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. \[
   \begin{array}{c}
   \text{a} \\
   \downarrow \\
   0 \\
   \hline
   0 \\
   x \\
   \end{array}
   \]
   B. \[
   \begin{array}{c}
   \text{a} \\
   \downarrow \\
   0 \\
   \hline
   0 \\
   x \\
   \end{array}
   \]
   C. \[
   \begin{array}{c}
   \text{a} \\
   \downarrow \\
   0 \\
   \hline
   0 \\
   x \\
   \end{array}
   \]
   D. \[
   \begin{array}{c}
   \text{a} \\
   \downarrow \\
   0 \\
   \hline
   0 \\
   x \\
   \end{array}
   \]

   (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. ![Graph A](#)

B. ![Graph B](#)

C. ![Graph C](#)

D. ![Graph 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. ![Graph A](#)

B. ![Graph B](#)

C. ![Graph C](#)

D. ![Graph 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.

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.</td>
<td>6.5 m</td>
</tr>
<tr>
<td>B.</td>
<td>13 m</td>
</tr>
<tr>
<td>C.</td>
<td>6.5 m</td>
</tr>
<tr>
<td>D.</td>
<td>13 m</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?

A. \( E_k \)  

B. \( E_k \)  

C. \( E_k \)  

D. \( E_k \)  

(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.

![Graph](image)

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.

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

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

(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
   ...............................................................................................................
Topic 4.2: Waves-Travelling waves

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

   A. 
   B. 
   C. 
   D. 

   (1)

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.

   (1)
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. \( \frac{x_3 - x_1}{t_2 - t_1} \)  

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

.......................................................................................................................... (1)

(ii) the frequency;

.......................................................................................................................... (2)

(iii) the speed of the wave.

.......................................................................................................................... (1)

(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.

.......................................................................................................................... (1)

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

.......................................................................................................................... (2)

(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.

[Diagram of wave oscillation]
(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.

(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 $\lambda$, 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.

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

(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.

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

(i) the wavelength.

(ii) the amplitude.

(iii) the speed.

(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.

<table>
<thead>
<tr>
<th>The speed of the wave front is</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. 0.15 cm s$^{-1}$</td>
</tr>
<tr>
<td>B. 1.5 cm s$^{-1}$</td>
</tr>
<tr>
<td>C. 15 cm s$^{-1}$</td>
</tr>
<tr>
<td>D. 30 cm s$^{-1}$</td>
</tr>
</tbody>
</table>

(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

<table>
<thead>
<tr>
<th>The phase difference is</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. $\frac{\pi}{8}$ rad.</td>
</tr>
<tr>
<td>B. $\frac{\pi}{4}$ rad.</td>
</tr>
<tr>
<td>C. $\frac{\pi}{2}$ rad.</td>
</tr>
<tr>
<td>D. $\pi$ rad.</td>
</tr>
</tbody>
</table>

(Total 1 mark)

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

<table>
<thead>
<tr>
<th>Property</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Displacement</td>
</tr>
<tr>
<td>B. Amplitude</td>
</tr>
<tr>
<td>C. Speed</td>
</tr>
<tr>
<td>D. Frequency</td>
</tr>
</tbody>
</table>

(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.

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.

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

A.  
B.  
C.  
D.  

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

   (a) Show that the intensity at 120 m from the source is approximately \(3 \times 10^{-6} \text{W} \cdot \text{m}^{-2}\).

   
   \[
   \text{Intensity at 120 m} = \frac{\text{Intensity at 15 m}}{(120/15)^2} = \frac{2 \times 10^{-4}}{(120/15)^2} = 3 \times 10^{-6} \text{W} \cdot \text{m}^{-2}
   \]

   
   (2)

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

   
   (2)

   (Total 4 marks)

2. This question is about the interference of waves.

   (a) State the principle of superposition.

   
   (2)

   A wire is stretched between two points A and B.

   \[
   \begin{array}{c}
   A \\
   \hline
   \end{array}
   \quad \begin{array}{c}
   \hline
   B
   \end{array}
   \]

   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.

Wave X

Wave Y

(Total 6 marks)
3. This question is about polarized light.

(a) Distinguish between polarized and unpolarized light.

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

(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 $180^\circ$.

![Graph of intensity vs. angle $\theta$]

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

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

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

A. \( \sin Z = \text{constant} \times \sin Y \)
B. \( \sin W = \text{constant} \times \sin Z \)
C. \( \sin X = \text{constant} \times \sin Z \)
D. \( \sin W = \text{constant} \times \sin Y \)

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.

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

A. I    B. II   C. III   D. IV
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. 
```
  ┌────┐
  │    │
  │    │
  │    │
  └────┘
  ▼
```

(1)

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.

```
  ┌───┐
  │   │
  │   │
  │   │
  └───┘
```

boundary

medium X

medium Y

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?

A. 

B. 

C. 

D. 

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.

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

A. 

B. 

C. 

D. 

(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.
   \[ d \]
   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.
   Which of the following best shows the shape of the wavefronts on the other side of the barrier?

   A.  
   B.  
   C.  
   D.  

(1)
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 $S_2$.

(1)

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

(1)

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>

(1)
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 between two media]

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

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

The diagram below shows the boundary between glass and air.

(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) 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.
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.

(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.
(b) (i) Explain how it can be deduced from the graph that the particle is oscillating.

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(2)

(ii) Determine the frequency of oscillation of the particle.

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(iii) Mark on the graph with the letter M one time at which the particle is at maximum displacement.

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(1)

(iv) Estimate the area between the curve and the x-axis from the time \( t = 0 \) to the time \( t = 1.5 \) ms.

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(v) Suggest what the area in b (iv) represents.

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(c) (i) State the principle of superposition.

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Two loudspeakers \( S_1 \) and \( S_2 \) are connected to the same output of a frequency generator and are placed in a large room as shown below.
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 $PM$.

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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.

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

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(Total 25 marks)
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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(3)

(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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(2)

(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.

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.

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>

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
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. $\begin{array}{c}
   \text{A. } d_Y \\
   \end{array}$
- B. $\begin{array}{c}
   \text{B. } d_Y \\
   \end{array}$
- C. $\begin{array}{c}
   \text{C. } d_Y \\
   \end{array}$
- D. $\begin{array}{c}
   \text{D. } d_Y \\
   \end{array}$

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?

- A. $\begin{array}{c}
   \text{A. } \text{P, Q} \\
   \end{array}$
- B. $\begin{array}{c}
   \text{B. } \text{P, Q} \\
   \end{array}$
- C. $\begin{array}{c}
   \text{C. } \text{P, Q} \\
   \end{array}$
- D. $\begin{array}{c}
   \text{D. } \text{P, Q} \\
   \end{array}$
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

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

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.

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.</td>
<td>same</td>
</tr>
<tr>
<td>B.</td>
<td>same</td>
</tr>
<tr>
<td>C.</td>
<td>different</td>
</tr>
<tr>
<td>D.</td>
<td>different</td>
</tr>
</tbody>
</table>

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

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.

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

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(2)

(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.

![Diagram of a standing wave](image)

(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 $t = \frac{T}{2}$.

$t = \frac{T}{4}$

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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.

![Graph of displacement vs time](image)

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.

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(Total 8 marks)
(b)  
(i) Outline the conditions necessary for the formation of a standing (stationary) wave.
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(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.

![Diagram of a horizontal tube with powder](image)

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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(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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(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.

![Diagram of wavefronts produced by two sources $S_1$ and $S_2$.]

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.

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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.

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

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(c) 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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(3)

(d) To demonstrate the production of a standing wave, Samantha attaches the end B of a length AB of rubber tubing to a rigid support. She holds the other end A of the tubing, pulls on it slightly and then shakes the end A in a direction at right angles to AB. At a certain frequency of shaking, the tubing is seen to form the standing wave pattern shown below.

Explain how this pattern is formed.

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(c) 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 $k$. 

(Total 20 marks)