SURFING

# VCE PHYSICS 4

## Unit 4 How Can Two Contradictory Models Explain Both Light and Matter?

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# Contents

# Introduction

This book covers the Physics content specified in the Victorian Certificate of Education Physics Study Design. Sample data has been included for suggested experiments to give you practice to reinforce practical work in class.

Each book in the *Surfing* series contains a summary, with occasional more detailed sections, of all the mandatory parts of the syllabus, along with questions and answers.

All types of questions – multiple choice, short response, structured response and free response – are provided. Questions are written in exam style so that you will become familiar with the concepts of the topic and answering questions in the required way.

Answers to all questions are included.

A topic test at the end of the book contains an extensive set of summary questions. These cover every aspect of the topic, and are useful for revision and exam practice.

# Words To Watch

**account, account for** State reasons for, report on, give an account of, narrate a series of events or transactions.

**analyse** Interpret data to reach conclusions.

**annotate** Add brief notes to a diagram or graph.

**apply** Put to use in a particular situation.

**assess** Make a judgement about the value of something.

**calculate** Find a numerical answer.

**clarify** Make clear or plain.

**classify** Arrange into classes, groups or categories.

**comment** Give a judgement based on a given statement or result of a calculation.

**compare** Estimate, measure or note how things are similar or different.

**construct** Represent or develop in graphical form.

**contrast** Show how things are different or opposite.

**create** Originate or bring into existence.

**deduce** Reach a conclusion from given information.

**define** Give the precise meaning of a word, phrase or physical quantity.

**demonstrate** Show by example.

**derive** Manipulate a mathematical relationship(s) to give a new equation or relationship.

**describe** Give a detailed account.

**design** Produce a plan, simulation or model.

**determine** Find the only possible answer.

**discuss** Talk or write about a topic, taking into account different issues or ideas.

**distinguish** Give differences between two or more different items.

**draw** Represent by means of pencil lines.

**estimate** Find an approximate value for an unknown quantity.

**evaluate** Assess the implications and limitations.

**examine** Inquire into.

**explain** Make something clear or easy to understand.

**extract** Choose relevant and/or appropriate details.

**extrapolate** Infer from what is known.

**hypothesise** Suggest an explanation for a group of facts or phenomena.

**identify** Recognise and name.

**interpret** Draw meaning from.

**investigate** Plan, inquire into and draw conclusions about.

**justify** Support an argument or conclusion.

**label** Add labels to a diagram.

**list** Give a sequence of names or other brief answers.

**measure** Find a value for a quantity.

**outline** Give a brief account or summary.

**plan** Use strategies to develop a series of steps or processes.

**predict** Give an expected result.

**propose** Put forward a plan or suggestion for consideration or action.

**recall** Present remembered ideas, facts or experiences.

**relate** Tell or report about happenings, events or circumstances.

**represent** Use words, images or symbols to convey meaning.

**select** Choose in preference to another or others.

**sequence** Arrange in order.

**show** Give the steps in a calculation or derivation.

**sketch** Make a quick, rough drawing of something.

**solve** Work out the answer to a problem.

**state** Give a specific name, value or other brief answer.

**suggest** Put forward an idea for consideration.

**summarise** Give a brief statement of the main points.

**synthesise** Combine various elements to make a whole.

SURFING

# VCE PHYSICS 4

## Area of Study 1

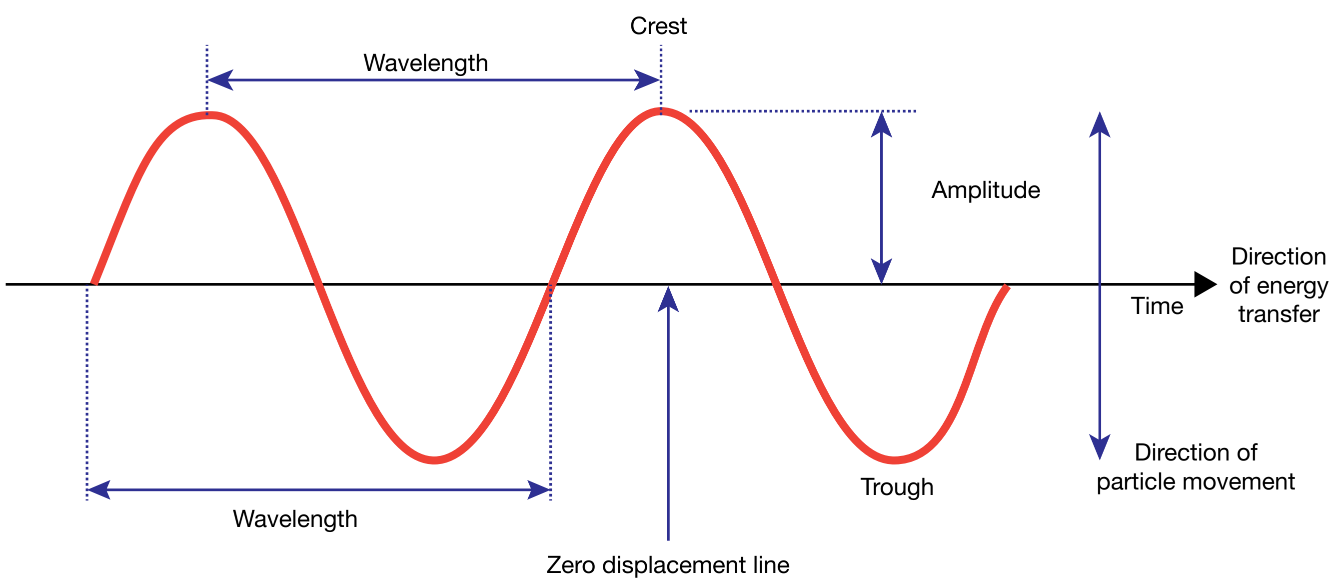
# How Can Waves Explain the Behaviour of Light?

# 1 Transverse Matter Waves

Matter waves need a medium in which to travel. Matter waves transfer energy through the movement and collisions of the particles of the matter through which they are travelling. Matter waves are also known as **mechanical waves**. They include water, sound and earthquake waves and waves in ropes and springs.

A **matter wave** can be thought of as a disturbance in a medium – such as air, water and rock – that transfers energy from place to place. Waves transfer energy without transferring the matter of the medium with the energy. The amount of energy carried is represented by the amplitude of the wave.

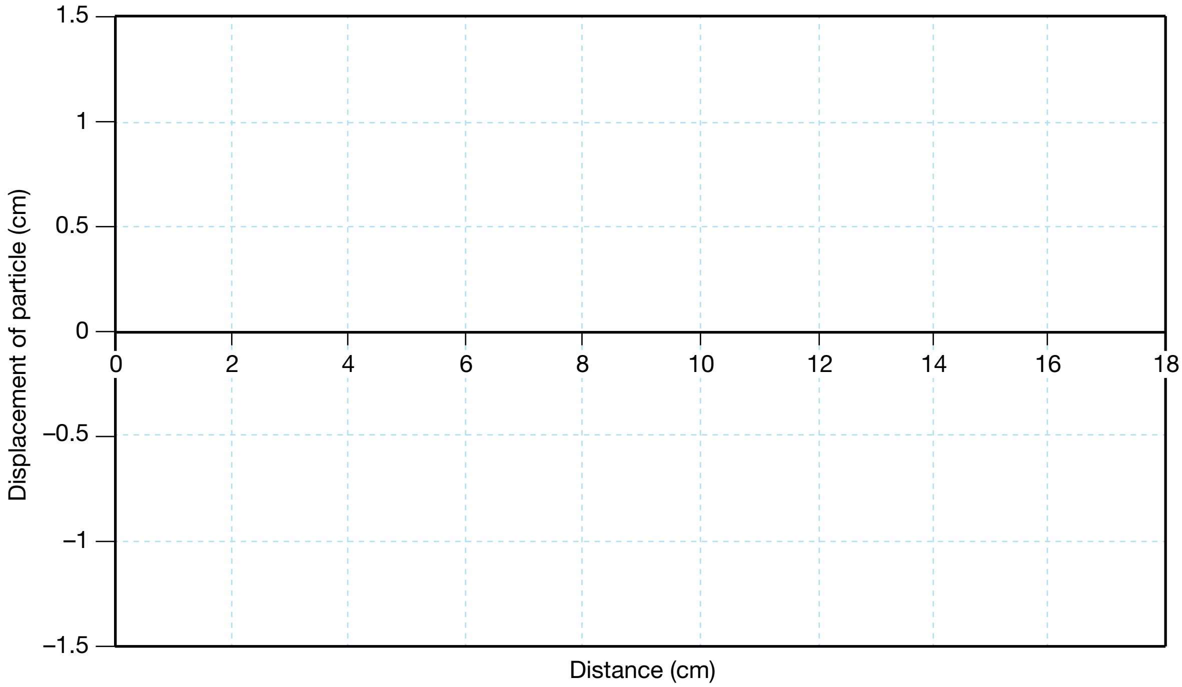
Matter waves are also classified how the particles move in the medium as energy passes through it. In **transverse waves** the particles oscillate at right angles to the direction of energy transfer. We represent transverse waves using a sine/cosine curve.



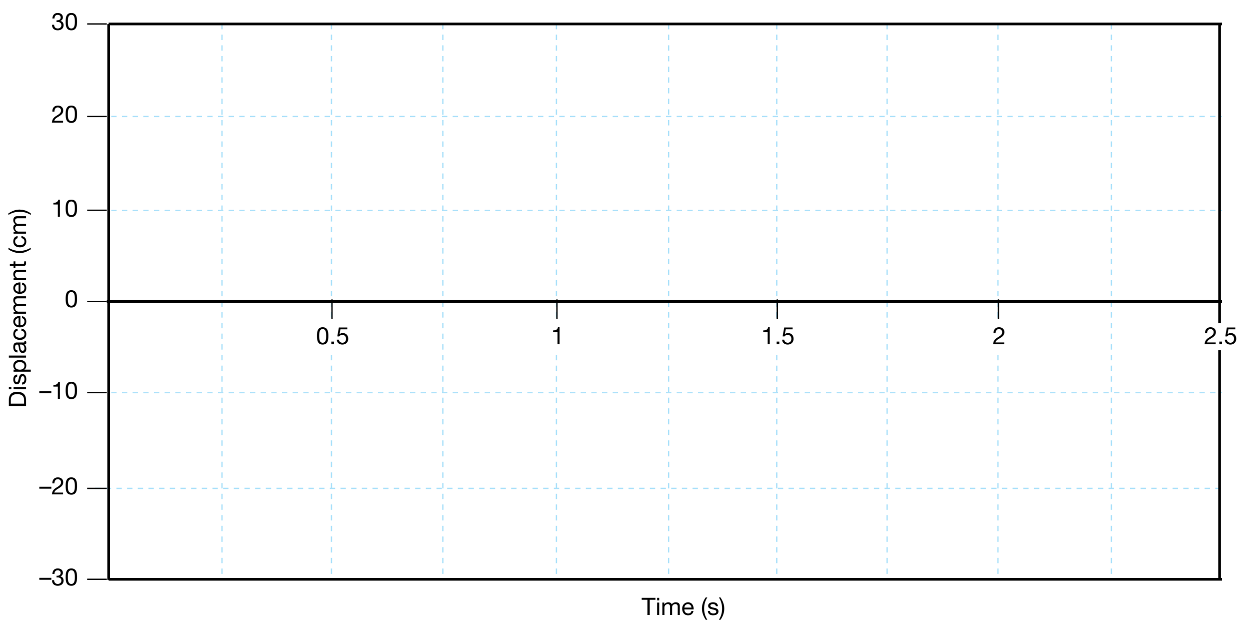

Typical transverse matter waves include a water wave, a wave in a skipping rope, or a violin string as it is bowed. These, as well as all electromagnetic waves, have the following properties (among others).

- The **wavelength** of a wave is the distance from one point on the wave to the next identical point on the wave. This is measured in centimetres or metres.
- The **period** of a wave is the time it takes one wave to pass a point, measured, e.g. in seconds or milliseconds.
- The **frequency** of a wave is the number of wavelengths that pass a point each second. Frequency is measured in hertz (Hz).
- The **energy** carried by a wave depends on its frequency and amplitude. The higher the frequency and the larger the amplitude, the more energy the wave carries.
- The **amplitude** of a wave is the distance from the zero displacement position of the matter particles to a maximum displacement position (a crest or trough). It is measured in centimetres or metres.
- The **zero displacement position** indicates where the particles would be if no energy was being transferred through the medium.
- A **crest** is a position of maximum upward displacement of a particle – the 'top of the wave'.
- A **trough** is a position of maximum downward displacement of a particle – the 'bottom of the wave'.

1. (a) On the grid below, draw, in red pen, two wavelengths of a wave which has an amplitude of 10 mm and a wavelength of 8 cm.
   (b) On the same axes draw three wavelengths of another graph (in blue) which has an amplitude of 12.5 mm and a wavelength of 5.0 cm.



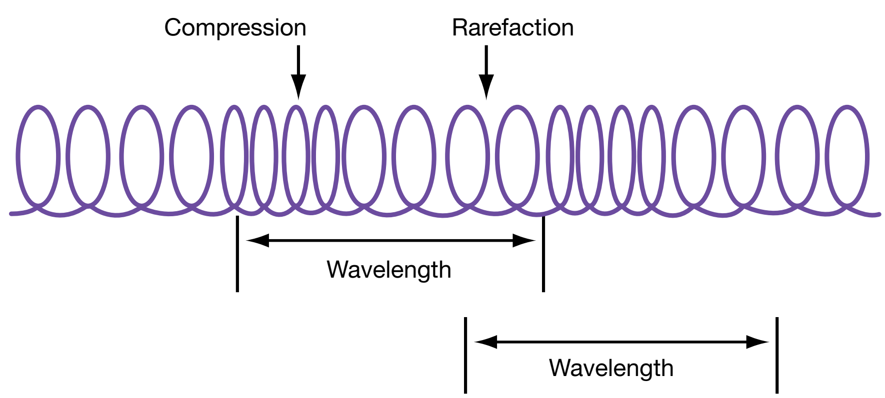

2. (a) On the grid below, draw, in blue pen, four wavelengths of a wave which has an amplitude of 20 mm and a frequency of 2.0 Hz.
   (b) On the same axes draw six wavelengths of another graph (in red) which has an amplitude of 25 mm and a frequency of 0.5 Hz.

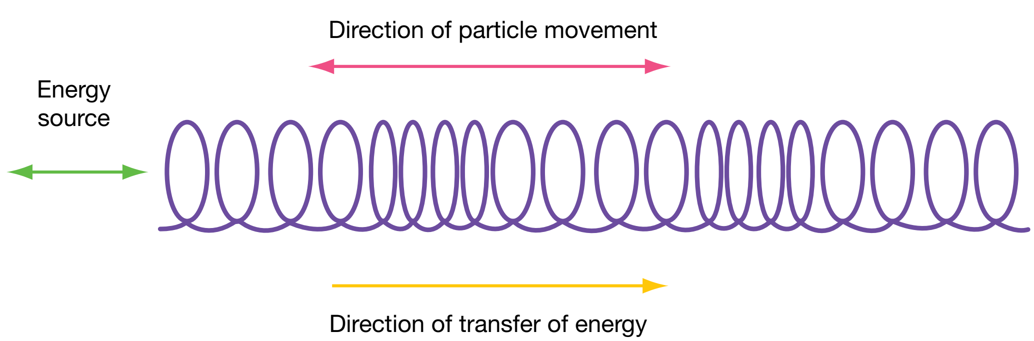


## 2 Longitudinal Matter Waves

Typical longitudinal matter waves include a soundwave in the air, the 'shock wave' produced when a plane breaks the sound barrier and some earthquake waves. They have the following properties.

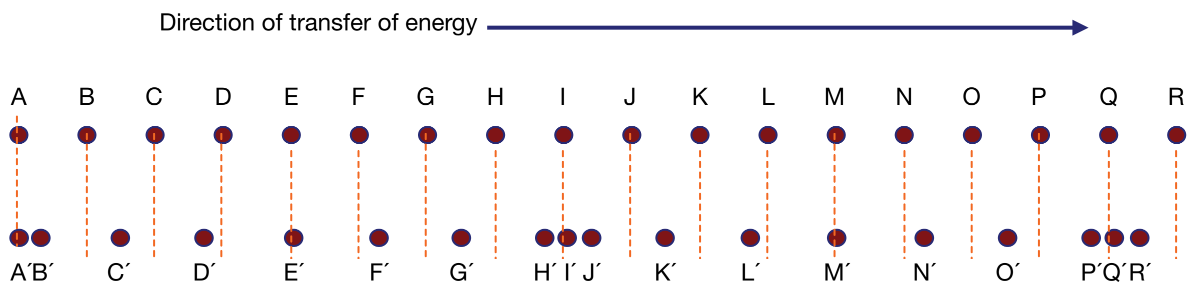
- The **wavelength** of a wave is the distance from one point on the wave to the next identical point on the wave. It is measured in centimetres or metres.
- The **period** of a wave is the time it takes one wave to pass a point.
- The **frequency** of a wave is the number of wavelengths that pass a point each second.
- The **energy** carried by a wave depends on its frequency and amplitude. The higher the frequency and the larger the amplitude, the more energy the wave carries.
- The **amplitude** of a wave is the distance from the zero displacement position of the matter particles to a maximum displacement position. It is measured in centimetres or metres.
- The **zero displacement position** indicates where the particles would be if no energy was being transferred through the medium.
- Both **rarefactions** and **compressions** are positions of zero displacement in a longitudinal wave.
- In a longitudinal wave, the direction of the movement of particles in matter is back and forth along the direction of the transfer of energy.
- When longitudinal waves pass through a solid medium, then the energy transfers through high and low pressure regions within the medium.
- Because longitudinal waves are also very difficult to draw using typical 'dotty' diagrams where each dot represents a particle of the medium, we often represent them as transverse wave diagrams too.



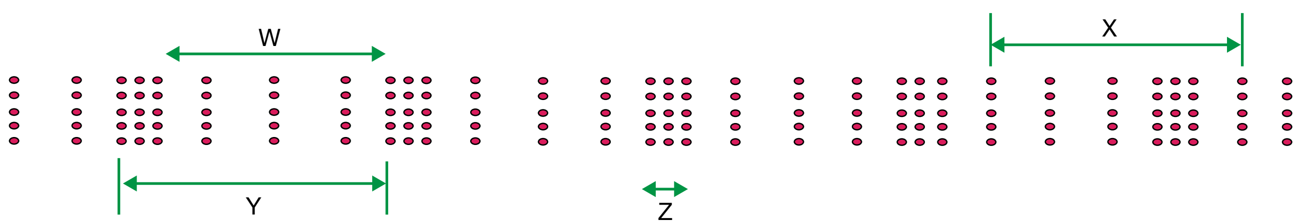



## QUESTIONS

1. Distinguish between a *compression* and a *rarefaction* in a longitudinal wave in a spring and in a longitudinal wave in a solid material like the crust of the Earth.
2. Contrast the direction of movement of the matter particles in a longitudinal wave and the direction the energy is carried.
3. (a) Define amplitude for a longitudinal wave.
   (b) How can you determine the amplitude in a longitudinal wave?
4. The diagram shows the undisturbed positions of the matter particles in a medium (first row of dots labelled A to R), and their positions when a longitudinal wave is passing through the medium (second row of dots, labelled A´ to R´). Vertical orange lines have also been provided to mark the zero displacement positions of each particle in the medium.




   On the diagram label:
   (a) Two wavelengths.
   (b) A compression.
   (c) A rarefaction.
   (d) Two particles at maximum displacement from their zero position.
   (e) Two particles with zero displacement.
5. The diagram represents a soundwave. Identify each labelled part of the diagram.




6. Which choice correctly defines the amplitude of a matter wave?
   (A) The distance between successive wave pulses.
   (B) The distance between two adjacent crests or troughs.
   (C) The distance from the top of a crest to the bottom of a trough.
   (D) The distance from zero displacement to a position of maximum displacement.
7. Which choice correctly describes how the particles of the medium carrying a soundwave move?
   (A) Oscillate up and down.
   (B) Oscillate left and right.
   (C) Oscillate in the same direction as energy is transferred.
   (D) Oscillate at right angles to the direction of energy transfer.

# 3 The Wave Equation

**Period and frequency.** The period of a wave motion is inversely proportional to its frequency. This applies to all forms of waves. This is represented mathematically by the following.

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

Where $T$ = period of the wave in s (seconds)

$f$ = frequency of the wave in $s^{-1}$ (hertz, Hz)

**Velocity, frequency, period and wavelength.** The relationship between velocity, frequency, period and wavelength is represented by the following.

$$v = f\lambda \quad \text{or} \quad v = \frac{\lambda}{T}$$

Where $v$ = velocity of the wave in m $s^{-1}$

$\lambda$ = wavelength of the wave in m (metres)

$T$ = period of the wave in s (seconds)

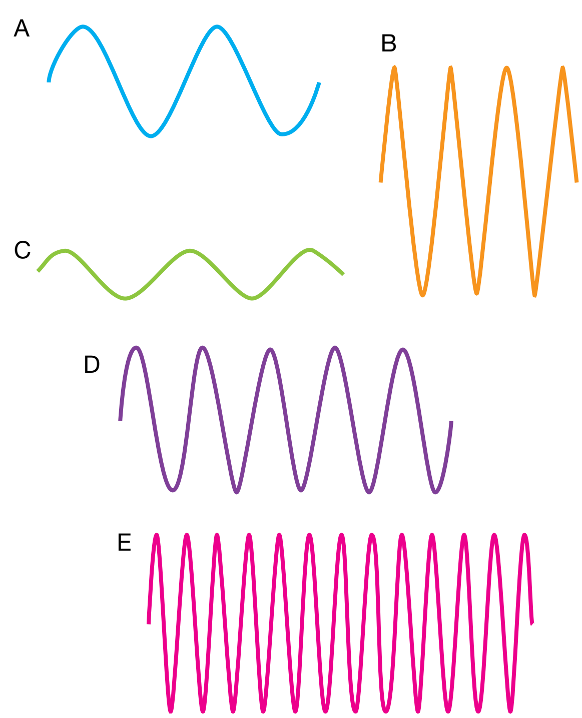
$f$ = frequency of the wave in $s^{-1}$ (hertz, Hz)

## QUESTIONS

1. Sound travels through air at about 330 m $s^{-1}$. Calculate the wavelength of the sound of frequency 256 Hz.
2. The 'C' above middle C on the piano has a frequency of 512 Hz. Calculate its wavelength.
3. The speed of light is $3 \times 10^8$ m $s^{-1}$. Violet light has a wavelength of about 400 nm (nm = $\times 10^{-9}$ m). Calculate the frequency of this light.
4. The table shows information about various colours of visible light. Calculate the missing data.

| Colour | Frequency (Hz) | Wavelength (nm) |
|---|---|---|
| Red | | 750 |
| Orange | | 600 |
| Yellow | | 580 |
| Green | | 540 |
| Blue | $6 \times 10^{14}$ | |
| Indigo | $6.67 \times 10^{14}$ | |

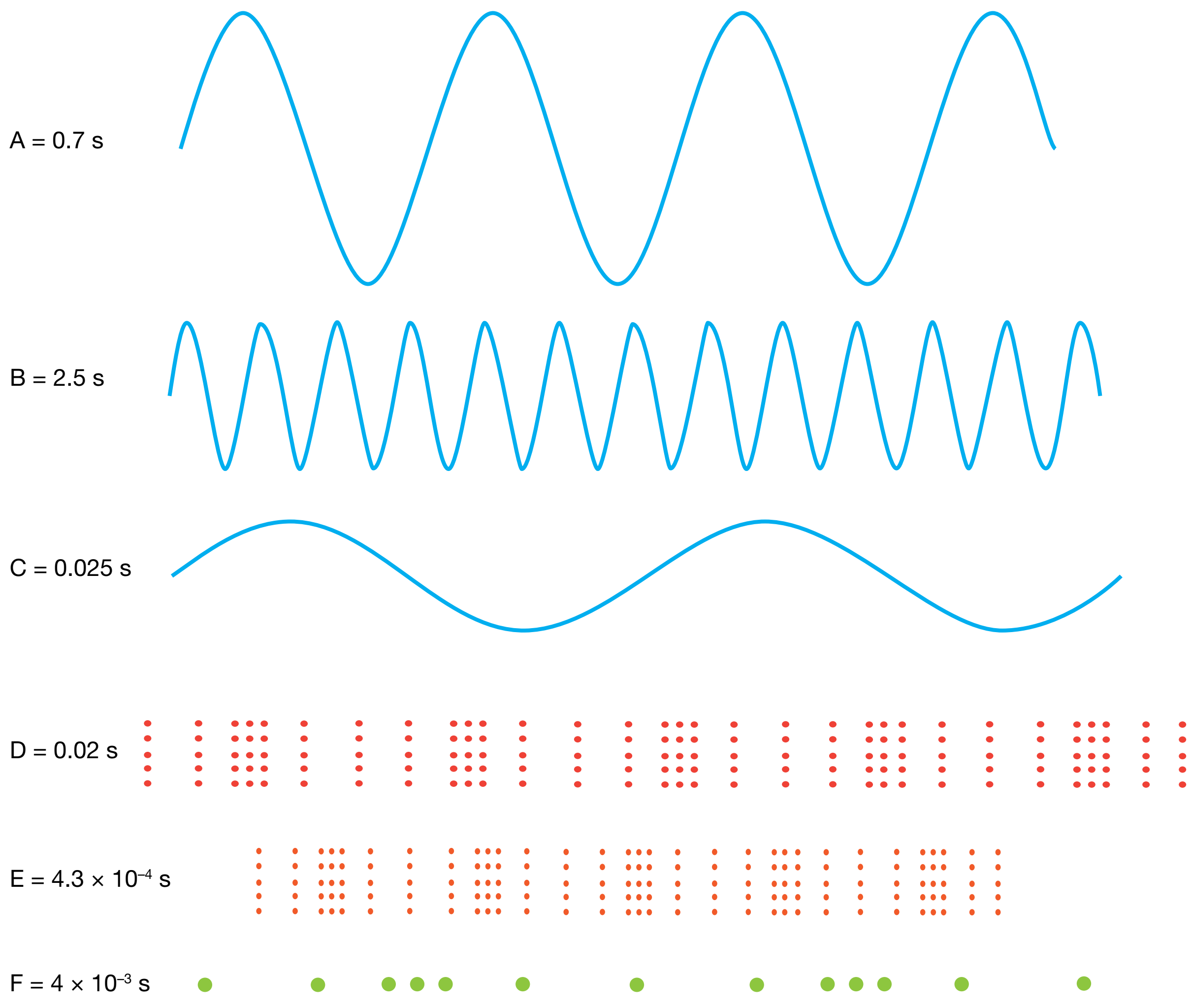
5. Each wave below has been drawn actual size. Each represents 1.0 s of time. For each find its frequency, wavelength, amplitude, period and velocity.



# 4 Analysing Wave Diagrams

## QUESTIONS

1. Below are shown several waves and the length of time each has been travelling. Analyse each to determine its wavelength, amplitude (A, B and C only), frequency, period and velocity. Each wave is shown actual size.




| Wave | Wavelength (cm) | Amplitude (cm) | Frequency (Hz) | Period (s) | Velocity (m $s^{-1}$) |
|---|---|---|---|---|---|
| A | | | | | |
| B | | | | | |
| C | | | | | |
| D | | | | | |
| E | | | | | |
| F | | | | | |

# 5 Analysing Wave Graphs 1

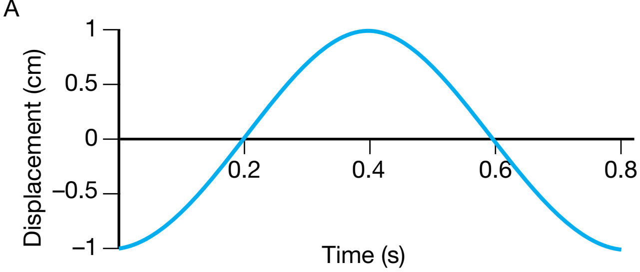
## Displacement-time and displacement-displacement graphs

We often represent wave motion graphically. Rather than draw the wave, we graph the displacement of a medium particle against time (which is the same thing for a transverse wave, but longitudinal waves also appear as sine/cosine curves in these situations), or we graph displacement of the particle against distance the energy has travelled. The graphs below (travelling left to right) show various examples of this. Analyse them to answer the questions.

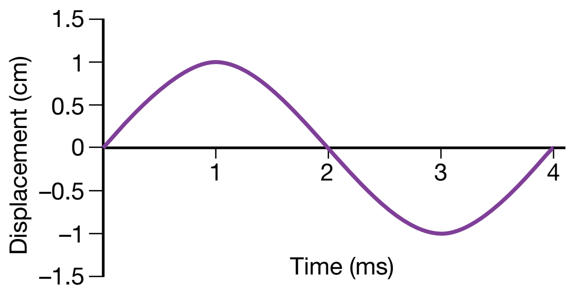
## QUESTIONS

**1.** The graphs shows the displacement of a particle in a wave of wavelength 4.0 m.

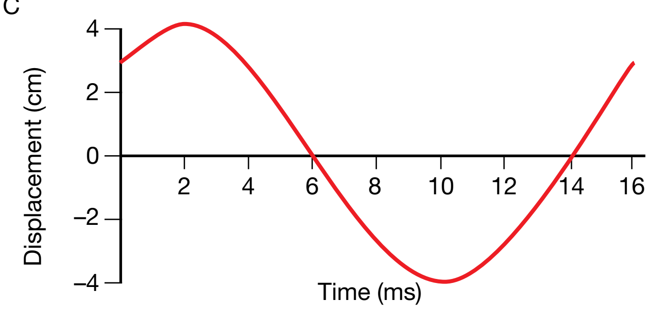
A




B



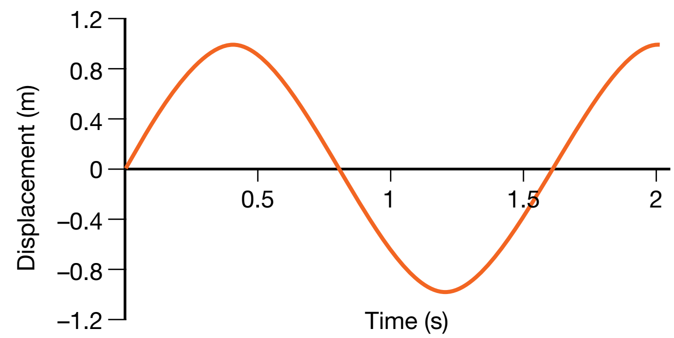

C

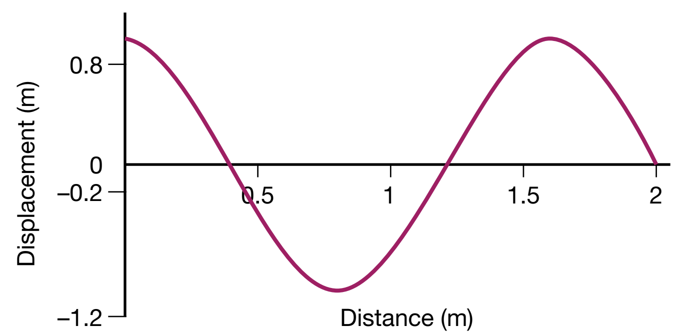



Determine the:

(a) Period.
(b) Frequency.
(c) Amplitude.
(d) Speed of the wave.

**2.** The graphs show the displacement of a water particle plotted against the distance the wave travels and time.



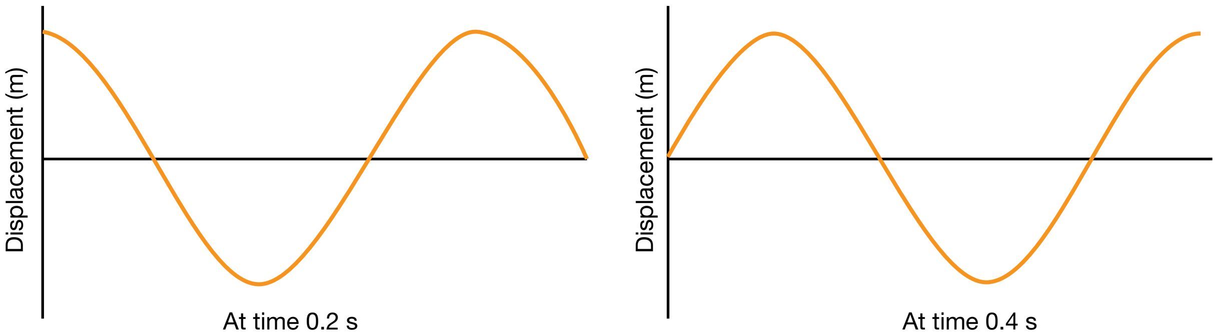

Analyse these graphs to determine the wavelength, period, frequency, amplitude and speed of the water wave.

# 6 Analysing Wave Graphs 2

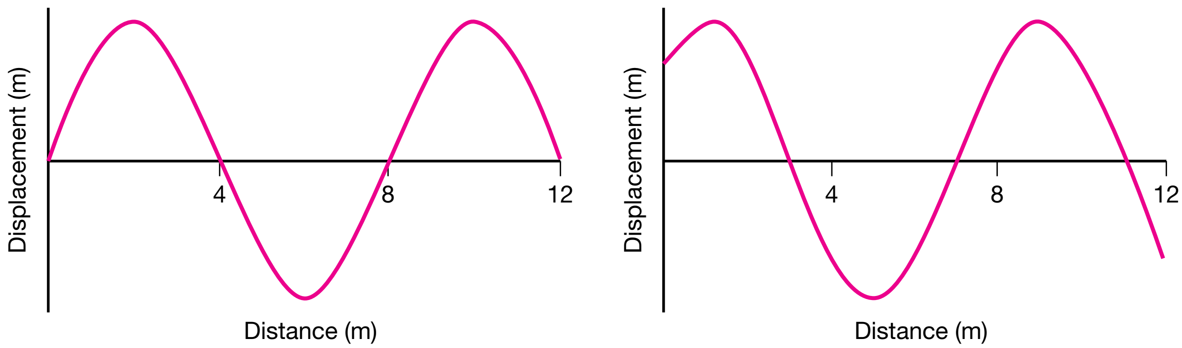
## Displacement-time graphs at two different times

### QUESTIONS

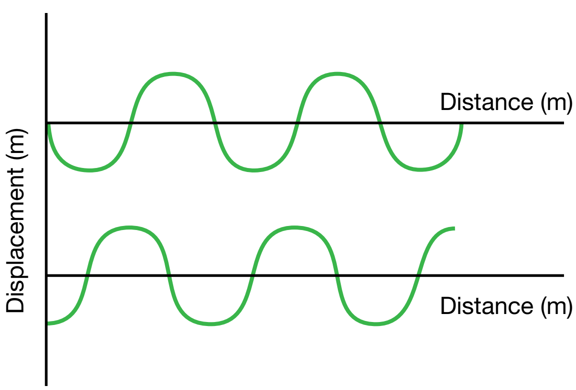
1. The graphs show the positions of the same wave 0.2 s apart. Analyse them to calculate the maximum possible period for the wave.



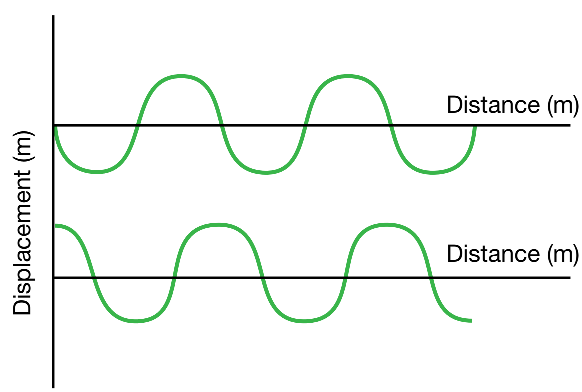

2. The graphs show two positions of a wave 0.1 s apart. Calculate the wavelength, frequency, period and speed of the wave.




3. The graphs show the positions of the same wave 0.2 s apart. Analyse them to calculate the maximum possible period for the wave.



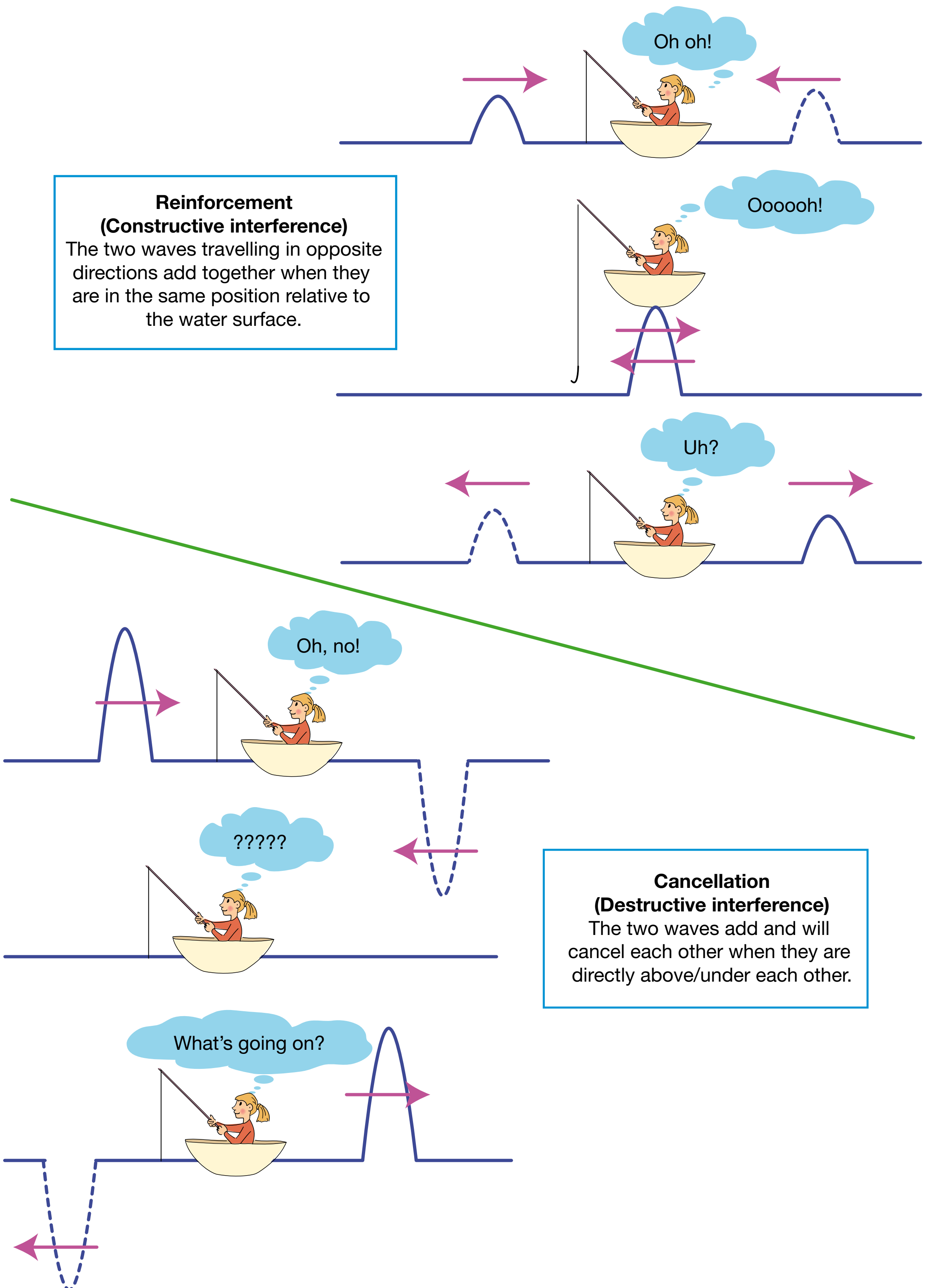

4. The graphs show the positions of the same wave 0.3 s apart. Analyse them to calculate the maximum possible period for the wave.



# 7 Superposition of Waves

When two (or more) sources of vibration each produce a wave in a medium, the waves **interfere** with each other. The amplitude of the combined wave is equal to the sum of the amplitudes of the component waves. This process is called **superposition** and the combination wave is the **resultant wave**. While waves interfere when they occupy the same positions in a medium, they continue on their respective journeys unaltered, except for the time they interfere.

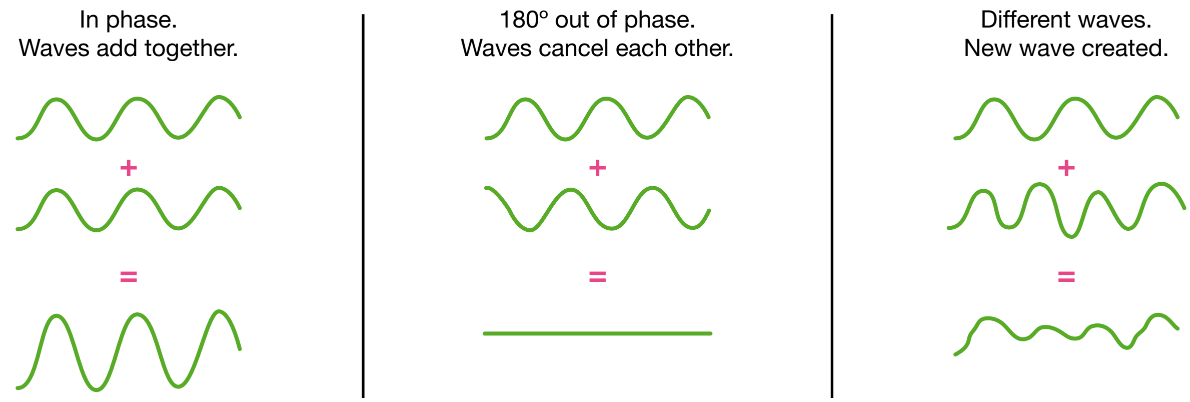
This is shown in the diagrams.




**Reinforcement**
**(Constructive interference)**
The two waves travelling in opposite directions add together when they are in the same position relative to the water surface.

**Cancellation**
**(Destructive interference)**
The two waves add and will cancel each other when they are directly above/under each other.

Another way of looking at this is to consider the phase of the two waves. Waves that mirror each other are said to be ‘in phase’. Waves that do not mirror each other are ‘out of phase’. The amount they are out of phase depends on the angular separation between them if they were plotted on the same axes. Refer to the following examples.

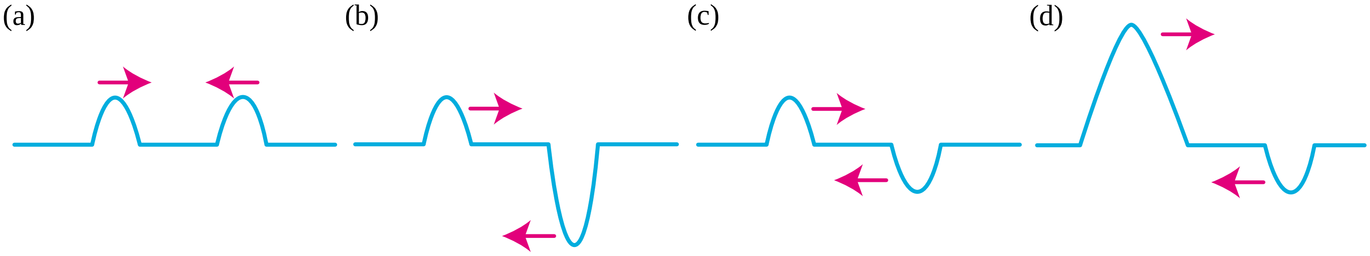



| | | |
|---|---|---|
| Path difference = $n\lambda$ | Path difference = $(n - \frac{1}{2})\lambda$ | If amplitudes and wavelengths differ a complex wave results regardless of phase difference. |

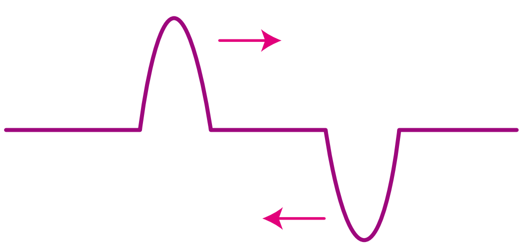
## QUESTIONS

1. The diagrams below show several pulses travelling through strings. In each case, predict the shape of the resultant wave as the pulses interfere, and classify each as *constructive* or *destructive* interference.

(a) (b) (c) (d)



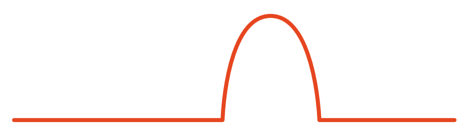
2. Two waves approach each other as shown.

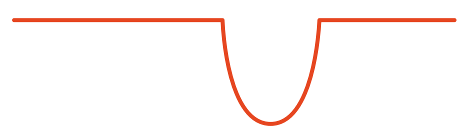


Which choice best describes how these pulses interact with each other?
(A) Constructive interference.
(B) Destructive interference.
(C) Pulse cancellation.
(D) Superposition.

3. Which choice correctly shows the resultant pulse when the two pulses in Question 2 interact?

(a) 

(b) 

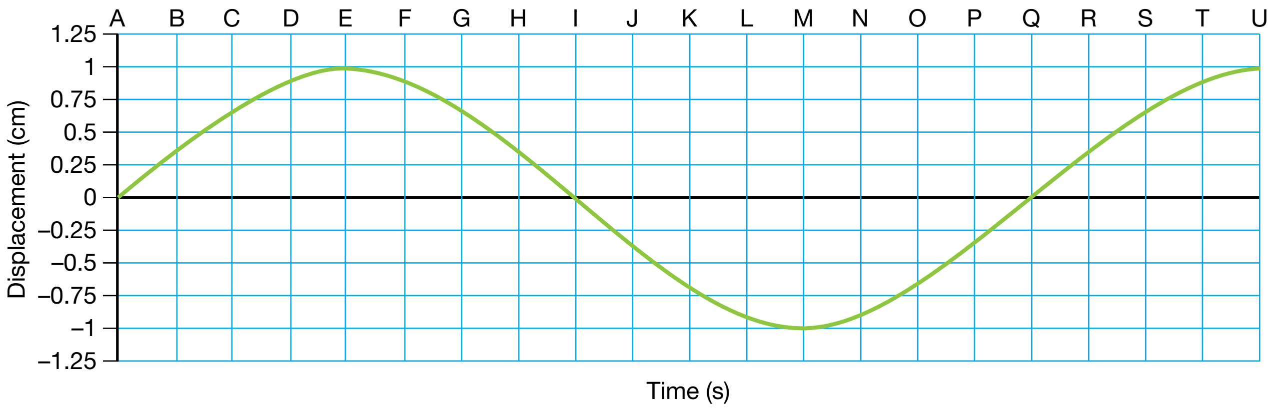
(c) 

(d) 

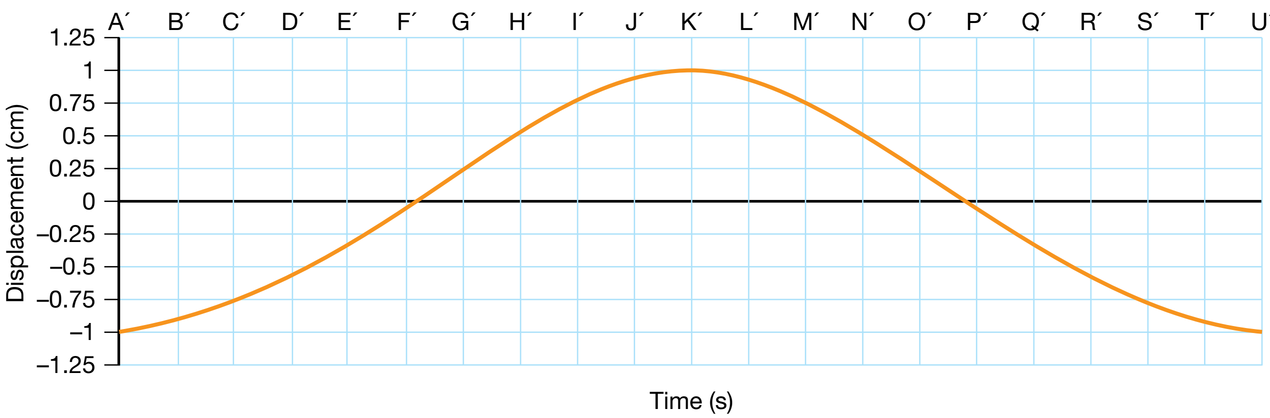
# 8 Superimposing Waves

To determine the shape of the resultant wave diagrammatically, we add the *y*-displacements of the component waves at enough positions along the *x*-axis to predict its detailed form. Consider the following examples.

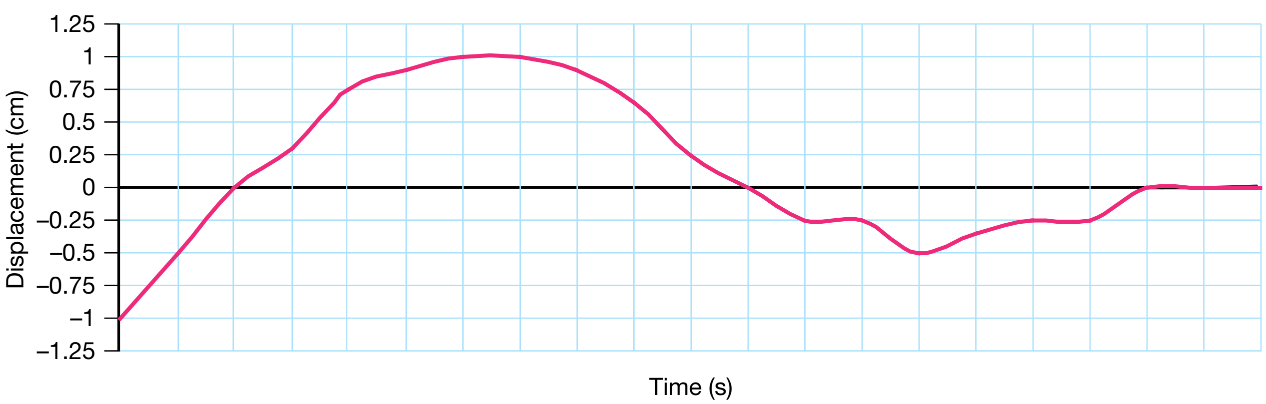
The graph below shows component wave 1 with *x*-axis gridlines labelled A to U.




The graph below shows component wave 2 with *x*-axis gridlines labelled A′ to U′.



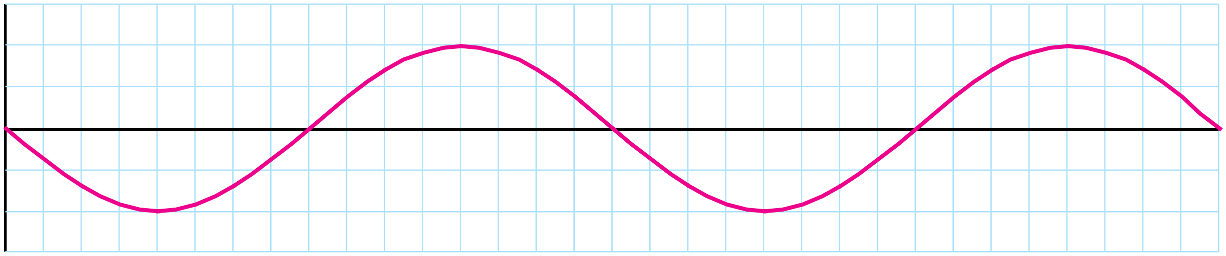

The graph below shows the wave formed by the superposition of graphs 1 and 2 formed by adding *y*-displacements A + A′, B + B′ etc of waves 1and 2. Note that it may not be sufficient just to add the *y*-displacements on the gridlines. It may be necessary to estimate values between these to get an accurate resultant graph.



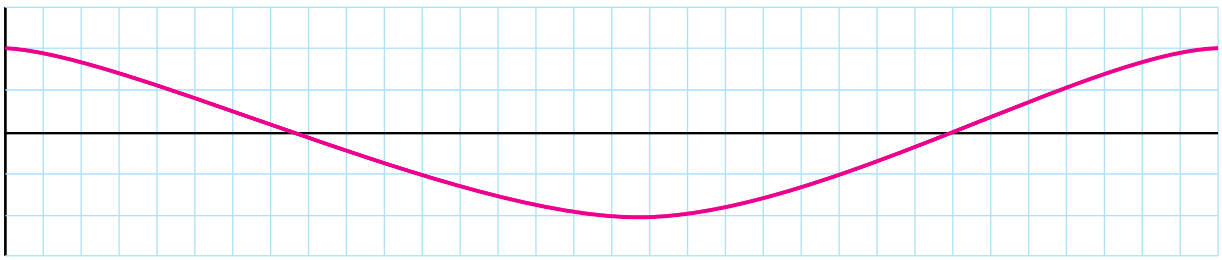
## QUESTIONS

The diagrams show three waves, A, B and C. Find the resultant graph formed by superimposing waves AB, AC. You will get better results if you do each superposition on graph paper, but space has been provided for you to do these superposition problems here.

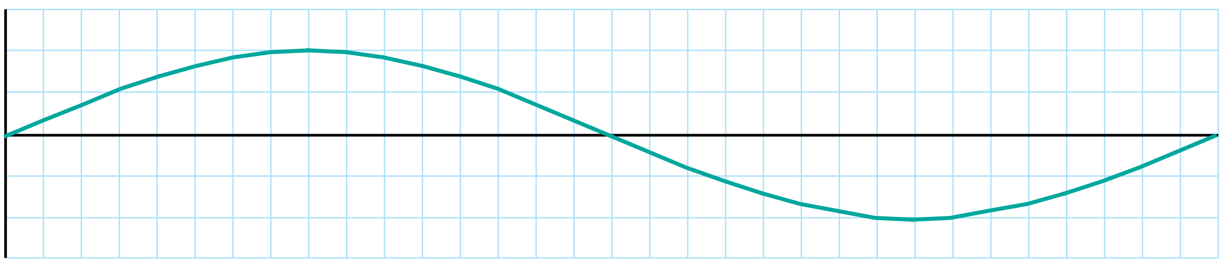
A



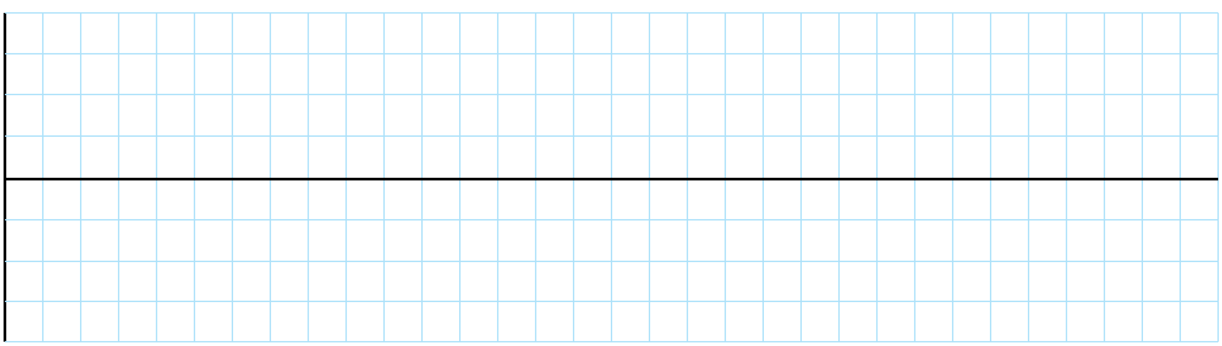
B



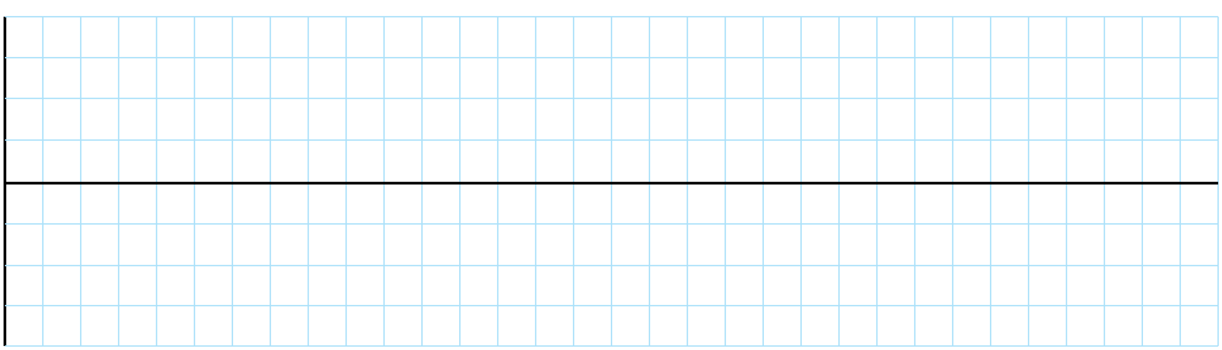
C



A + B

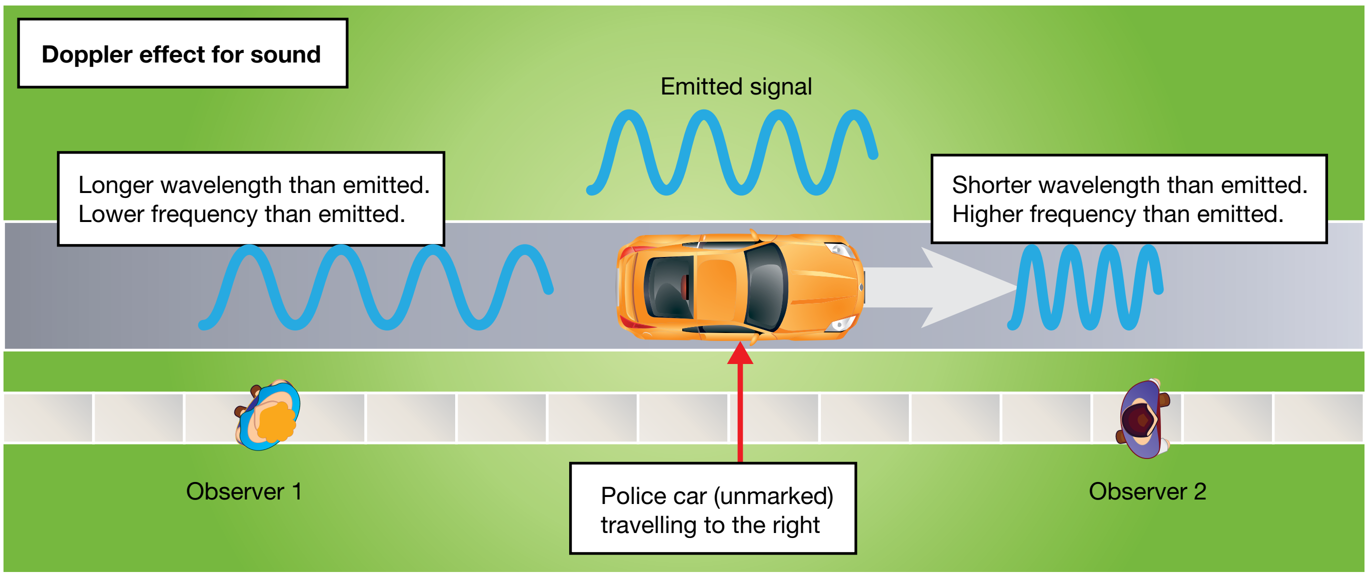


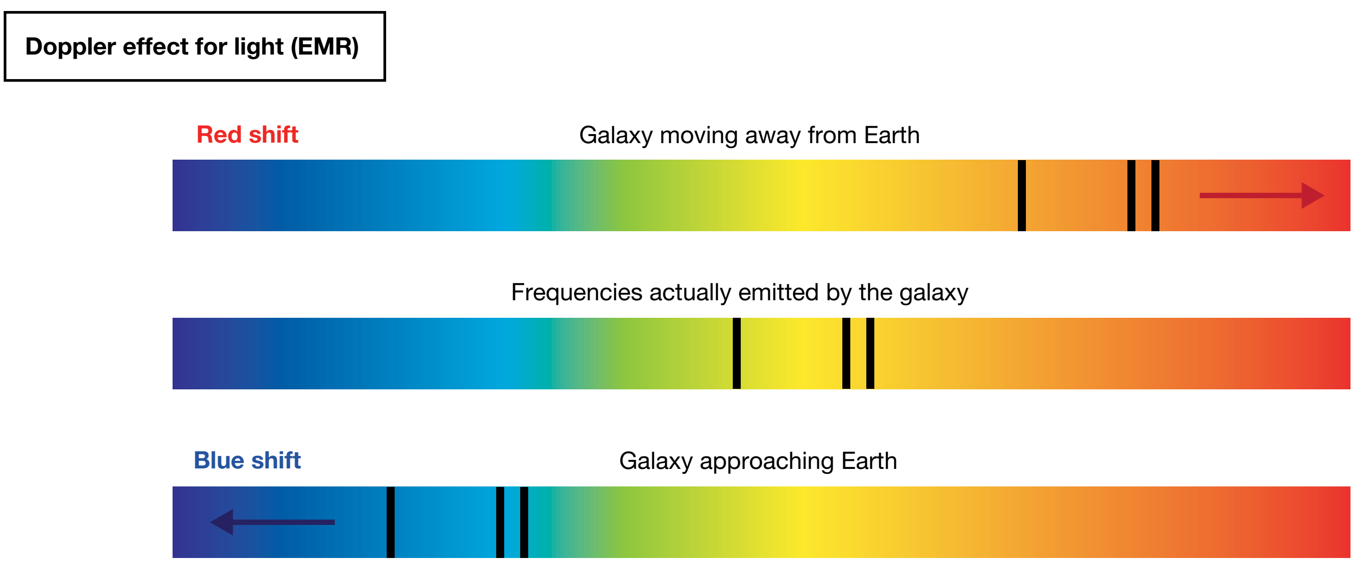
A + C



# 9 The Doppler Effect

When a fire engine or ambulance or police car with sirens going approach you, the pitch (frequency) of its siren rises. When it passes, the pitch falls. The light received by Earth from a galaxy moving away from us is **red shifted –** its frequency is lower than the frequency of the light it emits. If the galaxy is approaching Earth, the frequency of the light we receive will be higher than that emitted. – it will be **blue shifted.** This is known as the **Doppler effect**.




## The Doppler effect and sonic booms

The Doppler effect is observed whenever the speed of the source of the waves moves slower than the waves themselves.

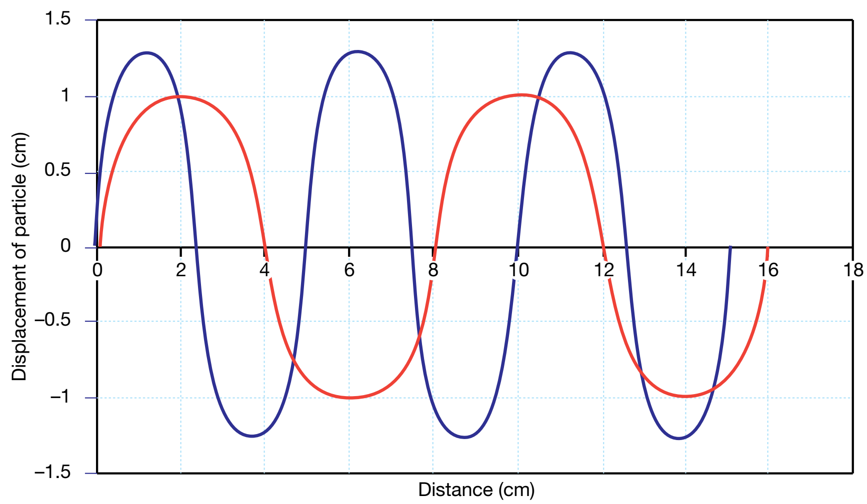
However, if the source moves at the same speed as or faster than the wave, a different phenomenon is observed because the source will always be at the leading edge of the waves that it produces.

If, for example, an aircraft approaches the same speed as sound, the soundwaves it produces become more and more compressed at the front of the aircraft producing what is referred to as a **shock wave** – an extreme example of the Doppler effect.

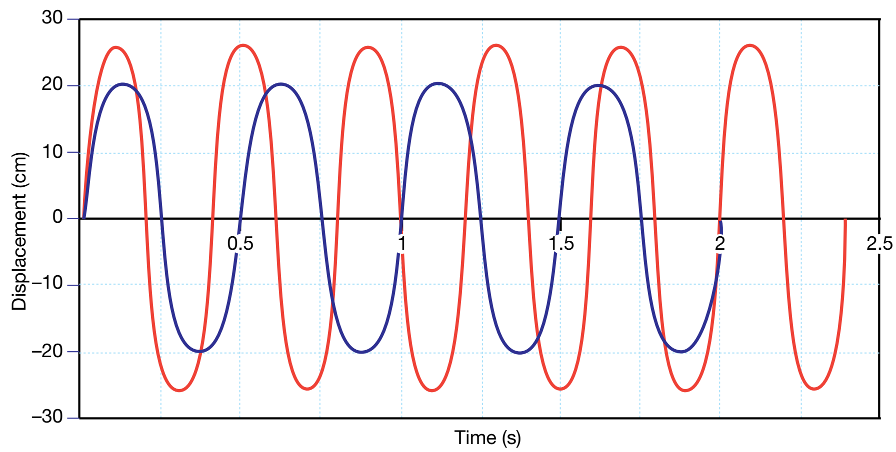
# Answers

## 1 Transverse Matter Waves

1.

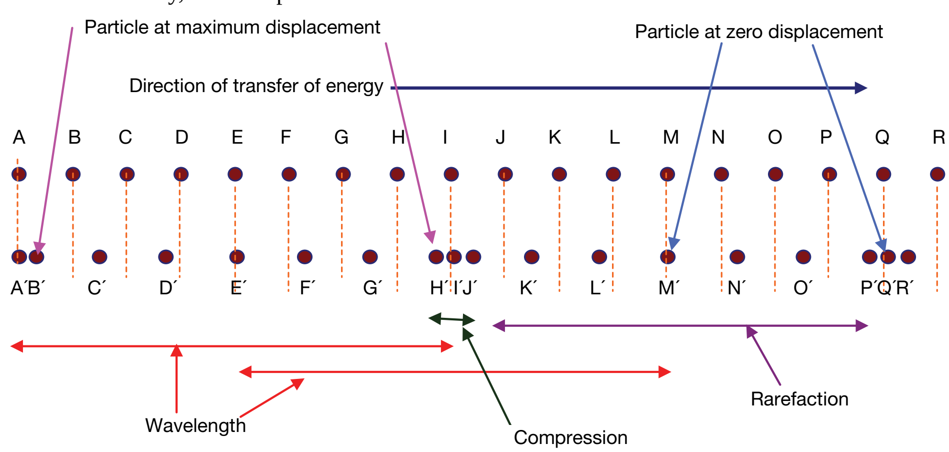



2.




## 2 Longitudinal Matter Waves

1. A compression is a region in a longitudinal wave where the particles are closer together than in the medium at rest. A rarefaction is a region where the particles are further apart than normal. In a solid material, the compression indicates a region of higher pressure, the rarefaction a region of lower pressure.
2. Particle movement is back and forth in the same plane as the direction of energy transfer.
3. (a) Amplitude is the maximum displacement of a particle from its rest position.
   (b) For a longitudinal wave, we would need to know the rest positions of the particles (as we also need to with transverse waves), and then measure the maximum displacement.
4. Answers will vary, for example:



5. W = rarefaction
   X = wavelength
   Y = wavelength
   Z = compression
6. D
7. C

## 3 The Wave Equation

1. $\lambda = \frac{v}{f} = \frac{330}{256} = 1.29$ m
2. $\lambda = \frac{v}{f} = \frac{330}{512} = 0.64$ m
3. $f = \frac{v}{\lambda} = \frac{3 \times 10^8}{400 \times 10^{-9}} = 7.5 \times 10^{14}$ Hz
4.

| Colour | Frequency (Hz) | Wavelength (nm) |
|---|---|---|
| Red | $4.0 \times 10^{14}$ | 750 |
| Orange | $5.0 \times 10^{14}$ | 600 |
| Yellow | $5.2 \times 10^{14}$ | 580 |
| Green | $5.6 \times 10^{14}$ | 540 |
| Blue | $6.0 \times 10^{14}$ | 500 |
| Indigo | $6.67 \times 10^{14}$ | 450 |

5.

| Wave | Frequency (Hz) | Wavelength cm) | Amplitude (cm) | Period (s) | Velocity (cm $s^{-1}$) |
|---|---|---|---|---|---|
| A | 2.0 | 1.65 | 0.7 | 0.5 | 3.3 |
| B | 3.5 | 0.7 | 1.45 | 0.28 | 2.45 |
| C | 2.5 | 1.6 | 0.3 | 0.4 | 4.0 |
| D | 5.0 | 0.84 | 0.9 | 0.2 | 4.2 |
| E | 12.5 | 0.36 | 1.1 | 0.08 | 4.5 |

## 4 Analysing Wave Diagrams

1.

| Wave | Wavelength (cm) | Amplitude (cm) | Frequency (Hz) | Period (s) | Velocity (m $s^{-1}$) |
|---|---|---|---|---|---|
| A | 3.37 | 1.75 | 4.3 | 0.233 | 0.14 |
| B | 1.0 | 0.95 | 5 | 0.2 | 0.05 |
| C | 6.4 | 0.7 | 80 | 0.0125 | 5.1 |
| D | 2.84 | - | 250 | 0.004 | 71 |
| E | 2.0 | - | 11 628 | $8.6 \times 10^{-5}$ | 2325.6 |
| F | 5.9 | - | 500 | $2 \times 10^{-3}$ | 295 |

## 5 Analysing Wave Graphs 1

1. A (a) $T = 0.8$ s
   (b) $f = \frac{1}{T} = \frac{1}{0.8} = 1.25$ Hz
   (c) $A = 1.0$ m
   (d) $v = f\lambda = 1.25 \times 4 = 5$ m $s^{-1}$
   B (a) $T = 4 \times 10^{-3}$ s
   (b) $f = \frac{1}{4 \times 10^{-3}} = 250$ Hz
   (c) $A = 1.0$ cm
   (d) $v = 250 \times 4 = 1000$ m $s^{-1}$
   C (a) $T = 16$ ms $= 1.6 \times 10^{-2}$ s
   (b) $f = \frac{1}{1.6 \times 10^{-2}} = 62.5$ Hz
   (c) $A = 4$ cm
   (d) $v = 62.5 \times 4 = 250$ m $s^{-1}$
2. $\lambda = 2 - 0.4 = 1.6$ m (from distance graph)
   $T = 1.6$ s (from time graph)
   $f = 0.63$ Hz
   $A = 1.0$ m
   $v = 1.0$ m $s^{-1}$

## 6 Analysing Wave Graphs 2

1. Wave has travelled $0.25\lambda$ left or $0.75\lambda$ right in 0.2 s; minimum $T = \frac{0.2}{0.75} = 0.27$ s
2. $\lambda = 8$ m (from graph)
   Travels $\frac{7\lambda}{8}$ in 0.1 s; $T = \frac{0.1 \times 8}{7} = 0.11$ s
   $f = \frac{1}{0.11} = 8.75$ Hz
   $v = f\lambda = 8.75 \times 8 = 70$ m $s^{-1}$