4 Waves

4.1 Oscillations

Name: ...........................................  Date: ...........................................

Oscillations 1
This is a graphical representation of a pendulum that is hanging from the edge of a tall office building.

1 What is the period of this wave?

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2 How many complete cycles are shown?

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3 What is the amplitude?

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4 What is the displacement at 5 seconds and at 11 seconds?

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5 List all of the times in which the graph cuts through equilibrium.

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6 What is the frequency of the pendulum?

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4.1 Oscillations

7 List the times that show maximum speed.

8 List the times that show maximum kinetic energy.

9 List the times that show maximum potential energy.
1 Why are there positive and negative values for velocity?
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2 At what times is the spring in its equilibrium position?
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3 At what times does the spring have zero displacement?
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4 At what times does the spring have maximum acceleration?
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5 At what times does the spring have maximum displacement?
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........................................................................................................................................
6 At what times does the spring have maximum kinetic energy?
4.1 Oscillations

7 At what time does the spring have maximum potential energy?

8 If positive velocity represents the spring going up, at what times is the tension in the spring the greatest?

9 At what times is the weight equal to the tension?
4 Waves

4.1 Oscillations

Name: ……………………………….
Date: ……………………………….

Oscillations 3

1. At what times is the displacement maximum?
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2. At what times is the displacement minimum?
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3. At what times is the velocity maximum?
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4. At what times is the velocity minimum?
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5. At what times is the kinetic energy maximum?
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6. At what times is the potential energy maximum?
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7. At what times is the object in equilibrium?
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Oscillations 4

1 Sketch on graph paper the velocity-time graph for the graph below – do not include units on the \( y \)-axis.

2 What is the period of this wave?

3 How many degrees are between the point at 5 seconds and the point at 11 seconds?

4 How many radians are between the point at 3 seconds and the point at 14 seconds?

5 What is the phase relationship between this graph and its corresponding acceleration-time graph?
4 Waves

4.2 Travelling waves

Travelling waves worksheet

For this worksheet you will need the following equations: \( v = f \lambda \) \( f = \frac{1}{T} \)

1. Forty waves pass a given point in 12 seconds. Calculate the frequency and period of the waves.

2. A ruler partially hangs over the end of a bench. It is supported at one end and made to vibrate at the other end in an attempt to display simple harmonic motion. If the ruler has an amplitude of 0.22 cm and makes twelve complete vibrations in 0.12 seconds, how far does the end of the ruler travel in 4.7 seconds?

3. The distance between successive crests of a wave is 2.4 cm. If the frequency of the wave is 6.2 Hz, what is the wave’s speed?

4. Determine the period, amplitude, and frequency of the following wave:

![Graph of a wave](image)
5 A second wave has the same amplitude as the wave in question 4. If the second wave’s frequency is four times that of the wave in question 4, at what time would the first crest appear? Assume that the second wave starts at the same time as the first and it has a displacement of 0 m at \( t = 0 \) s.

6 The distance between the first and third maximum compression in a longitudinal wave is 0.24 cm. If the wave has a frequency of 16 Hz, what is its speed?

7 The wavelength of a transverse wave is 0.80 m. What is the distance between two troughs if there are three crests in between?
4 Waves

4.2 Travelling waves

Name: ……………………………….
Date: ………………………………..

Wave terminology

1 On the above graph, label a crest.
2 On the above graph, label a trough.
3 On the above graph, label the amplitude with an “A”.
4 On the above graph, label the period with a “T”.
5 Explain how to calculate the wavelength if the speed of the above wave is known.

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6 On the above graph, label all of the places where the wave has a maximum speed.
7 On the above graph, label all of the places where the wave has a maximum acceleration.
8 On the above graph, label a point on the wave that is in phase with the point (4, 0).
9 The above graph shows a transverse wave – true or false?

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4 Waves

4.2 Travelling waves

Name: ……………………………….. Date: ………………………………..

Waves worksheet

1 A transverse wave is shown as it travels along a spring. When the time is zero seconds the displacement of the spring is zero. On the same axis draw the displacement when the time equals $T/8$.

2 Explain what is meant by the speed of a wave.

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Polarized light worksheet

1 Unpolarized light is incident on a polarizer which in turn, transmits polarized light to a second polarizer. If the original light has an intensity of $I_o$ and the intensity emerging from the second polarizer is 0.397 $I_o$, find the angle that the second polarizer’s axes make with the first.

2 Unpolarized light is incident on a polarizer which in turn, transmits polarized light to a second polarizer. If the second polarizer’s axes are at 57.0° with respect to the first polarizer and the intensity emerging from the second polarizer is 3.00 Wm$^{-2}$, find the original intensity of the unpolarized light.

3 Can longitudinal waves be polarized?

4 Three consecutive polarizers have axes that are parallel with respect to each other. If the intensity of light emerging from the third (final) polarizer is $x$, find the ratio of the intensity emerging from the second polarizer to the intensity emerging from the first polarizer.

5 Find the ratio of the light emerging from the third polarizer to the intensity of the unpolarized light in the previous question.
4.3 Wave characteristics

6 The intensity of unpolarized light incident on a polarizer is $I_o$. A second polarizer in line with the first has an axes that is parallel with respect to the first polarizer. If the first one is rotated clockwise to 90° of its original position and the second one is rotated clockwise to 60° of its original position, what is the intensity of the final emerging light?

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7 The intensity of unpolarized light incident on a polarizer is $I_o$. A second polarizer in line with the first has an axes that is parallel with respect to the first polarizer. If the first one is rotated clockwise to 45° of its original position and the second one is rotated anti-clockwise to 30° of its original position, what is the intensity of the final emerging light?

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8 Plane-polarized light of intensity $I_o$ is incident on a polarizer that produces an intensity of 0.75 $I_o$. If that polarizer is now rotated 90° from its original position what intensity is now emitted?

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Double slit questions

A laser rated at 675 nm strikes two vertical slits separated by 1.25 mm. If a screen is located 4.50 m away, behind the slits, what is the distance between the central maximum and the first maximum?

1. List your answer in mm.

2.

4.15 Use the graph in Figure 4.58a for this question. In a double-slit interference experiment the two slits are separated by a distance of $4.2 \times 10^{-4}$ m and the screen is 3.8 m from the slits.
   a Determine the wavelength of light used in this experiment.
   b Suggest the effect on the separation of the fringes of decreasing the wavelength of light.
   c State the feature of the graph that enables you to deduce that the slit width is negligible.
4 Waves

4.5 Standing waves

Open and closed tubes

1. The first harmonic for a closed tube is 512 Hz. If the air temperature is 20°C, determine the wavelength of the sound and the length of the tube.

2. What is the frequency of the next two harmonics in question 1?

3. The length of an open tube is 0.36 m. If the frequency of the fifth harmonic in this tube is 2500 Hz, find the temperature of the air.

4. The distance between successive nodes in a vibrating string is 0.17 m. If the frequency of the source is 120 Hz, what is the speed of the waves?

5. An open pipe is 74 cm long. If the frequency of the first harmonic of the open tube is the same as the frequency of the first harmonic of a closed tube, how long is the closed tube?
6 Consecutive harmonics in a closed tube are 220 Hz and 660 Hz. If the speed of sound is 350 m s$^{-1}$, how long is the tube?
46 A horizontal aluminium rod of length 1.2 m is hit sharply with a hammer. The hammer rebounds from the rod 0.18 ms later.
   a Explain why the hammer rebounds.
   b Calculate the speed of sound in aluminium.
   c The hammer created a longitudinal standing wave in the rod. Estimate the frequency of the sound wave by assuming that the rod vibrates in the first harmonic.

Exam-style questions

1 The diagram shows a point P on a string at a particular instant of time. A transverse wave is travelling along the string from left to right.

Which is correct about the direction and the magnitude of the velocity of point P at this instant?

<table>
<thead>
<tr>
<th>Direction</th>
<th>Magnitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>A up</td>
<td>maximum</td>
</tr>
<tr>
<td>B up</td>
<td>minimum</td>
</tr>
<tr>
<td>C down</td>
<td>maximum</td>
</tr>
<tr>
<td>D down</td>
<td>minimum</td>
</tr>
</tbody>
</table>

2 A tight horizontal rope with one end tied to a vertical wall is shaken with frequency $f$ so that a travelling wave of wavelength $\lambda$ is created on the rope. The rope is now shaken with a frequency $2f$. Which gives the new wavelength and speed of the wave?

<table>
<thead>
<tr>
<th>Wavelength</th>
<th>Speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>A $\lambda$</td>
<td>$f\lambda$</td>
</tr>
<tr>
<td>B $\lambda$</td>
<td>$2f\lambda$</td>
</tr>
<tr>
<td>C $\frac{\lambda}{2}$</td>
<td>$f\lambda$</td>
</tr>
<tr>
<td>D $\frac{\lambda}{2}$</td>
<td>$2f\lambda$</td>
</tr>
</tbody>
</table>
3 The graph shows the displacement of a medium when a longitudinal wave travels through the medium from left to right. Positive displacements correspond to motion to the right. Which point corresponds to the centre of a compression?

4 The diagram shows wavefronts of a wave entering a medium in which the wave speed decreases. Which diagram is correct?

5 The graph shows the variation with time of the displacement of a particle in a medium when a wave of intensity $I$ travels through the medium. The intensity of the wave is halved. Which graph now represents the variation of displacement with time? (The scale on all graphs is the same.)
6 Which of the following does not apply to longitudinal waves?

A superposition  
B formation of standing waves  
C interference  
D polarisation

7 Interference is observed with two identical coherent sources. The intensity of the waves at a point of constructive interference is I. What is the intensity when one source is removed?

A 0  
B I  
C \( \frac{I}{2} \)  
D \( \frac{I}{4} \)

8 Unpolarised light of intensity \( I_0 \) is incident on two polarisers, one behind the other, with parallel transmission axes. The first polariser is rotated by 30° clockwise and the second 30° counter-clockwise. What is the intensity transmitted?

A \( I_0 \)  
B \( \frac{I_0}{2} \)  
C \( \frac{I_0}{4} \)  
D \( \frac{I_0}{16} \)

9 A pipe of length 8.0 m is open at one end and closed at the other. The speed of sound is 320 m s\(^{-1}\). Which is the lowest frequency of a standing wave that can be established within this pipe?

A 5.0 Hz  
B 10 Hz  
C 15 Hz  
D 30 Hz

10 Travelling waves of wavelength 32 cm are created in a closed–open pipe X of length 40 cm and an open–open pipe Y of length 50 cm.

In which pipe or pipes will a standing wave be formed?

A X only  
B Y only  
C neither X nor Y  
D both X and Y

11 A longitudinal wave is travelling through a medium. The displacement of the wave at \( t = 10 \) s is shown below. Positive displacements are directed to the right.
Point P is at a distance of 20 cm from the origin. The graph shows the variation with time of the displacement of point P.

\[ 	ext{Graph showing displacement vs time} \]

**a** Distinguish a longitudinal from a transverse wave. [2]

**b** State, for this wave:
   1. the amplitude [1]
   2. the wavelength [1]
   3. the frequency. [1]

**c** Calculate the speed of the wave. [2]

**d** Suggest whether the wave is travelling to the right or to the left. [3]

**e** Point Q is a distance of 15 cm to the right of P. Draw the variation of the displacement of Q with time. [2]

**f** The travelling wave in parts a–d is directed towards a pipe that has one end closed and the other open.
   1. State and explain the length of the pipe so that a standing wave in its first harmonic is established within the pipe. [2]
   2. State two differences between a standing wave and a travelling wave. [2]
   3. In the context of a standing wave state the meaning of the term wave speed. [2]

12 Two pulses travel towards each other on the same taut rope. The two graphs show the pulses before and after the collision. The speed of the black pulse is 15 m s\(^{-1}\). The left diagram shows the pulses at \( t = 0 \).

\[ 	ext{Graphs showing pulses} \]

**a** State the principle of superposition. [2]

**b** State the speed of the grey pulse. [1]

**c** i Determine the time after which the two pulses completely overlap. [1]
   ii Draw the shape of the rope at the time of complete overlap. [2]

**d** i Suggest whether any energy was lost during the collision of the two pulses. [2]
   ii Comment on the shape of the rope in c ii by reference to your answer in d i. [3]
13. A man is swimming underwater at a depth of 2.0 m. The man looks upwards.
   a. Explain why he can see the world outside the water only through a circle on the surface of the water. [2]
   b. Calculate the radius of this circle given that the refractive index of water is 1.33. [2]
   c. Discuss how the answer to b changes (if at all) if he looks up from a greater depth. [2]
   d. Sound waves travelling in air approach an air–water boundary. The speed of sound in air is 340 m s$^{-1}$ and in water it is 1500 m s$^{-1}$. The wavefronts make an angle of 12° with the boundary.

   ![Diagram of air-water boundary with 12° angle]

   i. Calculate the angle the wavefronts in the water make with the boundary. [2]
   ii. Draw three wavefronts in the water. [2]
   iii. Use your answer to ii to suggest why a person swimming underwater near a noisy beach does not hear much noise. [2]

14. a. Describe what is meant by polarised light. [1]

   b. Unpolarised light of intensity 320 W m$^{-2}$ is incident on the first of three polarisers that are one behind the other. The first and third polarisers have vertical transmission axes. The middle polariser’s transmission axis is rotated by an angle $\theta$ to the vertical. The transmitted intensity is 10 W m$^{-2}$. Determine $\theta$. [3]

   c. Partially polarised light is a combination of completely unpolarised light and light that is polarised. Partially polarised light is transmitted through a polariser. As the polariser is rotated by 360° the ratio of the maximum to the minimum transmitted intensity is 7. Determine the fraction of the beam’s intensity that is due to the polarised light. [3]

   d. A person is sitting behind a vertical glass wall. The person cannot be clearly seen because of the glare of reflections from the glass wall. Suggest how the use of a polariser makes it easier to see the person more clearly. [3]

15. In a two-slit experiment, red light is incident on two parallel slits. The light is observed on a screen far from the slits. The graph shows how the intensity of the light on the screen varies with distance $y$ from M.

   ![Graph showing intensity variation with distance y from M]

   Intensity/W m$^{-2}$

   y/cm

   M

   -2 -1 0 1 2
a Explain why light is able to reach the middle of the screen. [2]
b One of the slits is covered. State and explain the intensity of the light at M. [3]
c State the feature of this graph that shows that the slit width is not negligibly small. [1]
The distance to the screen is 3.2 m and the separation of the slits is 0.39 mm.
d Determine the wavelength of the light. [2]
e The red light is replaced by blue light. Predict what (if anything) will happen to the separation of the bright fringes on the screen. [2]

16 a Outline how a standing wave may be formed. [2]

A source of sound is placed above a tube containing water. The longest length of the air column above the water for which a strong sound is heard from the tube is 61 cm. The next length of the air column for which another strong sound is heard is 49 cm.

b i Explain the origin of the loud sound from the tube. [2]
ii Suggest why a strong sound is heard for specific lengths of the air column. [2]
iii Predict the next length of the air column for which a loud sound will be heard. [1]
iv The frequency of the source is 1400 Hz. Estimate the speed of sound in the tube. [2]
Questions

1 (IB)

a) A pendulum consists of a bob suspended by a light inextensible string from a rigid support. The pendulum bob is moved to one side and then released. The sketch graph shows how the displacement of the pendulum bob undergoing simple harmonic motion varies with time over one time period.

On a copy of the sketch graph:
(i) Label, with the letter A, a point at which the acceleration of the pendulum bob is a maximum.
(ii) Label, with the letter V, a point at which the speed of the pendulum bob is a maximum.

b) Explain why the magnitude of the tension in the string at the midpoint of the oscillation is greater than the weight of the pendulum bob.

2 (IB)

The graph below shows how the displacement $x$ of a particle undergoing simple harmonic motion varies with time $t$. The motion is undamped.

a) Sketch a graph showing how the velocity $v$ of the particle varies with time.

b) Explain why the graph takes this form.

3 (IB)

a) In terms of the acceleration, state two conditions necessary for a system to perform simple harmonic motion.

b) A tuning fork is sounded and it is assumed that each tip vibrates with simple harmonic motion.

The extreme positions of the oscillating tip of one fork are separated by a distance $d$.

(i) State, in terms of $d$, the amplitude of vibration.

(ii) Sketch a graph to show how the displacement of one tip of the tuning fork varies with time.

(iii) On your graph, label the time period $T$ and the amplitude $A$.

(8 marks)

4 (IB)

a) Graph 1 below shows the variation with time $t$ of the displacement $d$ of a travelling (progressive) wave. Graph 2 shows the variation with distance $x$ along the same wave of its displacement $d$.

a) State what is meant by a travelling wave.
b) Use the graphs to determine the amplitude, wavelength, frequency and speed of the wave.

(5 marks)

5 (IB)

a) With reference to the direction of energy transfer through a medium, distinguish between a transverse wave and a longitudinal wave.

b) A wave is travelling along the surface of some shallow water in the x-direction. The graph shows the variation with time t of the displacement d of a particle of water.

Use the graph to determine the frequency and the amplitude of the wave.

c) The speed of the wave in b) is 15 cm s\(^{-1}\). Deduce that the wavelength of this wave is 2.0 cm.

d) The graph in b) shows the displacement of a particle at the position x = 0.

Draw a graph to show the variation with distance x along the water surface of the displacement d of the water surface at time t = 0.070 s.

(11 marks)

6 (IB)

a) By referring to the energy of a travelling wave, explain what is meant by:

(i) a ray

(ii) wave speed.

b) The following graph shows the variation with time t of the displacement x\(_A\) of wave A as it passes through a point P.

(11 marks)

7 (IB)

a) With reference to the direction of energy transfer through a medium, distinguish between a transverse wave and a longitudinal wave.

b) The graph shows the variation with time t of the displacement x\(_B\) of wave B as it passes through point P. The waves have equal frequencies.

(i) Calculate the frequency of the waves.

(ii) The waves pass simultaneously through point P. Use the graphs to determine the resultant displacement at point P of the two waves at time t = 1.0 ms and at time t = 8.0 ms.

(6 marks)
Use the graph to determine for the wave:
(i) the frequency
(ii) the amplitude.

c) The speed of the water wave is 12 cm s\(^{-1}\). Calculate the wavelength of the wave.
d) The graph in b) shows the displacement of a particle at the position \(x = 0\).
Sketch a graph to show the variation with distance \(x\) along the water surface of the displacement \(d\) of the water surface at time \(t = 0.20\) s.
e) The wave meets a shelf that reduces the depth of the water.

The polarizer is then rotated by 180° in the direction shown. Sketch a graph to show the variation with the rotation angle \(\theta\), of the transmitted light intensity \(I\), as \(\theta\) varies from 0° to 180°. Label your sketch-graph with the letter U.

b) The beam in a) is now replaced with a polarized beam of light of the same intensity. The plane of polarization of the light is initially parallel to the polarization axis of the polarizer.

The angle between the wavefronts in the shallow water and the shelf is 30°. The speed of the wave in the shallow water is 12 cm s\(^{-1}\) and in the deeper water is 18 cm s\(^{-1}\). For the wave in the deeper water, determine the angle between the normal to the wavefronts and the shelf.

(12 marks)

8 (IB)
a) A beam of unpolarized light of intensity \(I_0\) is incident on a polarizer. The polarization axis of the polarizer is initially vertical as shown.

The sound from X can be heard on Y due to
A. refraction
B. reflection
C. diffraction
D. transmission.
10 (IB)

A small sphere, mounted at the end of a vertical rod, dips below the surface of shallow water in a tray. The sphere is driven vertically up and down by a motor attached to the rod.

The oscillations of the sphere produce travelling waves on the surface of the water.

a) The diagram shows how the displacement of the water surface at a particular instant in time varies with distance from the sphere. The period of oscillation of the sphere is 0.027 s.

Use the diagram to calculate, for the wave:
(i) the amplitude
(ii) the wavelength
(iii) the frequency
(iv) the speed.

b) The wave moves from region A into a region B of shallower water. The waves move more slowly in region B. The diagram (not to scale) shows some of the wavefronts in region A.

(i) With reference to a wave, distinguish between a ray and a wavefront.
(ii) The angle between the wavefronts and the interface in region A is 60°. The refractive index \( n_A \) is 1.4. Determine the angle between the wavefronts and the interface in region B.
(iii) On the diagram above, construct three lines to show the position of three wavefronts in region B.

c) Another sphere is dipped into the water. The spheres oscillate in phase. The diagram shows some lines in region A along which the disturbance of the water surface is a minimum.

(i) Outline how the regions of minimum disturbance occur on the surface.
(ii) The frequency of oscillation of the spheres is increased. State and explain how this will affect the positions of minimum disturbance.

(15 marks)

11 (IB)

a) Describe two ways in which standing waves differ from travelling waves.

b) An experiment is carried out to measure the speed of sound in air, using the apparatus shown below.
A tube that is open at both ends is placed vertically in a tank of water until the top of the tube is just at the surface of the water. A tuning fork of frequency 440 Hz is sounded above the tube. The tube is slowly raised out of the water until the loudness of the sound reaches a maximum for the first time, due to the formation of a standing wave.

(i) Explain the formation of a standing wave in the tube.
(ii) State the position where a node will always be produced.
(iii) The tube is raised a little further. Explain why the loudness of the sound is no longer at a maximum.

c) The tube is raised until the loudness of the sound reaches a maximum for a second time. Between the two positions of maximum loudness the tube has been raised by 36.8 cm. The frequency of the sound is 440 Hz. Estimate the speed of sound in air.

12 (IB)

a) State two properties of a standing (stationary) wave.

b) The diagram shows an organ pipe that is open at one end.

The length of the pipe is $l$. The frequency of the fundamental (first harmonic) note emitted by the pipe is 16 Hz.

(i) On a copy of the diagram, label with the letter P the position along the pipe where the amplitude of oscillation of the air molecules is the largest.
(ii) The speed of sound in the air in the pipe is 330 m s$^{-1}$. Calculate the length $l$.

13 (IB)

A microwave transmitter emits radiation of a single wavelength towards a metal plate along a line normal to the plate. The radiation is reflected back towards the transmitter.

A microwave detector is moved along a line normal to the microwave transmitter and the metal plate. The detector records a sequence of equally spaced maxima and minima of intensity.

a) Explain how these maxima and minima are formed.

b) The microwave detector is moved through 130 mm from one point of minimum intensity to another point of minimum intensity. On the way it passes through nine points of maximum intensity. Calculate the

(i) wavelength of the microwaves.
(ii) frequency of the microwaves.

The microwave detector is moved along a line normal to the microwave transmitter and the metal plate. The detector records a sequence of equally spaced maxima and minima of intensity.

a) Explain how these maxima and minima are formed.

b) The microwave detector is moved through 130 mm from one point of minimum intensity to another point of minimum intensity. On the way it passes through nine points of maximum intensity. Calculate the

(i) wavelength of the microwaves.
(ii) frequency of the microwaves.

The length of the pipe is $l$. The frequency of the fundamental (first harmonic) note emitted by the pipe is 16 Hz.

(i) On a copy of the diagram, label with the letter P the position along the pipe where the amplitude of oscillation of the air molecules is the largest.
(ii) The speed of sound in the air in the pipe is 330 m s$^{-1}$. Calculate the length $l$.

c) Use your answer to b)(ii) to suggest why it is better to use organ pipes that are closed at one end for producing low frequency notes rather than pipes that are open at both ends.
Conceptual Questions

(These questions are not in an IB style but instead designed to check your understanding of the concept of this topic. You should try your best to appropriately communicate your answer using prose)

1. Give some examples of everyday vibrating objects. Which exhibit SHM, at least approximately?

2. Is the acceleration of a simple harmonic oscillator every zero? If so, where?

Calculation-based Questions

1. If a particle undergoes SHM with an amplitude of 0.18m what is the total distance it travels in one period?

2. If a pendulum undergoes exactly 20 oscillations in 34.6s, calculate (a) its frequency; (b) its angular frequency.

3. A child on a swing went through exactly five complete oscillations in 10.4s. (a) What was the period? (b) What was the frequency?
4. The graph below shows the position of a particle from the equilibrium with respect to time. (a) Write down the value of the amplitude with its units. (b) Write down the value of the period with its units. (c) Calculate the frequency of the oscillation and state its units.

5. For the diagram shown in question 4, sketch (a) the corresponding velocity-time graph; and (b) the acceleration-time graph. Draw each on separate axes.
6. A microwave is emitted as shown in the graph below. A additional microwaves are emitted a short time later with the same amplitude and wavelength except that they have a phase difference of (a) 45° and; (b) π radians. Sketch these additional waves on the same axis.

7. Two identical soundwaves are produced from two identical speakers. What is the phase difference between the two waves in (a) degrees; and (b) radians?
3. State what is meant by a progressive (travelling wave) in terms of medium, source and energy.

4. Distinguish between transverse and longitudinal waves. Give your answer in terms of the medium and propagation.

5. Describe the relationship between density and pressure for a longitudinal wave in air.

6. Give one example of a wave pulse and one example of a continuous progressive wave.

7. Do waves have to be sinusoidal? Discuss.

8. Draw, to scale, a diagram showing the wavefronts for (a) a plane wave with a wavelength of 1cm and (b) a circular wave with a wavelength of 1cm. On both diagrams, show with an arrow, the direction of propagation.
9. The diagram below shows three points on a string on which a transverse wave propagates to the right. **State** how these three points will move in the next instant of time.

![Diagram of a transverse wave with three points labeled](image)

10. Below is shown a picture of a longitudinal wave travelling towards the right taken at a specific time. The density of the lines is proportional to the density in the medium the wave travels through.

    ![Diagram of a longitudinal wave](image)

    On the diagram, **label** a compression and one rarefaction. Then **label** the wavelength of the wave.

11. Consider a continuous wave on a rope. **State** and explain whether the velocity of the wave moving along the rope is the same velocity of a particle of the rope.

12. Draw two suitably labelled diagrams to explain the terms:
   
   a. Wavelength
   b. Period
   c. Amplitude
   d. Crest
   e. Trough
Conceptual Questions

(These questions are not in an IB style but instead designed to check your understanding of the concept of this topic. You should try your best to appropriately communicate your answer using prose)

13. What does polarization tell us about the nature of light?

14. Explain the advantage of polarized sunglasses over normal tinted ones.

15. How can you tell if a pair of sunglasses is polarizing or not?

16. Two polarized sheets rotated at an angle of 90° with respect to each other will not let any light through. Three polarized sheets, each rotated at an angle of 45° with respect to each other, will let some light through. What will happen to unpolarized light if you align four polarized sheets, each rotated at an angle of 30° with respect to the one in front of it?

17. What would the colour of the sky be if the Earth had no atmosphere?

Calculation-based Questions

18. Two polarizers are oriented 65° to one another. Unpolarized light falls on them. What fraction of the light intensity is transmitted?
19. Two Polaroids are aligned so that the light passing through them is a maximum. At what angle should one of them be placed so that the intensity is subsequently reduced by half?

20. At what angle should the axes of two Polaroids be placed so as to reduce the intensity of the incident unpolarised light to (a) 1/3, (b) 1/10.

21. Two polarizers are oriented at 40° to each other and plane-polarized light is incident on them. If only 15% of the light gets through both of them, what was the initial polarization angle of the incident light?
Topic 4.4 Wave Properties Problems

Calculation-based Questions

1. Two mirrors meet at 135° angle. If light rays strike one mirror at 40° as shown, at what angle do they leave the second mirror.

2. A person whose eyes are 1.68m above the floor stands 2.20m in front of a vertical plane mirror whose bottom edge is 43cm above the floor. What is the horizontal distance x to the base of the wall supporting the mirror of the nearest point on the floor that can be seen reflected in the mirror?

3. The speed of light in ice is 2.29x108m/s. What is the index of refraction of ice?
4. A flashlight beam strikes the surface of a pane of glass \( n = 1.58 \) at an angle of 63° to the normal. What is the angle of refraction?

5. A diver shines a flashlight upward from beneath the water at a 42.5° angle to the vertical. At what angle does the light leave the water?

6. Light is incident on an equilateral glass prism at a 45.0° angle to one face. Calculate the angle at which light emerges from the opposite face. Assume that \( n = 1.58 \).

7. In searching the bottom of a pool at night a watchman shines a narrow beam of light from his flashlight, 1.3m above the water level, onto the surface of the water at a point 2.7m from the edge of the pool. Where does the spot of light hit the bottom of the pool, measured from the wall beneath his foot, if the pool is 2.1m deep?
1. An organ pipe is 112 cm long. What are the fundamental and first three harmonics if the pipe is (a) closed at one end; and (b) open at both ends? [4 marks]

2. (a) What resonant frequency would you expect from blowing across the top of an empty soda bottle that is 18 cm deep, if you assumed it was a closed tube? (b) How would that change if it was one-third full of soda? [2 Marks]
3. A tight guitar string has a frequency of 540Hz at its third harmonic. What will be its fundamental frequency if it is fingered at a length of only 60% of its original length?

[3 Marks]

4. A pipe in air at 20°C is designed to produce two successive harmonics at 240Hz and 280Hz. How long must the pipe be, and is it open or closed?

[3 Marks]
Calculation-based Questions

1. If 580-nm light falls on a slit 0.0440mm wide, what is the full angular width of the central diffraction peak? [2 Marks]

2. Monochromatic light falls on a slit that is 2.60x10^{-3} mm wide. If the angle between the first dark fringes on either side of the central maximum is 35.0° (dark fringe to dark fringe), what is the wavelength of light used? [2 Marks]
3. A single slit, 1.0mm wide, is illuminated by a 450-nm light. What is the width of the central maximum (in cm) in the diffraction pattern on a screen 5.0m away? [3 Marks]

4. How wide is the central diffraction peak on a screen 2.30m behind a 0.0348mm wide slit illuminated by a 589nm light? [3 Marks]
A beam of coherent monochromatic light from a distant galaxy is used in an optics experiment on Earth.

The beam is incident normally on a double slit. The distance between the slits is 0.300 mm. A screen is at a distance $D$ from the slits. The diffraction angle $\theta$ is labelled.

1a. A series of dark and bright fringes appears on the screen. Explain how a dark fringe is [3 marks] formed.

1b. The wavelength of the beam as observed on Earth is 633.0 nm. The separation between a dark and a bright fringe on the screen is 4.50 mm. Calculate $D$. [2 marks]
The air between the slits and the screen is replaced with water. The refractive index of water is 1.33.

1c. Calculate the wavelength of the light in water.  

[1 mark]

1d. State two ways in which the intensity pattern on the screen changes.  

[2 marks]

A loudspeaker emits sound towards the open end of a pipe. The other end is closed. A standing wave is formed in the pipe. The diagram represents the displacement of molecules of air in the pipe at an instant of time.

2a. Outline how the standing wave is formed.  

[1 mark]

X and Y represent the equilibrium positions of two air molecules in the pipe. The arrow represents the velocity of the molecule at Y.

2b. Draw an arrow on the diagram to represent the direction of motion of the molecule at X. [1 mark]

2c. Label a position N that is a node of the standing wave.  

[1 mark]
2d. The speed of sound is 340 m s\(^{-1}\) and the length of the pipe is 0.30 m. Calculate, in Hz, the frequency of the sound.
The loudspeaker in (a) now emits sound towards an air–water boundary. A, B and C are parallel wavefronts emitted by the loudspeaker. The parts of wavefronts A and B in water are not shown. Wavefront C has not yet entered the water.

2e. The speed of sound in air is 340 m s\(^{-1}\) and in water it is 1500 m s\(^{-1}\). \(\text{[2 marks]}\)

The wavefronts make an angle \(\theta\) with the surface of the water. Determine the maximum angle, \(\theta_{\text{max}}\), at which the sound can enter water. Give your answer to the correct number of significant figures.

\(\text{...} \)

\(\text{...}\)

\(\text{...}\)

\(\text{...}\)

2f. Draw lines on the diagram to complete wavefronts A and B in water for \(\theta < \theta_{\text{max}}\). \(\text{[2 marks]}\)
A large cube is formed from ice. A light ray is incident from a vacuum at an angle of 46° to the normal on one surface of the cube. The light ray is parallel to the plane of one of the sides of the cube. The angle of refraction inside the cube is 33°.

3a. Calculate the speed of light inside the ice cube. [2 marks]

3b. Show that no light emerges from side AB. [3 marks]

3c. Sketch, on the diagram, the subsequent path of the light ray. [2 marks]
Each side of the ice cube is 0.75 m in length. The initial temperature of the ice cube is –20 °C.

3d. Determine the energy required to melt all of the ice from –20 °C to water at a temperature of 0 °C. [4 marks]

Specific latent heat of fusion of ice = 330 kJ kg\(^{-1}\)
Specific heat capacity of ice = 2.1 kJ kg\(^{-1}\) \(\text{k}^{-1}\)
Density of ice = 920 kg m\(^{-3}\)

3e. Outline the difference between the molecular structure of a solid and a liquid. [1 mark]
4a. Outline what is meant by the principle of superposition of waves. [2 marks]

4b. Red laser light is incident on a double slit with a slit separation of 0.35 mm. [3 marks]
A double-slit interference pattern is observed on a screen 2.4 m from the slits.
The distance between successive maxima on the screen is 4.7 mm.
Calculate the wavelength of the light. Give your answer to an appropriate number of significant figures.
4c. Explain the change to the appearance of the interference pattern when the red-light laser is replaced by one that emits green light. [2 marks]

4d. One of the slits is now covered. [2 marks]
Describe the appearance of the pattern on the screen.
A student investigates how light can be used to measure the speed of a toy train.

Light from a laser is incident on a double slit. The light from the slits is detected by a light sensor attached to the train.

The graph shows the variation with time of the output voltage from the light sensor as the train moves parallel to the slits. The output voltage is proportional to the intensity of light incident on the sensor.

5a. Explain, with reference to the light passing through the slits, why a series of voltage peaks occurs. [3 marks]
5b. The slits are separated by 1.5 mm and the laser light has a wavelength of 6.3 \times 10^{-7} \text{ m}. \text{[1 mark]} 

The slits are 5.0 m from the train track. Calculate the separation between two adjacent positions of the train when the output voltage is at a maximum.

5c. Estimate the speed of the train. \text{[2 marks]}

5d. In another experiment the student replaces the light sensor with a sound sensor. The \text{[2 marks]} 

train travels away from a loudspeaker that is emitting sound waves of constant amplitude and frequency towards a reflecting barrier. 

The sound sensor gives a graph of the variation of output voltage with time along the track that is similar in shape to the graph shown in the resource. Explain how this effect arises.
6a. Two microwave transmitters, X and Y, are placed 12 cm apart and are connected to the same source. A single receiver is placed 54 cm away and moves along a line AB that is parallel to the line joining X and Y.

Maxima and minima of intensity are detected at several points along AB.
(i) Explain the formation of the intensity minima.
(ii) The distance between the central maximum and the first minimum is 7.2 cm. Calculate the wavelength of the microwaves.
6b. Radio waves are emitted by a straight conducting rod antenna (aerial). The plane of polarization of these waves is parallel to the transmitting antenna. [2 marks]

An identical antenna is used for reception. Suggest why the receiving antenna needs to be parallel to the transmitting antenna.
6c. The receiving antenna becomes misaligned by 30° to its original position. [3 marks]

The power of the received signal in this new position is 12 \( \mu \text{W} \).

(i) Calculate the power that was received in the original position.

(ii) Calculate the minimum time between the wave leaving the transmitting antenna and its reception.
A longitudinal wave is travelling in a medium from left to right. The graph shows the variation with distance $x$ of the displacement $y$ of the particles in the medium. The solid line and the dotted line show the displacement at $t=0$ and $t=0.882$ ms, respectively.

The period of the wave is greater than 0.882 ms. A displacement to the right of the equilibrium position is positive.

7a. State what is meant by a longitudinal travelling wave. \[1 \text{ mark}\]

7b. Calculate, for this wave, \[4 \text{ marks}\]
   (i) the speed.
   (ii) the frequency.
7c. The equilibrium position of a particle in the medium is at $x=0.80$ m. For this particle at $t=0$, state and explain

(i) the direction of motion.

(ii) whether the particle is at the centre of a compression or a rarefaction.
Topic 4.1: Waves-Oscillations

1. For a system executing simple harmonic motion, the restoring force acting on the system is proportional to the
   A. displacement of the system from equilibrium.
   B. amplitude of oscillation.
   C. elastic potential energy.
   D. frequency of oscillation.

   (Total 1 mark)

2. The graphs show how the acceleration $a$ of four different particles varies with their displacement $x$.
   Which of the particles is executing simple harmonic motion?
   A. 
   B. 
   C. 
   D. 

   (Total 1 mark)
3. The graph shows how the displacement varies with time for an object undergoing simple harmonic motion.

Which graph shows how the object’s acceleration $a$ varies with time $t$?

A.  
B.  
C.  
D.  

(Total 1 mark)

4. The graph below shows how the displacement $x$ of a particle undergoing simple harmonic motion varies with time $t$. The motion is undamped.

Which of the following graphs correctly shows how the velocity $v$ of the particle varies with $t$?

A.  
B.  
C.  
D.  

(Total 1 mark)
5. The graph shows measurements of the height $h$ of sea level at different times $t$ in the Bay of Fundy.

![Graph of sea level measurements over time]

Which of the following gives the approximate amplitude and period of the tides?

<table>
<thead>
<tr>
<th>Amplitude</th>
<th>Period</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. 6.5 m</td>
<td>6 hours</td>
</tr>
<tr>
<td>B. 13 m</td>
<td>12 hours</td>
</tr>
<tr>
<td>C. 6.5 m</td>
<td>12 hours</td>
</tr>
<tr>
<td>D. 13 m</td>
<td>6 hours</td>
</tr>
</tbody>
</table>

(Total 1 mark)

6. A particle oscillates with simple harmonic motion with period $T$.

At time $t = 0$, the particle has its maximum displacement. Which graph shows the variation with time $t$ of the kinetic energy $E_k$ of the particle?

![Graphs of variation of kinetic energy with time]

A.  
B.  
C.  
D.  

(Total 1 mark)
Short answer questions

7. Simple harmonic motion

(a) A body is displaced from equilibrium. State the two conditions necessary for the body to execute simple harmonic motion.

1. ........................................................................................................................................

2. ........................................................................................................................................

(b) In a simple model of a methane molecule, a hydrogen atom and the carbon atom can be regarded as two masses attached by a spring. A hydrogen atom is much less massive than the carbon atom such that any displacement of the carbon atom may be ignored.

The graph below shows the variation with time \( t \) of the displacement \( x \) from its equilibrium position of a hydrogen atom in a molecule of methane.

The mass of hydrogen atom is \( 1.7 \times 10^{-27} \) kg. Use data from the graph above

(i) to determine its amplitude of oscillation.

........................................................................................................................................

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(ii) to show that the frequency of its oscillation is \( 9.1 \times 10^{13} \) Hz.

........................................................................................................................................

........................................................................................................................................

(Total 5 marks)
8. Sketch two cycles of the displacement-time (x-t) relationship for a simple pendulum. Assume that its displacement is a maximum at time 0 seconds. Mark on the graph a time for which the velocity is maximum (labeled A), a time for which the velocity is zero (labeled B) and a time for which the acceleration is a maximum (labeled C).

9. The equation defining simple harmonic motion is $a = -kx$.
   a) what are the units of the constant $k$?

   ........................................................................................................................................

   ........................................................................................................................................

   b) Two similar systems oscillate with simple harmonic motion. The constant for system $S_1$ is $k$, while that for system $S_2$ is $4k$. Explain the difference between the oscillations of the two systems.

   ........................................................................................................................................

   ........................................................................................................................................

10. Calculate the phase difference between the two displacement-time graphs shown in the figure. Give your answers in
   a) seconds

   ..........................................................................................................................

   b) radians

   ..........................................................................................................................

   c) degrees

   ..........................................................................................................................
1. On which one of the following graphs is the wavelength \( \lambda \) and the amplitude \( a \) of a wave correctly represented?

A. ![Graph A]

B. ![Graph B]

C. ![Graph C]

D. ![Graph D]

2. The speed of a wave is defined as

A. the speed at which the particles of the wave vibrate.

B. the speed of the medium through which the wave passes.

C. the speed of transfer of the energy of the wave.

D. the speed at which the vibrations of the wave are produced.
3. Graph P shows how the displacement at one point in a wave varies with time.

Graph Q shows how the displacement in the same wave varies with distance along the wave at one particular time.

Which one of the following expressions gives the speed of the wave?

A. \( \frac{x_1}{t_1} \)  
B. \( \frac{x_2}{t_2} \)  
C. \( \frac{x_2 - x_1}{t_2 - t_1} \)  
D. \( \frac{x_3 - x_1}{t_2 - t_1} \)  

(1)

4. The diagram shows the variation with distance \( x \) along a wave with its displacement \( d \).

The wave is travelling in the direction shown.

The period of the wave is \( T \). Which one of the following diagrams shows the displacement of the wave at \( \frac{T}{4} \) later?

A.  
B.  
C.  
D.  

(1)
5. A source produces water waves of frequency 10 Hz. The graph shows the variation with horizontal position of the vertical displacement of the surface of water at one instant in time.

The speed of the water waves is

A. 0.20 cm s\(^{-1}\)  
B. 4.0 cm s\(^{-1}\)  
C. 10 cm s\(^{-1}\)  
D. 20 cm s\(^{-1}\).

(1)

6. A water surface wave (ripple) is travelling to the right on the surface of a lake. The wave has period \(T\). The diagram below shows the surface of the lake at a particular instant of time. A piece of cork is floating in the water in the position shown.

Which is the correct position of the cork a time \(\frac{T}{4}\) later?

(1)

7. The diagram below shows a transverse wave on a string. The wave is moving from right to left.

In the position shown, point X has zero displacement and point Y is at a position of maximum displacement. Which one of the following gives the subsequent direction of motion of point X and of point Y?

<table>
<thead>
<tr>
<th>Point X</th>
<th>Point Y</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. left</td>
<td>left</td>
</tr>
<tr>
<td>B. upwards</td>
<td>upwards</td>
</tr>
<tr>
<td>C. downwards</td>
<td>left</td>
</tr>
<tr>
<td>D. downwards</td>
<td>upwards</td>
</tr>
</tbody>
</table>

(1)
8. The diagram below shows the displacement-position graph at a particular instant for a longitudinal wave travelling along a spring.

A positive displacement on the graph indicates that the coils of the spring are displaced to the right of their equilibrium position.

At which position along the spring is the displacement of two adjacent coils a maximum?
A. A  B. B  C. C  D. D

9. Which of the following is a value of wavelength that is found in the visible region of the electromagnetic spectrum?
A. $4 \times 10^{-5}$ m
B. $4 \times 10^{-7}$ m
C. $4 \times 10^{-9}$ m
D. $4 \times 10^{-11}$ m

10. Which of the following electromagnetic waves has a frequency greater than that of visible light?
A. Ultraviolet  B. Radio  C. Microwaves  D. Infrared

Short answer questions

1. Waves on a string

A travelling wave is created on a string. The graph below shows the variation with time $t$ of the displacement $y$ of a particular point on the string.
The variation with distance $x$ of the displacement $y$ of the string at $t = 0$ is shown below.

(a) Use information from the graphs to calculate, for this wave,

(i) the wavelength;

(ii) the frequency;

(iii) the speed of the wave.

(b) The wave is moving from left to right and has period $T$.

(i) On graph 1, draw a labelled line to indicate the amplitude of the wave.

(ii) On graph 2, draw the displacement of the string at $t = \frac{T}{4}$.

(Total 7 marks)

2. This question is about wave properties and interference.

The diagram below represents the direction of oscillation of a disturbance that gives rise to a wave.
(a) By redrawing the diagram in the spaces below, add arrows to show the direction of wave energy transfer to illustrate the difference between

(i) a transverse wave and

(ii) a longitudinal wave.

A wave travels along a stretched string. The diagram below shows the variation with distance along the string of the displacement of the string at a particular instant in time. A small marker is attached to the string at the point labelled M. The undisturbed position of the string is shown as a dotted line.

Directions of wave travel

(b) On the diagram above

(i) draw an arrow to indicate the direction in which the marker is moving.

(ii) indicate, with the letter A, the amplitude of the wave.

(iii) indicate, with the letter λ, the wavelength of the wave.

(iv) draw the displacement of the string a time \( \frac{T}{4} \) later, where \( T \) is the period of oscillation of the wave. Indicate, with the letter N, the new position of the marker.
The wavelength of the wave is 5.0 cm and its speed is 10 cm s\(^{-1}\).

(c) Determine
  
  (i) the frequency of the wave.

  ...........................................................................................................................  

  (1)

  (ii) how far the wave has moved in \(\frac{T}{4}\) s.

  ...........................................................................................................................  

  (2)

(Total 10 marks)

3. This question is about sound waves.

A sound wave of frequency 660 Hz passes through air. The variation of particle displacement with distance along the wave at one instant of time is shown below.

(a) State whether this wave is an example of a longitudinal or a transverse wave.

  ...........................................................................................................................  

  (1)

(b) Using data from the above graph, deduce for this sound wave,

  (i) the wavelength.

  ...........................................................................................................................  

  (1)

  (ii) the amplitude.

  ...........................................................................................................................  

  (1)

  (iii) the speed.

  ...........................................................................................................................  

  ...........................................................................................................................  

  ............................................................................  

  (2)

(Total 5 marks)
Topic 4.3: Waves-Wave characteristics

1. The diagram below is a snapshot of wave fronts of circular waves emitted by a point source S at the surface of water. The source vibrates at a frequency \( f = 10.0 \) Hz.

![Wave diagram](image)

The speed of the wave front is

A. 0.15 cm s\(^{-1}\)  B. 1.5 cm s\(^{-1}\)  C. 15 cm s\(^{-1}\)  D. 30 cm s\(^{-1}\).

(Total 1 mark)

2. Two waves meet at a point. The waves have a path difference of \( \frac{\lambda}{4} \). The phase difference between the waves is

A. \( \frac{\pi}{8} \) rad.  B. \( \frac{\pi}{4} \) rad.  C. \( \frac{\pi}{2} \) rad.  D. \( \pi \) rad.

(Total 1 mark)

3. Two waves meet at a point in space. Which of the following properties always add together?

A. Displacement
B. Amplitude
C. Speed
D. Frequency

(Total 1 mark)
4. The two graphs show the variation with time of the individual displacements of two waves as they pass through the same point.

![Graphs showing wave displacements](image)

The displacement of the resultant wave at the point at time $T$ is equal to

A. $x_1 + x_2$.
B. $x_1 - x_2$.
C. $A_1 + A_2$.
D. $A_1 - A_2$.

(Total 1 mark)

5. The diagram below shows two wave pulses moving towards one another.

![Diagram of wave pulses](image)

Which one of the following diagrams shows the resultant pulse when the two pulses are superposed?

A. ![Diagram A](image)
B. ![Diagram B](image)
C. ![Diagram C](image)
D. ![Diagram D](image)

(1)
6. The diagram below shows two pulses on a string travelling toward each other.

Which of the following diagrams best shows the shape of the string after the pulses have passed through each other?

A. 
B. 
C. 
D. 

(1)

7. Two coherent point sources $S_1$ and $S_2$ emit spherical waves.

Which of the following best describes the intensity of the waves at $P$ and $Q$?

<table>
<thead>
<tr>
<th></th>
<th>P</th>
<th>Q</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>maximum</td>
<td>minimum</td>
</tr>
<tr>
<td>B</td>
<td>minimum</td>
<td>maximum</td>
</tr>
<tr>
<td>C</td>
<td>maximum</td>
<td>maximum</td>
</tr>
<tr>
<td>D</td>
<td>minimum</td>
<td>minimum</td>
</tr>
</tbody>
</table>

(Total 1 mark)
8. The diagram shows sunlight reflected from a lake surface. The reflected sunlight is plane-polarized.

The plane of polarization of the reflected sunlight is
A. parallel to the lake surface.
B. perpendicular to the lake surface.
C. parallel to the direction of the reflected sunlight.
D. in the plane of the diagram.

(Total 1 mark)

9. Unpolarized light of intensity $I_0$ is incident on a polarizer. The transmitted light is then incident on a second polarizer. The axis of the second polarizer makes an angle of $60^\circ$ to the axis of the first polarizer.

The cosine of $60^\circ$ is $\frac{1}{2}$. The intensity of the light transmitted through the second polarizer is
A. $I_0$, B. $\frac{I_0}{2}$, C. $\frac{I_0}{4}$, D. $\frac{I_0}{8}$.

(Total 1 mark)

10. Two polarizing sheets have planes of polarization that are initially parallel.

The incoming light on sheet 1 is unpolarized. The intensity of the light transmitted is $I$. To reduce the intensity to $\frac{I}{2}$, which sheet must be rotated and through what angle?
### Short answer questions

1. This question is about intensity and amplitude.

At a distance of 15 m from the source, the intensity of a loud sound is $2.0 \times 10^{-4} \text{W} \cdot \text{m}^{-2}$.

(a) Show that the intensity at 120 m from the source is approximately $3.0 \times 10^{-6} \text{W} \cdot \text{m}^{-2}$.

(b) Deduce how the amplitude of the wave changes.

2. This question is about the interference of waves.

(a) State the principle of superposition.

A wire is stretched between two points A and B.

A standing wave is set up in the wire. This wave can be thought of as being made up from the superposition of two waves, a wave X travelling from A to B and a wave Y travelling from B to A. At one particular instant in time, the displacement of the wire is as shown. A background grid is given for reference and the equilibrium position of the wire is shown as a dotted line.
(b) On the grids below, draw the displacement of the wire due to wave X and wave Y.
3. This question is about polarized light.

(a) Distinguish between polarized and unpolarized light.

............................................................................................................................
............................................................................................................................
............................................................................................................................
............................................................................................................................

(b) A beam of plane polarized light of intensity $I_0$ is incident on an analyser. The direction of the beam is at right angles to the plane of the analyser.

![Diagram of polarized light and analyser]

The angle between the transmission axis of the analyser and the plane of polarization of the light is $\theta$. In the position shown the transmission axis of the analyser is parallel to the plane of polarization of the light ($\theta = 0$).

On the axes, sketch a graph to show how the intensity $I$ of the transmitted light varies with $\theta$ as the analyser is rotated through 180°.

![Graph of transmitted intensity vs. angle]

(Total 4 marks)
**Topic 4.4: Waves-Wave behaviour**

1. Light travelling from water to air is incident on a boundary.

![Diagram of light travelling from water to air](image)

Which of the following is a correct statement of Snell’s law for this situation?

A. \( \sin Z = constant \times \sin Y \)

B. \( \sin W = constant \times \sin Z \)

C. \( \sin X = constant \times \sin Z \)

D. \( \sin W = constant \times \sin Y \)

2. Which one of the following correctly describes the change, if any, in the speed, wavelength and frequency of a light wave as it passes from air into glass?

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

3. Sound waves move faster in warm air than in cold air. The diagram below shows plane waves in cold air moving towards a boundary with warm air.

![Diagram of sound waves in cold air](image)

Which of the arrows shows the possible direction of waves after reaching the boundary?

A. I   B. II  C. III  D. IV

(1)
4. Which of the following diagrams best shows the path of a ray of monochromatic light through a glass prism in air?

A. 

B. 

C. 

D. 

5. The diagram below shows plane wavefronts of a wave that is approaching the boundary between two media, X and Y. The speed of the wave is greater in medium X than in medium Y. The wave crosses the boundary.

Which of the following diagrams is correct?

A. 

B. 

C. 

D. 

(1)
6. A pulse is travelling along a string attached to a wall.

Which of the following shows the shape of the string after reflection from the wall?

![Pulse direction diagram](image1)

A. ![Option A](image2)
B. ![Option B](image3)
C. ![Option C](image4)
D. ![Option D](image5)

7. A string is held horizontally with one end attached to a fixed support. Two pulses are created at the free end of the string. The pulses are moving towards the fixed support as shown in the diagram below.

![String and fixed support diagram](image6)

Which one of the following diagrams is a possible subsequent picture of the string?

A. ![Option A](image7)
B. ![Option B](image8)
C. ![Option C](image9)
D. ![Option D](image10)

(1)
8. The phenomenon of diffraction is associated with
   A. sound waves only.   B. light waves only.
   C. water waves only.   D. all waves.

9. A bat approaches an insect of wing span length $d$. The bat emits a sound wave. The bat detects the insect if the sound is reflected from the insect.

   ![Diagram of sound wave](image)

   The insect will not be located if
   A. the insect’s speed is less than the speed of the sound wave.
   B. the insect’s wing beat frequency is greater than the frequency of the sound wave.
   C. the length $d$ is much greater than the wavelength of the sound wave.
   D. the length $d$ is much smaller than the wavelength of the sound wave.

10. Plane wavefronts are incident on a barrier as shown below.

   ![Diagram of wavefronts](image)

   Which of the following best shows the shape of the wavefronts on the other side of the barrier?
   A. ![Diagram A]  
   B. ![Diagram B]  
   C. ![Diagram C]  
   D. ![Diagram D]
11. The diagram below shows the arrangement for a Young’s double slit experiment.

The function of the single slit is
A. to direct the light towards $S_1$ and $S_2$.
B. to ensure equal intensities of light at $S_1$ and $S_2$.
C. to produce coherent light at $S_1$ and $S_2$.
D. to reduce the intensity of light at $S_1$ and $S_2$.

12. The waves from two light sources meet at a point. Which condition is essential for interference to be observed?
A. Constant phase difference between the waves
B. Equal amplitude of the waves
C. Equal frequency of the waves
D. Equal intensities of the waves

13. Light from a double slit arrangement produces bright and dark fringes on a screen in the region near point P, as indicated below.

The light from the two slits has equal amplitudes on reaching point P.

Which one of the following gives the change, if any, in the appearance of the bright and the dark fringes when the amplitude of the light wave from one slit is reduced?

<table>
<thead>
<tr>
<th>Bright fringes</th>
<th>Dark fringes</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Remains the same</td>
<td>Remains the same</td>
</tr>
<tr>
<td>B. Becomes less bright</td>
<td>Remains the same</td>
</tr>
<tr>
<td>C. Becomes less bright</td>
<td>Becomes more bright</td>
</tr>
<tr>
<td>D. Remains the same</td>
<td>Becomes more bright</td>
</tr>
</tbody>
</table>
14. Two identical sources in a ripple tank generate waves of wavelength $\lambda$. The interfering waves produce the wave pattern shown below.

Along which of the labelled lines is the path difference between the waves from the sources equal to $1.5\lambda$?

A. I  B. II  C. III  D. IV

(1)

15. Water waves of wavelength 2.0 m are produced by two sources $S_1$ and $S_2$. The sources vibrate in phase.

Point P is 1 m from $S_1$ and 3 m from $S_2$. $S_1$ alone and $S_2$ alone each produce a wave of amplitude $a$ at P. Which one of the following is the amplitude of the resultant wave at point P when $S_1$ and $S_2$ are both emitting waves?

A. $2a$
B. $a$
C. $\frac{1}{2}a$
D. Zero

(1)
Short answer questions

1. This question is about refraction.

(a) The diagram below shows a ray of monochromatic light incident on the boundary between two media. The dotted line is the normal to the boundary.

![Diagram of light ray incident on boundary]

The refractive index of medium 1 is \( n_1 \) and that of medium 2 is \( n_2 \) and \( n_1 > n_2 \). The ray is incident at an angle to the normal that is less than the critical angle.

(i) Explain what is meant by critical angle.

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(2)

(ii) On the diagram above, draw lines to show the paths of the ray after it is incident on the boundary.

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(2)

(b) Derive a relationship between \( n_1, n_2 \) and the critical angle \( \phi_c \).

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(2)

(Total 6 marks)
2. This question is about refractive index and critical angle.

The diagram below shows the boundary between glass and air.

![Diagram of glass and air boundary with critical angle marked]

(a) On the diagram, draw a ray of light to illustrate what is meant by critical angle. Mark the critical angle with the letter “c”.

(b) A straight optic fibre has length 1.2 km and diameter 1.0 mm. Light is reflected along the fibre as shown below.

![Diagram of light path in the optic fibre]

At each reflection, the angle of incidence is equal in value to the critical angle. The refractive index of the glass of the fibre is 1.5.

(b) Deduce that the length of the light path along the optic fibre is about 1.8 km.

(c) Calculate the time for a pulse of light to travel the length of the fibre when its path is

(i) along the axis of the fibre.

The speed of light in the fibre is $2.0 \times 10^8$ m s$^{-1}$.

(c) Calculate the time for a pulse of light to travel the length of the fibre when its path is

(i) along the axis of the fibre.
3. This question is about waves.

(a) In the scale diagram below, plane wavefronts travel from medium 1 to medium 2 across the boundary AB.

State and explain in which medium the wavefronts have the greater speed.

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(b) By taking measurements from the diagram, determine the ratio

\[ \frac{\text{speed of wave in medium 1}}{\text{speed of wave in medium 2}} \]

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(Total 9 marks)
4. This question is about waves and wave properties.

The diagram below shows three wavefronts incident on a boundary between medium I and medium R. Wavefront CD is shown crossing the boundary. Wavefront EF is incomplete.

![Diagram of wavefronts](image)

(a) (i) On the diagram above, draw a line to complete the wavefront EF.

(ii) Explain in which medium, I or R, the wave has the higher speed.

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(3)

The graph below shows the variation with time $t$ of the velocity $v$ of one particle of the medium through which the wave is travelling.

![Graph of velocity vs time](image)

$\nu / \text{m.s}^{-1}$
(b) (i) Explain how it can be deduced from the graph that the particle is oscillating.
...........................................................................................................................................(2)
...........................................................................................................................................(2)
...........................................................................................................................................(2)
(ii) Determine the frequency of oscillation of the particle.
...........................................................................................................................................(2)
...........................................................................................................................................(2)
(iii) Mark on the graph with the letter \( M \) one time at which the particle is at maximum displacement.
...........................................................................................................................................(1)
(iv) Estimate the area between the curve and the \( x \)-axis from the time \( t = 0 \) to the time \( t = 1.5 \text{ ms} \).
...........................................................................................................................................(2)
...........................................................................................................................................(2)
...........................................................................................................................................(1)
(v) Suggest what the area in \( b \) (iv) represents.
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Sound waves of wavelength 40 cm and amplitude $A$ are emitted by both loudspeakers.

M is a point distance 550 cm from both $S_1$ and $S_2$. Point P is a distance 560 cm from $S_1$ and 580 cm from $S_2$.

(ii) State and explain what happens to the loudness of the sound detected by a microphone when the microphone is moved from point M to point P.

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(iii) Referring to the diagram above, the amplitude of the wave emitted by $S_1$ is now increased to $2A$. The wave emitted by $S_2$ is unchanged. Deduce what change, if any, occurs in the loudness of the sound at point M and at point P when this change in amplitude is made.

at point M: .......................................................................................................................................
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at point P: ...........................................................................................................................................
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(iv) The loudspeakers are now replaced with two monochromatic light sources. State the reason why bright and dark fringes are not observed along the line PM.

...........................................................................................................................................

Waves of frequency $f$ and speed $c$ are emitted by a stationary source of sound. An observer moves along a straight line towards the source at a constant speed $v$.

(d) State, in terms of $f$, $c$ and $v$, an expression for

(i) the wavelength of the sound detected by the observer.

...........................................................................................................................................

(ii) the apparent speed of the wave as measured by the observer.

.............................................................................................................................................

(Total 25 marks)
5. This question is about diffraction.

Plane wavefronts of monochromatic light of wavelength $\lambda$ are incident on a rectangular slit of width $b$. After passing through the slit, the light is brought to a focus on a screen distance $D$ from the slit as shown below. The width of the slit is comparable to the wavelength of the incident light and $b \ll D$. The point P on the screen is opposite the centre of the slit.

The sketch graph below shows that the variation with angle $\theta$ of the intensity of the light on the screen.
(a) Explain qualitatively, this intensity distribution.
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(b) The angle $\theta = \phi$ is the angular half-width of the central maximum of the intensity distribution and is given by the expression $\phi = \frac{\lambda}{b}$. Derive an expression in terms of $D$, $\lambda$ and $b$ for the half-width $d$ of the central maximum.
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(c) The single slit is replaced by two rectangular slits of width $b$. The distance between the centre of the slits is equal to $2b$.

On the axes below, draw a sketch of the intensity distribution on the screen. (The intensity distribution of a single slit is shown by the dotted line.)

(Total 7 marks)
6. This question is about two-source interference.

A double slit is illuminated normally with coherent light. The interference pattern is observed on a screen. The apparatus is shown below.

The width of both slits in the double slit arrangement is increased without altering the separation \( s \).

Describe and explain the effect, if any, of this change on

(a) the number of fringes observed;

(b) the intensity of the fringes.

(Total 5 marks)
7. This question is about interference and diffraction.

Light from a laser is incident on two slits of equal width. After passing through the slits, the light is incident on a screen. The diagram below shows the intensity distribution of the light on the screen.

(a) The wavelength of the light from the laser is 633 nm and the angular separation of the bright fringes on the screen is $4.00 \times 10^{-4}$ rad. Calculate the separation of the slits.

(b) Light from the laser is incident on many slits of the same width as the widths of the slits above. Draw, on the above diagram, a possible new intensity distribution of the light on the screen.

(c) The laser is replaced by a source of white light. Describe, if any, the changes to the fringes on the screen.

(Total 7 marks)
Topic 4.5: Waves-Standing waves

1. Standing waves in an open pipe come about as a result of
   A. reflection and superposition.
   B. reflection and diffraction.
   C. superposition and diffraction.
   D. reflection and refraction.

(1)

2. For a standing wave, all the particles between two successive nodes have the same
   A. amplitude only.
   B. frequency only.
   C. amplitude and frequency.
   D. frequency and energy.

(1)

3. Which one of the following is correct for transfer of energy along a standing wave and for amplitude of vibration of the standing wave?

<table>
<thead>
<tr>
<th>Transfer of energy along a standing wave</th>
<th>Amplitude of vibration of the standing wave</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. None</td>
<td>Constant amplitude</td>
</tr>
<tr>
<td>B. None</td>
<td>Variable amplitude</td>
</tr>
<tr>
<td>C. Energy is transferred</td>
<td>Constant amplitude</td>
</tr>
<tr>
<td>D. Energy is transferred</td>
<td>Variable amplitude</td>
</tr>
</tbody>
</table>

(1)

4. A standing wave is established on a string between two fixed points.

At the instant shown, point T is moving downwards. Which arrow gives the direction of movement of point U at this instant?

A. A  B. B  C. C  D. D

(1)
5. Two particles X and Y are situated a distance $\frac{1}{2} \lambda$ apart on a stationary wave of wavelength $\lambda$. The variation with time $t$ of the displacement $d_x$ of X is shown below.

Which one of the following correctly shows the variation with time $t$ of the displacement $d_y$ of particle Y?

A. $d_y$

B. $d_y$

C. $d_y$

D. $d_y$

(1)

6. The diagram below represents the fundamental (first harmonic) standing wave of sound inside a pipe.

Which of the following correctly represents the displacement of the air at P and Q?

<table>
<thead>
<tr>
<th>P</th>
<th>Q</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.</td>
<td></td>
</tr>
<tr>
<td>B.</td>
<td></td>
</tr>
<tr>
<td>C.</td>
<td></td>
</tr>
<tr>
<td>D.</td>
<td></td>
</tr>
</tbody>
</table>

(1)
7. A pipe, open at both ends, has a length $L$. The speed of sound in the air in the pipe is $v$. The frequency of vibration of the fundamental (first harmonic) standing wave that can be set up in the pipe is

A. $\frac{v}{2L}$  
B. $\frac{L}{2v}$  
C. $\frac{4v}{L}$  
D. $\frac{L}{4v}$.

(1)

8. A string with both ends fixed is made to vibrate in the second harmonic mode as shown by the dashed lines in the diagram below.

![Diagram of a string with both ends fixed and second harmonic mode indicated by dashed lines.]

The solid line shows a photograph of the string at a particular instant of time. Two points on the string have been marked P and Q.

Which of the following correctly compares both the period of vibration of P and Q and the average speed of P and Q?

<table>
<thead>
<tr>
<th>Period</th>
<th>Average speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. same</td>
<td>same</td>
</tr>
<tr>
<td>B. same</td>
<td>different</td>
</tr>
<tr>
<td>C. different</td>
<td>same</td>
</tr>
<tr>
<td>D. different</td>
<td>different</td>
</tr>
</tbody>
</table>

(1)

9. Two pipes P and Q are of the same length. Pipe P is closed at one end and pipe Q is open at both ends. The fundamental frequency (first harmonic) of the closed pipe P is 220 Hz.

The best estimate for the fundamental frequency of the open pipe Q is

A. 880 Hz  
B. 440 Hz  
C. 110 Hz  
D. 55 Hz.

(1)
10. A tube is filled with water and a vibrating tuning fork is held above its open end.

The tap at the base of the tube is opened. As the water runs out, the sound is loudest when the water level is a distance $x$ below the top of the tube. A second loud sound is heard when the water level is a distance $y$ below the top. Which one of the following is a correct expression for the wavelength $\lambda$ of the sound produced by the tuning fork?

A. $\lambda = y$  
B. $\lambda = 2x$  
C. $\lambda = y - x$  
D. $\lambda = 2(y - x)$

11. A source of sound is placed near the open end of a cylindrical tube that lies on a horizontal table. The tube has some powder sprinkled along its length. The powder collects in piles along the length of the tube as shown below.

The distance between two consecutive piles of powder is $d$ and the speed of sound in the tube is $v$. The frequency of the source is

A. $\frac{v}{2d}$  
B. $\frac{v}{d}$  
C. $dv$  
D. $2dv$

12. A vibrating tuning fork is held above the top of a tube that is filled with water. The water gradually runs out of the tube until a maximum loudness of sound is heard.

Which of the following best shows the standing wave pattern set up in the tube at this position?
Short answer questions

1. This question is about some properties of waves associated with the principle of superposition.

Stationary (standing) waves and resonance

(a) State two ways in which a standing wave differs from a continuous wave.

1. ........................................................................................................................................
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2. ........................................................................................................................................
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(b) State the principle of superposition as applied to waves.

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(c) A stretched string is fixed at one end. The other end is vibrated continuously to produce a wave along the string. The wave is reflected at the fixed end and as a result a standing wave is set up in the string.

The diagram below shows the displacement of the string at time $t = 0$. The dotted line shows the equilibrium position of the string.

(i) The period of oscillation of the string is $T$. On the diagrams below, draw sketches of the displacement of the string at time $t = \frac{T}{4}$ and at time $t = \frac{T}{2}$.

\[ t = \frac{T}{4} \]
2. This question is about wave phenomena.

(a) The graph below shows the variation with time \( t \) of the displacement \( x \) of one particle in a sound wave.

\[
\begin{align*}
x &/ \text{mm} \\
& 0.3 \\
& 0.2 \\
& 0.1 \\
& 0 \\
& -0.1 \\
& -0.2 \\
& -0.3 \\
\end{align*}
\]

The speed of the wave is 380 m s\(^{-1}\).

(i) Suggest, by marking the letter C on the \( t \)-axis of the graph above, one time at which the particle could be at the centre of a compression.

(ii) Deduce the wavelength of the wave.

\[
\begin{align*}
& \quad \text{(3)}
\end{align*}
\]
(b) (i) Outline the conditions necessary for the formation of a standing (stationary) wave.

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(2)

(ii) A horizontal tube, closed at one end, has some fine powder sprinkled along its length. A source S of sound is placed at the open end of the tube, as shown below.

source S

heap of powder

The frequency of the source S is varied. Explain why, at a particular frequency, the powder is seen to form small equally-spaced heaps in the tube.

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(2)

(iii) The mean separation of the heaps of powder in (b)(ii) is 9.3 cm when the frequency of the source S is 1800 Hz. Calculate the speed of sound in the tube.

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(2)

(c) The experiment in (b)(ii) is repeated on a day when the temperature of the air in the tube is higher. The mean separation of the heaps is observed to have increased for the same frequency of the source S. Deduce qualitatively the effect, if any, of temperature rise on the speed of the sound in the tube.

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(2)
(d) The diagram below shows wavefronts produced by two sources $S_1$ and $S_2$ of sound that are vibrating in phase.

The waves interfere constructively along the lines labelled A and B.

(i) State what is meant by constructive interference.

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(ii) On the diagram above, draw another line, labelled C, along which the waves interfere constructively.

(iii) On the diagram above, draw another line, labelled D, along which the waves interfere destructively.

3. This question is about waves and wave properties.

Travelling and standing (stationary) waves

(a) State two differences between a travelling wave and a standing (stationary) wave.

1. ...................................................................................................................................................
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2. ...................................................................................................................................................
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(Total 17 marks)
(b) In the scale diagram below, plane wavefronts travel from medium 1 to medium 2 across the boundary AB.

![Diagram showing wavefronts from medium 1 to medium 2]

State and explain in which medium the wavefronts have the greater speed.

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The speed \( v \) with which energy is propagated in the tubing by a travelling wave depends on the tension \( T \) in the tubing. The relationship between these quantities is

\[
v = k \sqrt{T}
\]

where \( k \) is a constant.

In an experiment to verify this relationship, the fundamental (first harmonic) frequency \( f \) was measured for different values of tension \( T \).

(i) Explain how the results of this experiment, represented graphically, can be used to verify the relationship \( v = k \sqrt{T} \).

(ii) In the experiment, the length of the tubing was kept constant at 2.4 m. The fundamental frequency for a tension of 9.0 N in the tubing was 1.8 Hz. Calculate the numerical value of the constant \( k \).
**Interference activity**

**Drawing**
The picture below shows two wave sources with equal frequencies emitting a wave.

a) Mark out the lines where you have constructive interference (crest-crest/trough-trough). This line is called an anti-nodal line.

b) Mark out the lines where you have destructive interference (crest-trough). This line is called a nodal line.

**Identifying**
Which of the labeled points are

a) On nodal lines?

b) On anti – nodal lines?

c) Formed as a result of constructive interference?

d) Formed as a result of destructive interference?
Identifying further
Which of these labeled points are
   a) On the central anti-nodal line?
   b) On the first anti-nodal line?
   c) On the second anti-nodal line?
   d) On the first nodal line?
   e) On the second nodal line?
   f) On the third nodal line?
**Path difference**

For the diagrams below, find:

a) Type of interference (constructive/destructive)

b) Path length in wavelengths for each wave. (fill in the boxes)

c) Path difference in wavelengths
Connection between path difference and the different maximas/minimas

a) For each nodal and anti–nodal line indicate the path difference between the two waves.
b) What do you notice?

Double – slit on the screen
Below is a schematic of the double slit interference. In the boxes below, indicate whether the screen will have a maximum or a minimum at that point. Also indicate the path difference (p.d) between the two waves at that point on the screen.