Edexcel International A Level (IAL) Physics

Your notes

Transverse & Longitudinal Waves

Contents

Your notes

Properties of Waves

- Waves are generated by **oscillating sources**
  - These oscillations travel **away** from the source
- Oscillations can propagate through a **medium** (e.g. air, water) or in a **vacuum** (i.e. no particles), depending on the wave type

Wave Features

- In order to describe the properties of travelling waves, the following keywords need to be defined:
  - **Wavelength** λ (m) is the distance between a point on a wave and the same point on the next cycle of the wave, e.g. two crests, or two troughs
  - **Amplitude** A (m) is the magnitude of the maximum displacement reached by an oscillation in the wave
  - **Period** T (s) is the time taken for one complete oscillation at one point on the wave
  - **Frequency** f (Hz) is the number of complete wave cycles per second
  - **Wave speed** c (m s^{-1}) is the rate of movement of the wave

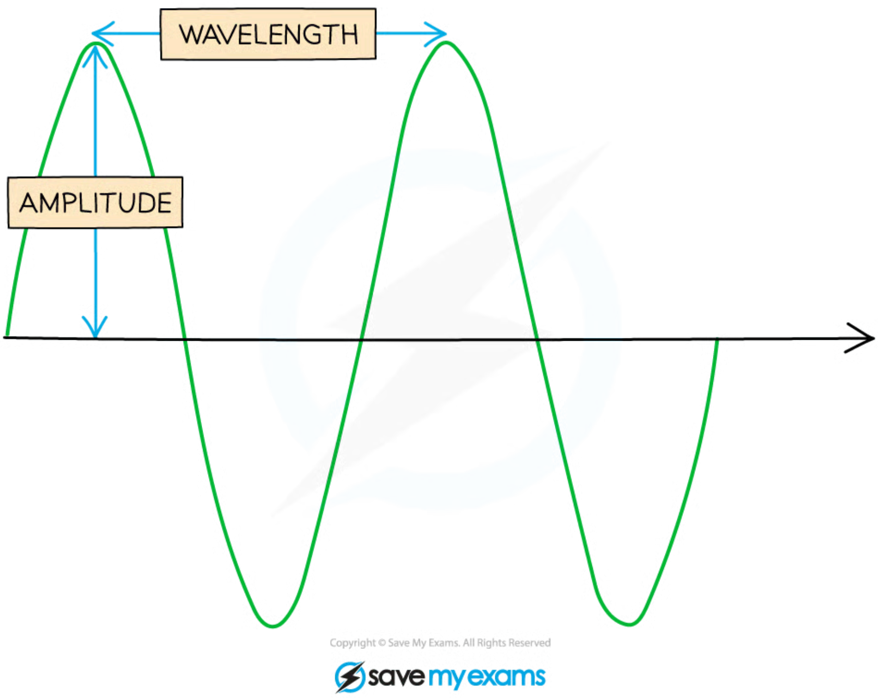
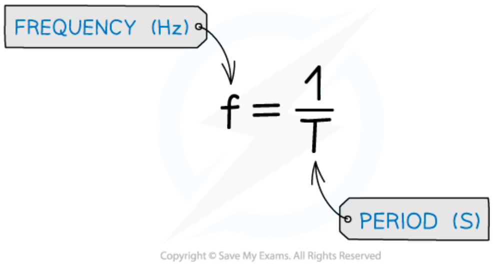


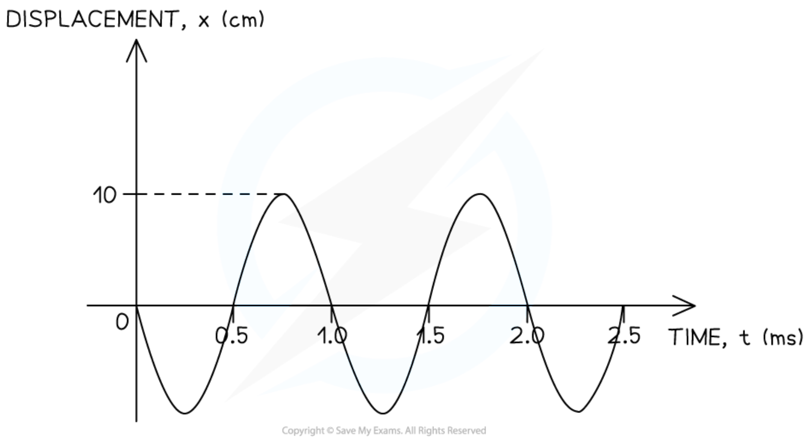
Diagram showing the amplitude and wavelength of a transverse wave

- The frequency f and the period T of a travelling wave are related to each other by the equation



Worked Example

The graph below shows a travelling wave.



Determine:

(i) The amplitude A of the wave in metres (m)

(ii) The frequency f of the wave in hertz (Hz)

Answer:

Part (i)

Identify the amplitude A of the wave on the graph

- The amplitude is defined as the maximum displacement from the equilibrium position ($x = 0$)

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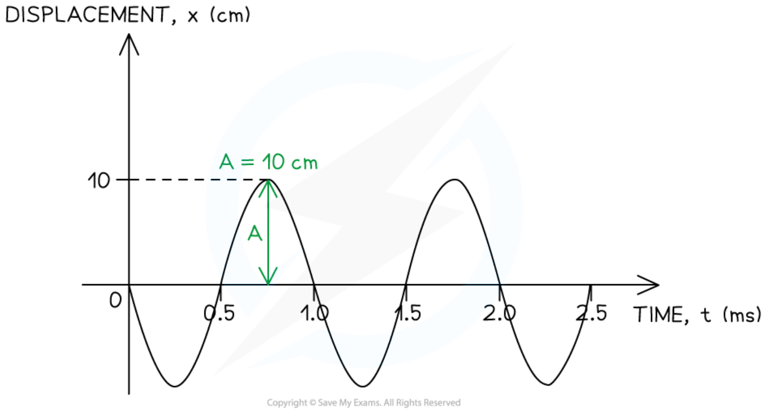


- The amplitude must be converted from centimetres (cm) into metres (m)

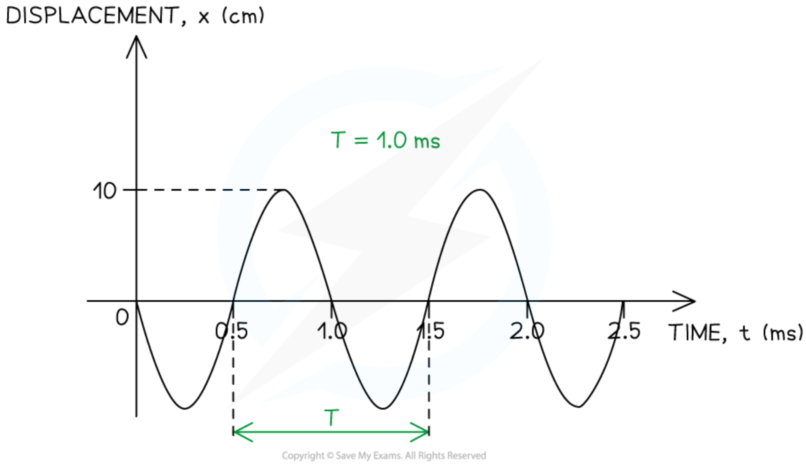
$$A = 0.1 \text{ m}$$

Part (ii)

Calculate the frequency of the wave

Step 1: Identify the period *T* of the wave on the graph

- The period is defined as the time taken for one complete oscillation to occur



- The period must be converted from milliseconds (ms) into seconds (s)

$$T = 1 \times 10^{-3} \text{ s}$$

Step 2: Write down the relationship between the frequency *f* and the period *T*

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

Step 3: Substitute the value of the period determined in Step 1

$$f = \frac{1}{1 \times 10^{-3}}$$

$$f = 1000 \text{ Hz}$$

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Examiner Tips and Tricks

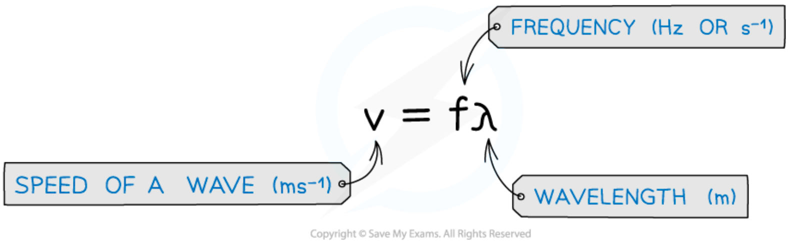
Every question about waves uses the vocabulary on this page. Many questions start by asking you to define one of them.

So your job is to learn the definitions to the point where you have them memorised.

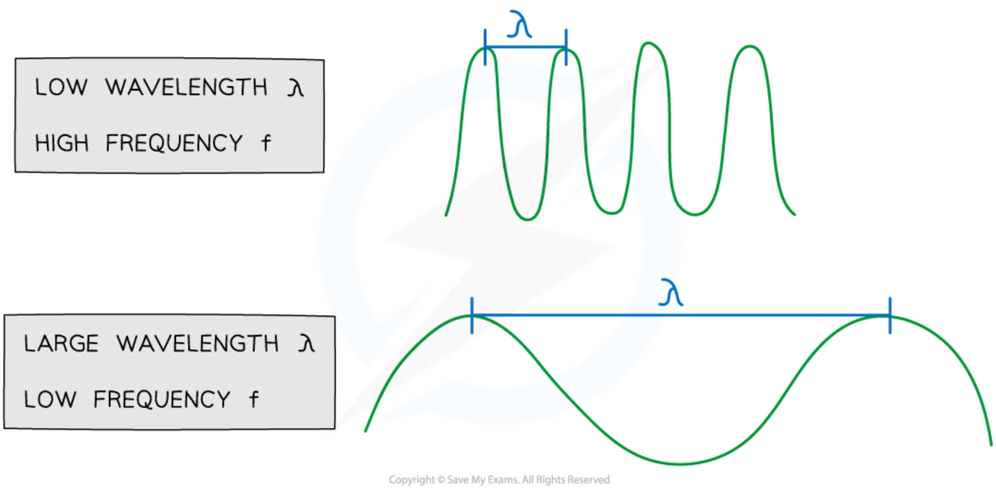
The Wave Equation

The Wave Equation

- This equation links wave speed, frequency and wavelength



- Where:
  - v = velocity of the wave (m s^{-1})
  - f = frequency of the wave (Hz)
  - λ = wavelength (m)
- The wave equation tells us that for a wave of constant speed:
  - As the wavelength **increases,** the frequency **decreases**
  - As the wavelength **decreases,** the frequency **increases**



The relationship between frequency and wavelength of a wave

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Worked Example

A travelling wave has a period of 1.0 μs and travels at a velocity of 100 cm s^{-1}.
Calculate the wavelength of the wave. Give your answer in metres (m).

Answer:

Step 1: Write down the known quantities

- Period, T = 1.0 μs = 1.0×10^{-6} s
- Velocity, c = 100 cm s^{-1} = 1.0 m s^{-1}

Note the conversions:

- The period must be converted from microseconds (μs) into seconds (s)
- The velocity must be converted from cm s^{-1} into m s^{-1}

Step 2: Write down the relationship between the frequency *f* and the period *T*

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

Step 3: Substitute the value of the period into the above equation to calculate the frequency

$$f = \frac{1}{1 \times 10^{-6}}$$

$$f = 1.0 \times 10^{6} \text{ Hz}$$

Step 4: Write down the wave equation

$$c = f\lambda$$

Step 5: Rearrange the wave equation to calculate the wavelength *λ*

$$\lambda = \frac{c}{f}$$

Step 6: Substitute the numbers into the above equation

$$\lambda = \frac{1.0}{1 \times 10^{6}}$$

$$\lambda = 1 \times 10^{-6} \text{ m}$$

Examiner Tips and Tricks

This is an important equation that comes up in many other topics. Get really familiar with using it and rearranging it.

Be ready to use **prefixes** with values, for example, nanometres (nm = m × 10^{-9}) or MHz (MHz = Hz × 10^{6}).

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Longitudinal Waves

Longitudinal Waves

- A longitudinal wave is one where the particles oscillate **parallel** to the;
  - Propagation of the wave
  - Direction of energy transfer
- Longitudinal waves show areas of
  - **High pressure,** called **compressions**
  - **Low pressure**, called **rarefactions**

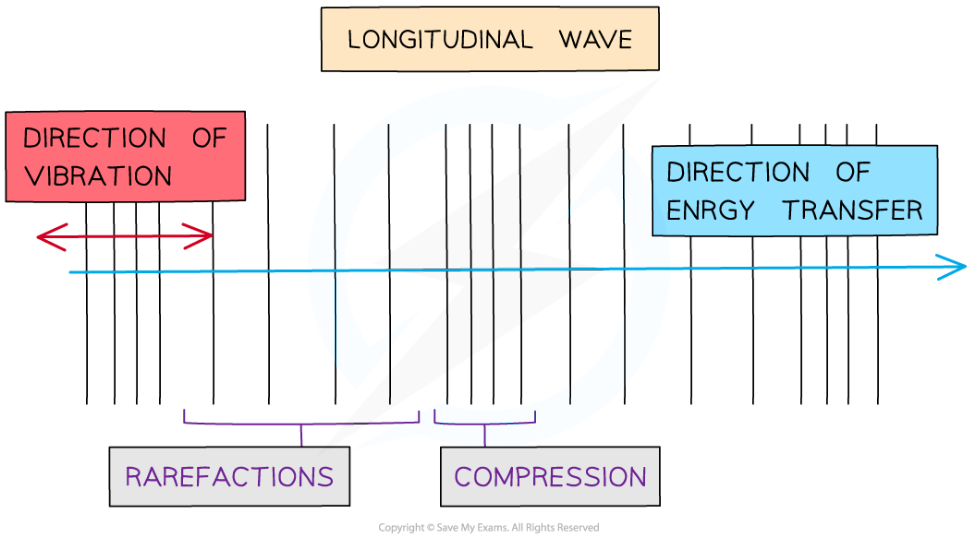


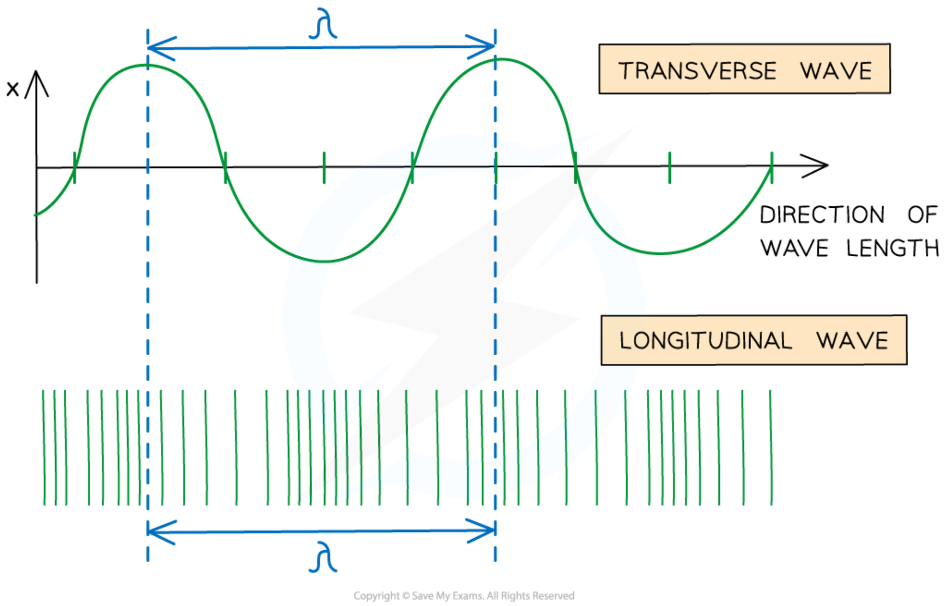
Diagram of a longitudinal wave

- Examples of longitudinal waves are:
  - Sound waves
  - Ultrasound waves
  - P-waves caused by earthquakes
- Longitudinal waves **cannot** be polarised

Labelling Longitudinal Waves

- You learned how to describe the properties of a wave, such as amplitude and wavelength at the start of this topic

- The diagram shows a wavelength on a longitudinal wave



Wavelength is shown on a longitudinal wave

Examiner Tips and Tricks

Questions about longitudinal waves typically start by asking for a definition, so be ready with a statement about areas of high and low pressure and the keywords compression and rarefaction.

Be careful with graphs of waves and don't assume a sinusoidal-shaped graph represents a transverse wave. Longitudinal waves can also look sinusoidal when plotted on a graph - make sure you read the question and look for whether the wave travels **parallel** (longitudinal) or **perpendicular** (transverse) to the direction of travel to confirm which type of wave it is.

Your notes

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Transverse Waves

Transverse Waves

- A transverse wave is one where the particles oscillate **perpendicular** to the direction of the
  - Propagation of the wave
  - Direction of energy transfer
- Transverse waves show areas of **crests** (peaks) and **troughs**

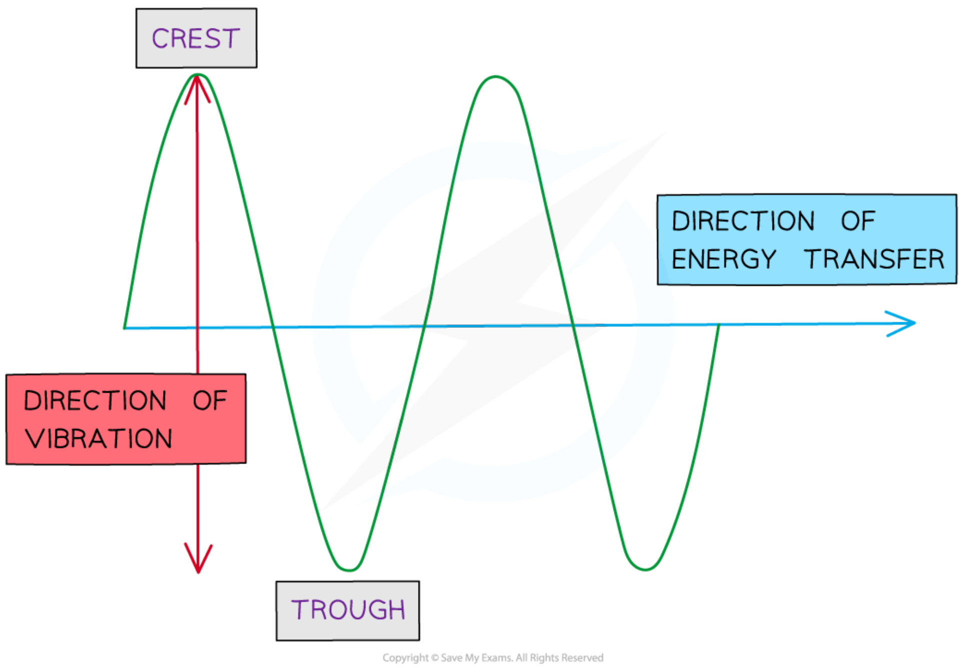


Diagram of a transverse wave

- Examples of transverse waves are:
  - Electromagnetic waves e.g. radio, visible light, UV
  - Vibrations on a guitar string
  - Waves on a rope or slinky
- Transverse waves can be polarised

Your notes

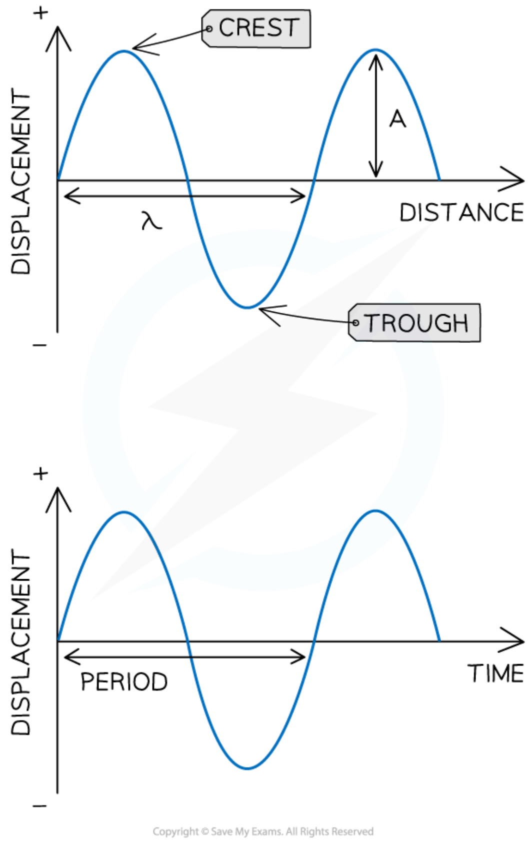
Examiner Tips and Tricks

Questions about transverse waves typically start by asking for a definition, so be ready with a statement about **vibrations** or **oscillations** being perpendicular to the travel of the wave.

Graphs of Transverse & Longitudinal Waves

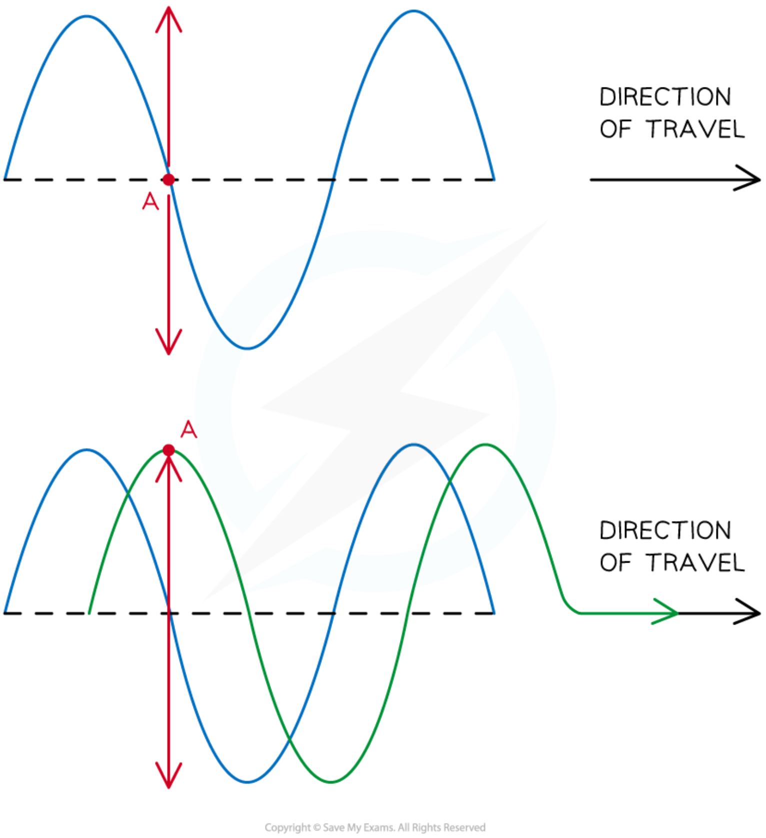
Representing transverse waves

- Transverse waves are commonly represented using:
  - displacement-distance graphs
  - displacement-time graphs
- On the **displacement-distance** graph:
  - amplitude A is measured from the rest position to the point of maximum displacement
  - wavelength λ is measured from one point on a wave to the same point on the next wave (e.g. two consecutive crests or troughs)
- On the **displacement-time** graph:
  - period T is measured from one point on a wave to the same point on the next wave
  - frequency can be calculated using $f = \frac{1}{T}$



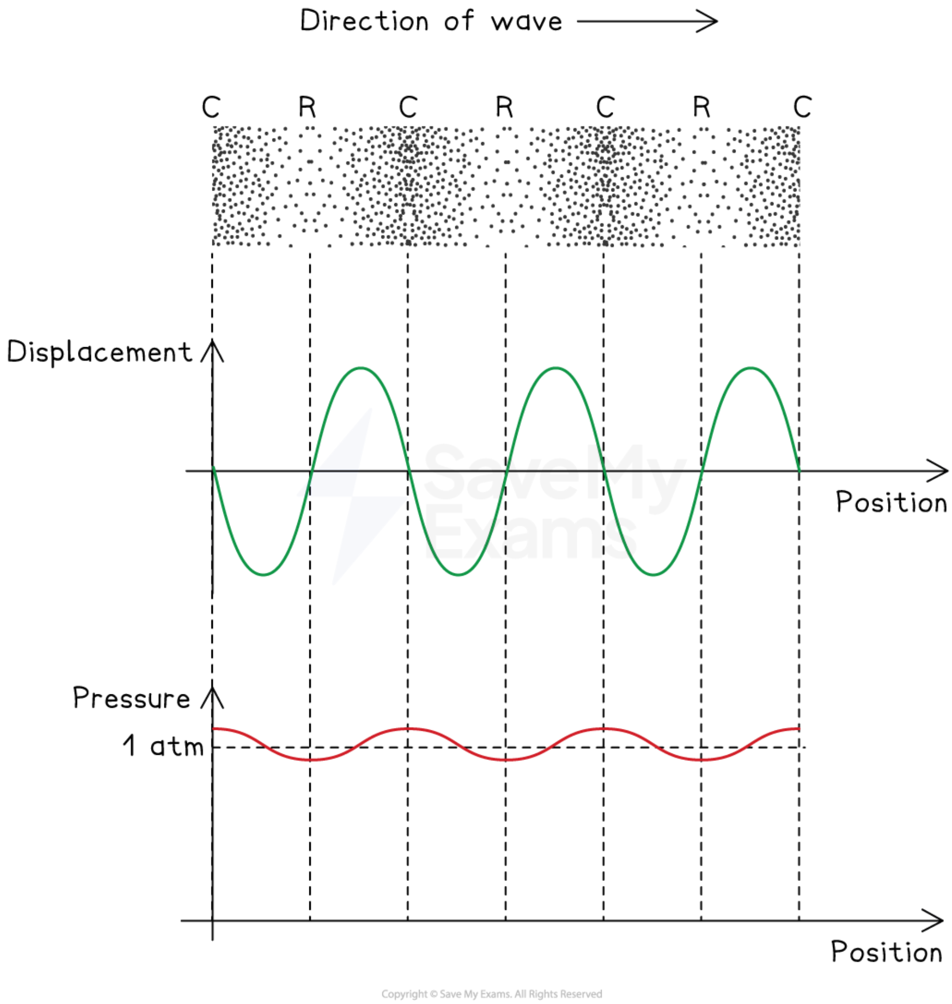
Transverse waves can be graphed to visualise the perpendicular vibrations over distance or time

- To determine the next position of a point on the wave
  - Sketch the full wave after time has passed by looking at the direction of travel
  - Each point oscillates perpendicular to the wave, so it remains on the normal line wherever the wave intersects, as shown in red below



Representing longitudinal waves

- Longitudinal waves can be represented using:
  - displacement-distance graphs
  - pressure-distance graphs
- On the **displacement-distance** graph:
  - the amplitude and wavelength can be measured in the same way as the transverse wave
  - zero displacement occurs at compressions and rarefactions
  - maximum displacement occurs halfway between compressions and rarefactions
- The **pressure-distance** graph is:
  - highest at compressions and lowest at rarefactions
  - 90° out of phase with the displacement graph



Longitudinal waves can be graphed to visualise the displacement of particles at different positions, as well as the pressure at each position

- A sound wave is a longitudinal wave caused by oscillations of particles in the medium, e.g. air molecules
- At a **compression**:
  - air molecules have **zero** displacement (compared to their equilibrium positions)
  - air molecules on either side are displaced **towards** it
  - This creates an area of **high** pressure
- At a **rarefaction**:
  - air molecules have **zero** displacement (compared to their equilibrium positions)
  - air molecules on either side are displaced **away** from it
  - This creates an area of **low** pressure

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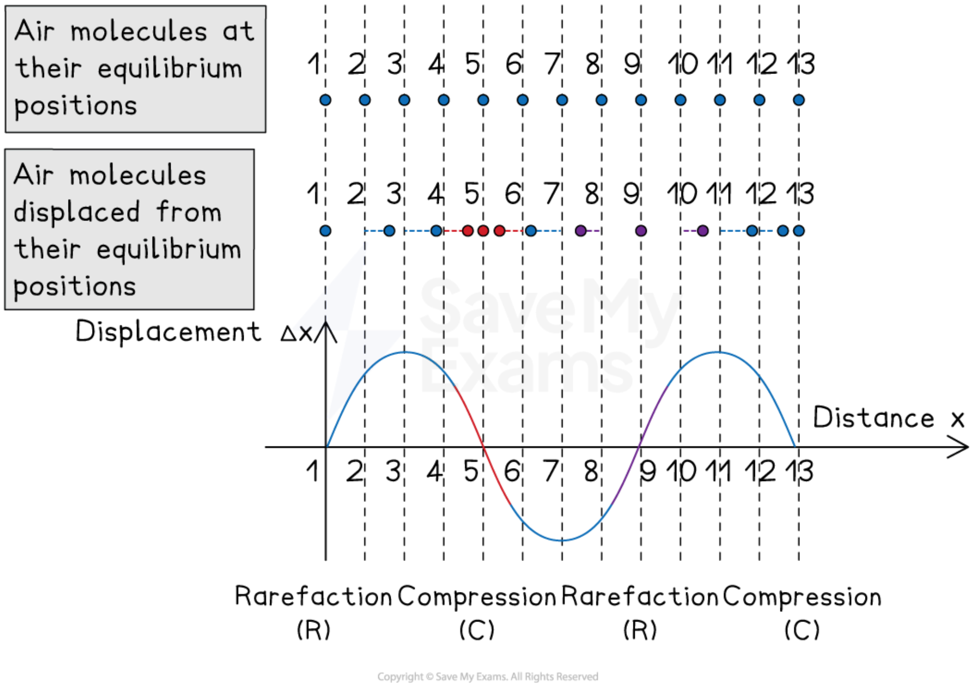
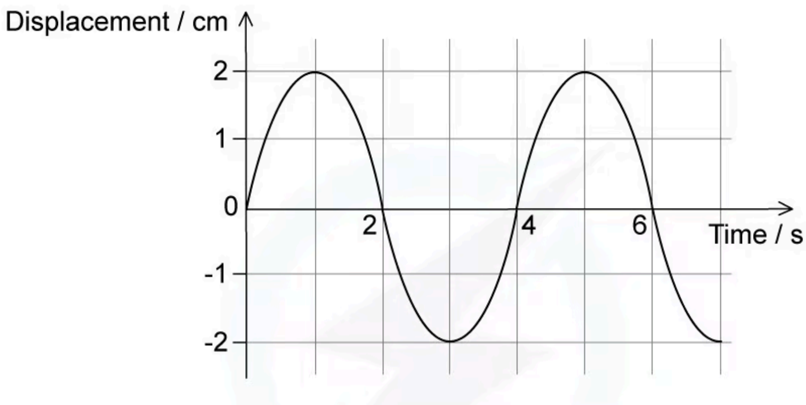


The positions of air molecules in a sound wave can be mapped onto a displacement-distance graph

Worked Example

The graph shows how the displacement of a particle in a wave varies with time.



Which statement is correct?

A. The wave has an amplitude of 2 cm and could be either transverse or longitudinal.

B. The wave has an amplitude of 2 cm and has a time period of 6 s.

C. The wave has an amplitude of 4 cm and has a time period of 4 s.

D. The wave has an amplitude of 4 cm and must be transverse.

Answer: A

THE WAVES AMPLITUDE IS THE DISPLACEMENT FROM THE EQUILIBRIUM POSITION

FROM THE GRAPH, THIS IS 2 cm

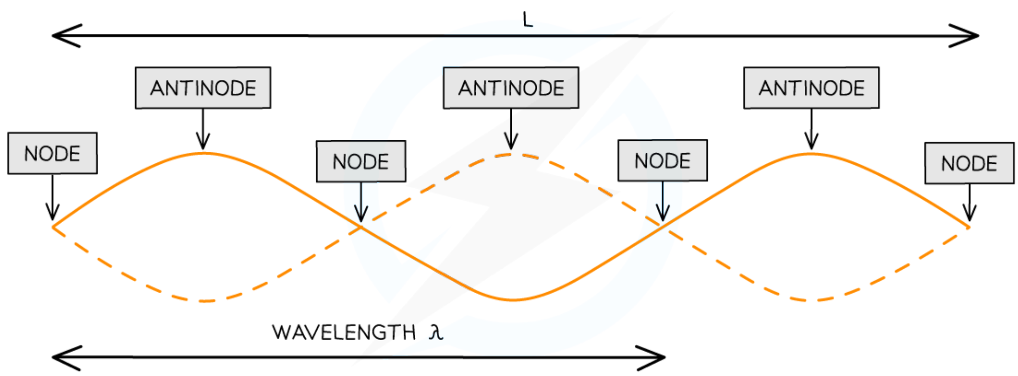
THE GRAPH IS DISPLACEMENT AGAINST TIME, NOT DISPLACEMENT AGAINST DIRECTION OF WAVE TRAVEL

THEREFORE, THE WAVE COULD BE EITHER TRANSVERSE OR LONGITUDINAL

Your notes

Graphs of Stationary Waves

- Stationary waves occur when a wave is reflected with a 180° phase difference, creating a wave with a series of nodes and antinodes
  - Stationary waves can be transverse or longitudinal
  - They are represented graphically in the same way as progressive (travelling) waves
- Graphs of standing waves can also be used to determine the position of nodes and antinodes



- *L* is the length of the string
- 1 wavelength λ is only a portion of the length of the string

Your notes

Examiner Tips and Tricks

Both transverse and longitudinal waves can look like transverse waves when plotted on a graph - make sure you read the question and look for whether the wave travels **parallel** (longitudinal) or **perpendicular** (transverse) to the direction of travel to confirm which type of wave it is.

Your notes

Core Practical 4: Investigating the Speed of Sound

Aim of the Experiment

- The aim of this experiment is to measure the speed of sound in air between two points using an oscilloscope and a signal generator

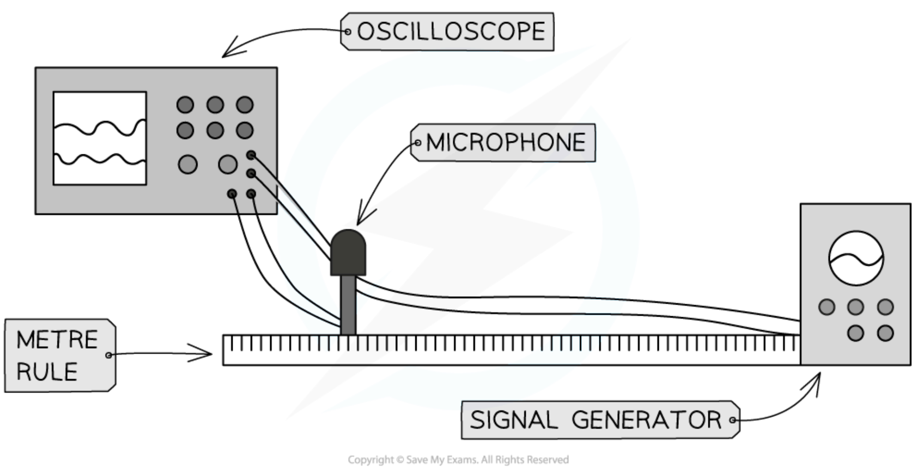
Variables

- Independent variable = Distance
- Dependent variable = Phase of received signals
- Control variables:
  - Same location to carry out the experiment
  - Same set of microphones for each trial
  - For **each set of readings**, the same frequency of sound

Equipment

- Signal generator with loudspeaker
- Oscilloscope with 2–beam facility
- Microphone
- 2 metre rulers or 1 measuring tape of at least 2 m length
- Connecting leads

Method



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1. Connect the microphone and signal generator to an oscilloscope, and set up the signal generator about 50 cm from the microphone
2. Set the signal to about 4 kHz
3. The oscilloscope should trigger when the microphone detects a sound, and adjust the time base so that the signal from the generator and the microphone can be on the screen with about three cycles visible
4. Adjust the separation so a trough on the upper trace coincides with a peak on the lower trace (this makes judging the point where the waves coincide easier)
5. Record the distance between the microphone and the signal generator
6. Move the microphone further away, watch the traces on the screen
7. When the next trough and peak coincide on the oscilloscope trace, record the new distance between the microphones and the signal generator
8. Repeat steps 6 and 7 as many times as possible in the available space
9. Calculate the mean wavelength of the sound
10. Using the oscilloscope trace find the frequency of the sound
11. Reduce the frequency to around 2 kHz (or half of the original value) and repeat steps 4–10.

Table of Results:

TIME PERIOD / μ s	FREQUENCY / kHz	d_1 / m	d_2 / m	d_3 / m

Analysis of Results

- The speed of sound can be calculated using the equation:

$$v = f\lambda$$

- Frequency is found from the time base of the oscilloscope by using

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

Your notes

Evaluating the Experiment

Systematic Errors:

- Ensure the scale of the time base is accounted for correctly
  - The scale is likely to be small (e.g. milliseconds) so ensure this is taken into account when calculating frequency
- Use the oscilloscope signal trace to find frequency to avoid relying on the dial of the signal generator

Random errors:

- Random errors in taking measurements can be reduced by doing repeat readings and taking an average
- The time interval is small so make the distance between the microphone and signal generator as large as is practical

Safety Considerations

- The voltage and current are low so that normal care with electrical equipment is sufficient (including checking the leads for any signs of damage)
- Keep sound at a normal listening volume to avoid damage to hearing

Examiner Tips and Tricks

When you are answering questions about methods to measure waves, the question could ask you to comment on the accuracy of the measurements

In the case of measuring the speed of sound this experiment is very accurate because the timing is done automatically so reaction time is not a factor