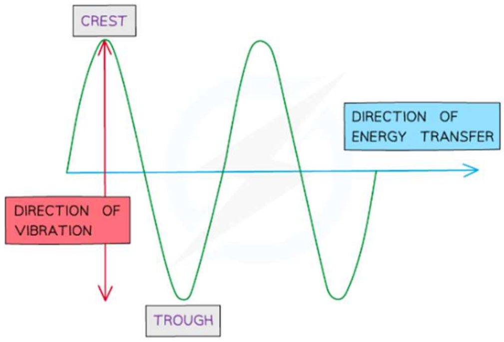
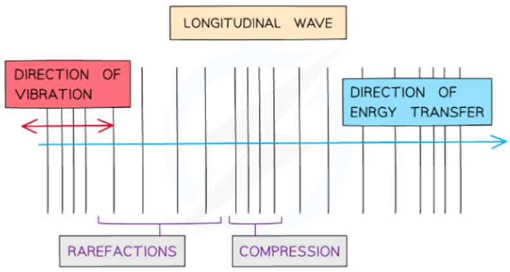
Lesson 5: Wave I

Lesson Objectives:

- Progressive Wave
- Electromagnetic Radiation
- Constructive & Destructive Interference
- Path & Phase Difference
- Stationary Wave



- Progressive Wave: A wave that transfers energy without transferring matter
- Waves DO NOT transport matter
- Each particle oscillates about its own equilibrium position.
- Transverse wave: the oscillations of particles are **perpendicular** to the direction of energy transfer (e.g. electromagnetic wave, ripples, guitar strings)
- Longitudinal wave: the oscillations of particles are parallel to the direction of energy transfer (e.g. sound wave, ultrasound, spring vibration)
- direction of wave energy transfer = direction of propagation

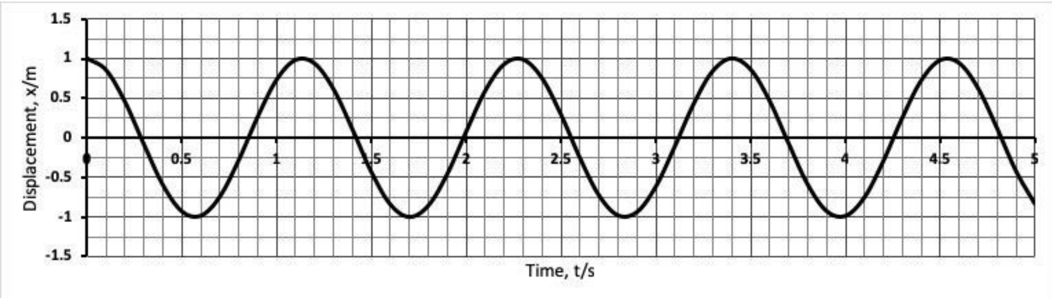


Match the key word to the definition.

Displacement (x)	is the **number of oscillations** (vibrations) **per unit time** of a point in the wave.
Amplitude (A)	of a particle is its **distance and direction from its equilibrium position**
Frequency (f)	is the **fraction of a cycle** difference between two oscillating particles orwaves
Phase difference	The least distance between adjacent particles which are in phase.
Wavelength (λ)	is the **maximum displacement** from the equilibrium position.
Period (T)	is the **time for one whole oscillation** (one cycle).

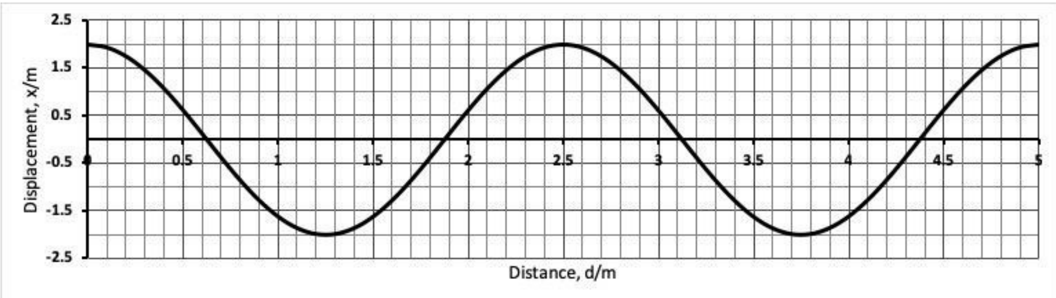
Displacement-time graphs

Displacement-time graphs show how the displacement of **one particle** changes over time as it oscillates about its equilibrium position (x=0). It shows how this particle moves around the phase diagram.



Displacement-distance graphs

Displacement-distance graphs show **at one moment** in time the displacements of particles along a section of a wave in the direction of propagation.



- The relationship of velocity (v), frequency (f) and wavelength (λ) of a certain wave:

$$v = f\lambda$$

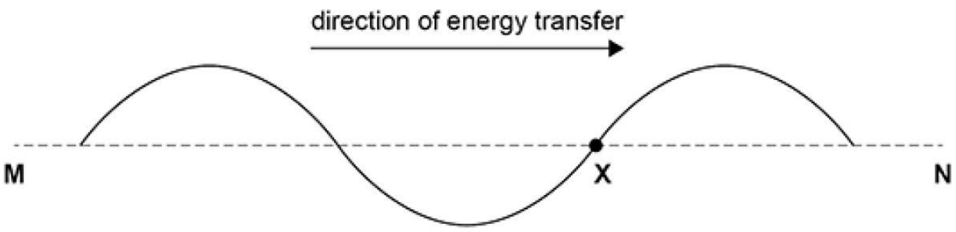
- The relationship between period (T) and frequency (f) of a wave:

$$T = \frac{1}{f}$$

Example

A progressive wave travels along a rope in the direction **M** to **N**.

X marks a point on the rope.

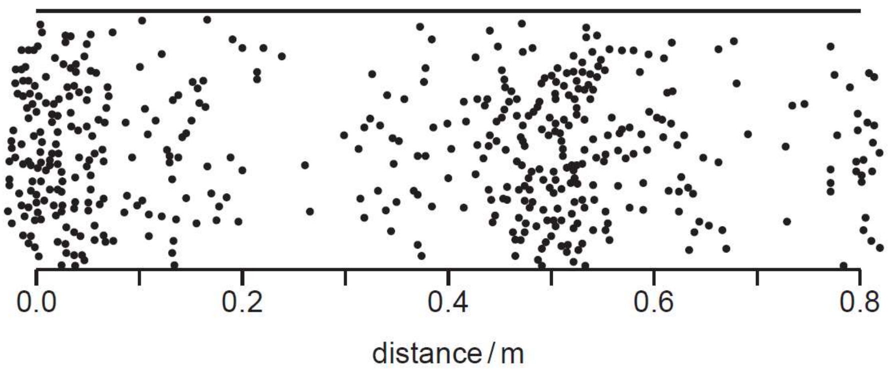


The wave has a frequency of 5.0 Hz, a wavelength of 1.0 m and an amplitude of 0.20 m.

Where will **X** be after 0.15 s?

Example

When a guitar string is plucked, it causes a longitudinal sound wave in the air, as shown.



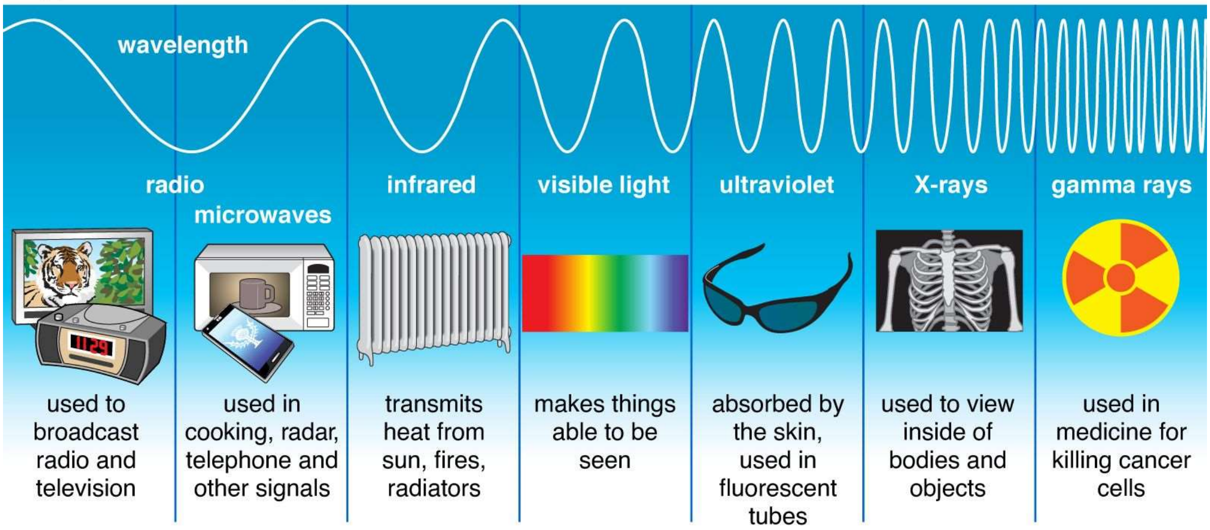
The speed of sound in the air is 340 $m s^{-1}$.

What is the approximate frequency of the sound wave shown?

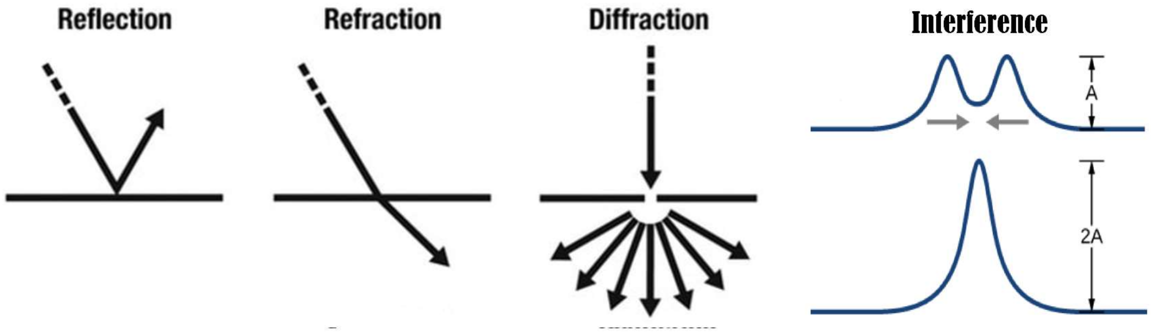
Electromagnetic Waves

- transverse waves which do not require a material medium
- oscillations of electric and magnetic fields
- travel at light speed (3.00×10^8 ms^{-1})
- it is very useful to remember all 7 types of EM waves:

Types of Electromagnetic Radiation

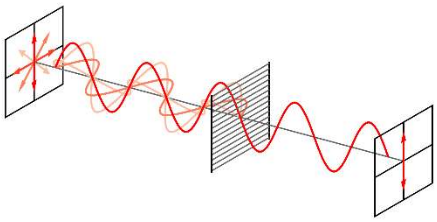


A list of wave behaviors:

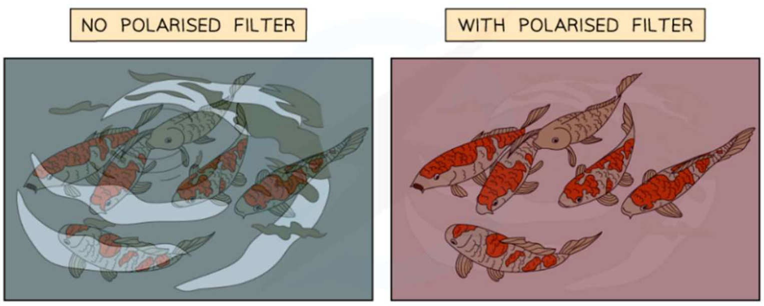


Polarization of transverse waves

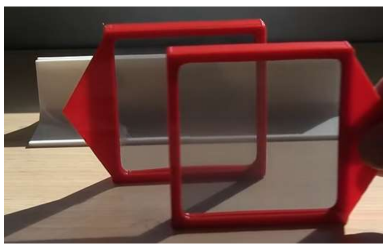
- only transverse wave can be unpolarised or polarised (because of the direction of oscillation)
- a polarised wave oscillates in only one plane
- a polarised filter, such as Polaroid sunglasses, can polarise light, reducing glare refracted from water



- partial polarisation is where more light is transmitted in one plane than other planes (light reflected off the surface of water, glass or metal is partially polarised)



one polarized filter

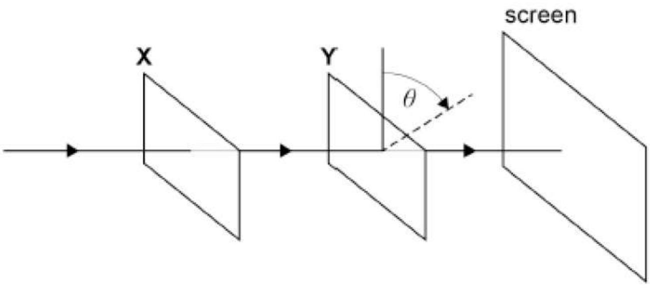


Two polarized filter
Both horitzontal

Two polarised filter
One horizontal, one vertical

Example

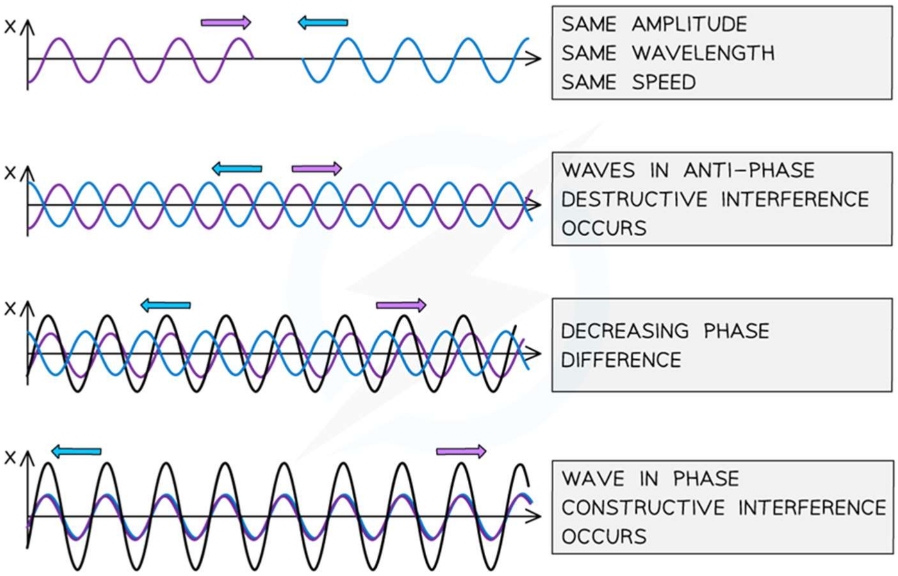
Unpolarised light travels through two polarising filters **X** and **Y** and is then incident on a screen. When **X** and **Y** are arranged as shown, there is a maximum intensity on the screen.
X is held stationary but **Y** is rotated in a plane at right angles to the beam so that θ increases.



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

Constructive & Destructive Interference

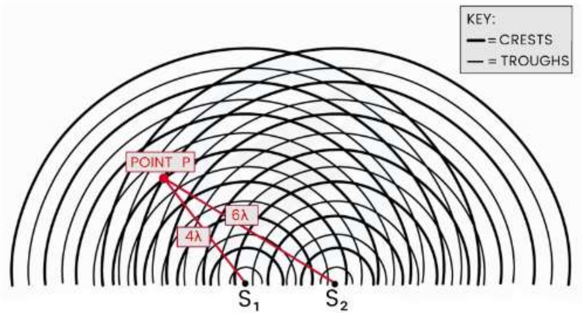
- **Superposition**: resultant displacement of two or more waves at a point is equal to the vector sum of the individual displacements of the waves
- sometimes it is referred to **interference**



- For interference to occur, coherent sources are sources which have same *f* and λ, and have a constant phase difference (e.g. monochromatic light)
  - Constructive interference: two waves in phase → amplitude will be double (maximum displacement)
  - Destructive interference: two waves anti-phase→ amplitude will be zero (minimum displacement)

Path & Phase Difference

- So when do constructive or destructive interference happen?
- It really depends on <u>path difference</u>: the difference in the distance travelled by two waves from the source. It can be calculated by:

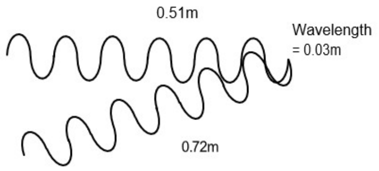


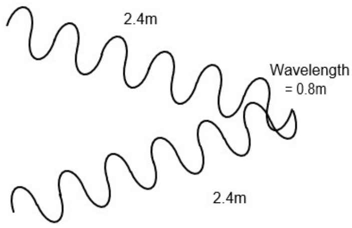
- Constructive interference: Path difference = n λ e.g. 0 λ ,1 λ ,2 λ ...
- Destructive interference: Path difference = (n+0.5) λ e.g. 0.5 λ ,1.5 λ ,2.5 λ ...

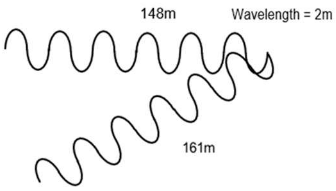
*n is an integer

<u>Example</u>

Find out i) whether it is constructive or destructive interference, ii) the path difference, iii) the phase difference of the following waves. (Hint: 1 λ = 2 π)

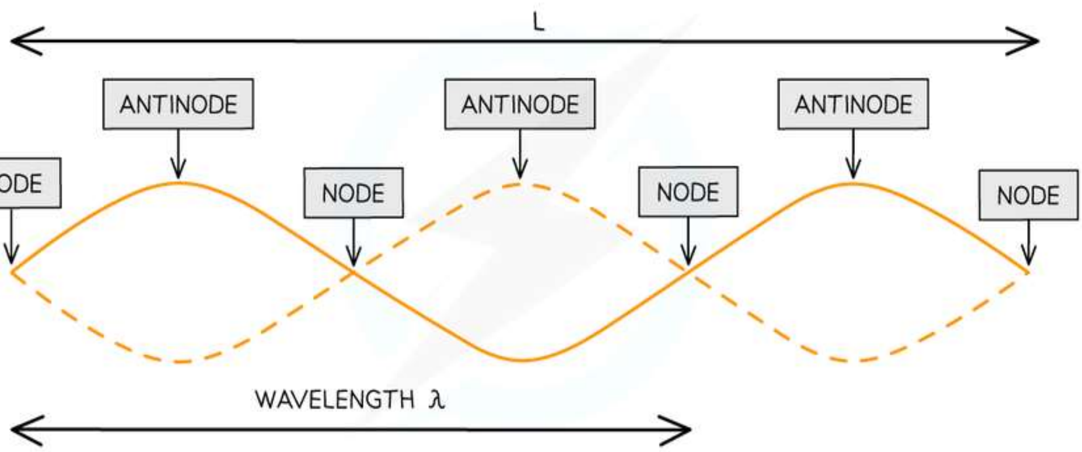


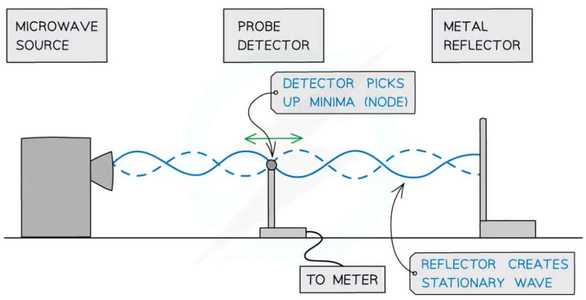


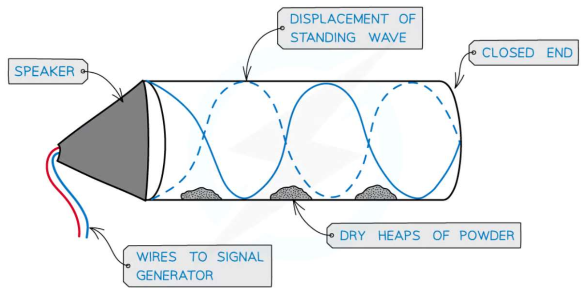


Stationary Wave

- Also sometimes known as <u>'standing wave'</u>
- produced by the <u>superposition</u> of two waves (same speed, f ,and λ and amplitude) usually one wave and its reflected wave from a fixed end
- It can be formed by wave a string attached to a wall, using microwave against a metal reflector or blasting a speaker against a close end
- <u>No energy is transferred</u> by a stationary wave





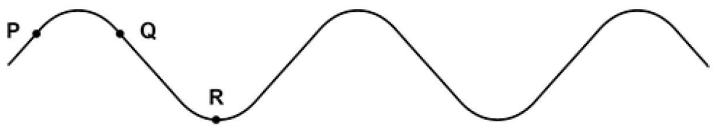


How does a stationary wave move? Let's look at a <u>video</u> of it...

<u>Example</u>

The diagram shows a stationary wave on a string at one instant in time.

P, **Q** and **R** are three points on the string.

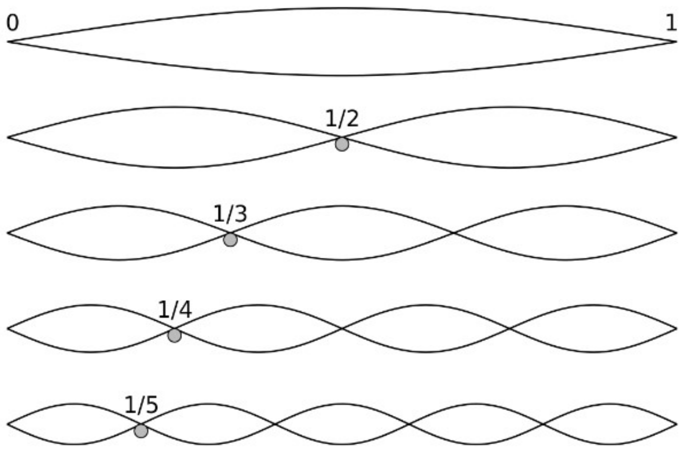


Which row is correct?

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

Harmonics

- The lowest frequency at which a stationary wave can form is called first harmonic
- Only half a wavelength (2 nodes and 1 antinode)



The equation for the frequency of the first harmonic is:

$$f = \frac{1}{2L}\sqrt{\frac{T}{\mu}}$$

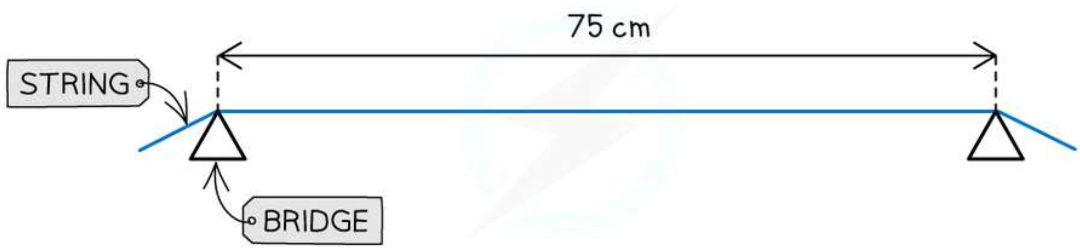
- L is the length of the string in m
- T is the tension in the string in N
- μ is the mass per unit length of the string measured in $kg.m^{-1}$.

The speed of the wave on the string is fixed for a particular string at a particular tension:

$$c = \sqrt{\frac{T}{\mu}}$$

Example

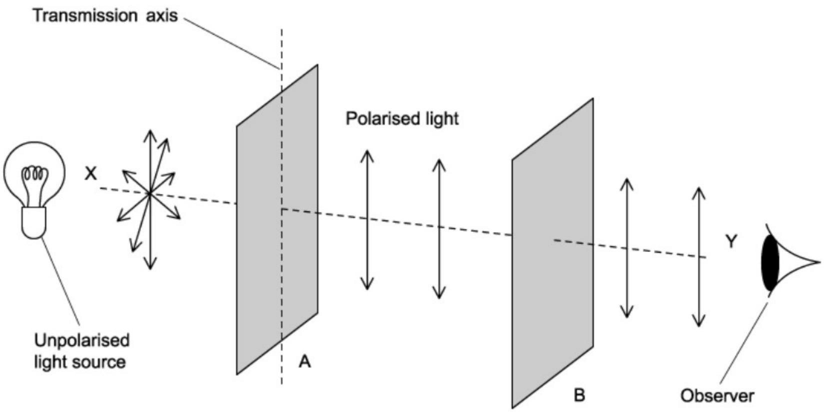
A guitar string of mass 3.2 g and length 90 cm is fixed onto a guitar. The string is tightened to a tension of 65 N between two bridges at a distance of 75 cm. Calculate the frequency of the first harmonic produced.



More exercises

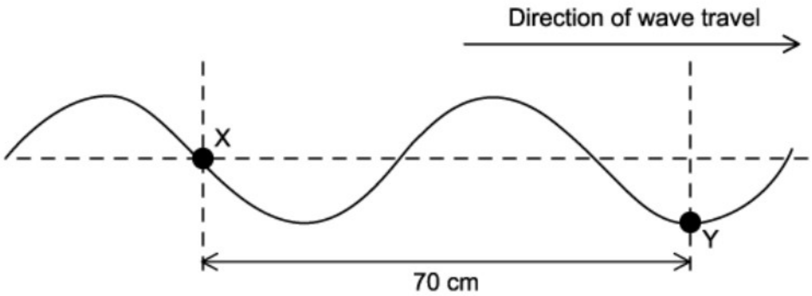
1a. State what is meant by polarisation and explain how it is used to distinguish between transverse and longitudinal waves.

1b. An unpolarised light source passes horizontally through a fixed polarising filter A. An observer views the light emerging through a second polarising filter B, which may be rotated about point XY as shown in the figure.



The observer rotates B slowly through 360° clockwise. Relative to polarising filter A, at which angles of polarising filter B does the observer see the maxima and minima amount of daylight.

2a. Below shows a progressive wave travelling from left to right on a stretched string. The frequency of the wave is 30 Hz. Calculate the speed of the wave.



2b. State the phase difference between points X and Y on the string.

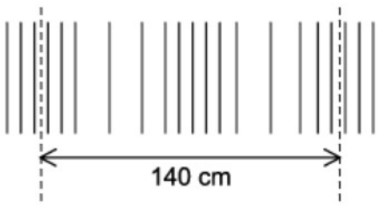
2c. Describe how the vertical displacement of point X varies in the next period.

2d. Determine the phase difference between the current position of X and the position of X after 0.0825 s.

3a. Short pulses of sound are reflected from a wall 30 m from the sound source. The reflected pulses return to the source after 0.18 s. Calculate the speed of sound.

3b. The figure shows the sound wave from (3a). Calculate its frequency/

Figure 1



4a.

The figure shows an experiment designed by a student to investigate vibrations in a stretched nylon string of fixed length l. The student measures how the frequency f of the first harmonic varies with the mass m suspended from the string

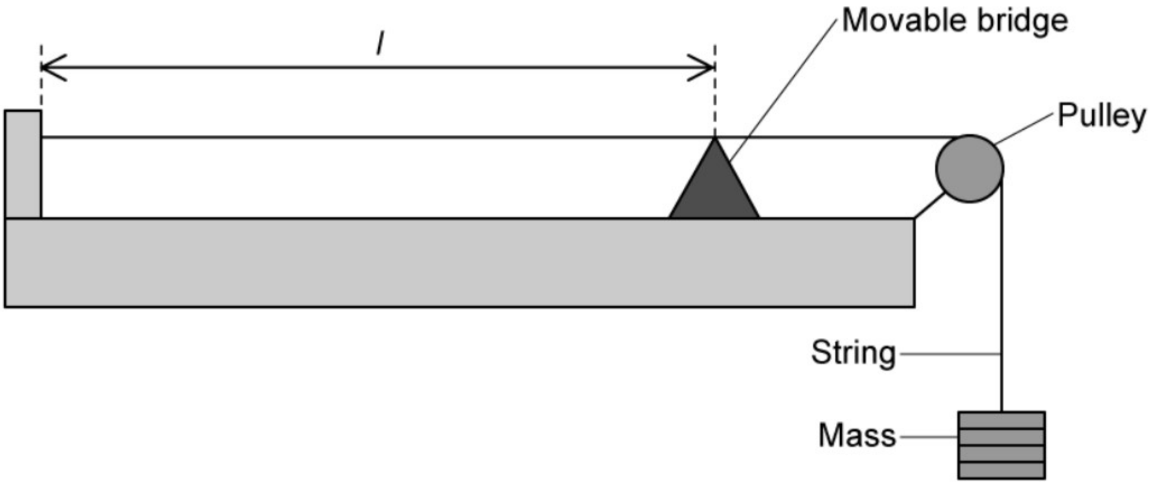


Table 1 shows the results they record from the experiment:

Table 1

m / g	*f* / Hz
500	110
800	140
1200	170

With reference to an appropriate proportionality, discuss the validity of the results in Table 1.

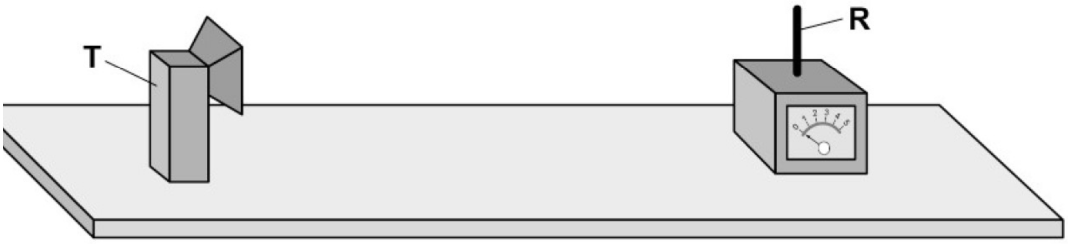
4b.

The student notes that the string has a uniform diameter of 4.0×10^{-4} m. The fixed length l of the vibrating string was also measured to be 0.80 m. Determine the density of the nylon string.

5a.

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

Figure 1



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

[5 marks]

5b

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

Figure 2a

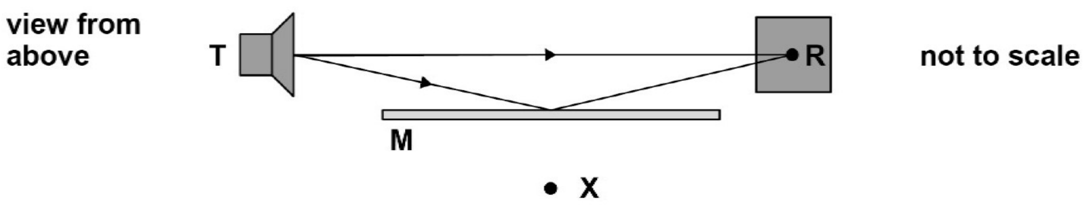
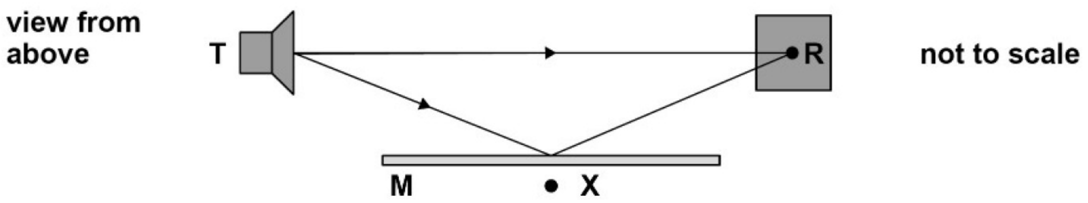


Figure 2b



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

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

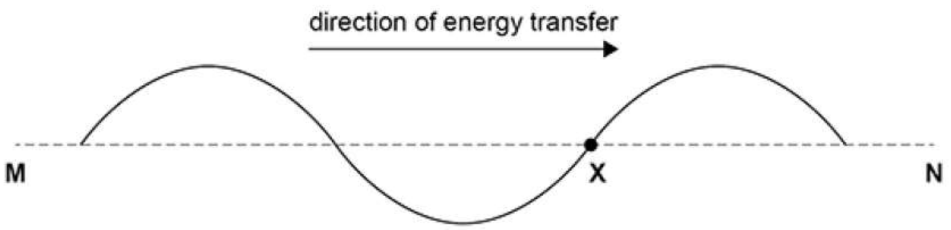
Explain what happens to the signal detected by **R** as **M** is moved slowly towards **X.**

[4 marks]

6.

A progressive wave travels along a rope in the direction **M** to **N**.

X marks a point on the rope.



The wave has a frequency of 5.0 Hz, a wavelength of 1.0 m and an amplitude of 0.20 m.

Where will **X** be after 0.15 s?

A below **MN** by 0.20 m ⬭

B above **MN** by 0.20 m ⬭

C nearer **N** by 0.15 m ⬭

D nearer **N** by 0.75 m ⬭

7.

The diagram shows a string stretched between two fixed points **O** and **R** which are 120 cm apart.

P and **Q** are points on the string.

OP = 30 cm
OQ = 90 cm

At a certain frequency the string vibrates at its first harmonic.

P and **Q** oscillate in phase.

The frequency is gradually increased.

What is the next harmonic at which **P** and **Q** will oscillate in phase?

A second ⬭

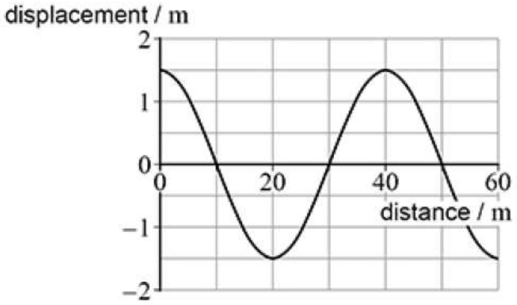
B third ⬭

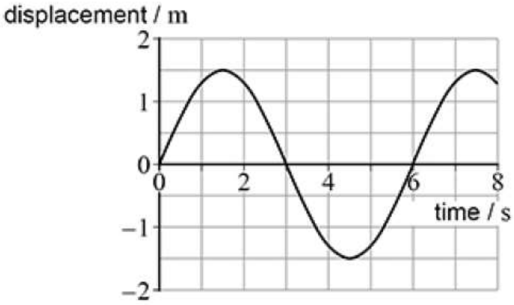
C fourth ⬭

D fifth ⬭

8.

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





Which is correct for this wave?

A The amplitude is 3.0 m.

B The wavelength is 6 m.

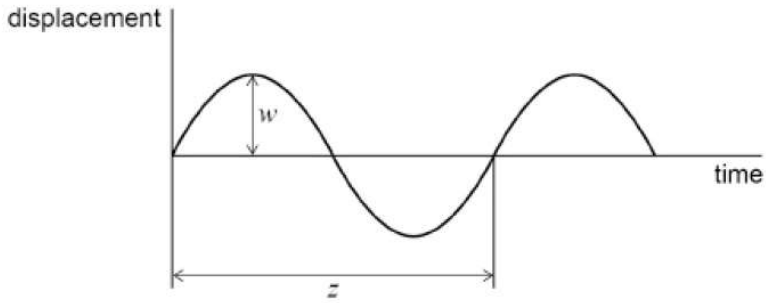
C The speed is 8.3 m s^{-1}.

D The frequency is 0.17 Hz.

9.

A wave travels along a water surface.

The variation with time of the displacement of a water particle at the surface is shown.



What properties of the wave are represented by w and z?

	w	z
A	phase	frequency
B	amplitude	wavelength
C	wavelength	phase
D	amplitude	period

10.

Two points on a progressive wave are out of phase by 0.41 rad.

What is this phase difference?

A 23°

B 47°

C 74°

D 148°

11.

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

Which statement is **not** correct?

A The first harmonic has a wavelength of 2.0 m.

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

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

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

12.

The frequency of the first harmonic of a wire fixed at both ends is 300 Hz.
The tension in the wire is now doubled.

What is the frequency of the first harmonic after this change?

A 150 Hz

B 210 Hz

C 420 Hz

D 600 Hz