Cambridge Assessment International Education

Teaching Pack

Demonstrating wave phenomena

Cambridge O Level

Physics 5054

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Cambridge Pathway

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Introduction

This pack will help you to develop your learners' experimental skills as defined by assessment objective 3 (AO3 Experimental skills and investigations) in the course syllabus.

> **Important note**
> Our *Teaching Packs* have been written by **classroom teachers** to help you deliver topics and skills that can be challenging. Use these materials to supplement your teaching and engage your learners. You can also use them to help you create lesson plans for other experiments.
>
> ***This content is designed to give you and your learners the chance to explore practical skills. It is not intended as specific practice for Paper 5 (Practical Test) or Paper 6 (Alternative to the Practical Test).***

There are two options for practising experimental skills. If you have laboratory facilities this pack will support you with the logistics of running the experiment. If you have limited access to experimental equipment and/or chemicals, this pack will help you to deliver a virtual experiment.

This is one of a range of *Teaching Packs*. Each pack is based on one experiment with a focus on specific experimental techniques. The packs can be used in any order to suit your teaching sequence.

The structure is as follows:

Briefing lesson (1 hour*)
This lesson introduces the focus experimental skills to be developed. It also introduces any content needed for your learners to understand the experiment being carried out in the *Lab lesson*.

↓

Lab lesson (1 hour*)	
Option 1: run the experiment	**Option 2: virtual experiment**
This lesson allows the experiment to be run with your learners, providing an opportunity to practise the experiment skills introduced in the *Briefing lesson*.	This lesson allows your learners to complete a virtual experiment, providing an opportunity to practise the experiment skills introduced in the *Briefing lesson*.

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Debriefing lesson (1 hour*)
This lesson develops your learners' ability to evaluate and draw conclusions. It also provides opportunities to practise extended writing skills.

**the timings given here are guides; you may need to adapt the lessons to suit your circumstances.*

In this *Teaching Pack* you will find the lesson plans, worksheets for learners and teacher resource sheets you will need to successfully complete this experiment.

Experiment: Demonstrating wave phenomena

This *Teaching Pack* focuses on demonstrating wave phenomena.

There are many different types of waves. Through the activities in this pack, your learners will make transverse and longitudinal waves to demonstrate and investigate the properties of waves.

The experiment has links to the following syllabus content (see syllabus for detail):

- 13.1 Describing wave motion
- 13.2 Wave terms
- 13.3 Wave behaviour

The experiments cover the following experimental skills, adapted from **AO3: Experimental skills and investigations** (see syllabus for assessment objectives):

- plan experiments and investigations
- make and record observations, measurements and estimates
- interpret and evaluate experimental observations and data

Prior knowledge

Knowledge from the following syllabus topics is useful for this experiment:

- 13.1 Describing wave motion
- 13.2 Wave terms
- 13.3 Wave behaviour

Going forward

The knowledge and skills gained from this set of experiments will be useful for when you teach learners about light.

Briefing lesson: Making observations and planning

Resources	• Worksheets A, B, C and D

Learning objectives	By the end of the lesson: • ***all*** learners should be able to give the meaning of speed, frequency, wavelength and amplitude • ***most*** learners should be able to demonstrate understanding that waves transfer energy without transferring matter • ***some*** learners will be able to relate the different properties of waves qualitatively as well as quantitatively

Timings	Activity
5 min	**Starter/Introduction** Ask your learners to name a wave. Suggestions they might give include: heat waves, Mexican waves, water waves, sound waves, gamma waves, microwaves, etc.
10 min 15 min 15 min 10 min	**Main lesson** Give out Worksheet A and ask your learners to read through and complete the tasks on the sheet. Pause after this and discuss the answers with the class. Provide Worksheet B and encourage your class to replicate the actions shown in the diagrams. With a large group, you could arrange your learners into two lines facing each other so that they can observe the waves created by the other half of the class. Your learners should then complete the tasks on the worksheet, following the instructions carefully. Now your learners should complete Worksheet C. Circulate around the room to monitor your learners' work and help with any of their queries. Ask your learners to plan a series of simple demonstrations using a large spring to demonstrate speed, frequency, wavelength and amplitude. Make sure your learners consider how an action (e.g. pushing the spring harder or moving it quicker) can affect the different variables. They should draft simple instructions on how to carry out their planned demonstrations. As an extension task, your learners can plan a simple demonstration to help explain that waves transfer energy without transferring matter. These ideas could be discussed in small groups or as a class.
5 min	**Plenary** Provide your learners with Worksheet D. They should match the variables to their symbols and units. Recap these definitions orally as a class.

Lab lesson: Option 1 – run the experiments

Resources	• Teacher notes • Teacher walkthrough video • Worksheets E, F, G and I • Equipment as outlined in the notes

Learning objectives	By the end of the lesson: • ***all*** learners should be able to make and record observations • ***most*** learners should be able to identify the phenomena of reflection, refraction and diffraction • ***some*** learners will be able to describe the phenomena of reflection, refraction and diffraction using key terminology

Timings	Activity
5 min	**Starter/Introduction** Explain the structure of the lesson to your learners: there are three worksheets (E, F and G) and three sets of equipment to carry out three short experiments. Your learners should make careful observations.
15 min 15 min 15 min	**Main lesson** Using the large spring, your learners should carry out the experiment as described on Worksheet E. Make sure that they identify the different variables and attempt to vary some of these. Your learners should make and record their observations. The instructions the worksheet should help them do this effectively. Your learners should carry out the experiment using the ray box, plane mirror and rectangular Perspex block as described on Worksheet F. Make sure that they observe reflection and refraction. They should follow the instructions on the worksheet and complete a table of their results. The final experiment for your learners to carry out uses the ripple tank as described on Worksheet G. In this activity they should observe diffraction and the effect of varying the frequency and gap size. To help them do this they should follow the instructions on the worksheet. For an extension task your learners can also attempt to demonstrate reflection and refraction using water waves. **Safety** Circulate the classroom at all times during the experiments so that you can make sure that your learners are safe and that the data they are collecting is accurate.
10 min	**Plenary** Provide your learners with Worksheet I. They need to match up the key observations and conclusions shown on the worksheet.

Teacher notes

Watch the teacher walkthrough video and read these notes.

Each group will require:

- a large spring
- plane mirror
- rectangular Perspex block
- plain paper
- equipment for ray box set up
    - ray box
    - power pack
    - connecting cables
    - lens
    - single slit plate
- ripple tank

Safety

The information in the table below is a summary of the key points you should consider before undertaking this experiment with your learners.

It is your responsibility to carry out an appropriate risk assessment for this experiment.

Substance	Hazard	First aid
	Electrocution	**If in casualty is in contact with live electricity supply:** break contact by switching off or removing the plug. If this is not possible, use a wooden broom handle or wear rubber gloves to pull the casualty clear. See a doctor. If the casualty is unconscious, check that airways are clear and that the casualty is breathing and has a pulse. If so, place the casualty in the ‘recovery position’. If a pulse is found but the casualty is not breathing, artificial ventilation is necessary. If no pulse is found and the casualty is not breathing, cardio-pulmonary resuscitation is necessary.

Teacher method

This is your version of the method for this set of experiments that accompanies the *Teacher walkthrough* video.

Do not share this method with your learners, give them Worksheet E, Worksheet F and Worksheet G.

Before you begin
Plan how you will group your learners during the experiment.

Think about:

- the number of groups you will need (group size 2–4 learners)
- the amount of equipment required
- whether you will need to demonstrate one or more of the experiments to save time.

Experiment: Waves in springs

Steps	Notes
1. One learner should hold one end of the spring firmly while their partner holds the other end.	*Learners can work in pairs or in small groups, depending on the number of large springs available.*
2. They should try the following actions and record their observations: a. Send wave pulses to create longitudinal waves. Vary the: i. frequency of the pulses ii. amplitude iii. speed the spring is moved back and forth. b. Create transverse wave pulses. Vary the: i. frequency of the pulses ii. amplitude iii. speed the spring is moved side to side.	
3. Draw and label diagrams of the spring when longitudinal and transverse waves travel through it.	*Alternatively, parts 4 to 6 can be completed in the debriefing lesson.*
4. Describe how to make a spring vary its wavelength properties.	
5. Describe the differences and similarities between transverse and longitudinal waves.	

Experiment: Reflection

Notes

Steps

Check the recommended voltage for the ray box and advise your learners to set the power pack accordingly.

1. Connect the ray box to the power supply and switch on.

2. Place the lens and the slit plate in the ray box to create a thin ray of light.

Parts of the ray box will get hot during the experiment. Make sure your learners take care.

3. Place the mirror on plain paper and draw along the back of the mirror with a sharp pencil.
4. Shine the ray of light towards the mirror so that it reflects off the surface of the mirror.
5. Using a pencil, mark two small crosses along the incident light ray and another two small crosses along the reflected light ray.
6. Turn off the power pack and move the mirror out of the way.
7. Use a ruler and the pencil to join the crosses marking the incident ray to show the incident ray travelling towards the mirror. Join the crosses marking the reflected ray to show the reflected ray travelling away from the mirror.

You may need to demonstrate this if your learners are not familiar with the concept of the normal line.

8. Use a protractor to draw a normal line at 90° to the surface of the mirror where the incident ray hits the mirror.

You may need to demonstrate this. Some learners may attempt to draw the lines freehand, which will give very poor results.

9. Use the protractor to measure the incident angle, that is, the angle between the incident ray and the normal. Note it in a table with column headings for ‘incident angle / °’ and ‘reflected angle / °’.

Your learners may need help with using the protractor depending on their ability.

10. Use the protractor to measure the reflected angle, that is, the angle between the reflected ray and the normal. Note it in the table.
11. Repeat steps 1 to 10 for several other different angles.

Notes

Experiment: Refraction

Steps

1. Connect the ray box to the power supply and switch on.

   Check the recommended voltage for the ray box and advise your learners to set the power pack accordingly.

2. Place the lens and the slit plate in the ray box to create a thin ray of light.
3. Place the rectangular block on plain paper and draw around the block with a pencil.

   Parts of the ray box will get hot during the experiment. Make sure your learners take care.

4. Shine the ray of light towards the block at an angle so that it refracts through and out of the opposite side of the block.
5. Using a pencil, mark two small crosses along the incident light ray and another two small crosses along the emerging light ray.

   You may need to demonstrate this. Some learners may attempt to draw the lines freehand, which will give very poor results.

6. Turn off the power and move the block out of the way.
7. Use a ruler and the pencil to join the crosses to show the incident ray travelling towards the block. Join the other crosses to show the emerging ray travelling away from the block
8. Join the incident ray to the emerging ray through the block. This is the refracted ray.
9. Use a protractor to draw a normal line at 90° to the surface of the boundary where the incident ray hits the block. This line should also be extended inside the rectangle.

   You may need to demonstrate this if your learners are not familiar with the concept of the normal line.

10. Use the protractor to measure the incident angle. Note it in a table with column headings for 'incident angle /°' and 'refracted angle/°'.

    Your learners may need help with using the protractor depending on their ability.

11. Use the protractor to measure the refracted angle. Note it in the table.
12. Repeat steps 1 to 11 for several other different angles.

Experiment: Waves in water

Steps

1. Turn on the ripple tank so that the motor is moving regularly and creating a continuous wave with straight wavefronts.
2. The wavefronts are visible as parallel lines in the water. The wave is moving at right angles to these visible wavefronts.
3. Vary the frequency and the amplitude of the motor to investigate how the visible wavefronts change.
4. Place an obstacle with a gap in it parallel to the wavefronts. Observe how the shape of the wavefronts changes.
5. The wavelength is the distance between two successive wavefronts. Set the wavelength to be similar in size to the gap set up in the water by varying the frequency of the motor. Observe the wavefronts.
6. Change the wavelength by varying the frequency of the motor so that it is significantly smaller than the gap. Observe the wavefronts.
7. Change the wavelength by varying the frequency of the motor so that it is significantly larger than the gap. Learners should observe the wavefronts.
8. Place an obstacle in the water parallel to the wavefronts so that the obstacle partially blocks the water waves, but allows some water waves to move around it. Observe the shape of the wavefronts.

Notes

If only one ripple tank is available, allow small groups of learners to work through the method for a set amount of time, then rotate the groups.

A simple ripple tank can be made by filling a shallow tray with water and manually dipping a ruler in to act as the plain wavefront dipper.

This effect is known as diffraction through a gap.

This should produce diffraction which does not curve so much. The gap is not changing the shape of the wavefronts as noticeably.

This effect is known as diffraction around an obstacle.

This should produce diffraction that does not spread out so much. The gap is absorbing some of the energy of the wave.

Clean-up

After the experiment learners should:

- tidy up their work space
- ensure any spillages have been mopped up
- return all equipment to you.

Lab lesson: Option 2 – virtual experiment

Resources	• Virtual experiment video • Worksheets H and I

Learning objectives	By the end of the lesson: • ***all*** learners should be able to make and record observations • ***most*** learners should be able to identify the phenomena of reflection, refraction and diffraction • ***some*** learners will be able to describe the phenomena of reflection, refraction and diffraction using key terminology

Timings	Activity
5 min	**Starter/Introduction** Recap the types of waves and wave properties with your learners using question and answer. Start by asking a question; the learner who can answer then asks the next question, and so on until all the learners have asked a question and given an answer. The questions could be as simple as 'What is wavelength measured in?' or more complex, such as asking for a definition.
45 min	**Main lesson** Provide your learners with Worksheet H. They should watch the virtual experiment video on waves. There are also tasks on the worksheet they will need to complete. You should discuss the answers to these as a class.
10 min	**Plenary** Provide learners with Worksheet I. Your learners need to match up key observations to the conclusions on the worksheet.

Debriefing lesson: Describing wave phenomena

Resources	• Worksheets J, K, L and M.
Learning objectives	By the end of the lesson: • ***all*** learners should be able to describe how waves can undergo reflection, refraction and diffraction • ***most*** learners should be able to interpret and evaluate experimental observations and data • ***some*** learners will be able to use terminology to properly explain the wave phenomena observed previously

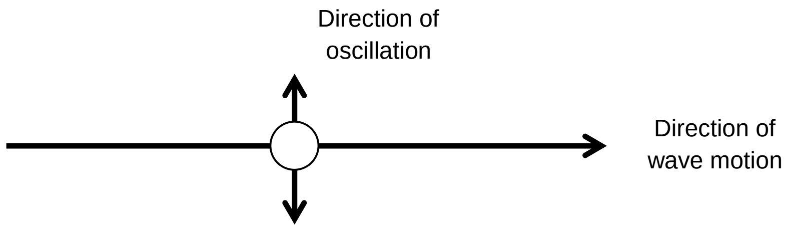
Timings	Activity
10 min	**Starter/Introduction** Provide your learners with Worksheet J. They should work in pairs to plan and draw simple diagrams to depict key terms or phenomena.
10 min	**Main lesson** Direct your learners to interpret their table of data on reflection from last lesson. They should write a simple qualitative conclusion. You should expect their conclusions to show that the angle of incidence is equal to the angle of reflection. Following this, ask your learners to evaluate the experiment. What was difficult? What could they improve?
10 min	Now your learners should look at their table of data on refraction from last lesson. Again, they should write a simple qualitative conclusion. You should expect them to mention that light rays bend towards the normal when they enter a denser medium like glass from air. Encourage them to try to explain why this happens (the light rays slow as they enter the block). Ask them to write their own simple and clear method for demonstrating the refraction of light. You may want to go through the method as a class, or to get learners to swap and improve each other's methods.
10 min	Give out Worksheet K. Your learners should work independently through the questions.
10 min	Provide your learners with Worksheet L. They should apply their understanding of how the size of the gap and the wavelength affect the diffraction of waves by completing the diagrams and answering the questions.
10 min	**Plenary** Give your learners Worksheet M. They should work in pairs to write clear and concise definitions or descriptions for each key term or phenomenon. Ask your learners to cut out the pairs, mix them up and swap the complete set with another pair. They can then work to match up the new set they have been given.

Worksheets and answers

Worksheet A: Introducing waves

There are two types of waves:

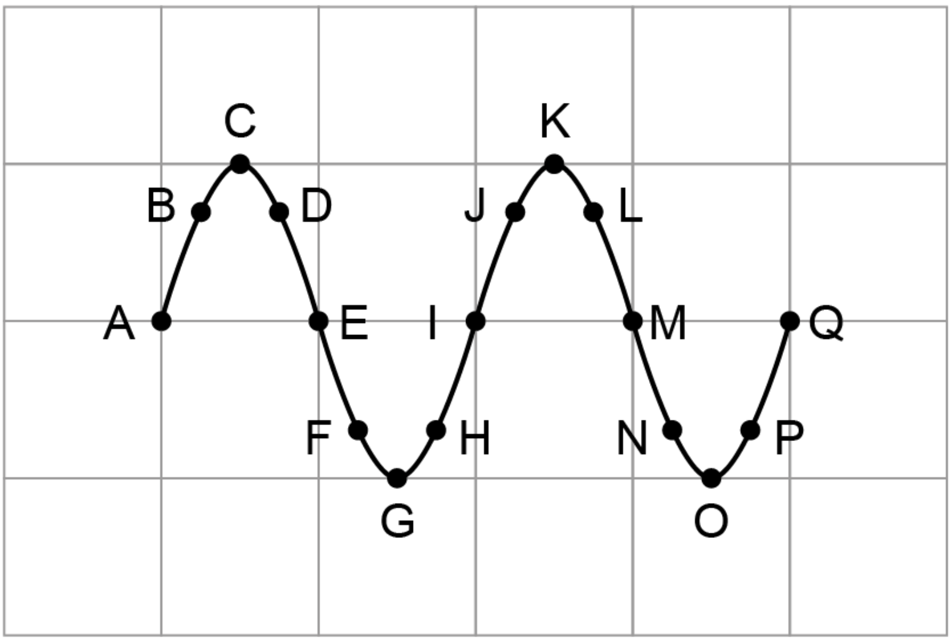
1. **Transverse waves**
   The oscillations in a transverse wave are at right angles to the direction that the wave travels. The oscillation and the wave motion are perpendicular to each other. An example of a transverse wave is light.



A transverse wave has peaks and troughs. A peak (or crest) is the highest point on the wave and a trough is the lowest point.

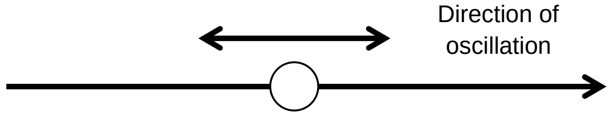
On the diagram below:

Circle the letters which label a peak
Put a cross through those which label a trough



Worksheet A: Introducing waves

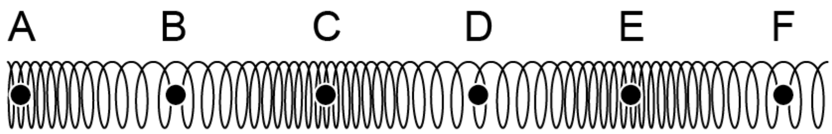
2. **Longitudinal waves**
The oscillations in a longitudinal wave are in the same direction as the direction that the wave travels. The oscillation and the wave motion are parallel to each other. An example of a longitudinal wave is sound.



A longitudinal wave has compressions and rarefactions. A compression is where the particles in the wave are closer together than normal. A rarefaction is where the particles are further apart than normal.

On the diagram below:

Circle the letters which label a compression
Put a cross through those which label a rarefaction



Using the table, **sort** the following list of waves into the two types: transverse or longitudinal.

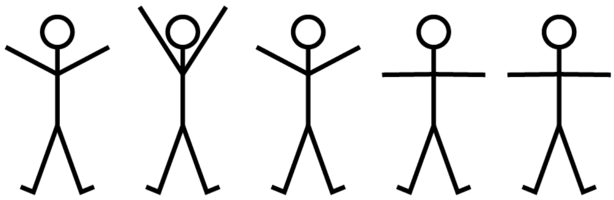
- light
- water wave
- sound
- radio wave
- seismic P wave
- infra-red

Add any others you may have already discussed.

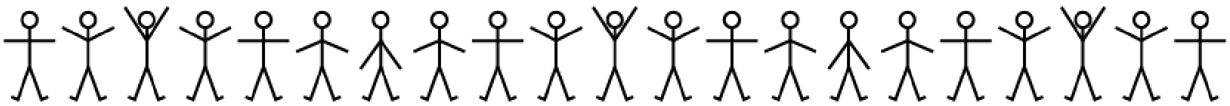
Transverse	Longitudinal

Worksheet B: Describing waves

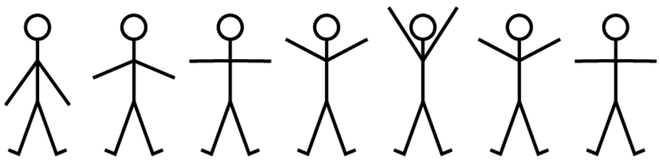
We can simulate waves with the movement of our arms – commonly known as Mexican waves. In the diagram you can see the stick person on the left has started a Mexican wave that is beginning to travel to the right as the motion is repeated down the line with a slight time delay. We will use this wave to define some of the basic properties of waves.



Wavelength (λ) is the distance a wave travels before the wave pattern repeats itself. It is the distance from peak to successive peak or from trough to successive trough. For our stick people, a 'peak' is when the hands are up highest and a 'trough' is when the hands are lowest. Label the wavelength on the diagram below.



Amplitude (A) is the maximum displacement of a particle in a wave from its equilibrium. For our stick people, the equilibrium is when they have their arms out straight at their sides. Label the amplitude on the diagram below.



As wavelength and amplitude are both distances, they both have the unit metres (m).

Frequency (f) is the number of waves in a second. For example, if a wave has a frequency of 50 Hertz (Hz), the wave oscillates 50 times in 1 second. How many times will a wave oscillate in 1 second if it has a frequency of 20 Hz?

Time **period** (T) is how long it takes to complete a full wave. It is related to frequency such that $f = 1 / T$ and $T = 1 / f$. For example, if a wave has a frequency of 2 Hz, the time period will be ½ seconds or 0.5 seconds, meaning there are two waves every second. What would be the time period for a wave with a frequency of 0.2 Hz?

Wave **speed** (v) is the speed that the wave travels. Wave speed can be calculated by multiplying the frequency by the wavelength, $v = f \times \lambda$.

Worksheet C: Wave equation calculations

The wave equation relates wave speed (v), frequency (f) and wavelength (λ).

$$v = f \times \lambda$$

Example:

A wave has a frequency of 50 Hz and a wavelength of 3 m.
Calculate the wave speed.

Step 1:	Write out the equation:	$v = f \times \lambda$
Step 2:	Substitute the values:	$v = 5 \times 3$
Step 3:	Solve:	wave speed = 150 m/s

Solve and show full working for the following questions:

1. Calculate the frequency of a wave if the time period is 4 seconds.
2. A wave has a frequency of 0.05 Hz.
    a. Calculate the time period.
    b. How many complete waves will there be in 1 minute?
3. A piece of string oscillates 20 times in 2 seconds.
    a. What is the frequency?
    b. What is the time period?
    c. Calculate the wave speed for a wavelength of 3 m.
    d. Calculate the wave speed for a wavelength of 20 cm.
4. Waves crash onto the shore 8 times in 1 minute.
    a. Calculate the time period.
    b. Calculate the frequency.
    c. Calculate the wave speed for a wavelength of 3 m.
5. What is the wavelength of a 230 Hz sound wave in the air if the speed of sound in air is 340 m/s?
6. Sound waves travel at 1500 m/s through water. Calculate the wavelength of a 250 Hz sound made under water.
7. A wave travels down a string at 14 m/s. It has a frequency of 3.5 Hz.
    a. Calculate the time period.
    b. Calculate its wavelength.
8. A spring oscillates with a wavelength of 40 mm. If its wave speed is 0.8 m/s, what is its frequency?
9. What is the speed of sound through an aluminium rod if a sound vibration of frequency 1500 Hz has a wavelength of 340 cm?
10. An ultrasound generator produces sounds of frequency of 30 000 Hz. Calculate their wavelength in air if the speed of sound is 340 m/s.

Worksheet D: Match up – wave properties

Match up the variables to their symbols and units:

Wavelength	A	m/s
Amplitude	T	Hz
Frequency	v	m
Period	f	m
Speed	λ	s

Using the symbols above:

1. provide an equation relating frequency and time period.

2. provide an equation for wave speed.

Worksheet E: Method – waves in springs

1. Collect a spring and place it on a flat surface.

2. Your partner should hold one end of the spring firmly while you hold the other.

3. Try the following actions and record your observations:

   a) Send wave pulses through the spring by pushing it back and forth to create longitudinal waves.
   Vary the:
      i. frequency of the pulses
      ii. amplitude
      iii. speed you move the spring back and forth.

   b) Create transverse wave pulses by moving the spring side to side.
   Vary the:
      i. frequency of the pulses
      ii. amplitude
      iii. speed you move the spring side to side.

4. Draw diagrams of the spring when:
      i. longitudinal waves are travelling through it.
      ii. transverse waves are travelling through it.

   Label the following on your diagrams:

   - compression
   - rarefaction
   - amplitude
   - peak
   - trough
   - wavelength

5. Describe how to make a spring increase its:

   - frequency
   - wavelength
   - amplitude
   - speed

6. Describe the differences and similarities between transverse and longitudinal waves.

Worksheet F: Method

Experiment 1: Reflection

1. Connect the ray box to the power supply and switch on.
2. Place the lens and the slit plate in the ray box to create a thin ray of light.
3. Place the mirror on plain paper and draw along the back of the mirror with a sharp pencil.
4. Shine the ray of light towards the mirror so that it reflects off the surface of the mirror.
5. Using a pencil, mark two small crosses along the incident light ray and another two small crosses along the reflected light ray.
6. Turn off the power pack and move the mirror out of the way.
7. Use a ruler and the pencil to join the crosses marking the incident ray to show the incident ray travelling towards the mirror. Also join the crosses marking the reflected ray to show the reflected ray travelling away from the mirror.
8. Use a protractor to draw a normal line at 90° to the surface of the mirror where the incident ray hits the mirror.
9. Use the protractor to measure the incident angle, that is, the angle between the incident ray and the normal. Note it in a table with column headings for incident angle (°) and reflected angle (°).
10. Use the protractor to measure the reflected angle, that is, the angle between the reflected ray and the normal. Note it in the table.
11. Repeat steps 1 to 10 for several other different angles.

Experiment 2: Refraction

1. Connect the ray box to the power supply and switch on.
2. Place the lens and the slit plate in the ray box to create a thin ray of light.
3. Place the rectangular block on plain paper and draw around the block with a pencil.
4. Shine the ray of light towards the block at an angle so that it refracts through and out of the opposite side of the block.
5. Using a pencil, mark two small crosses along the incident light ray and another two small crosses along the emerging light ray.
6. Turn off the power pack and move the block out of the way.
7. Use a ruler and the pencil to join the crosses marking the incident ray to show the incident ray travelling towards the block. Also join the crosses marking the emerging ray to show the emerging ray travelling away from the block.
8. Join the incident ray to the emerging ray through the outline of the block. This is the refracted ray.
9. Use a protractor to draw a normal line at 90° to the surface of the boundary where the incident ray hits the block. This line should also be extended inside the outline of the block.
10. Use the protractor to measure the incident angle, that is, the angle between the incident ray and the normal. Note it in a table with column headings for incident angle (°) and refracted angle (°).
11. Use the protractor to measure the refracted angle, that is, the angle between the refracted ray and the normal. Note it in the table.
12. Repeat steps 1 to 11 for several other different angles.

Worksheet G: Method

Experiment 3: Waves in water

1. Turn on the ripple tank so that the motor is moving regularly and creating a continuous wave with straight wavefronts.
2. The wavefronts are visible as parallel lines in the water. The wave is moving at right angles to these visible wavefronts.
3. Vary the frequency and the amplitude of the motor to investigate how the visible wavefronts change.
4. Place an obstacle with a gap in it in the water. Make sure it is parallel to the wavefronts. Observe how the shape of the wavefronts changes. This effect is known as diffraction through a gap.
5. The wavelength is the distance between two successive wavefronts. Set the wavelength to be similar in size to the gap in the obstacle by varying the frequency of the motor. Observe the wavefronts.
6. Change the wavelength by varying the frequency of the motor so that it is significantly smaller than the gap. Observe the wavefronts.
7. Change the wavelength by varying the frequency of the motor so that it is significantly larger than the gap. Observe the wavefronts.
8. Remove the obstacle with the gap. Place an obstacle in the water parallel to the wave, so that the obstacle partially blocks the water waves, but allows some waves to move around the obstacle. Observe the shape of the wavefronts. This effect is known as diffraction around a gap.

Worksheet H: Virtual experiments

You will need to complete the tasks below in your lab book, or on paper.

Draw a diagram of the spring when a longitudinal wave is travelling through it.

1. Label the following things on your diagram.
   - compression
   - rarefaction
   - wavelength
   - amplitude

2. Draw a diagram of the spring when a transverse wave is travelling through it.

3. Label the following things on your diagram:
   - amplitude
   - wavelength
   - peak
   - trough

4. Describe the differences and similarities between transverse and longitudinal waves.

5. Draw the ray diagram for reflection. Make sure that you label the:
   a) angle of incidence and angle of reflection
   b) incident ray and reflected ray
   c) normal

6. Note down the law of reflection and describe clearly how you can prove this using the equipment in the video.

7. If light travels from air into the following substances, predict whether it will slow down or speed up:
   - diamond
   - glass
   - helium
   - Perspex
   - vacuum
   - water

8. When the light ray enters the glass block it bends. Look closely at the video image. Record any other observations you make.

9. Draw the ray diagram for refraction. Make sure that you label the:
   a) angle of incidence and angle of refraction
   b) incident ray and refracted ray
   c) normal

10. Now you have watched the information on the diffraction of waves, try the following questions:
    a) Draw a diagram of diffraction of water waves through a small gap.
    b) Describe how widening the gap affects the water waves.
    c) Explain why changing the frequency affects the diffraction.
    d) Describe an everyday situation that proves sound also undergoes diffraction.

Worksheet I: Match up – conclusions

Using a line, match the observations from the three experiments to appropriate conclusions:

In a longitudinal wave each loop of the spring moves forwards and backwards around a central point.	$T = \frac{1}{f}$
A plane mirror reflects light. A longitudinal wave in a spring bounces back from the fixed end.	$v = f \times \lambda$
If the angle of incidence is 30°, the angle of reflection is 30°. If the angle of incidence is 40°, the angle of reflection is 40°.	Waves undergo reflection.
Light rays bend at the boundary between two different materials such as air and glass.	Frequency is inversely proportional to wavelength, and the speed of waves in water is constant.
Light rays reflect from the boundary of two materials, as well as refracting through.	The angle of incidence always equals the angle of reflection.
Changing the frequency of water waves changes the diffraction. The gap remains the same size.	Waves transfer energy, not matter.
Doubling the frequency while halving the wavelength keeps the wave speed constant.	Light slows down as it enters glass, causing the change in direction we observe.
Halving the frequency doubles the period.	Not all light is refracted when it travels into a different material.

Worksheet J: Wave terms and phenomena

Plan and draw simple diagrams to depict the following key terms or phenomena:

Wavelength	**Speed**	**Reflection**
Amplitude	**Transverse**	**Refraction**
Frequency	**Longitudinal**	**Diffraction**

Worksheet K: Calculating the refractive index

The reason light rays bend as they travel into a different material is because their speed changes. The refractive index, *n,* is a ratio between the speeds of the wave. As it is a ratio, it does not have a unit.

For light travelling from air to water:

$$n=\frac{\textit{speed in air}}{\textit{speed in water}}$$

The refractive index of a material can also be calculated if the angle of incidence, *i,* and angle of refraction, *r*, is known:

$$n = \frac{\sin i}{\sin r}$$

Work through the following calculations. Show full working.

1. Calculate the speed of light in water. The refractive index of water is 1.33 and the speed of light in air is 300 million m/s.

2. Calculate the speed of light in diamond. The refractive index of diamond is 2.42.

3. Calculate the refractive index of sapphire. The speed of light in sapphire is 169 million m/s.

4. A light ray approaches a Perspex block with an angle of incidence of 42° and refracts inside the block at an angle of 26°. Calculate the refractive index.

5. The refractive index of glass is 1.52. Complete the table below:

Angle of incidence (°)	Angle of refraction (°)
22	
35	
	25
	29
53	
60	
	39
	41

6. A light ray approaches a silicon block with an angle of incidence of 25 and refracts inside the block at an angle of 7°. Calculate the refractive index.

7. The refractive index of glycerol is 1.47. Calculate the angle of incidence if the angle of refraction is 26°.

Worksheet L: Diffraction of waves

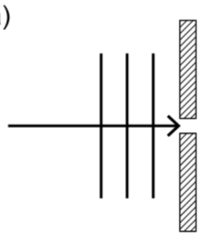
1. Describe how diffraction affects water waves.

2. Describe the situation that would produce the most extreme case of diffraction.

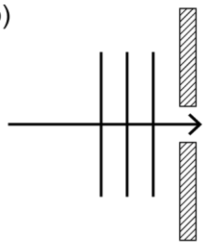
3. Complete the following diagrams by drawing the position of the wavefronts after they have been diffracted through the gaps in the barriers:

The parallel lines represent the wavefronts of the water waves and the arrow shows the direction of the wave travel.

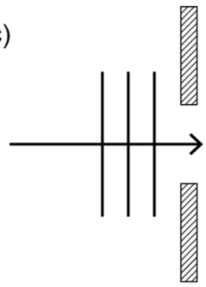
(a)



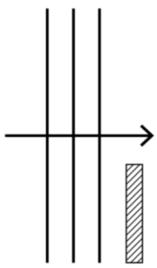
(b)



(c)



4. Complete the following diagram by drawing the position of the wavefronts after they have been diffracted around an obstacle:



Worksheet M: Match up – terms and definitions

Below is a list of key terms and phenomena for the topic of waves.

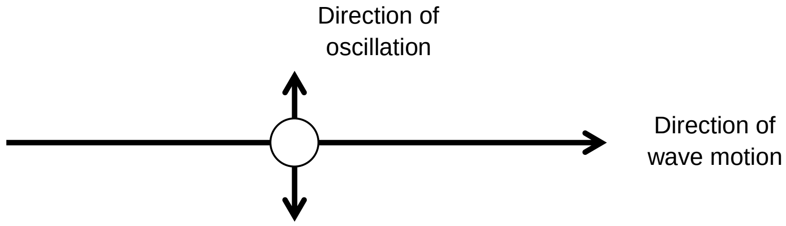
1. Write clear and concise definitions or descriptions for each.
2. Cut out the pairs and mix them up.
3. Swap your set of pairs with another person in the class.
4. Try to match up their pairs before they can match up yours.

Wavelength	
Amplitude	
Frequency	
Speed	
Transverse	
Longitudinal	
Reflection	
Refraction	
Diffraction	

Worksheet A: Answers

There are two types of waves:

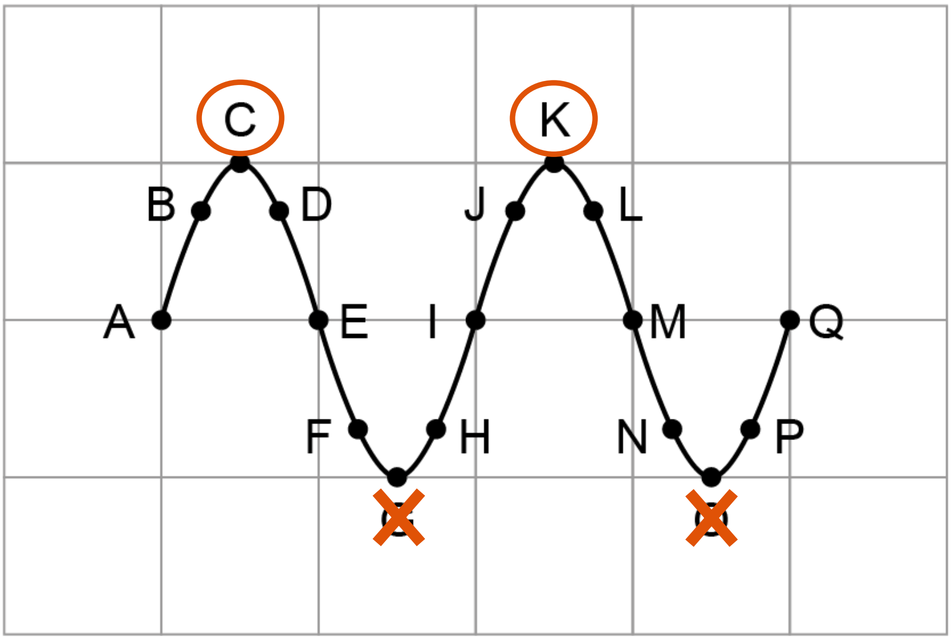
1. **Transverse waves**
   The oscillations in a transverse wave are at right angles to the direction that the wave travels. The oscillation and the wave motion are perpendicular to each other. An example of a transverse wave is light.



A transverse wave has peaks and troughs. A peak (or crest) is the highest point on the wave and a trough is the lowest point.

On the diagram below:

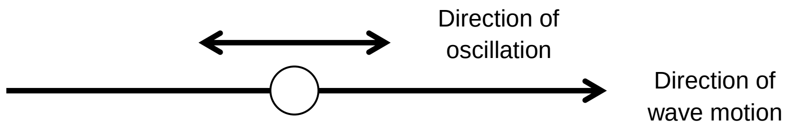
Circle the letters which label a peak
Put a cross through those which label a trough



Worksheet A: Answers

2. Longitudinal waves

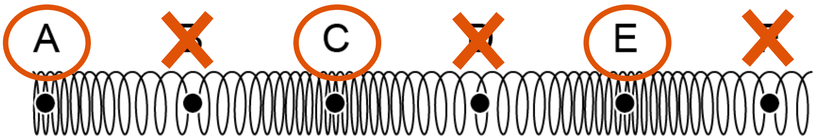
The oscillations in a longitudinal wave are in the same direction as the direction that the wave travels. The oscillation and the wave motion are parallel to each other. An example of a longitudinal wave is sound.



A longitudinal wave has compressions and rarefactions. A compression is where the particles in the wave are closer together than normal. A rarefaction is where the particles are further apart than normal.

On the diagram below:

Circle the letters which label a compression
Put a cross through those which label a rarefaction



Using the table, **sort** the following list of waves into the two types: transverse or longitudinal.

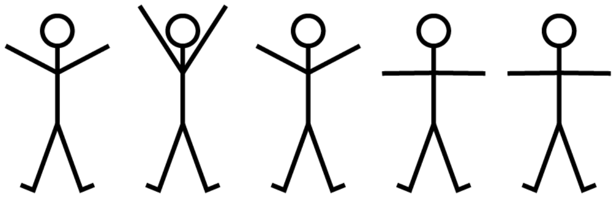
- light
- water wave
- sound
- radio wave
- seismic P wave
- infrared

Add any others you may have already discussed.

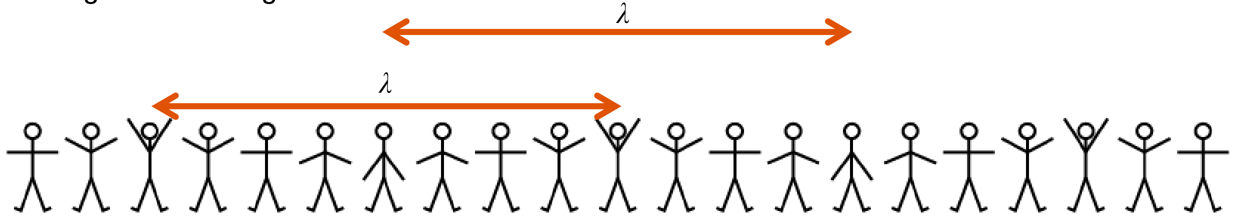
Transverse	Longitudinal
light	sound
water wave	seismic P wave
radio wave	
infrared	

Worksheet B: Answers

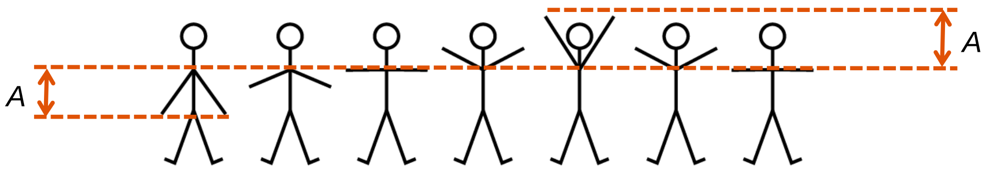
We can simulate waves with the movement of our arms – commonly known as Mexican waves. In the diagram you can see the stick person on the left has started a Mexican wave that is beginning to travel to the right as the motion is repeated down the line with a slight time delay. We will use this wave to define some of the basic properties of waves.



Wavelength (λ) is the distance a wave travels before the wave pattern repeats itself. It is the distance from peak to successive peak or from trough to successive trough. For our stick people, a 'peak' is when the hands are up highest and a 'trough' is when the hands are lowest. Label the wavelength on the diagram below.



Amplitude (*A*) is the maximum displacement of a particle in a wave from its equilibrium. For our stick people, the equilibrium is when they have their arms out straight at their sides. Label the amplitude on the diagram below.



As wavelength and amplitude are both distances, they both have the unit metres (m).

Frequency (*f*) is the number of waves in a second. For example, if a wave has a frequency of 50 Hertz (Hz), the wave oscillates 50 times in 1 second. How many times will a wave oscillate in 1 second if it has a frequency of 20 Hz?

20 times

Time **period** (T) is how long it takes to complete a full wave. It is related to frequency such that $f = 1 / T$ and $T = 1 / f$. For example, if a wave has a frequency of 2 Hz, the time period will be ½ seconds or 0.5 seconds, meaning there are two waves every second. What would be the time period for a wave with a frequency of 0.2 Hz?

$T = 1/0.2 = 5$ seconds

Wave **speed** (v) is the speed that the wave travels. Wave speed can be calculated by multiplying the frequency by the wavelength: $v = f \times \lambda$.

Worksheet C: Answers

The wave equation relates wave speed (*v*), frequency (*f*) and wavelength (λ).

$$v = f \times \lambda$$

Example:
A wave has a frequency of 50 Hz and a wavelength of 3 m.
Calculate the wave speed.

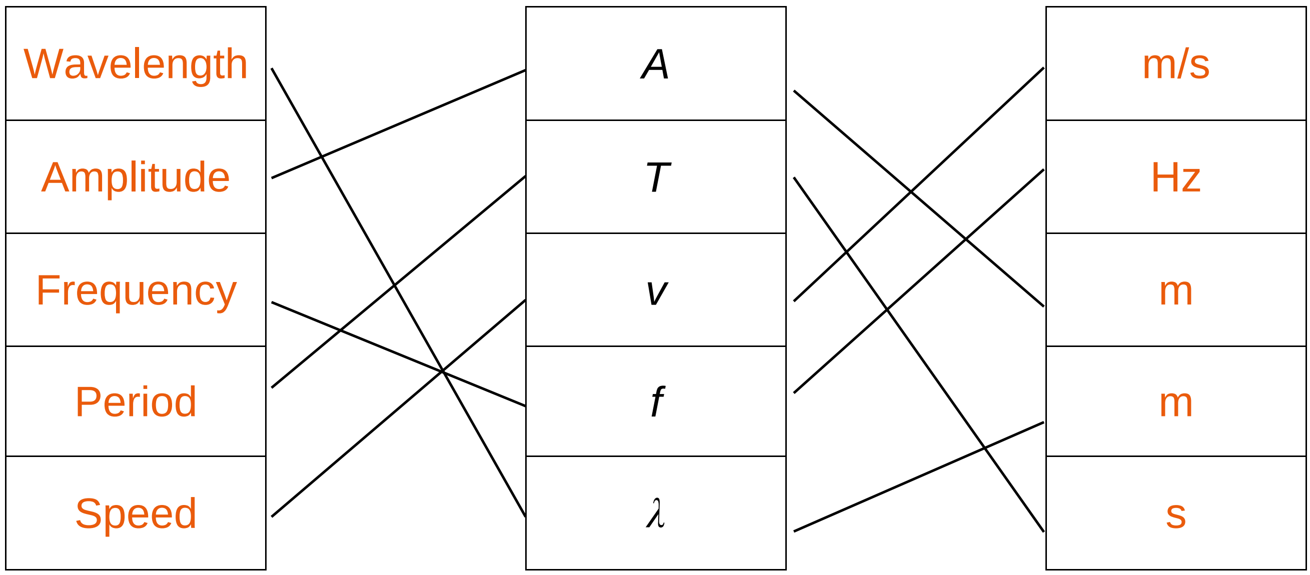
Step 1:	Write out the equation:	$v = f \times \lambda$
Step 2:	Substitute the values:	$v = 50 \times 3$
Step 3:	Solve:	wave speed = 150 m/s

Solve and show full working for the following questions:

1. Calculate the frequency of a wave if the time period is 4 seconds. 0.25 Hz
2. A wave has a frequency of 0.05 Hz.
   a. Calculate the time period. 20 s
   b. How many complete waves will there be in 1 minute? 3 complete waves
3. A piece of string oscillates 20 times in 2 seconds.
   a. What is the frequency? 10 Hz
   b. What is the time period? 0.1 s
   c. Calculate the wave speed for a wavelength of 3 m. 30 m/s
   d. Calculate the wave speed for a wavelength of 20 cm. 2m/s
4. Waves crash onto the shore 8 times in 1 minute.
   a. Calculate the time period. 7.5 s
   b. Calculate the frequency. 0.133 Hz
   c. Calculate the wave speed for a wavelength of 3 m. 0.4 m/s
5. What is the wavelength of a 230 Hz sound wave in the air if the speed of sound in air is 340 m/s? 1.5 m
6. Sound waves travel at 1500 m/s through water. Calculate the wavelength of a 250 Hz sound made under water. 6 m
7. A wave travels down a string at 14 m/s. It has a frequency of 3.5 Hz.
   a. Calculate the time period. 0.29 s
   b. Calculate its wavelength. 4 m
8. A spring oscillates with a wavelength of 40 mm. If its wave speed is 0.8 m/s, what is its frequency? 20 Hz
9. What is the speed of sound through an aluminium rod if a sound vibration of frequency 1500 Hz has a wavelength of 340 cm? 5100 m/s
10. An ultrasound generator produces sounds of frequency of 30 000 Hz. Calculate their wavelength in air if the speed of sound is 340 m/s. 0.011 m or 11 mm

Worksheet D: Answers

Match up the variables to their symbols and units:



Note: both amplitude and wavelength have the unit of metres, so the lines may be swapped around and therefore slightly different from the answer shown above.

Using the symbols above,

1. provide an equation relating frequency and time period.

   Frequency = 1 / Period

   Or

   Period = 1 / Frequency

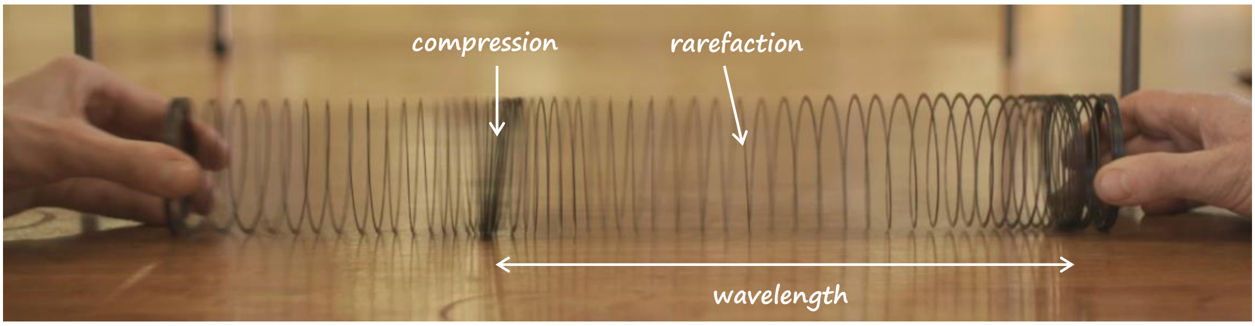
2. provide an equation for wave speed.

   Wave speed = Frequency x Wavelength

Worksheet H: Answers

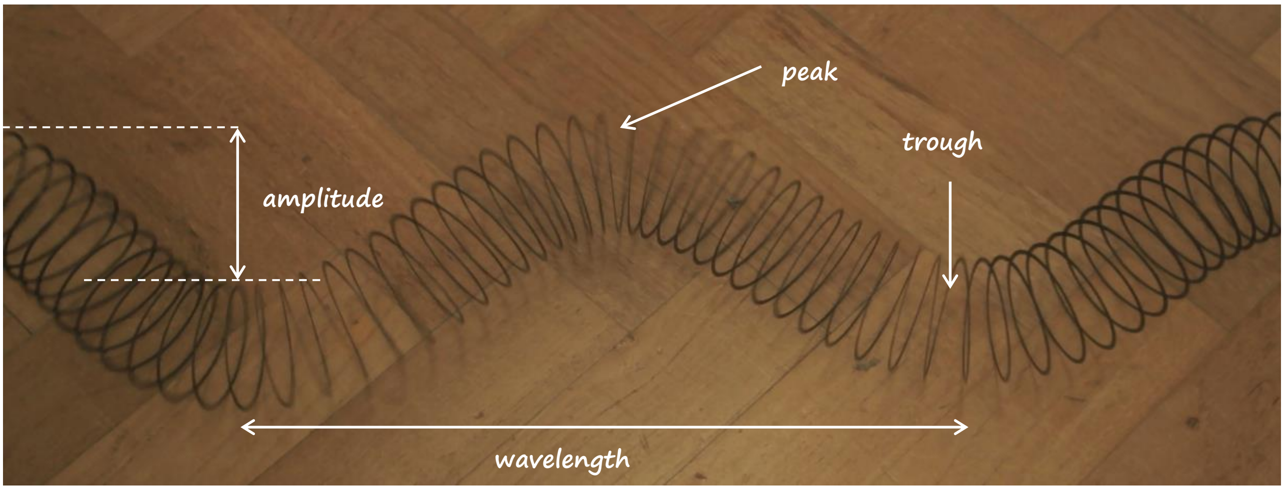
1. Draw a diagram of the spring when a longitudinal wave is travelling through it.

2. Label the following things on your diagram:
   a. compression
   b. wavelength
   c. rarefaction



3. Draw a diagram of the spring when a transverse wave is travelling through it.

4. Label the following things on your diagram:
   a. amplitude
   b. wavelength
   c. peak
   d. trough

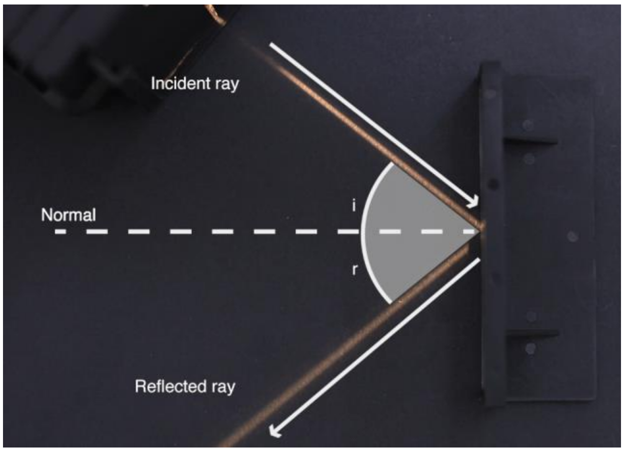


5. Describe the differences and similarities between transverse and longitudinal waves.

In longitudinal waves, energy travels parallel to the direction of wave oscillation. In transverse waves, the energy travels perpendicular to the direction of wave oscillation. Longitudinal waves have compressions and rarefactions, transverse waves have peaks and troughs. In both waves the amplitude is the distance the spring moves from the point of rest. The wavelength is the distance between two compressions or rarefactions in a longitudinal wave or two peaks and troughs in a transverse wave.

Worksheet H: Answers

6. Draw the ray diagram for reflection. Make sure that you label the:
    a) angle of incidence and angle of reflection
    b) incident ray and reflected ray
    c) normal



7. Note down the law of reflection and describe clearly how you can prove this using the equipment in the video.

    Angle of incidence = Angle of reflection

    The mirror angle can be moved and the angles of incidence and reflected ray can be repeatedly measured.

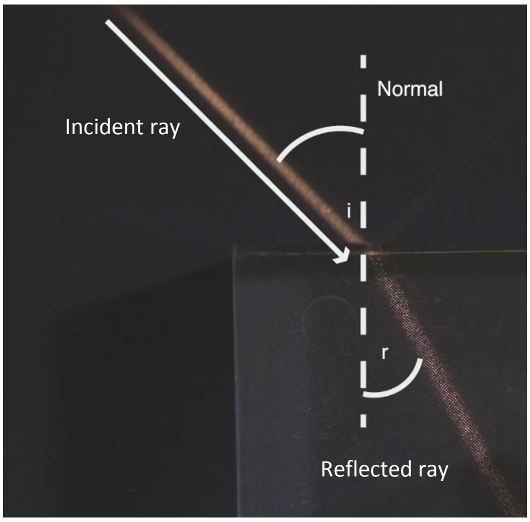
8. If light travels from air into the following substances, predict whether it will slow down or speed up:
    - Diamond (*slow*)
    - Glass (*slow*)
    - helium (*speed up*)
    - Perspex (*slow*)
    - Vacuum (*speed up*)
    - water (*slow*)

9. When the light ray enters the glass block it bends. Look closely at the video image. Record any other observations you make.

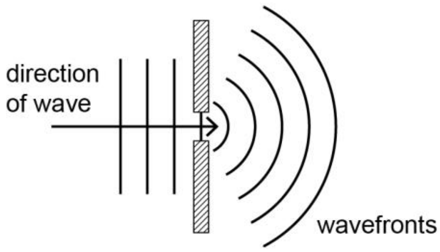
    There is evidence of some weak reflection from the surface of the block.

Worksheet H: Answers

10. Draw the ray diagram for refraction. Make sure that you label the:
    a) angle of incidence and angle of refraction
    b) incident ray and refracted ray
    c) normal



11. Now you have watched the information on the diffraction of waves, try the following questions:
    a) Draw a diagram of diffraction of water waves through a small gap.



b) Describe how widening the gap affects the water waves.
Widening the gap reduces the amount of diffraction (curving of the wavefront)

c) Explain why changing the frequency affects the diffraction.
Increasing or decreasing the frequency causes the gap between the wavefronts to increase or decrease. This in turn effects how much diffraction occurs.

d) Describe an everyday situation that proves sound also undergoes diffraction.
Sound waves do diffract around walls and other objects which is why you can hear someone, but cannot necessarily see them.

Worksheet I: Answers

In a longitudinal wave each loop of the spring moves forwards and backwards around a central point.	Waves transfer energy, not matter.
A plane mirror reflects light. A longitudinal wave in a spring bounces back from the fixed end.	Waves undergo reflection.
If the angle of incidence is 30°, the angle of reflection is 30°. If the angle of incidence is 40°, the angle of reflection is 40°.	The angle of incidence always equals the angle of reflection.
Light rays bend at the boundary between two materials such as air and glass.	Light slows down as it enters glass, causing the change in direction we observe.
Light rays reflect from the boundary of two materials, as well as refracting through.	Not all light is refracted when it travels into a different material.
Changing the frequency of water waves changes the diffraction. The gap remains the same size.	Frequency is inversely proportional to wavelength, and the speed of waves in water is constant.
Doubling the frequency while halving the wavelength keeps the wave speed constant.	$v = f \times \lambda$
Halving the frequency doubles the period.	$T = \frac{1}{f}$

Worksheet K: Answers

The reason light rays bend as they travel into a different material is because their speed changes. The refractive index, *n*, is a ratio between the speeds of the wave. As it is a ratio, it does not have a unit.

For light travelling from air to water:

$$n = \frac{\text{speed in air}}{\text{speed in water}}$$

The refractive index of a material can also be calculated if the angle of incidence, *i*, and angle of refraction, *r*, is known:

$$n = \frac{\sin i}{\sin r}$$

Work through the following calculations. Show full working.

1. Calculate the speed of light in water. The refractive index of water is 1.33 and the speed of light in air is 300 million m/s.

   226 million m/s

2. Calculate the speed of light in diamond. The refractive index of diamond is 2.42.

   124 million m/s

3. Calculate the refractive index of sapphire. The speed of light in sapphire is 169 million m/s.

   1.77

4. A light ray approaches a Perspex block with an angle of incidence of 42° and refracts inside the block at an angle of 26°. Calculate the refractive index.

   1.52

5. The refractive index of glass is 1.52. Complete the table below:

Angle of incidence (°)	Angle of refraction (°)
22	14
35	22
40	25
47	29
53	32
60	35
75	39
86	41

6. A light ray approaches a silicon block with an angle of incidence of 25° and refracts inside the block at an angle of 7°. Calculate the refractive index.

   3.46

7. The refractive index of glycerol is 1.47. Calculate the angle of incidence if the angle of refraction is 26°.

   40°

Worksheet L: Answers

These are suggested answers

1. Describe how diffraction affects water waves.

   Diffraction causes water waves to curve and spread out. It does not change any of the properties of the water waves, but it changes the shape of the wavefronts.

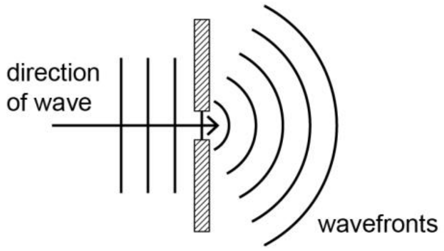
2. Describe the situation that would produce the most extreme case of diffraction.

   A gap identical in size to the wavelength of the water wave will allow the most energy to diffract through the gap and produce the most curved wavefront with the most spreading.

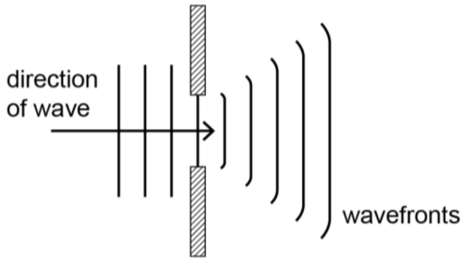
3. Complete the following diagrams by drawing the position of the wavefronts after they have been diffracted through the gaps in the barriers:
   a. Gap < wavelength

      The diagram would be similar to b. but with less spreading, as energy is lost.

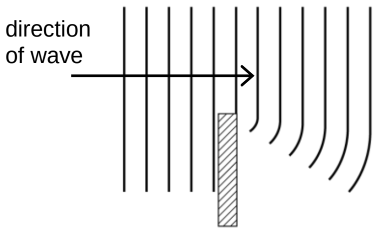
   b. Gap = wavelength



   c. Gap > wavelength



4. Complete the following diagram by drawing the position of the wavefronts after they have been diffracted around an obstacle:



The wavefronts should curve around the object, spreading out but leaving a calm area of water where the waves do not reach.

Cambridge Assessment International Education
The Triangle Building, Shaftesbury Road, Cambridge, CB2 8EA, United Kingdom
t: +44 1223 553554
e: info@cambridgeinternational.org   www.cambridgeinternational.org