1. Monochromatic light of wavelength 490 nm falls normally on a diffraction grating that has $6 \times 10^5$ lines per metre. Which one of the following is correct?

A. The first order is observed at angle of diffraction of 17°.

B. The second order is observed at angle of diffraction of 34°.

C. The third and higher orders are not produced.

D. A grating with more lines per metre could produce more orders.

(Total 1 mark)

2. Which of the following is correct when total internal reflection occurs?

A. the angle of incidence is less than the critical angle

B. the light meets an optically less dense medium

C. the light enters a medium with a higher refractive index

D. the angles that the incident and refracted rays make with the normal are the same

(Total 1 mark)

3. A discharge lamp emits light of four colours: red, green, blue and violet. The diagram shows light from the lamp incident normally on a diffraction grating with slit separations of $1.8 \times 10^{-6}$ m. The light is viewed through a telescope which can be rotated as shown.

As the telescope is rotated from the straight-through position, each of the four colours is observed as a bright line at its corresponding first-order diffraction angle.
(a) Which colour would be observed first as the telescope is rotated from the straight-through position?

Place a tick (✔) in the right-hand column to show the correct answer.

<table>
<thead>
<tr>
<th></th>
<th>✔ if correct</th>
</tr>
</thead>
<tbody>
<tr>
<td>red</td>
<td></td>
</tr>
<tr>
<td>green</td>
<td></td>
</tr>
<tr>
<td>blue</td>
<td></td>
</tr>
<tr>
<td>violet</td>
<td></td>
</tr>
</tbody>
</table>

(b) Explain how a bright line is formed by the diffraction grating at the first-order diffraction angle.

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(c) (i) The wavelength of the green light is $5.3 \times 10^{-7}$ m.

Calculate the first-order diffraction angle for this colour.

$$\text{angle} = \text{__________________________ degree}$$

(ii) As the telescope is rotated further, higher-order diffraction maxima are observed.

Calculate the highest order observed for the green light.

$$\text{highest order} = \text{__________________________}$$

(Total 9 marks)
(a) Explain what is meant by a progressive wave.

(b) **Figure 1** shows the variation with time of the displacement of one point in a progressive wave.

**Figure 1**

![Figure 1](image1)

**Figure 2** shows the variation of displacement of the same wave with distance.

**Figure 2**

![Figure 2](image2)
Use Figures 1 and 2 to determine

(i) the amplitude of the wave

\[
\text{amplitude} = \text{______________________ mm} \quad (1)
\]

(ii) the wavelength of the wave

\[
\text{wavelength} = \text{______________________ m} \quad (1)
\]

(iii) the frequency of the wave

\[
\text{frequency} = \text{______________________ Hz} \quad (1)
\]

(iv) the speed of the wave

\[
\text{speed} = \text{______________________ m s}^{-1} \quad (1)
\]

(c) Which of the following statements apply?
Place a tick (✔) in the right-hand column for each correct statement.

<table>
<thead>
<tr>
<th>Statement</th>
<th>✔ if correct</th>
</tr>
</thead>
<tbody>
<tr>
<td>sound waves are transverse</td>
<td>✔</td>
</tr>
<tr>
<td>sound waves are longitudinal</td>
<td></td>
</tr>
<tr>
<td>sound waves can interfere</td>
<td></td>
</tr>
<tr>
<td>sound waves can be polarised</td>
<td></td>
</tr>
</tbody>
</table>
(d) In an investigation, a single loudspeaker is positioned behind a wall with a narrow gap as shown in Figure 3.

A microphone attached to an oscilloscope enables changes in the amplitude of the sound to be determined for different positions of the microphone.

**Figure 3**

The amplitude of sound is recorded as the microphone position is moved along the line AB a large distance from the gap.
The result of the measurements is shown in Figure 4.

Figure 4

The signal generator is adjusted so that sound waves of the same amplitude but of a higher frequency are emitted by the loudspeaker. The investigation using the apparatus shown in Figure 3 is then repeated. Explain the effect this has on Figure 4.

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(3)
(Total 10 marks)
White light passes through a single narrow slit and illuminates a screen.

What is observed on the screen?

A. a set of equally spaced white fringes
B. a central maximum made up of a spectrum surrounded by white fringes
C. a white central maximum surrounded by coloured fringes
D. a single narrow white line

(Total 1 mark)

In a diffraction-grating experiment the maxima are produced on a screen.

What causes the separation of the maxima of the diffraction pattern to decrease?

A. using light with a longer wavelength
B. increasing the distance between the screen and grating
C. increasing the distance between the source and grating
D. using a grating with a greater slit separation

(Total 1 mark)

A student aligns the longer edge of a rectangular glass block along a line LR, as shown in Figure 1.

Figure 1
The student marks the outline of the block and directs a ray along \( PQ \).

The student marks the direction of the emergent ray then removes the block and marks a line perpendicular to \( LR \) where \( PQ \) and \( LR \) intersect.

The student then marks the points \( W, X, Y \) and \( Z \) that are defined in Figure 2.

**Figure 2**
(a) Show that the refractive index $n$ of the block is given by the equation

$$n = \frac{XZ \times WY}{YZ \times WX}$$

You may wish to use the equation $n = \frac{\sin \theta_1}{\sin \theta_2}$

where $\theta_1$ and $\theta_2$ are the angles shown in Figure 3.

You may also wish to illustrate your answer with a diagram.

**Figure 3**

![Diagram of light ray incident and emergent angles](image_url)
(b) The student repeats the procedure for different directions of the incident ray $PQ$. The student measures $XZ$, $WX$, $YZ$ and $WY$ for each direction of $PQ$. 
State and explain how the student can use these results to obtain a value of $n$ by a graphical method.

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(2)

(c) The student used a block with dimensions 114 mm × 65 mm × 19 mm to perform the experiment.

The student’s data are shown in the table below.

<table>
<thead>
<tr>
<th>WX/mm</th>
<th>WY/mm</th>
<th>XZ/mm</th>
<th>YZ/mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>130</td>
<td>78</td>
<td>113</td>
<td>44</td>
</tr>
<tr>
<td>103</td>
<td>75</td>
<td>80</td>
<td>38</td>
</tr>
<tr>
<td>90</td>
<td>73</td>
<td>63</td>
<td>33</td>
</tr>
<tr>
<td>81</td>
<td>71</td>
<td>49</td>
<td>27</td>
</tr>
<tr>
<td>75</td>
<td>69</td>
<td>38</td>
<td>22</td>
</tr>
<tr>
<td>67</td>
<td>66</td>
<td>15</td>
<td>10</td>
</tr>
</tbody>
</table>

Explain whether the range of measurements made by the student is suitable.

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(3)

(Total 7 marks)
Monochromatic light may be characterised by its speed, frequency and wavelength. Which of the following quantities change when monochromatic light passes from air into glass?

A Speed only.  
B Speed and wavelength only.  
C Speed and frequency only.  
D Wavelength and frequency only.  

(Total 1 mark)

Read through the following passage and answer the questions that follow it.

Measuring the speed of sound in air

After the wave nature of sound had been identified, many attempts were made to measure its speed in air. The earliest known attempt was made by the French scientist Gassendi in the 17th century. The procedure involved timing the interval between seeing the flash of a gun and hearing the bang from some distance away.

Gassendi assumed that, compared with the speed of sound, the speed of light is infinite. The value he obtained for the speed of sound was 480 m s\(^{-1}\). He also realised that the speed of sound does not depend on frequency.

A much better value of 350 m s\(^{-1}\) was obtained by the Italian physicists Borelli and Viviani using the same procedure. In 1740 another Italian, Bianconi, showed that sound travels faster when the temperature of the air is greater.

In 1738 a value of 332 m s\(^{-1}\) was obtained by scientists in Paris. This is remarkably close to the currently accepted value considering the measuring equipment available to the scientists at that time. Since 1986 the accepted value has been 331.29 m s\(^{-1}\) at 0 °C.

(a) Suggest an experiment that will demonstrate the wave nature of sound (line 1).

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___________________________________________________________________  
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(1)

(b) Using Gassendi’s value for the speed of sound (line 6), calculate the time between seeing the flash of a gun and hearing its bang over a distance of 2.5 km.

\[
time = \underline{\underline{\ldots\ldots}} \text{ s}
\]

(1)
(c) Explain why it was necessary to assume that ‘compared with the speed of sound, the speed of light is infinite’ (line 5).

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(1)

(d) Explain one observation that could have led Gassendi to conclude that ‘the speed of sound does not depend on frequency’ (line 7).

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(2)

(e) Explain how the value obtained by Borelli and Viviani was ‘much better’ than that obtained by Gassendi (line 8).

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(1)

(f) The speed of sound $c$ in dry air is given by

$$c = k\sqrt{\theta + 273.15}$$

where $\theta$ is the temperature in °C, and $k$ is a constant.

Calculate a value for $k$ using data from the passage.

$$k = \text{_________________________} \text{ m s}^{-1} \text{ K}^{-\frac{1}{2}}$$

(2)
When comparing X-rays with UV radiation, which statement is correct?

A X-rays have a lower frequency.
B X-rays travel faster in a vacuum.
C X-rays do not show diffraction and interference effects.
D Using the same element, photoelectrons emitted using X-rays have the greater maximum kinetic energy.

A student has a diffraction grating that is marked $3.5 \times 10^3$ lines per m.

(a) Calculate the percentage uncertainty in the number of lines per metre suggested by this marking.

\[
\text{percentage uncertainty} = \frac{\text{uncertainty}}{\text{value}} \times 100\% 
\]
(b) Determine the grating spacing.

\[ \text{grating spacing} = \underline{\phantom{0000}} \text{ mm} \]  

(2)

(c) State the absolute uncertainty in the value of the spacing.

\[ \text{absolute uncertainty} = \underline{\phantom{0000}} \text{ mm} \]  

(1)
(d) The student sets up the apparatus shown in Figure 1 in an experiment to confirm the value marked on the diffraction grating.

![Figure 1](image)

The laser has a wavelength of 628 nm. Figure 2 shows part of the interference pattern that appears on the screen. A ruler gives the scale.

![Figure 2](image)

Use Figure 2 to determine the spacing between two adjacent maxima in the interference pattern. Show all your working clearly.

\[
\text{spacing} = \text{________________________ mm} \quad (1)
\]

(e) Calculate the number of lines per metre on the grating.

\[
\text{number of lines} = \text{________________________} \quad (2)
\]
(f) State and explain whether the value for the number of lines per m obtained in part (e) is in agreement with the value stated on the grating.

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(2)

(g) State one safety precaution that you would take if you were to carry out the experiment that was performed by the student.

___________________________________________________________________

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___________________________________________________________________

(1)

(Total 10 marks)

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

___________________________________________________________________

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(3)
(b) A signal is to be transmitted along an optical fibre of length 1200 m. The signal consists of a square pulse of white light and this is transmitted along the centre of a fibre. The maximum and minimum wavelengths of the light are shown in the table below.

<table>
<thead>
<tr>
<th>Colour</th>
<th>Refractive index of fibre</th>
<th>Wavelength / nm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blue</td>
<td>1.467</td>
<td>425</td>
</tr>
<tr>
<td>Red</td>
<td>1.459</td>
<td>660</td>
</tr>
</tbody>
</table>

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

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(c) Discuss two changes that could be made to reduce the effect described in part (b).

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(2)

(Total 7 marks)
A light source emits light which is a mixture of two wavelengths, $\lambda_1$ and $\lambda_2$. When the light is incident on a diffraction grating it is found that the fifth order of light of wavelength $\lambda_1$ occurs at the same angle as the fourth order for light of wavelength $\lambda_2$. If $\lambda_1$ is 480 nm what is $\lambda_2$?

A  400 nm  
B  480 nm  
C  600 nm  
D  750 nm  

(Total 1 mark)

A diffraction pattern is formed by passing monochromatic light through a single slit. If the width of the single slit is reduced, which of the following is true?

<table>
<thead>
<tr>
<th></th>
<th>Width of central maximum</th>
<th>Intensity of central maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>unchanged</td>
<td>decreases</td>
</tr>
<tr>
<td>B</td>
<td>increases</td>
<td>increases</td>
</tr>
<tr>
<td>C</td>
<td>increases</td>
<td>decreases</td>
</tr>
<tr>
<td>D</td>
<td>decreases</td>
<td>decreases</td>
</tr>
</tbody>
</table>

(Total 1 mark)
Electrons and protons in two beams are travelling at the same speed. The beams are diffracted by objects of the same size.

Which correctly compares the de Broglie wavelength $\lambda_e$ of the electrons with the de Broglie wavelength $\lambda_p$ of the protons and the width of the diffraction patterns that are produced by these beams?

<table>
<thead>
<tr>
<th>comparison of de Broglie wavelength</th>
<th>diffraction pattern</th>
</tr>
</thead>
<tbody>
<tr>
<td>A $\lambda_e &gt; \lambda_p$</td>
<td>electron beam width &gt; proton beam width</td>
</tr>
<tr>
<td>B $\lambda_e &lt; \lambda_p$</td>
<td>electron beam width &gt; proton beam width</td>
</tr>
<tr>
<td>C $\lambda_e &gt; \lambda_p$</td>
<td>electron beam width &lt; proton beam width</td>
</tr>
<tr>
<td>D $\lambda_e &lt; \lambda_p$</td>
<td>electron beam width &lt; proton beam width</td>
</tr>
</tbody>
</table>

(Total 1 mark)

Monochromatic light of wavelength 600 nm is used to illuminate a pair of slits 0.50 mm apart. The fringes are observed at a distance of 1.50 m from the slits.

What is the separation of the fringes?

- A $2.0 \times 10^{-7}$ mm
- B $1.8 \times 10^{-3}$ mm
- C $5.6 \times 10^{-1}$ mm
- D 1.8 mm

(Total 1 mark)
Microwaves from a transmitter are incident on a gap between two metal plates. The microwaves that pass through the gap are detected by a receiver.

The receiver is placed at O.

What change causes the received signal to decrease and then increase?

A. make the gap narrower
B. move the receiver towards X
C. rotate the receiver through 90°
D. move the transmitter away from the receiver

(Total 1 mark)

When a parallel beam of monochromatic light is directed at two narrow slits, $S_1$ and $S_2$, interference fringes are observed on a screen.
Which line in the table gives the changes that will increase the spacing of the fringes?

<table>
<thead>
<tr>
<th></th>
<th>Slit spacing</th>
<th>Distance from slits to screen</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>halved</td>
<td>halved</td>
</tr>
<tr>
<td>B</td>
<td>halved</td>
<td>doubled</td>
</tr>
<tr>
<td>C</td>
<td>doubled</td>
<td>halved</td>
</tr>
<tr>
<td>D</td>
<td>doubled</td>
<td>doubled</td>
</tr>
</tbody>
</table>

(Total 1 mark)

Two coherent sources generate sound waves of wavelength 0.40 m. The waves leave the sources in phase. A detector some distance from the sources receives the sound waves. The path difference between the detector and the sources is 0.90 m.

What is the phase difference between the waves arriving at the detector?

A zero
B 45°
C 90°
D 180°

(Total 1 mark)

A layer of liquid of refractive index 1.6 covers the horizontal flat surface of a glass block of refractive index 1.5. A ray of light strikes the boundary between them at an angle such that it travels along the boundary afterwards.

How does the ray strike the boundary?

A it travels in glass at an angle of 70° to the boundary
B it travels in glass at an angle of 20° to the boundary
C it travels in the liquid at an angle of 70° to the boundary
D it travels in the liquid at an angle of 20° to the boundary

(Total 1 mark)
A parallel beam of monochromatic light is directed normally at a plane transmission grating which has \( N \) slits per metre. The second order diffracted beam is at angle \( \theta \) to the zero order transmitted beam.

The grating is then replaced by a plane transmission grating which has \( 2N \) slits per metre.

Which one of the following statements is correct?

A. With the first grating, the first order beam is at angle \( 0.5\theta \) to the zero order transmitted beam.

B. With the second grating, the first order beam is at angle \( 0.5\theta \) to the zero order transmitted beam.

C. With the second grating, the first order beam is at angle \( \theta \) to the zero order transmitted beam.

D. With the second grating, the second order beam is at angle \( \theta \) to the zero order transmitted beam.

(Total 1 mark)

Which of the following statements about the behaviour of waves is incorrect?

A. All waves can be diffracted.

B. All waves can be made to undergo superposition.

C. All waves can be refracted.

D. All waves can be polarised.

(Total 1 mark)
Two loudspeakers emit sound waves.

Which line in the table gives the correct frequency condition and the correct phase condition for the waves from the loudspeakers to be coherent?

<table>
<thead>
<tr>
<th>Frequency condition</th>
<th>Phase condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>A same frequency</td>
<td>variable phase difference</td>
</tr>
<tr>
<td>B constant frequency difference</td>
<td>constant phase difference</td>
</tr>
<tr>
<td>C constant frequency difference</td>
<td>in phase</td>
</tr>
<tr>
<td>D same frequency</td>
<td>constant phase difference</td>
</tr>
</tbody>
</table>

(Total 1 mark)

Cosmic rays are high-energy particles coming from Space. They collide with the air molecules in the Earth’s atmosphere to produce pions and kaons.

(a) Pions and kaons are mesons. Identify the quark–antiquark composition for a meson.

Tick (✔️) the correct answer in the right-hand column.

<table>
<thead>
<tr>
<th></th>
<th>✔️ if correct</th>
</tr>
</thead>
<tbody>
<tr>
<td>qqq</td>
<td></td>
</tr>
<tr>
<td>q̅q̄q̄</td>
<td></td>
</tr>
<tr>
<td>q̅q̄</td>
<td></td>
</tr>
<tr>
<td>q̅q̄</td>
<td></td>
</tr>
<tr>
<td>q̅q̄</td>
<td></td>
</tr>
</tbody>
</table>

(b) A positron with a kinetic energy of 2.0 keV collides with an electron at rest, creating two photons that have equal energy.

Show that the energy of each photon is $8.2 \times 10^{-14}$ J.
(c) Calculate the wavelength of a photon of energy $8.2 \times 10^{-14}$ J.

wavelength = _______________________ m

(d) Show that the speed of the positron before the collision was about $2.7 \times 10^7$ m s$^{-1}$.

(e) Calculate the de Broglie wavelength of the positron travelling at a speed of $2.7 \times 10^7$ m s$^{-1}$.

wavelength = _______________________ m
(f) The separation between the carbon atoms in graphite is about 0.15 nm.

Discuss whether electrons travelling at $2.7 \times 10^7$ m s$^{-1}$ can be used to demonstrate diffraction as they pass through a sample of graphite.

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(4)
(Total 15 marks)

When light of wavelength $5.0 \times 10^{-7}$ 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?

A  $2.5 \times 10^2$
B  $2.5 \times 10^5$
C  $1.0 \times 10^3$
D  $1.0 \times 10^6$

(Total 1 mark)
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.

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

Figure 3

![Diagram showing M moved slowly away from R and T](image)

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

(a) 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.

________________________________________________________________________________________

(b) Explain why the minimum reading is not zero when the distance x is measured.

________________________________________________________________________________________

________________________________________________________________________________________

________________________________________________________________________________________

(1)
(c) 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.
It can be shown that

\[ \sqrt{4x^2 + y^2} - y \]

where \( \lambda \) 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 \( G_{\text{max}} \) of a line that passes through all the error bars
• the minimum gradient \( G_{\text{min}} \) of a line that passes through all the error bars.

\[ G_{\text{max}} = \text{______________} \]
\[ G_{\text{min}} = \text{______________} \]

(3)

(e) Determine \( \lambda \) using your results for \( G_{\text{max}} \) and \( G_{\text{min}} \).

\[ \lambda = \text{______________} \text{ m} \]

(2)
(f) Determine the percentage uncertainty in your result for $\lambda$. 

percentage uncertainty in $\lambda = \underline{\ \ \ \ \ \ \ \ \ \ %}$

(3)
(g) Explain how the graph in Figure 4 can be used to obtain the value of y. You are not required to determine y.

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(h) Suppose that the data for \( n = 13 \) had not been plotted on Figure 4.

Add a tick (✔) in each row of the table to identify the effect, if any, on the results you would obtain for \( G_{\text{max}} \), \( G_{\text{min}} \), \( \lambda \) and y.

<table>
<thead>
<tr>
<th>Result</th>
<th>Reduced</th>
<th>Not affected</th>
<th>increased</th>
</tr>
</thead>
<tbody>
<tr>
<td>( G_{\text{max}} )</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( G_{\text{min}} )</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( \lambda )</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>y</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(4)

(Total 18 marks)

Figure 1 shows a ray of monochromatic green light incident normally on the curved surface of a semicircular glass block.
(a) 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.

\[ \text{angle of incidence} = \ \text{__________ degrees} \]  

(b) A thin film of liquid is placed on the flat surface of the glass block as shown in Figure 2.

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.

\[ \text{refractive index} = \ \text{__________} \]
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.

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?

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

(Total 1 mark)
Figure 1 shows an arrangement used to investigate double slit interference using microwaves. Figure 2 shows the view from above.

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

The receiver is moved along the dotted line \( AE \). As it is moved, maximum and minimum signals are detected. Maximum signals are first detected at points \( B \) and \( C \). The next maximum signal is detected at the position \( D \) shown in Figure 2.

Figure 2 shows the distances between each of the two slits, \( S_1 \) and \( S_2 \), and the microwave receiver when the aerial is in position \( D \).
\( S_1D \) is 0.723 m and \( S_2D \) is 0.667 m.

(a) Explain why the signal strength falls to a minimum between \( B \) and \( C \), and between \( C \) and \( D \).
(b) Determine the frequency of the microwaves that are transmitted.

\[ \text{frequency} = \underline{} \text{ Hz} \]

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

Explain why the minimum intensity between C and D is not zero.
The vertical aerial is placed at position **B** and is rotated slowly through 90° until it lies along the direction **AE**. State and explain the effect on the signal strength as it is rotated.

Light of wavelength 500 nm is passed through a diffraction grating which has 400 lines per mm. What is the angular separation between the two second-order maxima?

A  11.5°
B  23.1°
C  23.6°
D  47.2°
Intensity maxima are produced on a screen when a parallel beam of monochromatic light is incident on a diffraction grating. Light of a longer wavelength can be used or the distance from the diffraction grating to the screen can be increased.

Which row gives the change in appearance of the maxima when these changes are made independently?

<table>
<thead>
<tr>
<th></th>
<th>Longer wavelength</th>
<th>Distance from grating to screen increased</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>closer together</td>
<td>more widely spaced</td>
</tr>
<tr>
<td>B</td>
<td>more widely spaced</td>
<td>more widely spaced</td>
</tr>
<tr>
<td>C</td>
<td>more widely spaced</td>
<td>closer together</td>
</tr>
<tr>
<td>D</td>
<td>closer together</td>
<td>closer together</td>
</tr>
</tbody>
</table>

(Total 1 mark)

The diagram shows a ray of light travelling in air and incident on a glass block of refractive index 1.5

What is the angle of refraction in the glass?

A 22.5°

B 23.3°

C 33.1°

D 59.4°

(Total 1 mark)
33 Which row shows the change in velocity, frequency and wavelength of an electromagnetic wave as it travels from an optically less dense to an optically more dense medium?

<table>
<thead>
<tr>
<th></th>
<th>Velocity</th>
<th>Frequency</th>
<th>Wavelength</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>decreases</td>
<td>decreases</td>
<td>unchanged</td>
</tr>
<tr>
<td>B</td>
<td>increases</td>
<td>unchanged</td>
<td>increases</td>
</tr>
<tr>
<td>C</td>
<td>decreases</td>
<td>unchanged</td>
<td>decreases</td>
</tr>
<tr>
<td>D</td>
<td>increases</td>
<td>increases</td>
<td>unchanged</td>
</tr>
</tbody>
</table>

(Total 1 mark)

34 Which statement suggests that electrons have wave properties? Tick (✔) the correct answer.

- Electrons are emitted in photoelectric effect experiments.  
- Electrons are released when atoms are ionised.  
- Electrons produce dark rings in diffraction experiments.  
- Electron transitions in atoms produce line spectra.  

(Total 1 mark)

35 What is the speed of light in glass of refractive index 1.42?

- A 4.26 × 10⁷ m s⁻¹
- B 2.11 × 10⁸ m s⁻¹
- C 3.00 × 10⁸ m s⁻¹
- D 4.73 × 10⁸ m s⁻¹

(Total 1 mark)
A wave transfers energy from one point to another ✔
without transferring material / (causing permanent displacement of the medium) ✔ owtte

(b) (i) 0.6 (mm) or 0.60 (mm) ✔

(ii) 0.080 (m) ✔
    
    Allow 1 sig fig

(iii) \( f = \frac{1}{T} = \frac{1}{0.044} = 23 \text{ (Hz)} \) ✔ (22.7 Hz)
(iv) \( v = f \lambda = 22.7 \times 0.080 = 1.8 \text{ (m s}^{-1})\) ✔ (1.82 m s\(^{-1}\))
allow CE \( v = (biii) \times (bii) \) but working must be shown
1 sig fig not acceptable

(c)

<table>
<thead>
<tr>
<th>sound waves are transverse</th>
<th>sound waves are longitudinal</th>
<th>sound waves can interfere</th>
<th>sound waves can be polarised</th>
</tr>
</thead>
<tbody>
<tr>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
</tr>
</tbody>
</table>

(d) the wavelength would be smaller
smaller spread in main peak or more peaks (between A and B)
the central peak is higher (owtte)
as the energy is concentrated over a smaller area (owtte)
reference to \( \sin \theta_{\text{min}} = \lambda/d \)
✔ ✔ ✔ any 3 lines max 3

Note that the marks here are for use of knowledge rather than performing calculations.

No bod if writing does not make increase or decrease clearly distinct.
Marking should be lenient.

5 C

6 D

7 (a) \( \sin \theta_1 = \frac{XZ}{WX} \text{ and } \sin \theta_2 = \frac{YZ}{WY} \) or \( \frac{\sin \theta_1}{\sin \theta_2} = \frac{(XZ) \times (WX)}{(YZ) \times (WY)} \) 1 ✔

(must see this step either separately or in substitution for \( \frac{\sin \theta_1}{\sin \theta_2} \) or 0/2

condone i and r for \( \theta \) etc.)

\( \eta = \frac{(XZ) \times (WX)}{(YZ) \times (WY)} = \frac{XZ \times WY}{WX \times YZ} \) ✔

\( = \frac{(XZ) \times (WY)}{(WX) \times (YZ)} \)
(b) idea implied that \((XZ) \times (WY) = n \times (WX) \times (YZ)\) is of form \(y = mx + c\);

\[
\text{plot } (XZ) \times (WY) \text{ against } (WX) \times (YZ) \left[ \frac{XZ}{WX} \text{ against } \frac{YZ}{WY} \text{ etc} \right] \text{ or } 0/2, \checkmark
\]

calculate gradient to find \(n\) (false plot loses both marks) \(2 \checkmark\)

[must mention \(XZ, WX, YZ\) and \(WY\) for full credit: bland ‘plot \(\sin \theta_1\) against \(\sin \theta_2\) and calculate gradient to find \(n\)’ = 1 MAX]

[alternative method is to plot \(XZ\) against \(WX\) to find \(G_1\) and plot \(YZ\) against \(WY\) to find \(G_2\); evaluate \(\frac{G_1}{G_2}\) to find \(n\) \(2 \checkmark\)]

(c) upper limit of \((XZ)\) range [largest value] is suitable \(1 \checkmark\)

largest \(XZ\) value \(\approx\) length of block (114)

[largest \(WX\) value \(\approx\) diagonal distance (131) across block / used

(approximately) largest value of \(XZ, WX\) available] \(2 \checkmark\)

lower limit of \((XZ\) or \(YZ)\) range [smallest value] is not suitable \(3 \checkmark\)

smallest \(YZ\) \(\approx\) \(XZ\) values have large percentage uncertainty / are unreliable \(4 \checkmark\) (reject idea these values are too close to zero)

smallest \(WX\) value \(\approx\) width of block (65) \(5 \checkmark\)

[statement that range is suitable plus quantitative comment comparing length of block (114) with 98 (the range of \(XZ\) data) or covers more than 85% of available range] \(12 \checkmark \checkmark\)

equivalent statement regarding \(WX\): compares available range (131 to 65 = 66) with 63 (the range of \(WX\) data) \(12 \checkmark \checkmark = 2 \text{ MAX}\)

statement that range is suitable plus simple qualitative comment relating range to the block, e.g. ‘a large fraction / part of the available \(XZ, WX\) range is covered’ \(12 \checkmark\) = 1 MAX (bland ‘range is large / wide’ is not enough)]

MAX 3

8

B

9

(a) Suitable experiment eg diffraction through a door / out of a pipe \(\checkmark\)

(b) Using \(c = \frac{d}{t}\)

\[
\text{t} = 2 \, 500 / 480 = 5.2 \, \text{s} \checkmark
\]
(c) (Measured time is difference between time taken by light and time taken by sound)

Calculation assumes that light takes no time to reach observer, i.e., speed is infinite ✓

*Do not allow “could not know speed of light”*

(d) Sound from gun is a mixture of frequencies. ✓

*Alternative for 1st mark ‘(so speed is independent of frequency) the sound of the gun is similar when close and far away’*

All the sound reaches observer at the same time, ✓

(e) More accurate, as it is closer to the accepted value. ✓

(f) When \( \theta = 0 \, ^\circ C \) \( c = 331.29 \, m \, s^{-1} \)

Therefore

\[
331.29 = k \sqrt{273.15} ✓
\]

\[
k = 20.045 ✓
\]

(g) The method and value are published ✓

other scientists repeat the experiment using the same method ✓

\[10\]

\[1\]

D

11

(a) 2.9% ✓

*Allow 3%*

(b) \[ \frac{1}{3.5 \times 10^3} \] seen ✓

0.29 mm or 2.9 x 10^{-4} m ✓ must see 2 sf **only**

(c) ± 0.01 mm ✓

1
(d) Clear indication that at least 10 spaces have been measured to give a spacing = 5.24 mm

   spacing from at least 10 spaces  
   Allow answer within range ±0.05

(e) Substitution in \( d \sin \theta = n \lambda \)

   The 25 spaces could appear here as \( n \) with \( \sin \theta \) as \( 0.135 / 2.5 \)

   \[ d = 0.300 \times 10^{-3} \text{ m} \]
   number of lines = \( 3.34 \times 10^3 \)

   Condone error in powers of 10 in substitution  
   Allow ecf from 1-4 value of spacing

(f) Calculates % difference (4.6%)  

   and makes judgement concerning agreement  
   Allow ecf from 1-5 value

(g) care not to look directly into the laser beam  
   OR  
   care to avoid possibility of reflected laser beam  
   OR  
   warning signs that laser is in use outside the laboratory  
   ANY ONE

(a) Core is transmission medium for em waves to progress (by total internal reflection)  
   Allow credit for points scored on a clear labelled diagram.

   Cladding provides lower refractive index so that total internal reflection takes place  

   And offers protection of boundary from scratching which could lead to light leaving the core.
(b) Blue travels slower than red due to the greater refractive index

Red reaches end before blue, leading to material pulse broadening √

*The first mark is for discussion of refractive index or for calculation of time difference.*

Alternative calculations for first mark

Time for blue = \( \frac{d}{v} = \frac{d}{c/n} = \frac{1200}{(3 \times 10^8 / 1.467)} = 5.87 \times 10^{-6} \text{ s} \)

Time for red = \( \frac{d}{v} = \frac{d}{c/n} = \frac{1200}{(3 \times 10^8 / 1.459)} = 5.84 \times 10^{-6} \text{ s} \)

Time difference = \( 5.87 \times 10^{-6} - 5.84 \times 10^{-6} = 3.2 \times 10^{-8} \text{ s} \) √

*The second mark is for the link to material pulse broadening*

(c) Discussions to include:

Use of monochromatic source so speed of pulse constant

Use of shorter repeaters so that the pulse is reformed before significant pulse broadening has taken place.

Use of monomode fibre to reduce multipath dispersion √ √

*Answer must make clear that candidate understands the distinction between modal and material broadening.*

[7] C

[1] D

[1] C

[1] A

[1] B

[1] C
(a) \[ q \bar{q} \checkmark \]

(b) Total energy = 2keV + 2 \times 511 keV = 1024 keV

\[ = 1024 \times 1.6 \times 10^{-19} = 1.64 \times 10^{-13} J \checkmark \]

Energy of each photon = \[ 1.64 \times 10^{-13} / 2 = 8.19 \times 10^{-14} (J) \checkmark \]

First mark for calculating the total energy in keV.
Second mark is for converting correctly into joules.
Third mark is for dividing by two so ecf for incorrect conversion into joules. Student must show at least 3sf.

(c) \[ \lambda = \frac{\hbar c}{E} = \frac{6.63 \times 10^{-34} \times 3 \times 10^8}{8.19 \times 10^{-14}} \checkmark \]

\[ = 2.43 \times 10^{-12} (m) \checkmark \]

First mark for the correctly rearranged equation or correct values substituted into equation.
Correct answer only scores 2 marks, ecf from 1 (b)

(d) \[ E_k = 2 \text{keV} = 2000 \times 1.6 \times 10^{-19} \text{J} = 3.2 \times 10^{-16} J \checkmark \]

\[ v = \sqrt{\frac{2E_k}{m}} = \sqrt{\frac{2 \times 3.2 \times 10^{-16}}{9.11 \times 10^{-31}}} \checkmark \]

\[ = 2.65 \times 10^7 (m \text{ s}^{-1}) \checkmark \]

First mark for converting KE into joules.
Second mark for rearranging equation correctly or substituting correct values into equation.
Third mark for correct answer, must be to at least 3sf.
(e) \[ \lambda = \frac{h}{mv} = \frac{6.63 \times 10^{-34}}{9.11 \times 10^{-31} \times 2.65 \times 10^7} \]

\[ = 2.75 \times 10^{-11}(m) \] 

First mark for rearranging equation correctly or substituting correct values into equation.
Second mark for correct answer.

(f) Recognition that separation is \(1.5 \times 10^{-10}\) m and compared to \(0.28 \times 10^{-10}\) (ecf)✓

wavelength is about 5 times less than gap width✓

\[ \sin \theta = \frac{\lambda}{d} = 0.2 \rightarrow \theta \sim 11^\circ \] ✓

yes (diffraction would be observable)✓

Or words to that effect

A

25

(a) 180 degrees

accept ° for degrees

OR

\[ \pi \text{ radians} \] ✓

condone ° or ‘rad’ for radian
reject ‘half a cycle’
treat ‘\(\pi\) radians in phase’ as talk out

(b) (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’
(c) valid use of a set square or protractor against TR (to ensure perpendicular) 1 ✔

measure x at two different points [at each end of M] and adjust until [make sure] both distances are the same 2 ✔

OR

use of set square to align M with the perpendicular line earns 2 ✔

if method used does not allow continuous variation in x then award maximum 1 mark

OR

align graph paper 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
(d) $G_{\text{max}}$ line ruled through bottom of $n = 3$ error bar and through top of $n = 11$ error bar 1 ✔

$G_{\text{min}}$ line ruled through top of $n = 5$ error bar and through bottom of $n = 13$ error bar 2 ✔

$G_{\text{max}}$ and $G_{\text{min}}$ calculated from valid $y$ step divided by valid $x$ step; both $n$ steps $\geq 6$ 3 ✔

allow 1 mm tolerance when judging intersection of gradient lines with error bars
ignore any unit given with $G_{\text{max}}$ or $G_{\text{min}}$; 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 $G_{\text{max}} = 3.2(1) \times 10^{-2}$ and $G_{\text{min}} = 2.5 (2.49) \times 10^{-2}$
(e) \( \lambda \left( \frac{G_{\text{max}} + G_{\text{min}}}{2} \right) \)

AND

result in range 2.8(0) to 2.9(0) \( \times 10^{-2} \) (m) 1 ✔ 2 ✔

OR

award one mark for

2.7(0) to 3.0(0) \( \times 10^{-2} \) (m) 12 ✔

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 \( G_{\text{max}} \) and \( G_{\text{min}} \) lines and the gradient of this is calculated award 1 mark for \( \lambda \) in range 2.8(0) to 3.0(0) \( \times 10^{-2} \) (m)

(f) uncertainty in \( \lambda = G_{\text{max}} - \lambda \)

OR

\( \lambda - G_{\text{min}} \)

OR

\[ \left( \frac{G_{\text{max}} - G_{\text{min}}}{2} \right) \]

1 ✔

percentage uncertainty = \((\text{uncertainty}/\lambda)\times 100\) 2 ✔

result in range 11(.0) % to 14(.0) % 3 ✔

1 ✔ can be earned by showing a valid uncertainty then dividing by \( \lambda \)

ecf their \( \lambda, G_{\text{max}} \) and \( G_{\text{min}} \) for 1 ✔ and 2 ✔

allow \( \lambda \) found from best fit line

accept \( \left( \frac{G_{\text{max}} - \lambda}{\lambda} \right) \times 100 \) or \( \left( \frac{G_{\text{max}} - G_{\text{min}}}{G_{\text{max}} + G_{\text{min}}} \right) \times 100 \) etc for 12 ✔

allow \( \left( \frac{\Delta \lambda}{\lambda} \right) \times 100 \) where \( \Delta \lambda \) is any plausible uncertainty for 2 ✔

numerical answer without valid working can only earn 3 ✔
(g) (states) calculate the (vertical) intercept

OR

outlines a valid calculation method to calculate $y$

determine the intercept for both lines and calculate average value

OR

determine the (vertical) intercept of the line of best fit (between $G_{\text{max}}$ and $G_{\text{min}}$)

$\text{draw the line of best fit (between } G_{\text{max}} \text{ and } G_{\text{min}}\text{); perform calculation to find intercept earns } 12$

(h)

<table>
<thead>
<tr>
<th>result</th>
<th>reduced</th>
<th>not affected</th>
<th>increased</th>
</tr>
</thead>
<tbody>
<tr>
<td>$G_{\text{max}}$</td>
<td></td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>$G_{\text{min}}$</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\lambda$</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$y$</td>
<td></td>
<td>✓</td>
<td></td>
</tr>
</tbody>
</table>

**general marker question**

allow any distinguishing mark as long as only one per row

for ✓ and X in same row ignore X

for ✓ and ✓ in same row give no mark

ignore any crossed-out response
alternative approach: single best fit line drawn on Figure 4

(d) \( G \) calculated from \( y \) step divided by \( x \) step;

\[
 n \text{ step} \geq 6 \quad \checkmark 
\]

\( \text{MAX 1} \)

(e) \( \lambda \) in range 2.8(0) to 2.9(0) \( \times 10^{-2} \) \( \checkmark \)

\( \text{MAX 1} \)

(f) percentage uncertainty in \( \lambda = \left( \frac{\Delta \lambda}{\lambda} \right) \times 100 \)

AND

result in range 11(.0) % to 14(.0) % \( \checkmark \)

\( \text{MAX 1} \)

(g) calculate intercept

OR

outlines a valid calculation method to find \( y \) \( \checkmark \)

\( \text{MAX 1} \)

(h) as main scheme

\( \text{no ecf possible} \)

alternative approach: non-crossing lines for \( G_{\text{max}} \) and \( G_{\text{min}} \) on Figure 4:
includes lines that meet but do not cross

(d) \( G_{\text{max}} \) and \( G_{\text{min}} \) calculated from \( y \) step divided by \( x \) step; both \( n \) steps \( \geq 6 \quad \checkmark \)

\( \text{MAX 1} \)

(e) to (h) as main scheme

\[ [18] \]

(a) \( i = \sin^{-1} \left( \frac{1}{1.6} \right) = 39^\circ \) \( \checkmark \)

\( 1 \)

(b) \( \sin 58 = n/1.6 \) \( \checkmark \)

\( n = 1.4 \ (1.36) \) \( \checkmark \)

\( 1 \)
(c) 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 ✔

Allow correct description of refraction. Ignore statements about
towards/away from normal

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 ✔

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)
(c) Intensity decreases with distance ✔

One wave travels further than the other ✔

Amplitudes/intensities of the waves at the minimum points are not equal ✔

Or “do not cancel out”

max 2

(d) The signal decreases/becomes zero ✔

The waves transmitted are polarised ✔

zero when detector at 90° to the transmitting aerial/direction of polarisation of wave ✔

max 3

[11]

30 D [1]

31 B [1]

32 C [1]

33 C [1]

34 3rd box

(Electrons produce dark rings in diffraction experiments) ✔

[1]

35 B [1]