# Cambridge (CIE) IGCSE Physics

Your notes

## General Properties of Waves

### Contents

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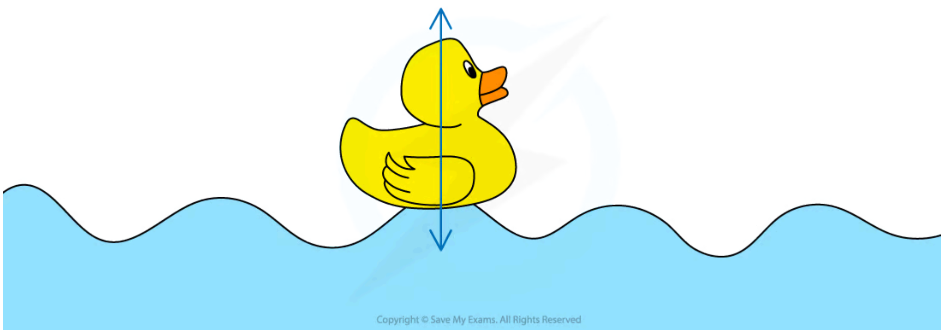
# Waves & energy transfer

- Waves transfer **energy without** transferring **matter**
    - For sound waves, this means it is the **wave** and not the **air molecules** (the matter) itself that travels
- Objects floating on water provide evidence that waves only transfer energy and **not** matter
    - It is possible to see objects on the surface of the water bob up and down but not change their position
    - This is because the **wave** and not the **water** (the matter) itself that travels
- Waves are described as **oscillations** or **vibrations** about a fixed point
    - For example, **ripples** cause particles of water to oscillate up and down
    - **Sound** waves cause particles of air to vibrate back and forth

## Worked Example

The diagram below shows a toy duck bobbing up and down on top of the surface of some water, as waves pass it underneath.




Use this image

Explain how the toy duck demonstrates that waves do not transfer matter.

**Answer:**

- The plastic duck moves up and down but does not travel with the wave along the surface of the water
- The water waves transfer **energy**, but the water particles do not move
- This means when a wave travels between two points, no matter travels with it, the points on the wave vibrate up and down about **fixed** positions

- Objects floating on the water bob up and down when waves pass under them, demonstrating that there is **no movement of matter** in the direction of the wave, only **energy**

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### Examiner Tips and Tricks

There is a key distinction between the particles (or oscillations) of a wave, and the wave itself.

The motion of the wave **causes** the particles to move. The particles themselves are not the wave.

# Wave motion

- Wave motion can be illustrated by:
  - vibrations in ropes and springs
  - experiments using water waves

## Wave vibrations

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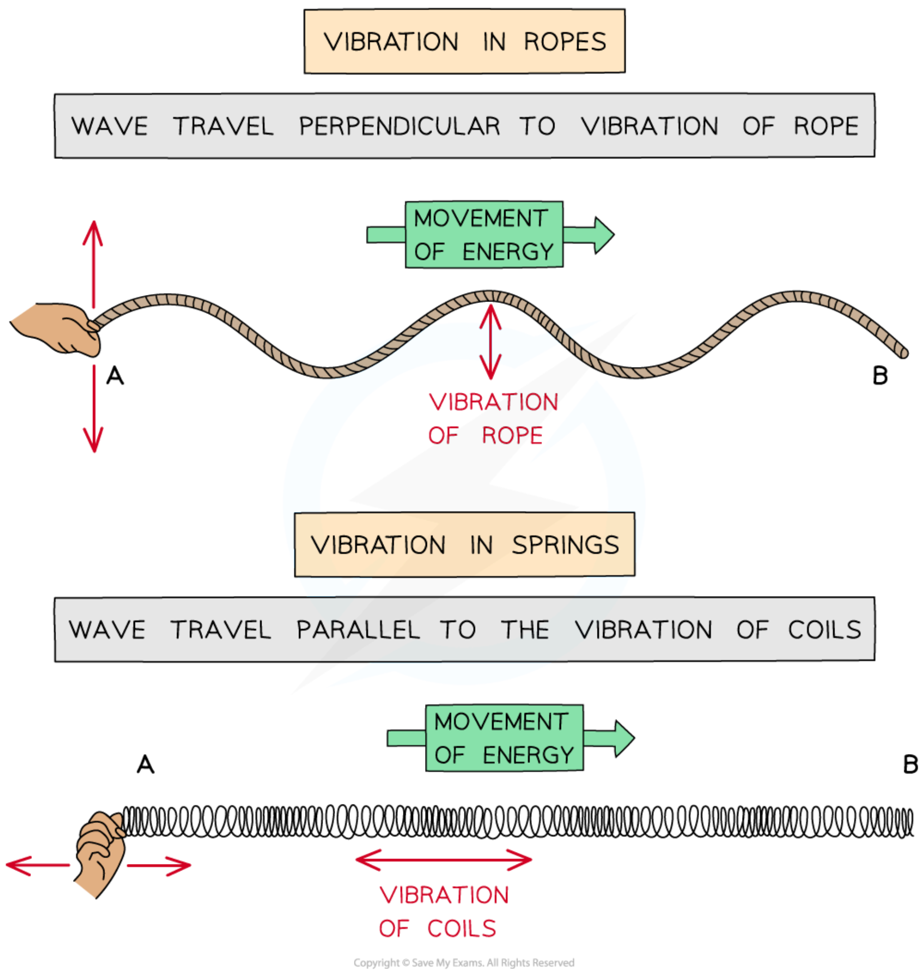
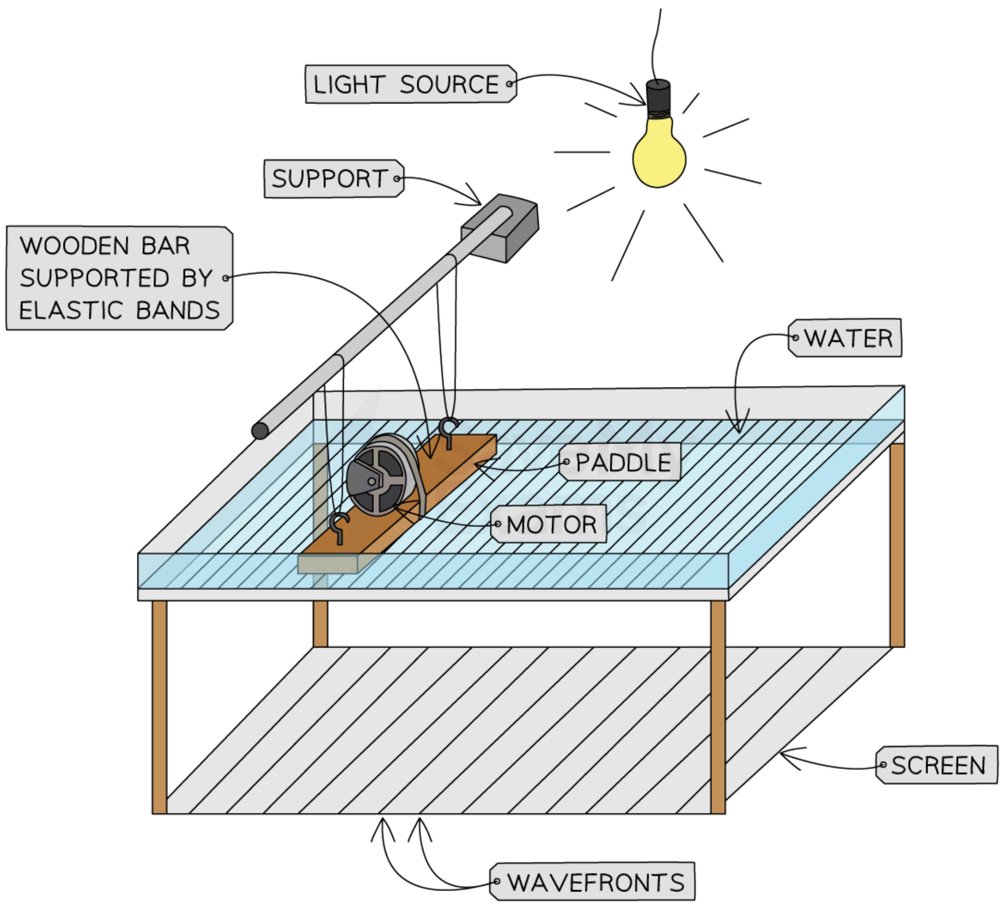



Use this image

*Waves can be shown through vibrations in ropes or springs*

- Properties of waves can be observed using water waves in a **ripple tank**
  - These properties include frequency, wavelength, amplitude, and wave speed

## Wave motion in a ripple tank





Use this image

*Wave motion of water waves may be demonstrated using a ripple tank*

# Features of a Wave

- When describing wave motion, there are several terms which are important to know, including:
  - wavefront
  - amplitude
  - wavelength
  - frequency
  - crest (peak)
  - trough
  - wave speed

## Wavefront

- Wavefronts are a useful way of picturing waves from above

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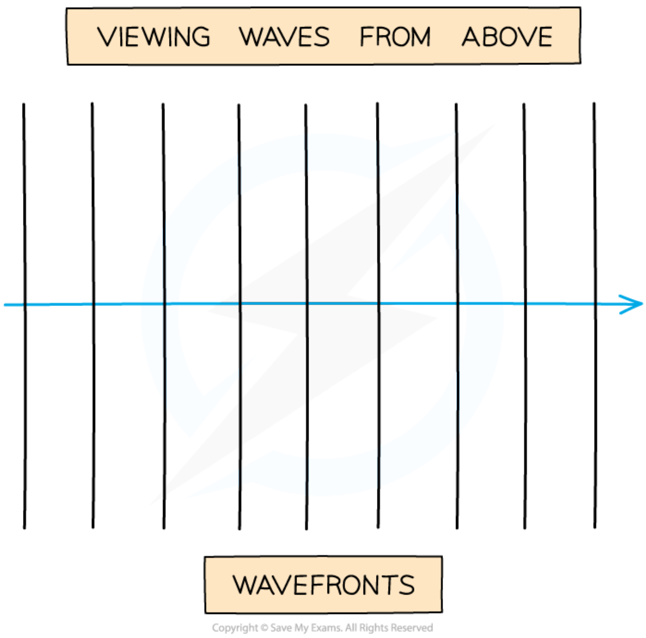
- Each wavefront, drawn as a single line, is used to represent a single wave
- The image below illustrates how wavefronts are visualised:
  - The arrow shows the direction the wave is moving and is sometimes called a **ray**
  - The space between each wavefront represents the **wavelength**
  - When the wavefronts are **close together**, this represents a wave with a **short** wavelength
  - When the wavefronts are **far apart**, this represents a wave with a **long** wavelength

## Wavefronts as viewed from above




Use this image

***Diagram showing a wave moving to the right, drawn as a series of wavefronts***

## Amplitude

- Amplitude is defined as:

**The maximum displacement of a wave from its undisturbed position**

- It is given the symbol $A$ and is measured in **metres (m)**
- On a graph where the vertical axis is **displacement**, amplitude is measured from the **undisturbed position** to either the highest point of the wave (peak) or the lowest point (trough)

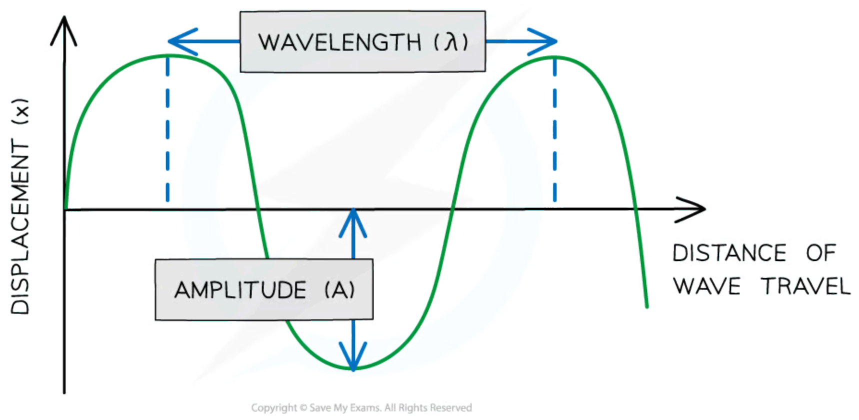
## Wavelength

- Wavelength is defined as:

**The distance from one point on the wave to the same point on the next wave**

- In a **transverse** wave:
  - The wavelength can be measured from one peak to the next peak
- In a **longitudinal** wave
  - The wavelength can be measured from the centre of one compression to the centre of the next
- Wavelength is given the symbol $\lambda$ (lambda) and is measured in **metres (m)**
- On a graph where the horizontal axis is **distance**, the wavelength can be determined by measuring the distance from one point on the wave to the same point on the next wave

## Using a graph to determine wavelength and amplitude




Use this image

***Diagram showing the amplitude and wavelength of a wave***

# Frequency

- Frequency is defined as:

**The number of waves passing a point in a second**

- Frequency is given the symbol $f$ and is measured in **hertz (Hz)**

# Crests & troughs

- A crest, or a peak, is defined as:

**The highest point on a wave above its undisturbed position**

- A trough is defined as

**The lowest point on a wave below its undisturbed position**

## Wave crests and troughs

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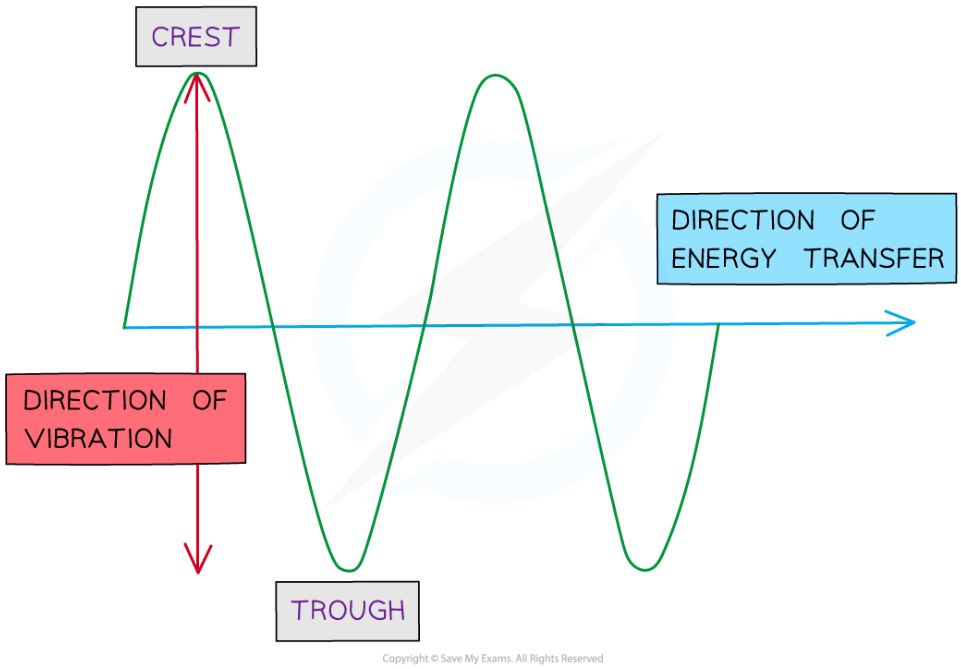


Use this image

*Diagram showing a crest and a trough on a transverse wave*

## Wave speed

- Wave speed is the speed at which **energy** is transferred through a medium
- Wave speed is defined as:

**The distance travelled by a wave each second**

- The equation used to calculate wave speed is explained in The wave equation

### Worked Example

Small water waves are created in a ripple tank by a wooden bar. The wooden bar vibrates up and down hitting the surface of the water. The diagram below shows a cross-section of the ripple tank and water.

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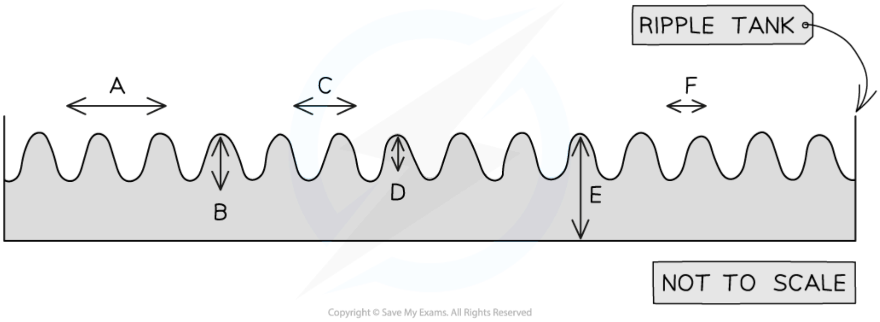



Use this image

Identify the letter which shows:

a) the amplitude of a water wave.

b) the wavelength of the water wave.

**Answer:**

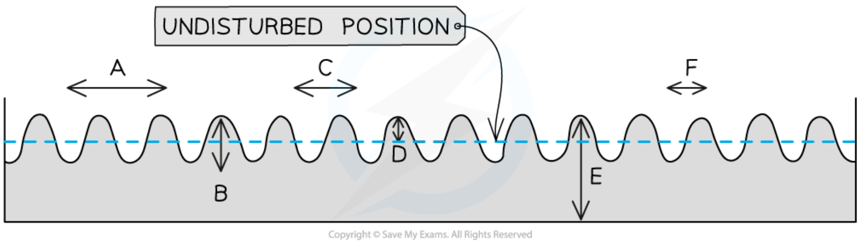
Part (a)

**Step 1: Recall the definition of amplitude**

- Amplitude = The distance from the undisturbed position to the peak or trough of a wave

**Step 2: Mark the undisturbed position on the wave**

- This is the centre of the wave

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**Step 3: Identify the arrow between the undisturbed position and a peak**

- The amplitude is shown by arrow **D**

Part (b)

**Step 1: Recall the definition of wavelength**

- Wavelength = The distance from one point on the wave to the same point on the next wave

**Step 2: Draw lines on each horizontal arrow**

- This helps to identify the points on the wave the arrows are referring to

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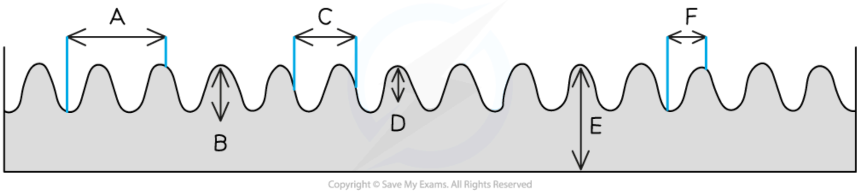


Use this image

**Step 3: Identify the arrow between two of the same points on the wave**

- The wavelength is shown by arrow **C**

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# The wave equation

- The equation used to calculate wave speed is:

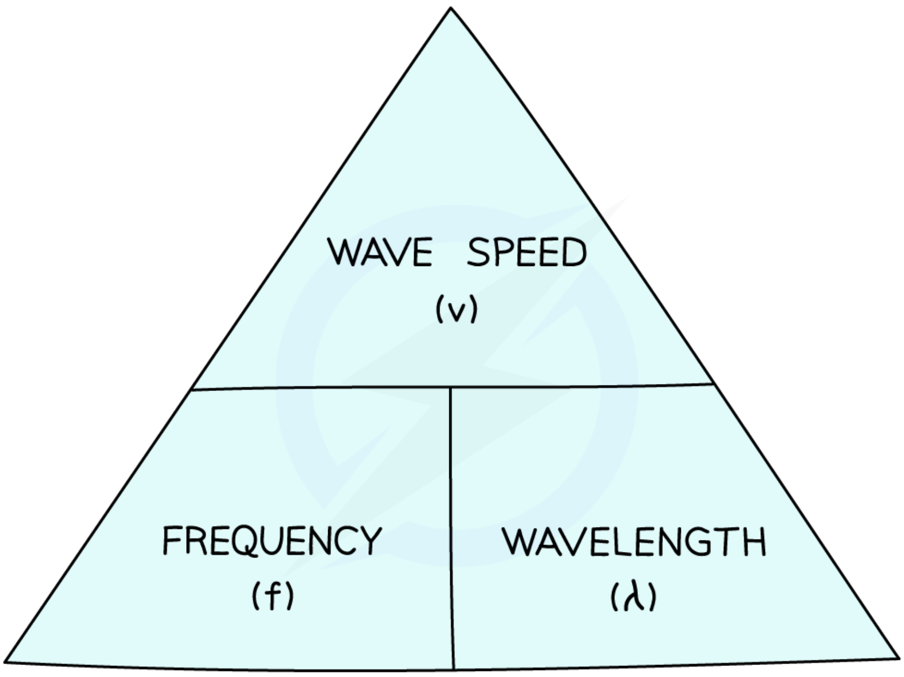
$$v = f \times \lambda$$

- Where:
  - $v$ = wave speed, measured in metres per second (m/s)
  - $f$ = wave frequency, measured in hertz (Hz)
  - $\lambda$ = wavelength, measured in metres (m)
- Wave speed is defined as:

**The distance travelled by a wave each second**

- Wave speed is the speed at which energy is transferred through a medium
- Transverse and longitudinal waves both obey the wave equation

## Wave speed formula triangle






- For more information on how to use a formula triangle, refer to the revision note on speed & velocity

## Frequency and period

Your notes

- The period of a wave is defined as:

**The time taken for one complete oscillation to pass a fixed point**

- The frequency of a wave is related to its period by the following equation:

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

- And therefore,

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

- Where:
  - $f$ = frequency, measured in Hz
  - $T$ = period, measured in s

### Worked Example

A wave in a pond has a speed of 0.15 m/s and a time period of 2 seconds. Calculate:

a) The frequency of the wave

b) The wavelength of the wave

**Answer:**

Part (a)

**Step 1: List the known quantities**

- Time period, $T$ = 2 s

**Step 2: State the equation relating time period and frequency**

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

**Step 3: Rearrange for frequency, *f*, and calculate the answer**

$$f = \frac{1}{T} = \frac{1}{2}$$

Frequency, $f$ = **0.5 Hz**

Part (b)

**Step 1: List the known quantities**

- Wave speed, $v$ = 0.15 m/s
- Frequency, $f$ = 0.5 Hz

**Step 2: Write out the wave speed equation**

$$v = f \times \lambda$$

**Step 3: Rearrange the equation to calculate the wavelength**

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

**Step 4: Use the frequency you calculated in part (a) and put the values into the equation**

$$\lambda = \frac{0.15}{0.5}$$

Wavelength, $\lambda$ = **0.30 m**

## Examiner Tips and Tricks

When stating equations make sure you use the right letters. For example, use λ for wavelength, not L or W

If you can't remember the correct letters, then just state the word equations

Be careful with units: wavelength is usually measured in metres and speed in m/s, but if the wavelength is given in cm you might have to provide the speed in cm/s

Likewise, watch out for the frequency given in kHz: 1 kHz = 1000 Hz

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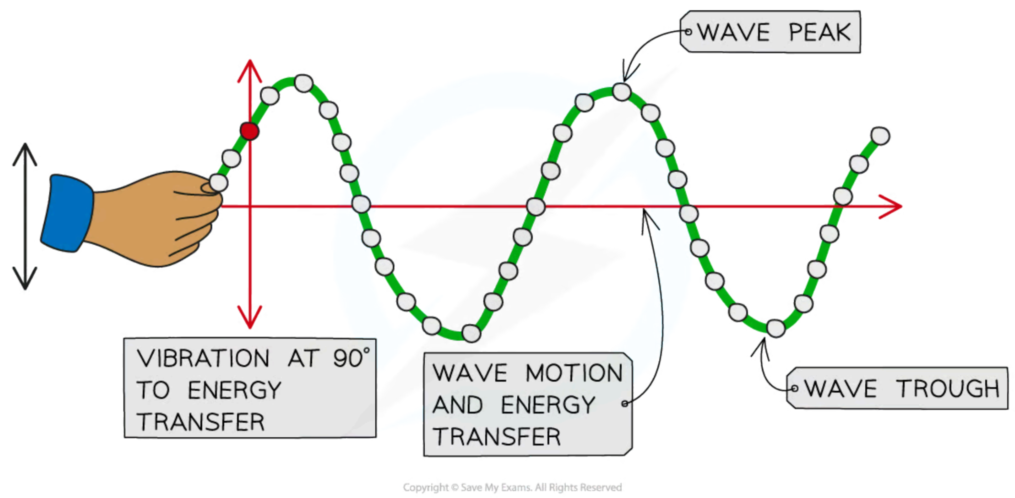
# Transverse waves

- Waves can exist as one of two types:
  - **Transverse**
  - **Longitudinal**
- Transverse waves are defined as:

**Waves where the direction of vibration is at right angles to the direction of energy transfer**

- For a transverse wave, the oscillation is **perpendicular to** the direction the wave is travelling in
- Mechanical transverse waves can move in **solids**, and on the surface of liquids, but not in liquids or gases
- Non-mechanical transverse waves can move in a **vacuum**

## Transverse wave motion




***Transverse waves can be seen in a rope when it is moved quickly up and down***

- Examples of waves that can be modelled as transverse are:
  - Electromagnetic waves (such as radiowaves, visible light, X-rays etc)
  - Ripples on the surface of water
  - Seismic S-waves (secondary earthquake waves)

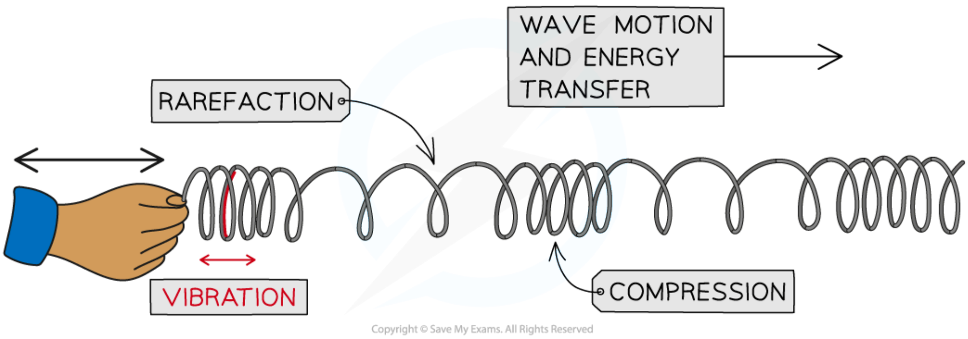
# Longitudinal waves

- Longitudinal waves are defined as:

**Waves where the direction of vibration is parallel to the direction of propagation**

- For a longitudinal wave:
  - The energy transfer is in the **same direction** as the wave motion
  - They can move in solids, liquids and gases
  - They can **not** move in a vacuum (since there are no particles)
- The key features of a longitudinal wave are where the points are:
  - Close together, called **compressions**
  - Spaced apart, called **rarefactions**

## Longitudinal wave motion




***Longitudinal waves can be seen in a slinky spring when it is moved quickly backwards and forwards***

- Examples of waves that can be modelled as longitudinal waves are:
  - Sound waves
  - Seismic P-waves (primary earthquake waves)

# Difference between transverse and longitudinal waves

## Comparing transverse and longitudinal waves

| Property | Transverse waves | Longitudinal waves |
|---|---|---|
| Structure | Peaks and troughs | Compressions and rarefactions |
| Vibration | Right angles to the direction of energy transfer | Parallel to the direction of energy transfer |

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| | | |
|---|---|---|
| Vacuum | Only electromagnetic waves can travel in a vacuum | Cannot travel in a vacuum |
| Material | Can move in solids and the surfaces of liquids | Can move in solids, liquids and gases |
| Density | A constant density | The density of the wave changes |
| Pressure | Has a constant pressure | Pressure in the wave changes |
| Speed of wave | Depends on the material the wave is travelling in | Depends on the material the wave is travelling in |

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### Examiner Tips and Tricks

The key difference between transverse and longitudinal waves is the direction of the vibrations with respect to the direction of the wave itself. For transverse waves, these are perpendicular to each other, whilst for longitudinal waves, these are parallel.

# Reflection, refraction & diffraction

- All waves, whether transverse or longitudinal, can undergo:
  - **reflection** at a plane surface
  - **refraction** due to a change of speed
  - **diffraction** through a narrow gap
- In optics, a transparent material is called a **medium**
  - When referring to more than one medium these are called **media**
- Angles of light are measured from an imaginary line called the **normal**
  - The normal is always **drawn perpendicular** to the **boundary** between two media

## Reflection

- Reflection occurs when:

**A wave hits a boundary between two media at a plane surface and does not pass through, but instead stays in the original medium**

### An example of reflection


*An identical image of the tree is seen in the water due to reflection*

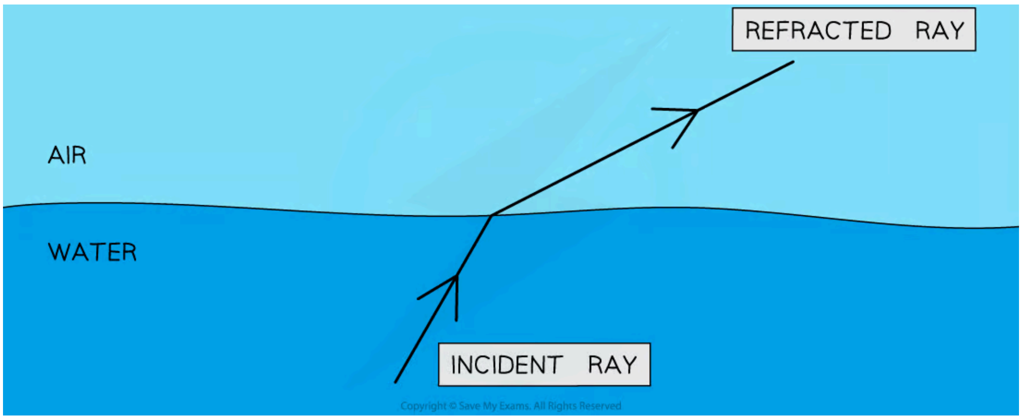
# Refraction

- When waves enter a different medium, their speed can change
- This effect is called **refraction** and it occurs when:

**A wave passes a boundary between two different transparent media and undergoes a change in speed**

- When a wave **refracts**, as well as a change in speed, the wave also undergoes:
  - A change in **wavelength** (but frequency stays the same)
  - A change in **direction**

## An example of refraction




***Waves can change direction when moving between materials with different densities***

- The direction of the incident and refracted rays are also taken from the **normal** line
- If the waves **slow down**, they will bunch together, causing the wavelength to decrease
  - The waves will also start to turn slightly **towards** the normal
- If the waves **speed up** then they will spread out, causing the wavelength to increase
  - The waves will also turn slightly **away from** the normal

# Diffraction

- When waves pass through a narrow gap, **the waves spread out**
- This effect is called **diffraction**

## Waves diffracting through a narrow gap

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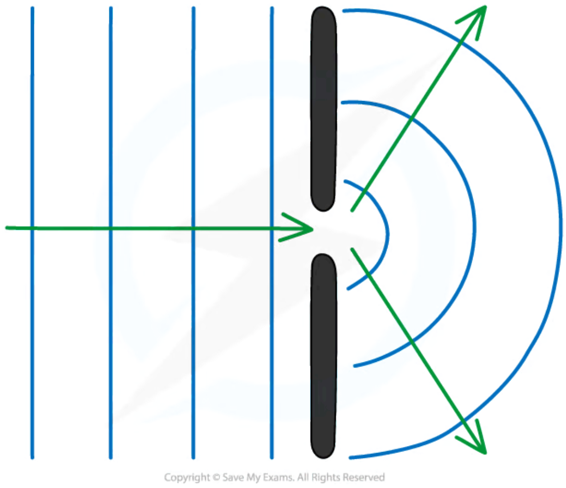



***Diffraction: when a wave passes through a narrow gap, it spreads out***

### Examiner Tips and Tricks

When drawing waves being reflected take care to:

- Make sure that the angle of incidence is equal to the angle of reflection
- Keep the wavelength of the waves the same

Similarly, when waves are diffracted **the wavelength remains constant.**

Refraction is the only wave effect in which the wavelength changes.

**Remember**:

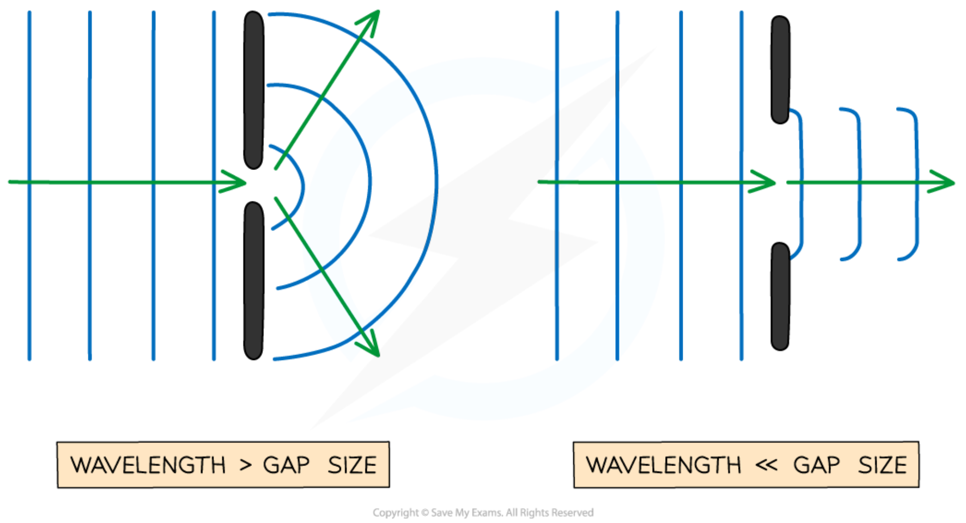
Refraction is the name given to the change in the speed of a wave when it passes from one medium to another. The change in direction is a consequence of this.

# Factors affecting diffraction

**Extended tier only**

- The extent of diffraction depends on the **width** of the gap compared with the **wavelength** of the waves
    - Diffraction is the most prominent when the **width** of the slit is approximately **equal** to the **wavelength**
- As the **gap gets bigger**, the **effect** gradually gets **less pronounced** until, in the case that the gap is very much larger than the wavelength, the waves no longer spread out at all

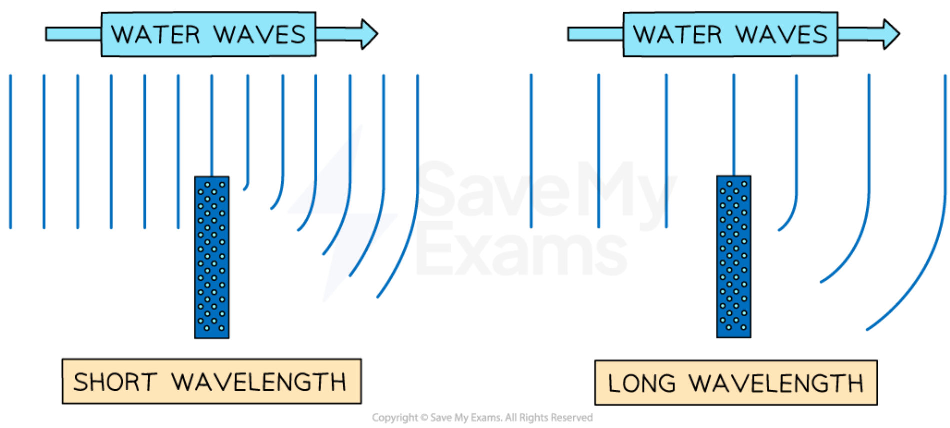
## Effect of gap size on diffraction




***The size of the gap (compared to the wavelength) affects how much the waves spread out***

- Diffraction can also occur when waves curve around an **edge** or **barrier**
- The waves spread out to fill the gap behind the object
- The extent of this diffraction also depends upon the wavelength of the waves
  - The **greater** the **wavelength** then the greater the **diffraction**

## Effect of wavelength on diffraction around an edge




***When a wave goes past the edge of a barrier, the waves can curve around it. Shorter wavelengths undergo less diffraction than longer wavelengths***

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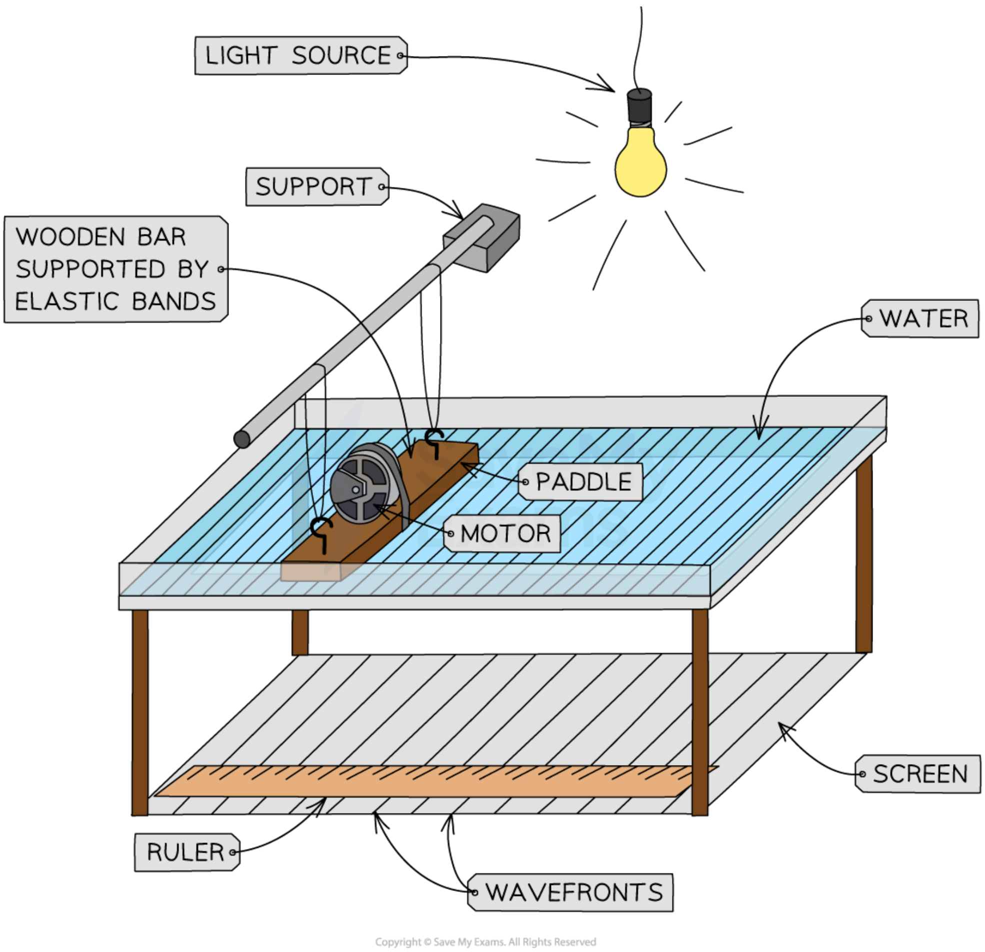
# Investigating waves with a ripple tank

- Ripple tanks are commonly used in experiments to demonstrate the following properties of water waves:
  - **Reflection** at a plane surface
  - **Refraction** due to a change in speed caused by a change in depth
  - **Diffraction** due to a **gap**
  - **Diffraction** due to an **edge**

## Ripple tank experimental set-up




***Reflection, refraction and diffraction can be demonstrated using a ripple tank***

- **Wavefronts** from the transverse water surface waves can be viewed and analysed on the screen illuminated to show below the tank

## Investigating Reflection

- **Wavefronts** are reflected off a metal bar (plane surface) placed in the water of the ripple tank
- When the bar is placed at an angle to the wavefronts of the waves generated by the paddle reflect according to the Law of reflection

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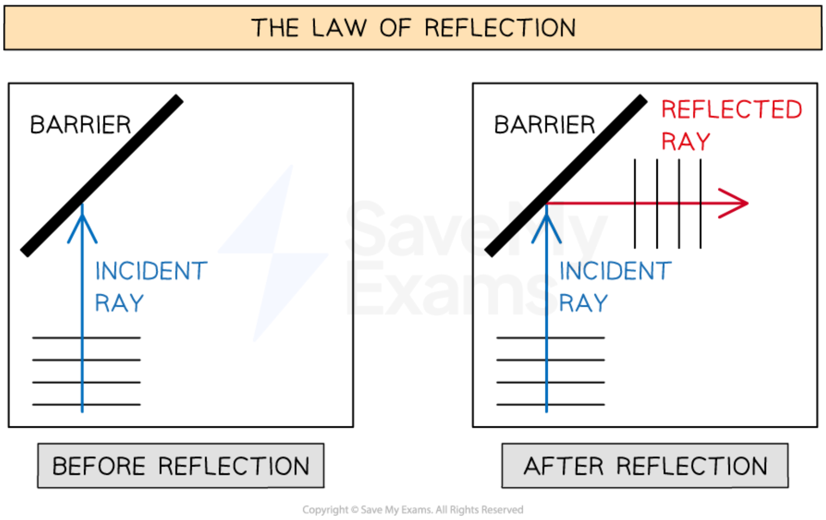
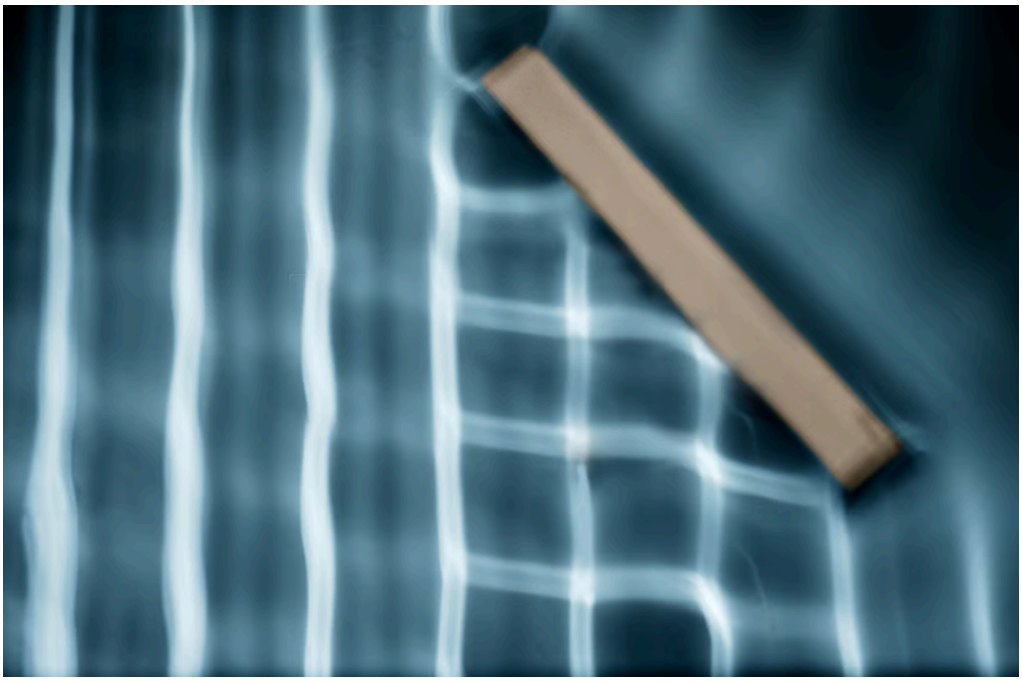
## Diagram of reflected wavefronts in a ripple tank




*Incident wavefronts are reflected at 90 degrees against a barrier*

## Reflected wavefronts in a ripple tank

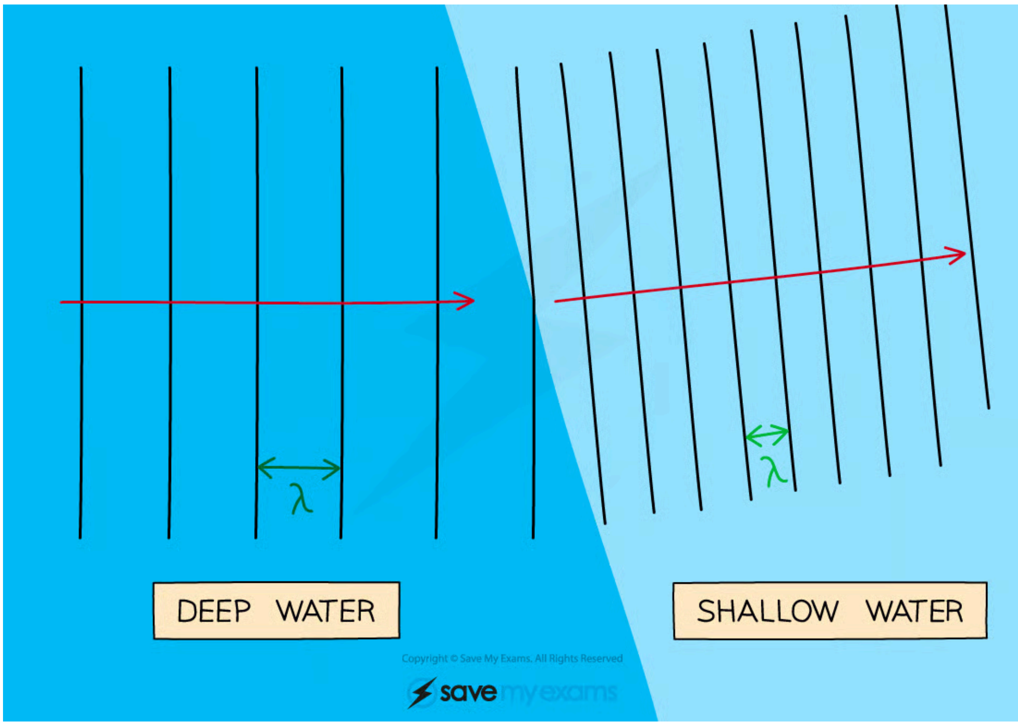


*Wavefronts of incident and reflected waves form right angles to each other*

# Investigating refraction

- Refraction can be shown by placing a **glass block** in the tank
  - The glass block should sit below the surface of the water and cover only some of the tank floor
- The depth of water becomes **shallower** where the glass block is placed
  - Since speed depends on depth, the ripples slow down when travelling over the block
- The water surface waves **slow down** when passing from **deep to shallow** water in the ripple tank

## Refracted wavefronts in a ripple tank




*When water waves travel from deep areas to shallow areas they slow down*

# Investigating diffraction

- **Diffraction** can be shown in a ripple tank by placing small barriers with a **gap** or an **edge** in the tank
- The amount of Diffraction that occurs can be changed by changing the wavelength of the waves compared to the gap size

## Changing the gap size for diffraction in a ripple tank

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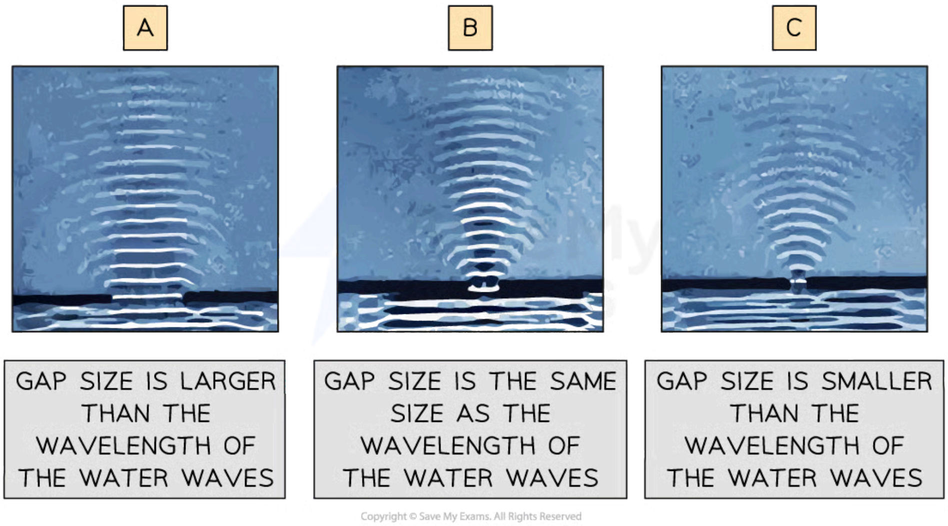


***When the gap size is bigger than the wavelength less diffraction occurs and the waves spread out less after passing through***

## Changing the wavelength of waves in the ripple tank

- The **motor** creates the up-and-down movement of the **paddle**
- The frequency of the motor affects the wavelength of the waves generated by the paddle
- The diagram below shows how the wavelengths differ with frequency in a ripple tank
    - The **higher** the frequency of the motor, the **shorter** the wavelength
    - The **lower** the frequency of the motor, the **longer** the wavelength

## Wavelength and frequency of waves in a ripple tank

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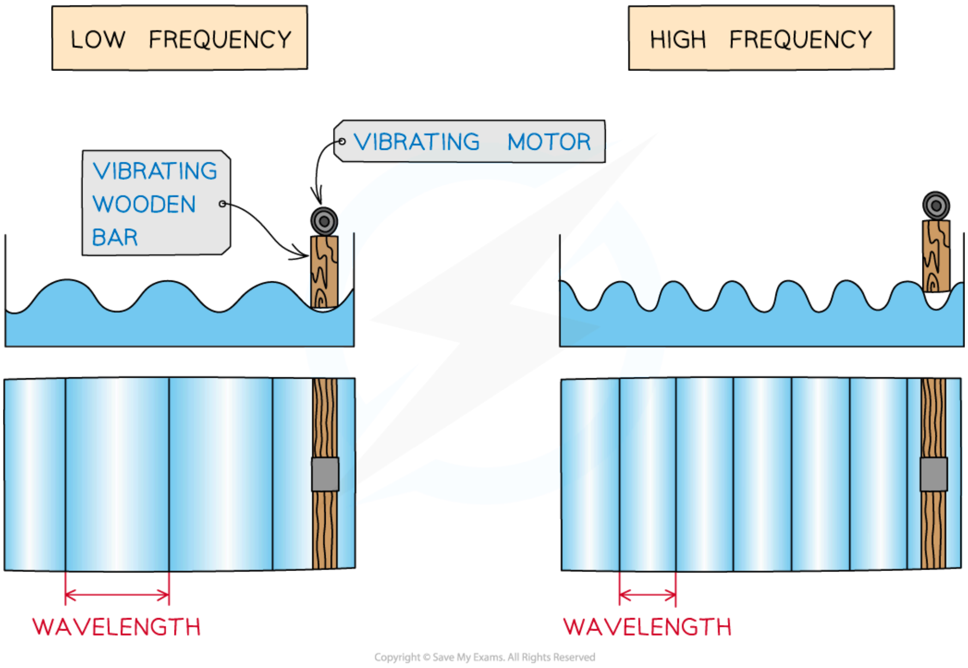


*Ripple tank patterns for low and high-frequency vibration*