflecting boundary})</math> Accept answer that rounds to 5.3° 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.	4	AO1

Question	Answers	Additional comments/Guidelines	Mark	AO
04.5	Using 60° prism (Fig 9) does not work because: - light would not leave the prism at the original angle ✓ - idea that light will escape from second reflection ✓ A smaller n (Fig 10) does not work because: - larger critical angle ✓ - which would reduce the value of θ ✓	Suggestion that the design would work limits the mark to Max 1 for that design. Alternative for MP2 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	4	AO3
Total			14	

Question	Answers	Additional comments/Guidelines	Mark	AO
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C



D



A



D



13	A
----	---



C



16	B	muon electron
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16	A (AO1)	electron diffraction photoelectric effect
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17

D (AO2)

a proton moving at $8 \times 10^5 \text{ m s}^{-1}$ 

29

C (AO1)

the existence of gamma radiation



13

A

decreasing the kinetic energy of the electrons



11

C

3

AO1



12	D	1800	AO2
12	D	1800	AO2



12

C

using a light source that emits light of a shorter wavelength

AO1



13	C	photoelectric effect	diffraction	AO1
		1		



27

A

$$2.2 \times 10^{-13} \text{ m}$$

AO1



26	C	0.103 MeV	AO2
		122	122



08.1	$QV = \frac{1}{2}mv^2$ OR $v = \sqrt{\frac{2QV}{m}}$ ✓ To get answer that rounds to $6.8 \times 10^6 \text{ (m s}^{-1}\text{)}$ ✓		2	AO2
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Question	Answers	Additional comments/Guidance	Mark	AO
08.2	Idea that the (average) KE of (current) electrons is reduced through inelastic collisions (with mercury atoms) ✓	Condone 'electrons transfer (kinetic) energy to mercury/gas atoms' Allow particles for atoms	1	AO1

Question	Answers	Additional comments/Guidance	Mark	AO
08.3	Yes AND idea that the graph shows that substance X released (most) photons in the UV part of the spectrum ✓ Idea that UV radiation excites (atoms in) the coating to give longer wavelength radiation (when atoms de-excite) ✓	Accept appropriate synonym for 'radiation' Accept for 'coating': phosphor/lining/fluorescent material	2	1 × AO3 1 × AO1

Question	Answers	Additional comments/Guidance	Mark	AO
08.4	Max 2 from ✓✓ $2.55 \times 10^{-7} \text{ m}$ used their energy = $\frac{hc}{\text{their wavelength}}$ Converts their energy to eV 4.9 eV ✓	Do not condone POT error in MP1 bullet point 1 Acceptable range: 250 nm to 260 nm Energy: 4.77 eV to 4.97 eV Accept 5.0	3	1 × AO1 2 × AO2
Total			8	

Question	Key	Answer	AO		
09	C	$d\bar{u}$	AO1		
10	A	energy is conserved.	AO1		
11	A	<table><tr><td>1 mN</td><td>1 km</td></tr></table>	1 mN	1 km	AO1
1 mN	1 km				
12	C	using a light source that emits light of a shorter wavelength	AO1		
13	C	<table><tr><td>photoelectric effect</td><td>diffraction</td></tr></table>	photoelectric effect	diffraction	AO1
photoelectric effect	diffraction				
14	A	$\frac{1}{\text{diameter of the wire}}$	AO1		
15	C	light from adjacent slits arrives at the screen in phase.	AO1		
16	A	The resistance of the diode decreases as V increases for $V > V_s$.	AO1		
17	D	$\frac{Y_s}{\lambda D}$	AO1		
18	D	2.32	AO2		

19	B	$2.1 \times 10^8 \text{ m s}^{-1}$	AO2		
20	D	17	AO2		
21	B	The drag force when her velocity is v_2 is equal to the drag force when her velocity is v_1 .	AO2		
22	B	$3.5 \times 10^{-19} \text{ J}$	AO2		
23	B	5.3°	AO2		
24	D	4.7 N	AO2		
25	B	<table><tr><td>maximum</td><td>minimum</td></tr></table>	maximum	minimum	AO1
maximum	minimum				
26	A	$\rho_1 + \rho_2$	AO2		
27	A	$2.2 \times 10^{-13} \text{ m}$	AO1		
28	C	<table><tr><td>18</td><td>18</td></tr></table>	18	18	AO2
18	18				
29	A	1.44 C	AO1		

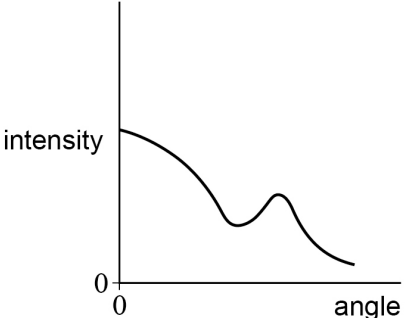
30	D	$\frac{q}{r}$	AO1
31	A	190 g	AO2
32	B	1.1 Hz	AO2
33	C	6	AO1

05.1	(using mass defect = $\Delta m = Z m_p + N m_n - M_{\text{Co}}$) $\Delta m = 27 \times 1.00728 + 32 \times 1.00867 - 58.93320$ (u) ✓ $\Delta m = 0.5408$ (u) ✓ Binding Energy = $0.5408 \times 931.5 = 503.8$ (MeV) ✓ (CE this mark stands alone for the correct energy conversion even if more circular routes are followed.	Look at use of first equation and if electrons are used or mass of proton and neutron confused score = 0. If subtraction is the wrong way round lose 1 mark. Data may come from rest mass eg $m_n = 939.551$ MeV or 1.675×10^{-27} kg or 1.00867 u. So if kg route used $\Delta m = 8.83 \times 10^{-28}$ kg BE = 7.95×10^{-28} J and 497 MeV. Conversion mark (2nd) may come from a wrong value worked through. 0.47(5)	3
05.2	$(2.52 - 1.76) \times 10^{-13} = 7.6 \times 10^{-14}$ J ✓ $7.6 \times 10^{-14} / 1.60 \times 10^{-13} = 0.47$ or 0.48 MeV ✓ (0.475 MeV)	Correct answer scores both marks.	2
05.3	6 (specific wavelengths)		1
05.4	(longest wavelength = lowest frequency = smallest energy) $(2.29 \times 10^{-13} - 2.06 \times 10^{-13}) = 2.3 \times 10^{-14}$ (J) ✓ $\lambda (= h c / E) = 6.63 \times 10^{-34} \times 3.00 \times 10^8 / 2.3 \times 10^{-14}$ ✓ $\lambda = 8.6 - 8.7 \times 10^{-12}$ (m) ✓ (8.6478×10^{-12} m)	Allow a CE in the second mark only if the energy corresponds to an energy gap including those to the ground state. The allowed energy gaps for CE are: 2.29, 2.06, 1.76, 0.53, 0.30 all $\times 10^{-13}$ J Note substitution rather than calculation gains mark. The final mark must be as shown here and not from a CE above.	3
Total			9

Question	Answers	Additional Comments/Guidelines	Mark
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01.1	Any one from: ✓ • $(\Delta)E_k = (\Delta)E_p$ seen • $E_k = 1.60 \times 10^{-19} \times 5.59 \times 10^6$ or 8.94×10^{-13} seen • $Q_\alpha = 2e$ and $Q_{Au} = 79e$ An energy $= \frac{Q_\alpha Q_{Au}}{4\pi\epsilon_0 r}$ seen in any form ✓ $r \left(= \frac{2 \times 1.60 \times 10^{-19} \times 79 \times 1.6 \times 10^{-19}}{4\pi \times 8.85 \times 10^{-12} \times 5.59 \times 10^6 \times 1.60 \times 10^{-19}} \right)$ ($\leq$) 4.1×10^{-14} (m) ✓ (allow 1 sf) cao	MP1 may be seen in substitution for r Condone PoT error in MP1 and MP2. In MP2: Allow use of $E = QV$ and $V = \frac{Q}{4\pi\epsilon_0 r}$ with Q_α and Q_{Au} in either order. Condone use of k for $\frac{1}{4\pi\epsilon_0}$ unless contradicted by use of 1.38×10^{-23} Condone use of E_k in MeV. Condone 10^{-14} if supported by some correct substitution. Correct answer to at least 1 SF gains all 3 marks.	3	AO2
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Question	Answers	Additional comments/Guidance	Mark	AO
01.2	Any two from: ✓✓ - Idea that alpha particles give an upper limit on size of the nucleus / estimate is larger than nuclear radius - Idea that (distance of closest approach) depends on the energy of the alpha particle - Idea that recoil of nucleus is ignored - Idea that alpha particle has finite size	Ignore references to shape of nucleus. bullet 1: condone idea that it does not hit the nucleus. Referencing the distance of closest approach is not enough. bullet 2: is for the idea that the closest approach method does not give a single value Condone does not take into account neutrons / only considers charge / only considers number of protons. If no other mark awarded allow max 1 for reference to not taking into account the effect of the strong nuclear force.	2	AO1

Question	Answers	Additional comments/Guidance	Mark	AO
01.3	When angle = 0 there is a maximum and first minimum is not zero and at least one subsequent smaller maximum ✓ Idea that nuclear radius is determined from (first diffraction) minimum ✓	 Allow subsequent peaks Condone the line meeting the intensity axis at non-zero but negative gradient. Do not allow double slit (even superposed with single slit) or diffraction grating (light-like) patterns. Allow suitable annotation of diagram for answer Ignore any equation given.	2	AO1

Question	Answers	Additional comments/Guidance	Mark	AO
01.4	Any one of: ✓ • volume of a nucleus is (approximately) spherical • $V = \frac{4}{3}\pi R^3$ or $V = \frac{4}{3}\pi R_0^3 A$ • volume is proportional to A • mass = $A \times$ mass of nucleon • mass (/kg) = $A \times 1.661 \times 10^{-27}$ • mass is proportional to A Density $\left(= \frac{m}{V} \right) = \frac{Am_{(n)}}{\frac{4}{3}\pi R_0^3 A} = \frac{m_{(n)}}{\frac{4}{3}\pi R_0^3}$ AND where all are constants / equation is independent of A. OR Combining of two proportional statements and cancelling of A ✓	Do NOT accept bullets 3, 4,5 or 6 when A is referred to as area, activity or any other incorrect quantity. $R \propto A^{\frac{1}{3}}$ or $R^3 \propto A$ is not enough. Accept alternative values or u in bullet 5	2	AO1
Total			9	

Question	Answers	Additional comments/Guidance	Mark	AO
		Any suggestion that particles do not follow		



01.1	${}_{19}^{40}\text{K} + {}_{-1}^0e \rightarrow {}_{18}^{40}\text{Ar} + \nu_{(e)} \checkmark \checkmark$	first mark for 40 and 18 second mark for electron neutrino if negative superscript on neutrino mark not awarded	1 1
01.2	is the weak interaction/weak nuclear force $\checkmark$ because involves leptons <u>and</u> hadrons/ because quark character/flavour/identity/type changed $\checkmark$	allow change in quark composition allow second mark if applied to stated interaction e.g. up quark changes to down quark	1 1
01.3	(use of $E=hf$) energy in J = $1.46 \times 10^6 \times 1.6 \times 10^{-19} \checkmark (= 2.336 \times 10^{-13})$ $f = (\frac{E}{h}) = \frac{2.336 \times 10^{-13}}{6.63 \times 10^{-34}} \text{ AND } \lambda = \frac{3 \times 10^8}{f}$ OR $\lambda = \left(\frac{hc}{E} \right) = \frac{3 \times 10^8 \times 6.63 \times 10^{-34}}{2.336 \times 10^{-13}} \text{ seen directly } \checkmark$ $8.51 \times 10^{-13} \text{ m } \checkmark$	1 for the attempt at the conversion to J allowing POT 1 for attempt to sub in hf and c/λ (or hc/λ) allow energy substituted in MeV or eV for second mark 1 for the correct answer (not awarded if eV used or MeV or if POT error) Accept 8.52×10^{-13}	1 1 1
01.4	identifies the decay as beta emission $\checkmark$ <i>so will expect to see:</i> electron released (from nucleus) correct details of how electron detected antineutrino released no photon released } 2 from 4	If state incorrect interaction e.g. beta plus decay the wrong Physics and no consequential error(CE) and therefore zero. If no interaction stated then can score next 2 marks. e.g. cloud chamber or absorption If give correct equation for beta decay award mark for	3

		electron and antineutrino	
Total			10



Question	Answers	Additional Comments/Guidelines	Mark
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02.1	three correct values plus conclusion ✓ ratio approach $v_1/v_2 = \lambda_2/\lambda_1$ shown for 2 sets of data ✓ shown for two other sets of data + conclusion ✓	May predict one of the values assuming inverse proportionality and compare with table value (once for 1 mark; twice for 2 marks)	
02.2	$h = \lambda mv$ or substitution of correct data in any form ✓ 6.7(0) x 10⁻³⁴ from first and third data set; 6.6(0) x 10⁻³⁴ from second ✓	May determine average value using mean constant from 2.1 or average 3 calculations in this part.	1 1

02.3	Particle behaviour would only produce a patch/circle of light /small spot of light or Particles would scatter randomly✓ Wave property shown by diffraction/ interference✓ Graphite causes (electron)waves/beam to spread out /electrons to travel in particular directions✓ Bright rings/maximum intensity occurs where waves interfere constructively/ are in phase✓ for a diffraction grating maxima when $\sin\theta = n\lambda/d$ ✓	Marks are essentially for 1. Explaining appearance of screen if particle 2. Identifying explicitly a wave property 3. Explaining what happens when diffraction occurs 4. Explaining cause of bright rings 5. Similar to diffraction grating formula (although not same) NB Not expected: For graphite target maxima occur when $\sin\theta = \lambda/2d$ (d =spacing of atomic layers in crystal)	Max 3 1 1 1
02.4	Electrons must provide enough (kinetic) energy 'instantly' to cause the excitation OR the atom or energy transfer in 1 to 1 interaction OR Electron can provide the energy in discrete amounts OR energy cannot be provided over time as it would be in a wave Any 2 from Idea of light emission due to excitation and de-excitation of electrons/atoms✓ Idea of collisions by incident electrons moving electrons in atoms between energy levels/shells/orbits✓ Light/photon emitted when atoms de-excite or electrons move to lower energy levels✓	Description of Photoelectric effect = 0 Not allowed: any idea that wave cannot pass on energy, e.g. waves pass through the screen	1 1 1

Total			10
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	Waves travel to the boundaries and are reflected✓	Not bounce off	Max 3
	two waves travelling in opposite directions interfere/superpose✓	Not superimpose or interferes with itself	1
	Fixed boundaries (cannot move so) are nodes✓	creates nodes and antinodes bland =0	1

02.1	reads off λ_p 1✓	for 1✓ condone POT; expect $\lambda_p = 635 \pm 2$ (nm) / $635 \pm 0.02 \times 10^{-9} / 6.35 \pm 0.02 \times 10^{-7}$ (m) allow evidence of working on Figure 3	1	AO1-1a
	use of $n \times$ their $\lambda_p = d \sin \theta$ 2✓	for 2✓ accept subject N with no / incomplete substitution, eg $N = \frac{\sin \theta}{n \times \lambda_p}$ OR subject d and <u>full</u> substitution, eg $d = \frac{5 \times \text{their } \lambda_p}{\sin 76.3} / 5.15 \times \text{their } \lambda_p$ OR correct result $d = 3.27 (\times 10^{-6} \text{ (m)})$; allow ECF in λ_p including POT; allow recognisable $d / 2$ sf intermediate result	1	AO2-1h
	$N = \left(= \frac{1}{d} = \frac{1}{3.27 \times 10^{-6}} \right) = 3.06 \times 10^5$ 3✓	for 3✓ accept ≥ 3 sf in range 3.05 to 3.07×10^5 OR	1	AO3-1b

		$N = \frac{0.194}{\text{their } \lambda_p}$ (allow ECF for λ_p out of range but not if due to POT)		
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Question	Answers	Additional comments/Guidelines	Mark	AO
02.2	identifies an appropriate physical characteristic that makes the measurement of the (5 th) maximum more difficult ✓	take 'it' to be the 5th maximum / peak (see rubric marking point 3.3) (centre difficult to locate because) (5th) 'maximum is wider' / 'peak less pronounced' / 'less defined' or wtte; allow 'maximum more spread out' / 'less pronounced' OR maximum 'is fainter' / 'less bright' / 'intensity reduced'; reject 'not as clear' OR (cannot use edges to determine location of centre because) 'whole maximum (may be) not visible' / 'can't see edges' OR (L_R produces a range of wavelengths so) 4th and 5th / adjacent fringes may overlap	1	AO1-1b

Question	Answers	Additional comments/Guidelines	Mark	AO
02.3	extrapolation of linear region of the L_R characteristic $_1✓$ V_A for L_R in range 1.91 to 1.93 (V) $_2✓$	for $_1✓$ reads off where a ruled extrapolation to the linear region of the L_R characteristic reaches the horizontal axis the line must be free from discontinuities; condone a ruled dashed line condone tangent meeting curve at $I \geq 10$ mA for $_2✓$ > 3 sf acceptable if rounding to 3 sf	2	AO1-1b

Question	Answers	Additional comments/Guidelines	Mark	AO
02.4	any fully correct calculation of the Planck constant $_1✓$	for $_1✓$ allow 2 sf use of $c = 3(.00) \times 10^8$ AND $e = 1.6(0) \times 10^{-19}$ AND EITHER V_A from 02.3 AND λ_p in range 620 to 650 nm / ECF their λ_p from 02.1 OR $V_A = 2.00$ AND λ_p in range 550 to 580 nm;	1	AO3-1b

	calculates mean of two valid calculations of the Planck constant; result in range 6.10 to 6.50×10^{-34} (J s) $2\checkmark$	for $2\checkmark$ Planck constant result rounding to correct 3 sf (check very carefully working leading to data booklet value 6.63×10^{-34})	1	AO1-1b
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Question	Answers	Additional comments/Guidelines	Mark	AO
02.5	V_F corresponding to $I_F = 21$ mA read from L_R graph in Figure 4 ; calculates R from $\frac{6.1 - \text{their } V_F}{21(.0 \times 10^{-3})}$ $1\checkmark$	use of $V_F = 2.01$ (V) leading to $R = 195$ (Ω) earns both marks for $1\checkmark$ accept evidence of working on Figure 4 condone 2 sf eg $V_F = 2.0$ (V) allow POT error for I_F	1	AO1-1b
	$R = 195$ (Ω) from $\frac{6.10 - 2.01}{21(.0) \times 10^{-3}} = 195$ $2\checkmark$	for $2\checkmark$ evidence to show use of $V_F = 2.01 \pm 0.01$ (V) must be seen, ie allow $\frac{6.10 - 2.00}{21(.0) \times 10^{-3}} = 195$ OR $\frac{6.10 - 2.02}{21(.0) \times 10^{-3}} = 194$	1	AO2-1d
Total			10	

Question

Answers

Additional comments/Guidelines

Mark

AO

