<u>Waves</u>

- Waves transfer energy between points, without transferring matter:
- When a wave travels between two points, no matter actually travels with it: The points on the wave simply vibrate back and forth about fixed positions.

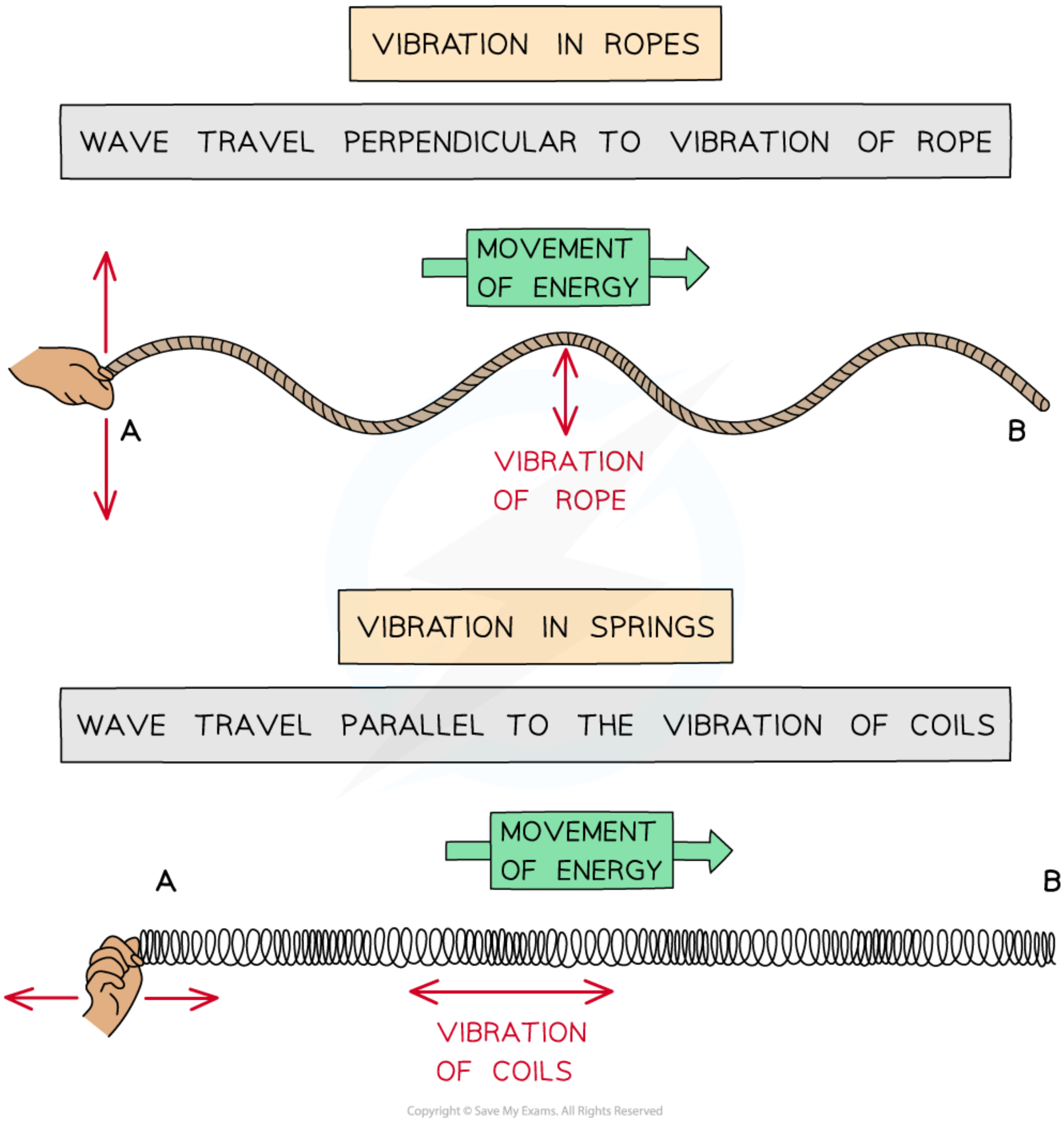
Waves - Basic

- Waves transfer **energy** and **information**
- 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
- In all cases, waves transfer **energy without** transferring **matter**
    - For water waves, this means it is the **wave** and not the **water** (the matter) itself that travels
    - 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

Wave Motion

- Wave vibrations can be shown on **ropes** (transverse) and **springs** (longitudinal)

Motion of Transverse and Longitudinal Waves

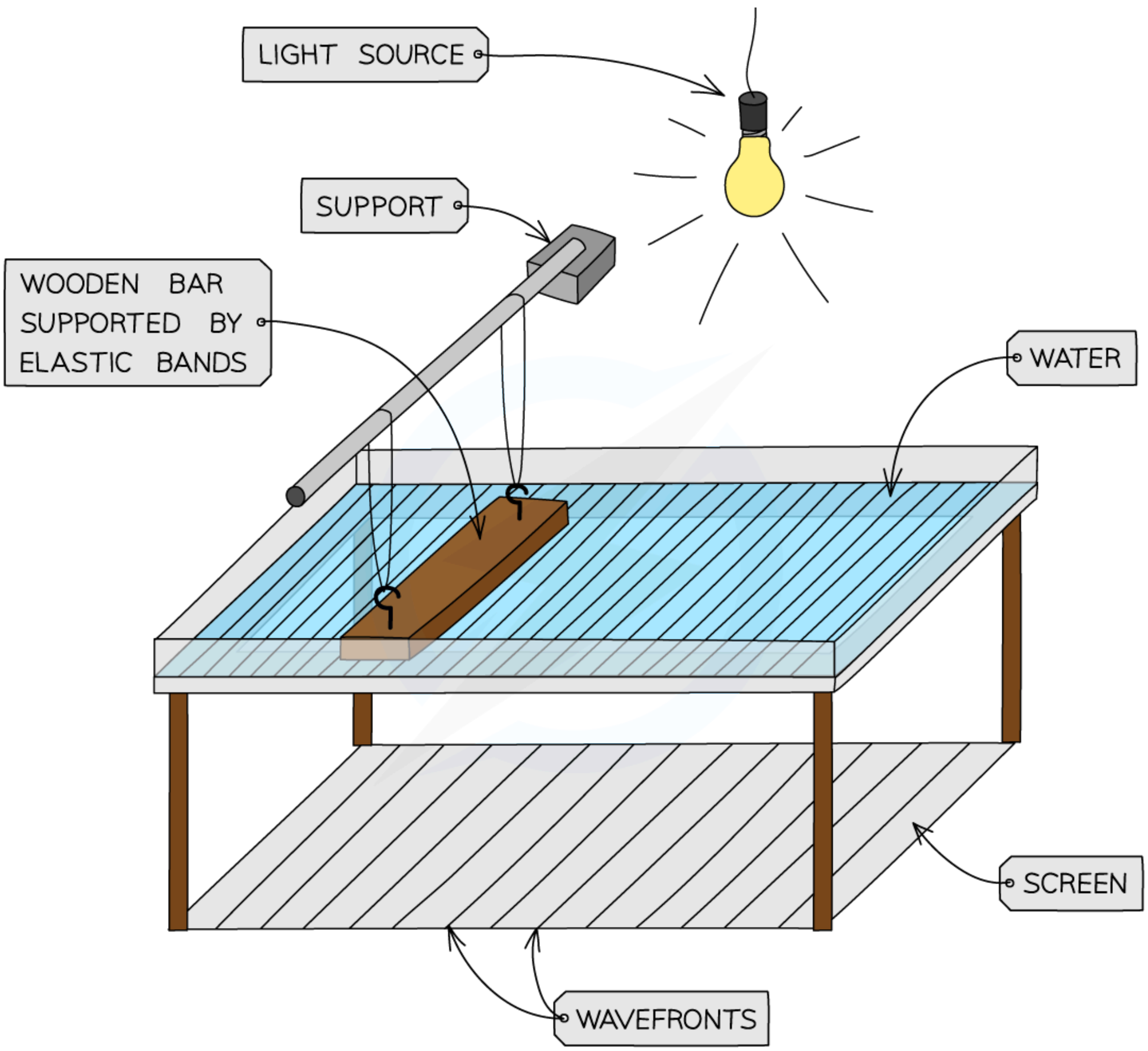


Waves can be shown through vibrations in ropes or springs

Demonstrating Wave Motion

- Properties of waves, such as frequency, wavelength and wave speed, can be observed using water waves in a ripple tank

Ripple Tank



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

- The **wavelength** of the waves can be determined by:
  - Using a ruler to measure the length of the screen
  - Dividing this distance by the number of wavefronts
- The **frequency** can be determined by:

- Timing how long it takes for a given number of waves to pass a particular point
    - Dividing the number of wavefronts by the time taken
- The **wave speed** can then be determined by:
    - Using the equation *wave speed* = *frequency* × *wavelength*

Features of a Wave

- When describing wave motion, there are several terms which are important to know, including:
    - Crest (Peak)
    - Trough
    - Amplitude
    - Wavelength
    - Frequency
    - Time period
    - Wave speed
    - Wavefront

Crests & Troughs

- A crest, or a peak, is defined as:
  The highest point on a wave above the equilibrium, or rest, position
- A trough is defined as
  The lowest point on a wave below the equilibrium, or rest, position

Crest and Trough of a Wave

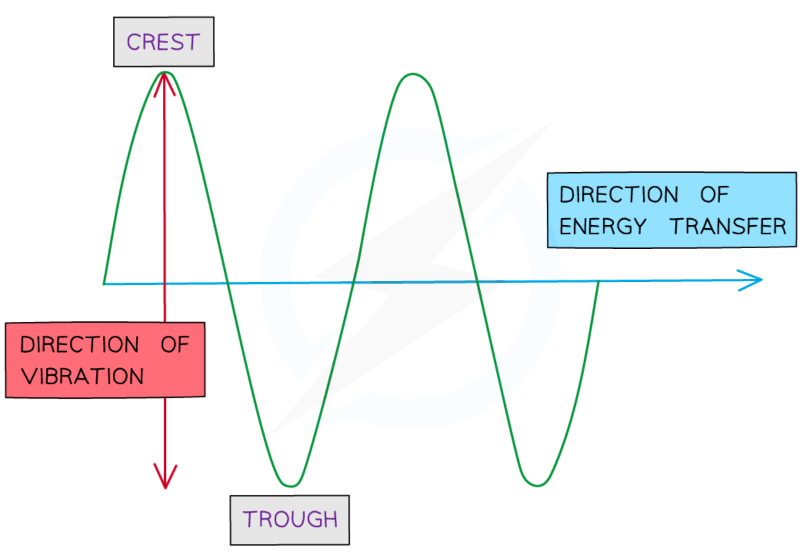


Diagram showing a crest and a trough on a transverse wave

Amplitude

- Amplitude is defined as:
  The distance from the undisturbed position to the crest or trough of a wave
- It is given the symbol **A** and is measured in **metres (m)**
- Amplitude is the maximum or minimum **displacement** from the **undisturbed position**

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
- The wavelength is given the symbol **λ** (lambda) and is measured in **metres** (**m**)
- The distance along a wave is typically put on the x-axis of a wave diagram

Wavelength and Amplitude

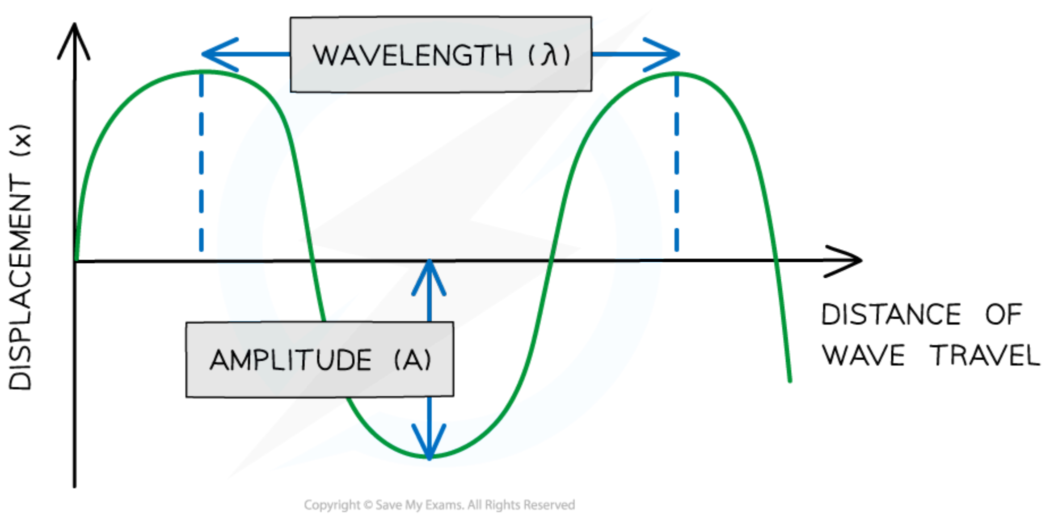


Diagram showing the amplitude and wavelength of a wave

Frequency

- Frequency is defined as:
  The number of waves passing a point in a second - /s
- Frequency is given the symbol ***f*** and is measured in **Hertz (Hz)**

Wave Speed

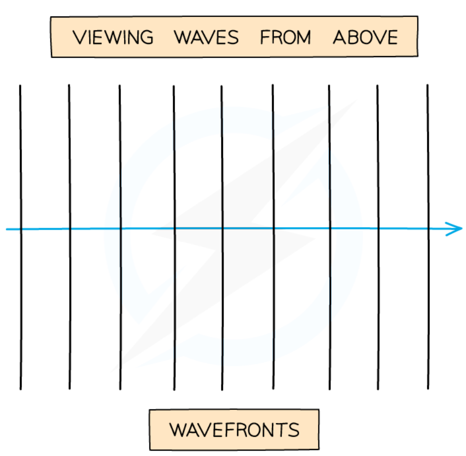
- Wave speed is the speed at which **energy** is transferred through a medium
- Wave speed is defined as:
  The distance travelled by a wave each second
- Wave speed is given the symbol, *v*, and is measured in **metres per second (m/s),** it can be calculated using:

wave speed = frequency × wavelength

Wavefronts

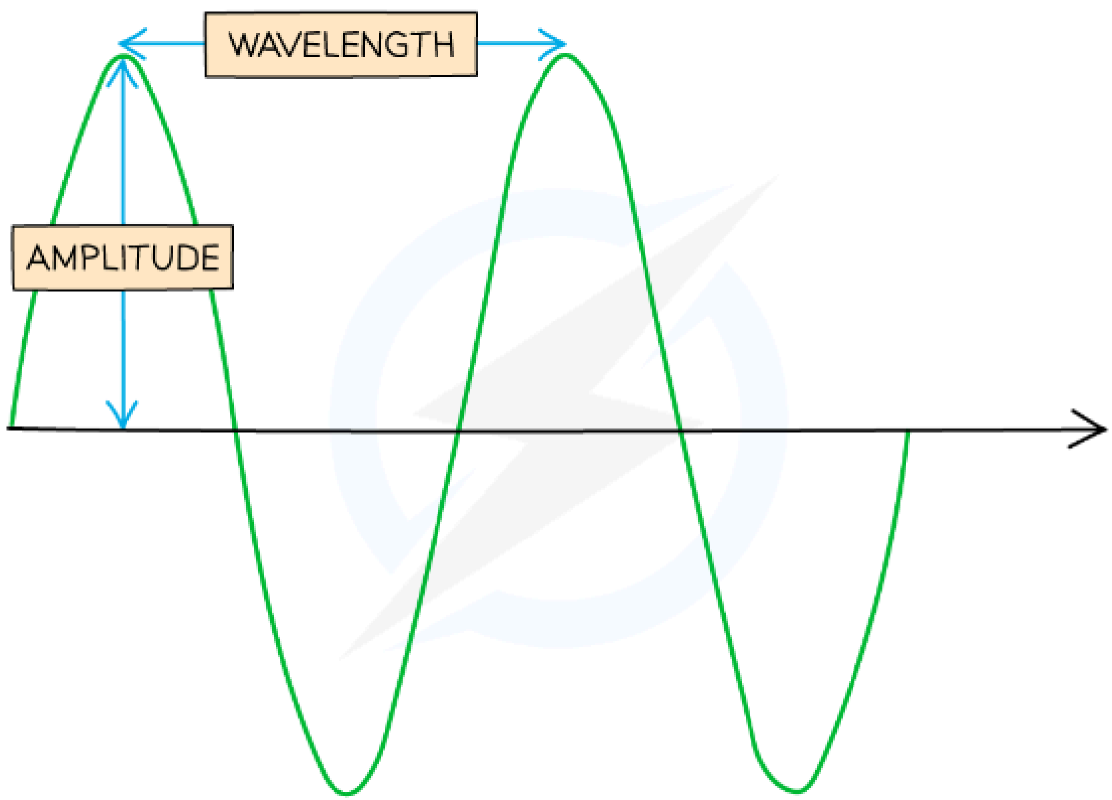
- Wavefronts are a useful way of picturing waves from above: each wavefront is used to represent a single wave
- The image below illustrates how wavefronts are visualised:
  - The arrow shows the direction the wave is moving and is sometimes called a **ray**
  - The space between each wavefront represents 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



<u>Basic Terminologies:</u>

- The wavelength of a wave is the distance from a point on one wave to the same point on the next wave. Usually this is measured from the top of one wave to the top of the next wave
  Wavelength is usually measured in metres (a distance)
- The amplitude of a wave is its height, measured from the middle of the wave to its top (or from the middle to its bottom)



- The **frequency (f)** of a wave is the number of waves passing a point (or being created or received) every second - it is helpful to think of it as being the **waves per second**
- The units of frequency are **hertz (Hz).**
- Time period is the time it takes to complete one wave. It is represented by **T** and the unit is S.

$T = 1/f$ $\qquad$ $f=1/T$

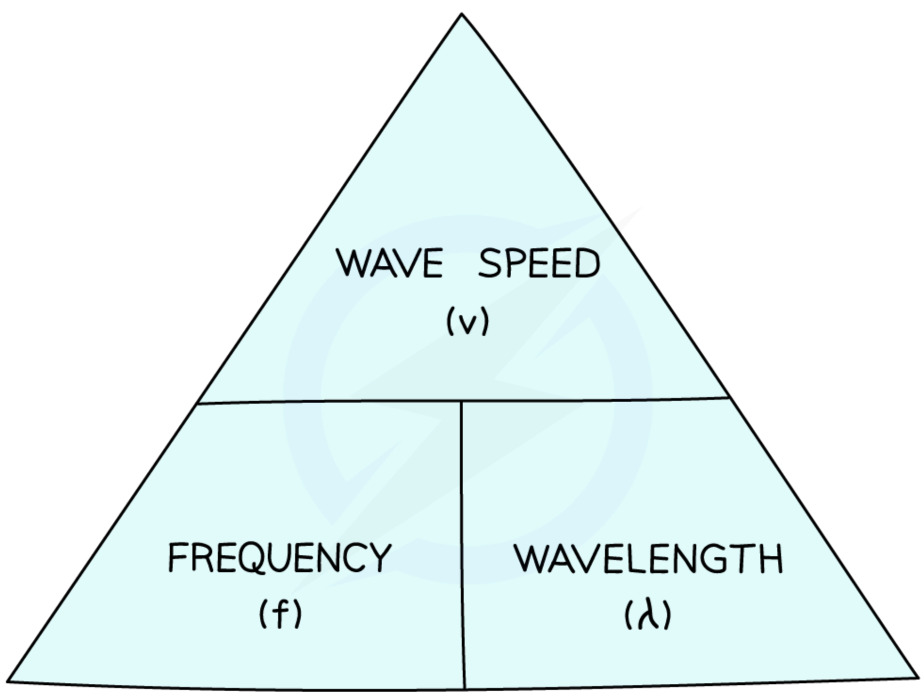
The Wave Equation

- The speed of a wave (*v)* is related to the frequency (*f*) and wavelength (*λ*) by the equation:
- Wave speed is defined as:
  The distance travelled by a wave each second
- Wave speed is given the symbol *v* and is measured in **metres per second (m/s)**
- Wave speed is the speed at which energy is transferred through a medium
- Transverse and longitudinal waves both obey the wave equation:

$$\text{WAVE SPEED} = \text{FREQUENCY} \times \text{WAVELENGTH}$$

$$v = f \times \lambda$$

- You can rearrange this equation with the help of the formula triangle:



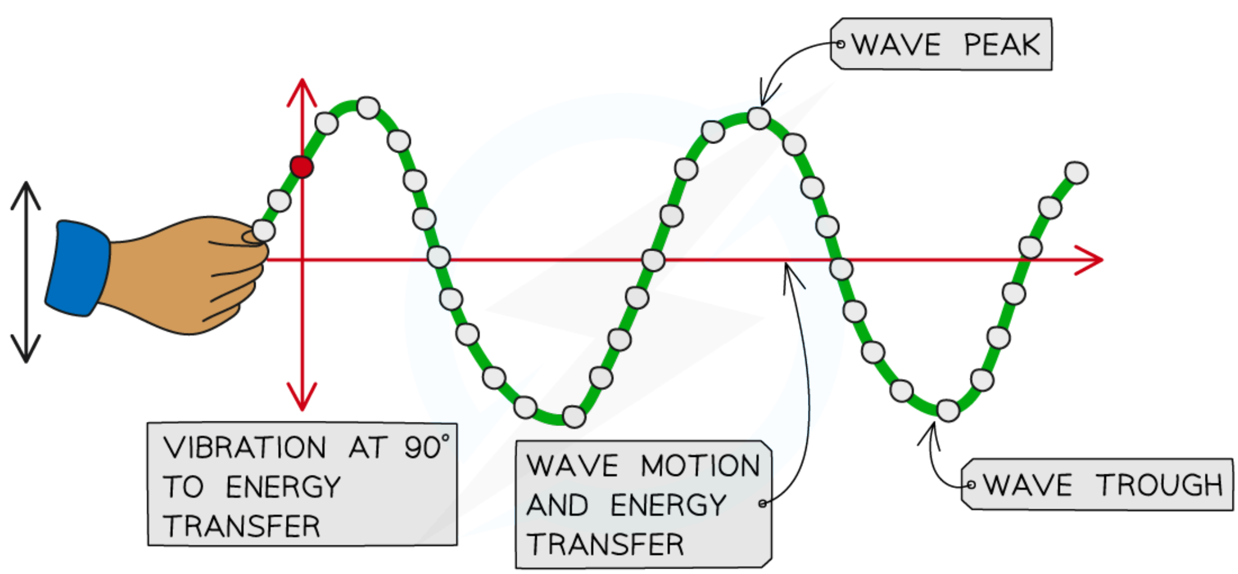
Transverse Waves

- Waves are repeated vibrations that transfer **energy**
- Waves can exist as one of two types:
  - **Transverse**
  - **Longitudinal**

Transverse Waves

- Transverse waves are defined as:
  Waves where the points along its length vibrate at 90 degrees to the direction of energy transfer
- For a transverse wave:
  - The energy transfer is in the **same direction** as the wave motion
  - They transfer energy, but not the particles of the medium
  - They can move in **solids** and on the **surfaces of liquids** but **not** inside liquids or gases
  - Some transverse waves (electromagnetic waves) can move in solids, liquids and gases and in a vacuum
- The point on the wave that is:
  - The highest above the rest position is called the **peak**, or **crest**
  - The lowest below the rest position is called the **trough**

Vibrations of a Transverse Wave



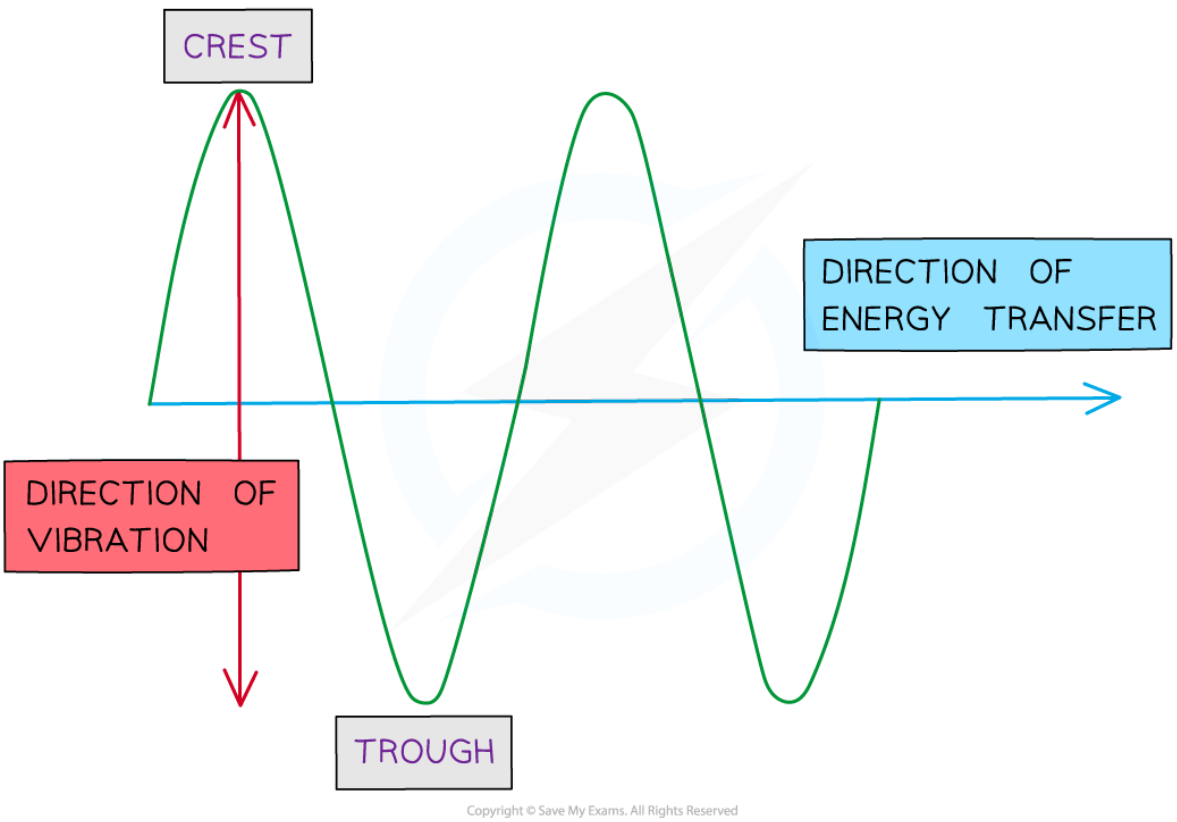
Transverse waves can be seen in a rope when it is moved quickly up and down

- Examples of transverse waves are:
    - Ripples on the surface of water
    - Vibrations on a guitar string
    - S-waves (a type of seismic wave)
    - Electromagnetic waves (such as radio, light, X-rays etc)

Representing Transverse Waves

- Transverse waves are drawn as a single continuous line, usually with a central line showing the **undisturbed position**
- The curves are drawn so that they are **perpendicular** to the direction of energy transfer
    - These represent the peaks and troughs

Transverse Wave Graph

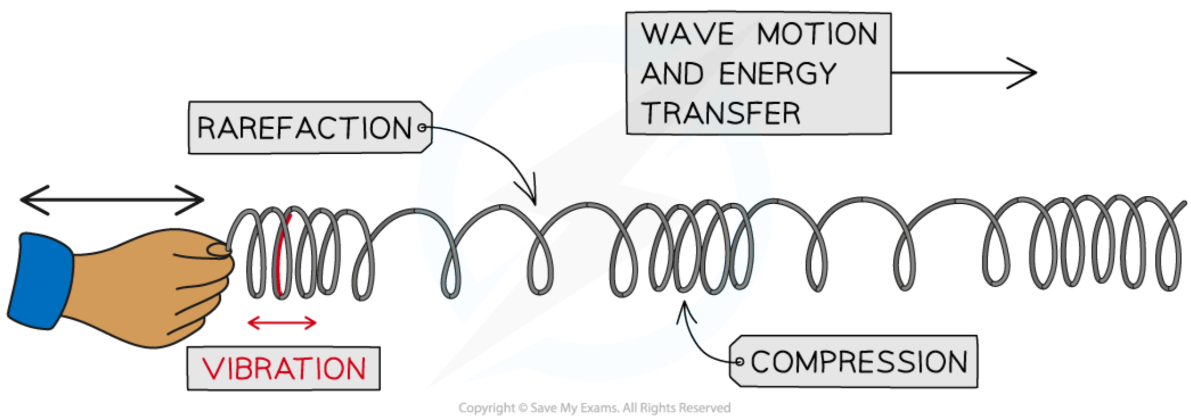


Transverse waves are represented as a continuous solid line

Longitudinal Waves

- Longitudinal waves are defined as:
  Waves where the points along its length vibrate parallel to the direction of energy transfer
- For a longitudinal wave:
  - The energy transfer is in the **same direction** as the wave motion
  - They transfer energy, but not the particles of the medium
  - 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 on a Spring



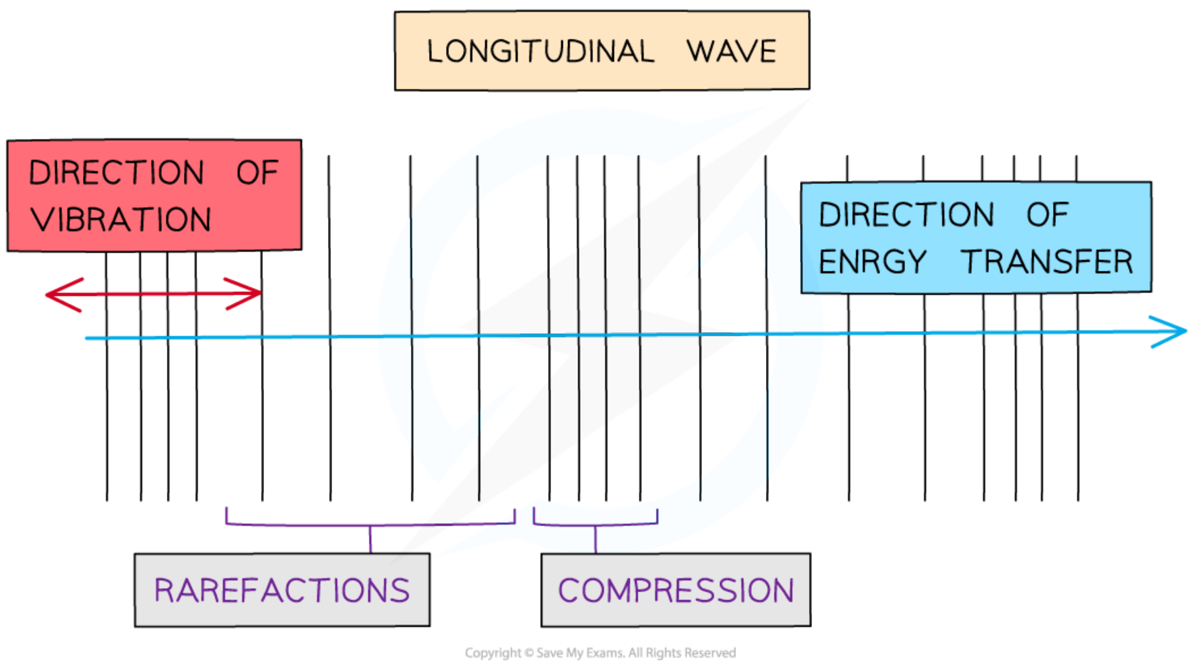
Longitudinal waves can be seen in a slinky spring when it is moved quickly backwards and forwards

- Examples of longitudinal waves are:
  - Sound waves
  - P-waves (a type of seismic wave)
  - Pressure waves caused by repeated movements in a liquid or gas

Representing Longitudinal Waves

- Longitudinal waves are usually drawn as several lines to show that the wave is moving **parallel** to the direction of energy transfer
  - Drawing the lines closer together represents the **compressions**
  - Drawing the lines further apart represents the **rarefactions**

Diagram of a Longitudinal Wave



Longitudinal waves are represented as sets of lines with rarefactions and compressions

Comparing Transverse & Longitudinal Waves

- The different properties of transverse and longitudinal waves are shown in the table:

Transverse Waves v Longitudinal Waves Table

Property	Transverse Waves	Longitudinal Waves
Structure	Peaks and troughs	Compressions and rarefactions
Vibration	90° to direction of energy transfer	Parallel to direction of energy transfer
Vacuum	Electromagnetic waves (a transverse wave) can travel through a vacuum	Cannot travel in a vacuum

Material	Can move in solids, liquids and gases	Can move in solids, liquids and gases
Density	Constant density	Changes in density
Pressure	Constant pressure	Changes in pressure
Speed of wave	Dependent on the material it travels in	Dependent on the material it travels in

Reflection, Refraction & Diffraction

- All waves, whether transverse or longitudinal, can be **reflected, refracted** and **diffracted**

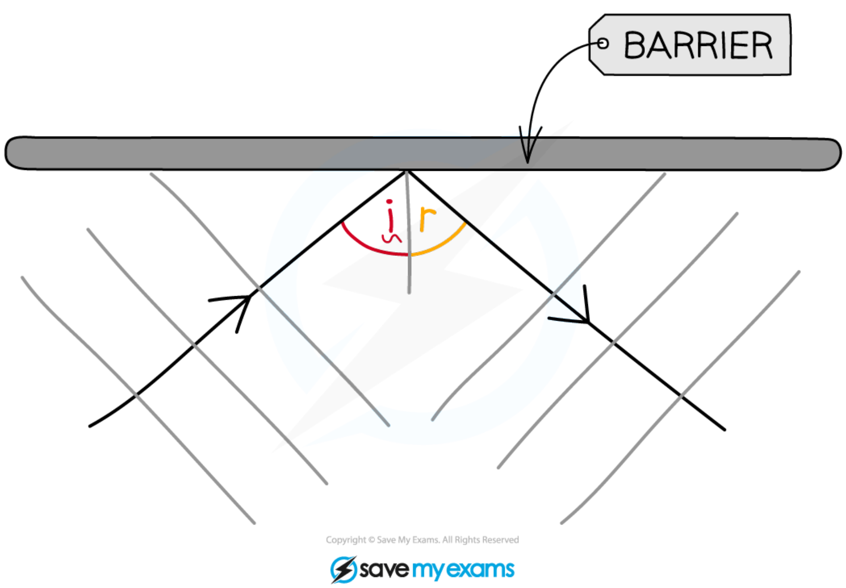
Reflection

- Reflection occurs when:
  A wave hits a boundary between two media and does not pass through, but instead stays in the original medium
- The law of reflection states:

The angle of incidence = The angle of reflection

- When waves hit an object, such as a barrier, they can be reflected:

Reflection

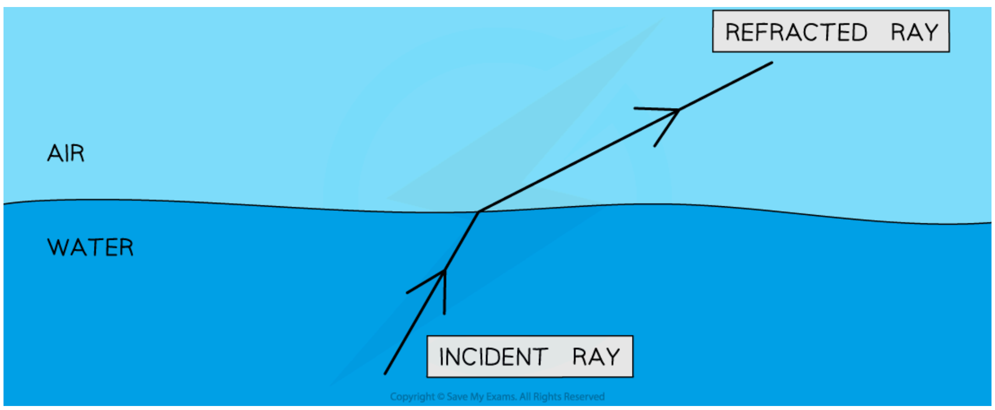


When waves reflect off a barrier, the angle of reflection, r, is equal to the angle of incidence, i

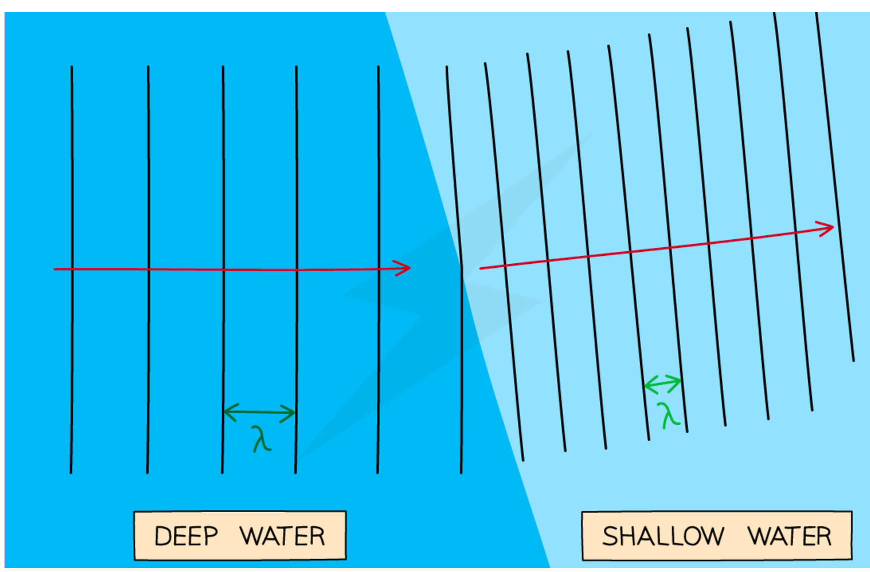
Refraction

- Refraction occurs when:
  A wave passes a boundary between two different transparent media and undergoes a change in direction
- When waves enter a different medium, their speed can change
- This effect is called **refraction**, and it can have two other effects:
  - The wavelength of the waves can increase or decrease
  - The waves can change direction

Refraction



Waves can change direction when moving between materials with different densities

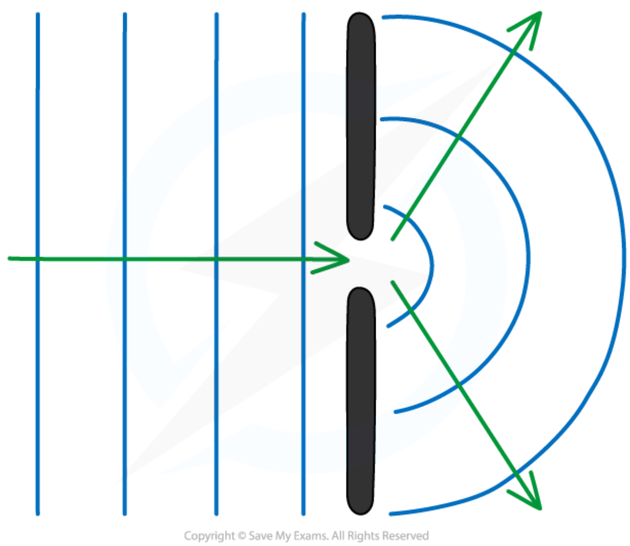


- If the waves **slow down**, the waves will bunch together, causing the wavelength to decrease
  - The waves will also start to turn slightly **towards** the normal
- If the waves **speed up** then they will spread out, causing the wavelength to increase
  - The waves will also turn slightly **away from** the normal

Diffraction

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

Diffraction

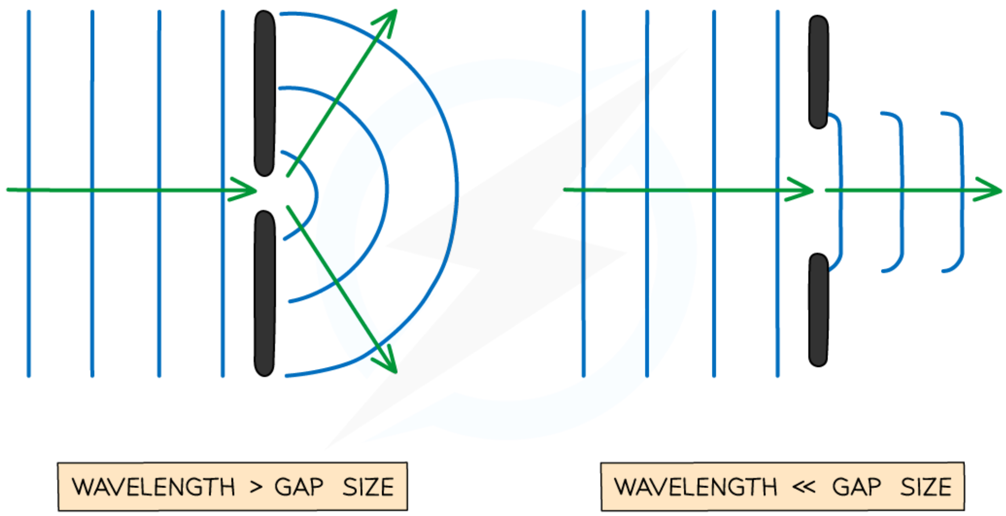


Diffraction: when a wave passes through a narrow gap, it spreads out

Factors Affecting Diffraction

- Diffraction, as shown above, only generally happens when the gap is smaller than the wavelength of the wave
- 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

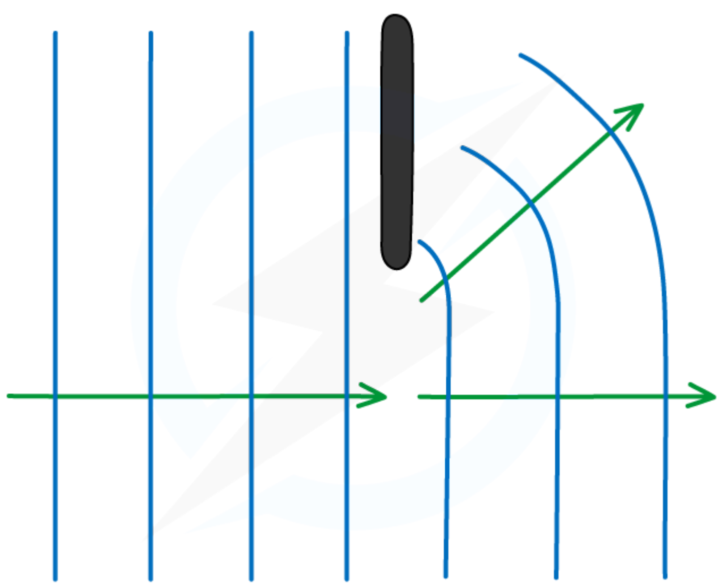
Diffraction and Gap Size



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

- Diffraction can also occur when waves pass an edge

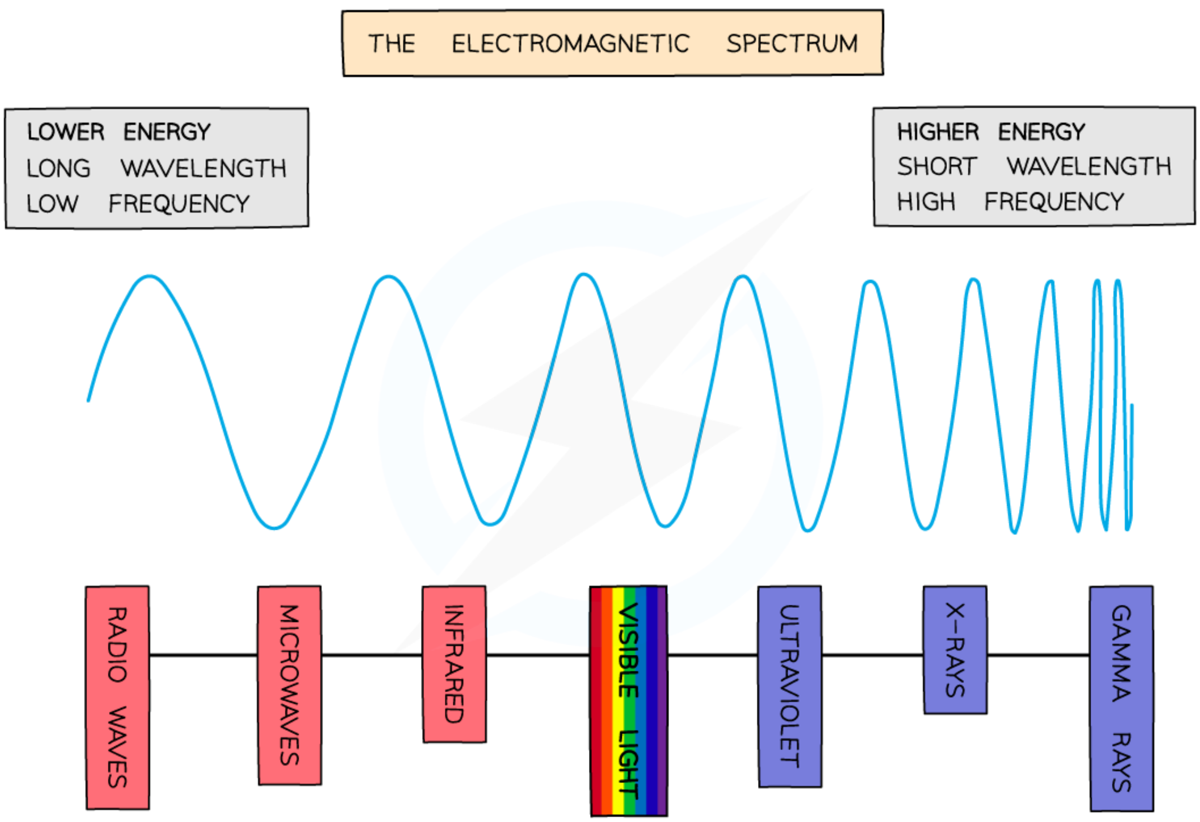
Diffraction around an Edge



When a wave goes past the edge of a barrier, the waves can curve around the edge

Electromagnetic Spectrum

Electromagnetic spectrum consists of 7 waves each having its own name and properties.



- All electromagnetic waves share several properties:
  - They are all transverse
  - They can all travel through a vacuum
  - All electromagnetic waves travel with the same high speed of *300000000 m/s* in a vacuum and approximately the same speed in air.

Uses of Electromagnetic Waves

- Electromagnetic waves have a large number of uses. The main ones are summarised in the table below.

WAVE	USE
RADIO	• COMMUNICATION (RADIO AND TV)
MICROWAVE	• HEATING FOOD • COMMUNICATION (WIFI, MOBILE PHONES, SATELLITES)
INFRARED	• REMOTE CONTROLS • FIBRE OPTIC COMMUNICATION • THERMAL IMAGING (MEDICINE AND INDUSTRY) • NIGHT VISION • HEATING OR COOKING THINGS • MOTION SENSORS (FOR SECURITY ALARMS)
VISIBLE LIGHT	• SEEING AND TAKING PHOTOGRAPHS/VIDEOS
ULTRAVIOLET	• SECURITY MARKING (FLUORESCENCE) • FLUORESCENT BULBS • GETTING A SUNTAN.
X-RAYS	• X-RAY IMAGES (MEDICINE, AIRPORT SECURITY AND INDUSTRY)
GAMMA RAYS	• STERILISING MEDICAL INSTRUMENTS TREATING CANCER

- Radio waves and microwaves
  - These two parts of the spectrum share a lot of similarities and uses. Their main uses concern wireless communication – in fact many things that people often assume use radio waves actually use microwaves (e.g. WiFi, radar, mobile phones, satellite communications…)
  - At very high intensity, microwaves can also be used to heat things: This is what happens in a microwave oven
- Infrared
  - Infrared is emitted by warm objects and can be detected using special cameras (thermal imaging cameras). These can be used in industry, in research and also in medicine
  - Many security cameras are capable of seeing slightly into the infrared part of the spectrum and this can be used to allow them to see in the dark: Infrared lights are used to illuminate an area without being seen, which is then detected using the camera
  - Remote controls also have small infrared LEDs that can send invisible signals to an infrared receiver on a device such as a TV
  - Infrared travels down fibre optic cables more efficiently than visible light, and so most fibre optic communication systems use infrared
- Ultraviolet
  - Ultraviolet is responsible for giving you a suntan, which is your body's way of protecting itself against the ultraviolet
  - When certain substances are exposed to ultraviolet, they absorb it and re-emit it as visible light (making them glow). This process is known as fluorescence
  - Fluorescence can be used to secretly mark things using special ink – in fact most bank notes have invisible fluorescent markings on them
  - Fluorescent light bulbs also use this principle to emit visible light
- X-rays
  - The most obvious use of x-rays is in medicine. X-rays are able to pass through most body tissues, but are absorbed by the denser parts of the body, such as bones. When exposed to x-rays, bones create a shadow which can be seen using a special x-ray detector or using photographic film

- Gamma rays
  - Gamma rays are very dangerous and can be used to kill cells and living tissue
    If the gamma rays are carefully aimed at cancerous tissue they can be very effective at killing it
    Gamma rays can also be used to sterilise things by killing off the bacteria

Dangers

- Electromagnetic Waves can have some harmful side effects. In particular:

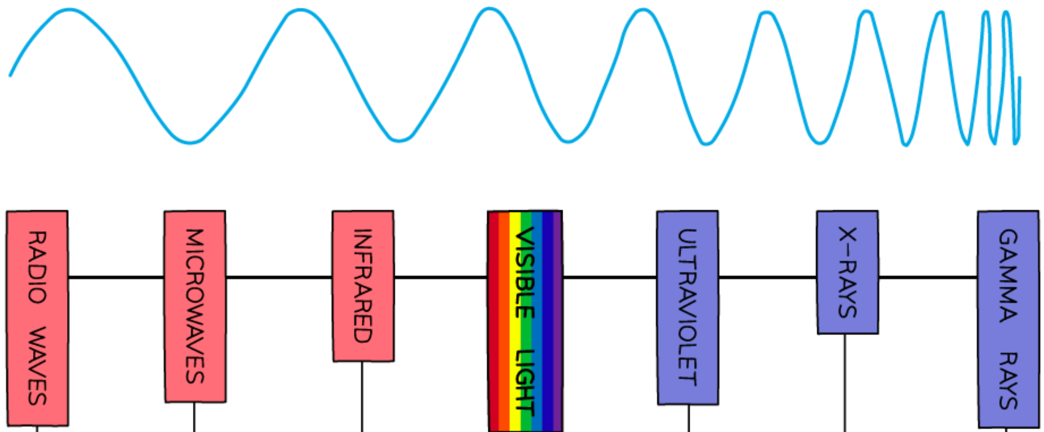
Microwaves

- High levels of microwaves can cause heating of internal organs. (Although there is no evidence that the levels emitted by mobile phones or WiFi devices cause any harm)

X-Rays

- X-rays, Gamma rays and (to a lesser extent) ultra-violet are all ionising. This means that they can cause harm to living tissues: killing cells or possibly mutating them or causing cancer
- Whilst the levels used in most medical x-rays pose a minimum risk, hospitals are careful to minimise the amount of x-ray exposure that individuals (including hospital staff) receive

THE ELECTROMAGNETIC SPECTRUM
SUMMARY OF USES AND DANGERS



RADIO WAVES

USE: USED FOR LONG-RANGE COMMUNICATIONS

REASON: BECAUSE THEY CAN BE REFLECTED FROM THE EARTH'S ATMOSPHERE

MICROWAVES

USE: SATELLITE COMMUNICATIONS

REASON: BECAUSE MICROWAVES CAN PENETRATE EARTH'S ATMOSPHERE

INFRARED

USE: OPTICAL FIBRE COMMUNICATION

REASON: BECAUSE THEY CAN UNDERGO TOTAL INTERNAL REFLECTION

VISIBLE LIGHT

USE: TAKING PHOTOS AND VIDEOS

REASON: CAMERAS ARE SET UP TO DETECT VISIBLE LIGHT

ULTRAVIOLET

USE: FOR DETECTING SECURITY INK

REASON: BECAUSE IT FLUORESCES WITH ULTRAVIOLET LIGHTING

X-RAYS

USE: TO PHOTOGRAPH BONES

REASON: BECAUSE X-RAYS CAN PENETRATE SOFT TISSUES BUT NOT BONE

GAMMA RAYS

USE: TO STERILISE MEDICAL TOOLS

REASON: BECAUSE GAMMA KILLS BACTERIA

DANGER: HIGH INTENSITY MICROWAVES CAN CAUSE HEATING OF INTERNAL ORGANS

REASON: WATER MOLECULES ABSORB MICROWAVES STRONGLY

DANGER: GAMMA X-RAYS AND HIGH INTENSITY UV CAN HARM CELLS AND CAUSE CANCER

REASON: THEY ARE HIGHLY IONISING DUE TO HAVING A LOT OF ENERGY

Videos

Reflection of waves in a ripple tank:

https://youtu.be/iGuUKRmytLw?si=TMqMSFHmURcostnq

Refraction of waves in a ripple tank:

https://youtu.be/7wfEczDapHA?si=m52FmlxJNIiS_XlH

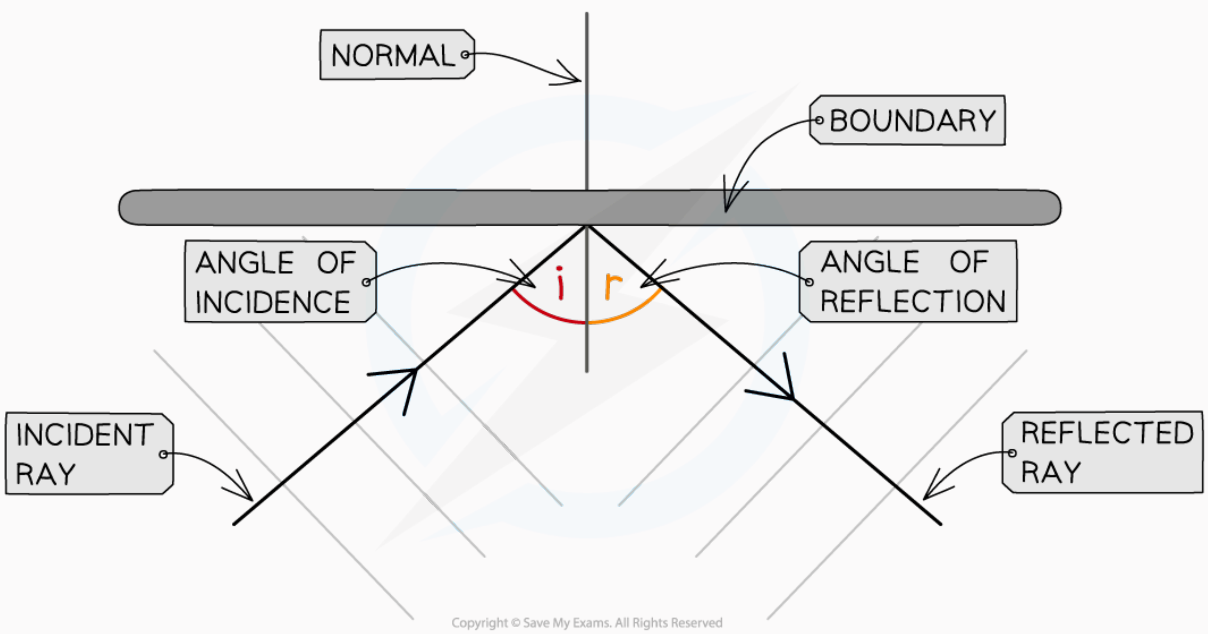
Diffraction of waves in a ripple tank:

https://youtu.be/KSIg_EaIFrw?si=smiaUKLJJYpidzYy

Ray Diagrams

- Angles are measured between the wave direction (ray) and a line at 90 degrees to the boundary
  - The angle of the wave approaching the boundary is called the angle of incidence (i)
  - The angle of the wave leaving the boundary is called the angle of reflection (r)
- The line at right angles (90°) to the boundary is known as the normal
- When drawing a ray diagram an arrow is used to show the direction the wave is travelling
  - An incident ray has an arrow pointing towards the boundary
  - A reflected ray has an arrow pointing away from the boundary
- The angles of incidence and reflection are usually labelled i and r respectively

Reflection



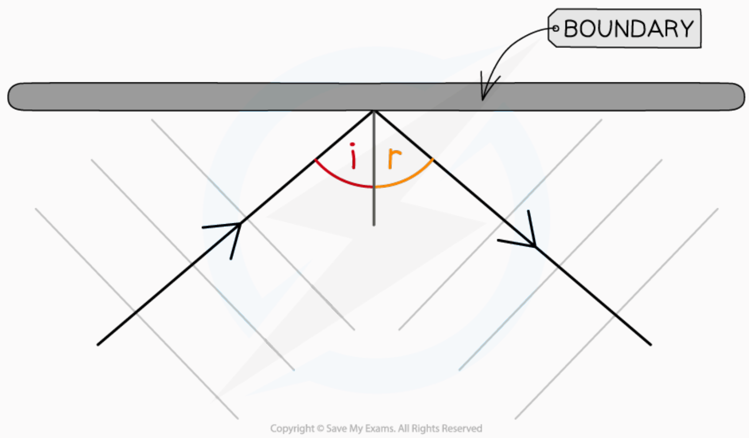
A ray diagram for light reflecting at a boundary, showing the normal, angle of incidence and angle of reflection

The Law of Reflection

- The law of reflection states that these angles are the same:

Angle of incidence (i) = Angle of reflection (r)

Law of Reflection



Reflection of a wave at a boundary, i = r

Virtual Images

- A virtual image is defined as:
  An image that is formed when the light rays from an object do not meet but appear to meet behind the lens and cannot be projected onto a screen
- A virtual image is formed by the divergence of light away from a point
- Virtual images are always upright
- Virtual images cannot be projected onto a piece of paper or a screen
  - An example of a virtual image is a person's reflection in a mirror

Virtual Image in a Reflection

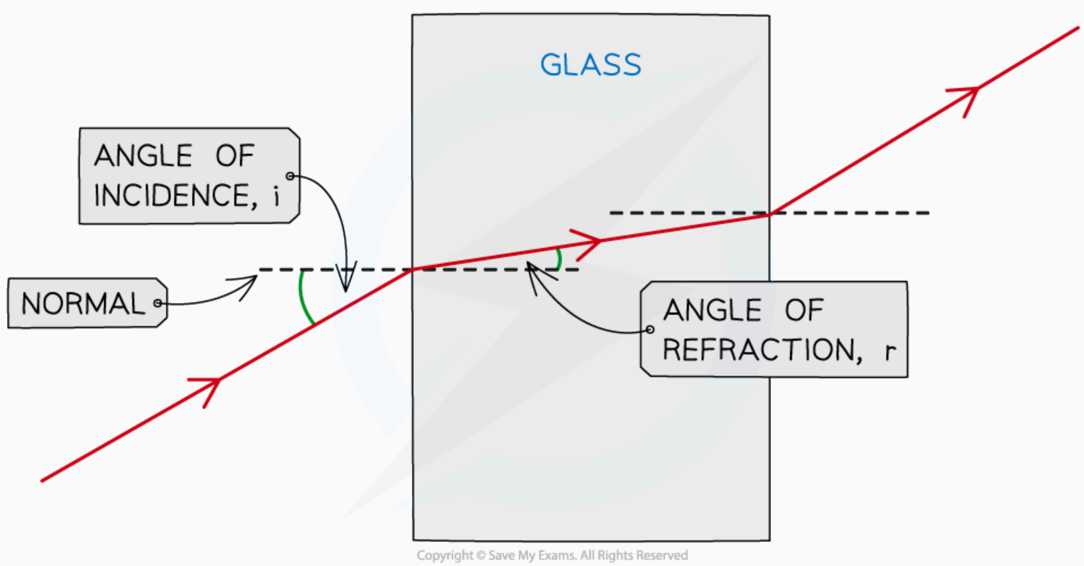
Refractive Index & Snell's Law

Refractive Index

- The refractive index is a number which is related to the speed of light in the material (which is always less than the speed of light in a vacuum):
- The refractive index is a number that is always larger than 1 and is different for different materials
    - Objects which are more optically dense have a higher refractive index, eg. *n* is about 2.4 for diamond
    - Objects which are less optically dense have a lower refractive index, eg. *n* is about 1.5 for glass
- Since refractive index is a ratio, it has no units

Snell's Law

- When light enters a denser medium (such as glass) it slows down and bends towards the normal
    - How much the light bends depends on the density of the material



Angle of incidence i and angle of refraction r through a glass block

- If light travels from a less dense to a more dense medium (e.g. air to glass), *r* < i (bends towards the normal)
- If light travels from a more dense to a less dense medium (e.g. glass to air), *r* > i (bends away from the normal)

- The angles of incidence and refraction are related by an equation known as Snell's Law:

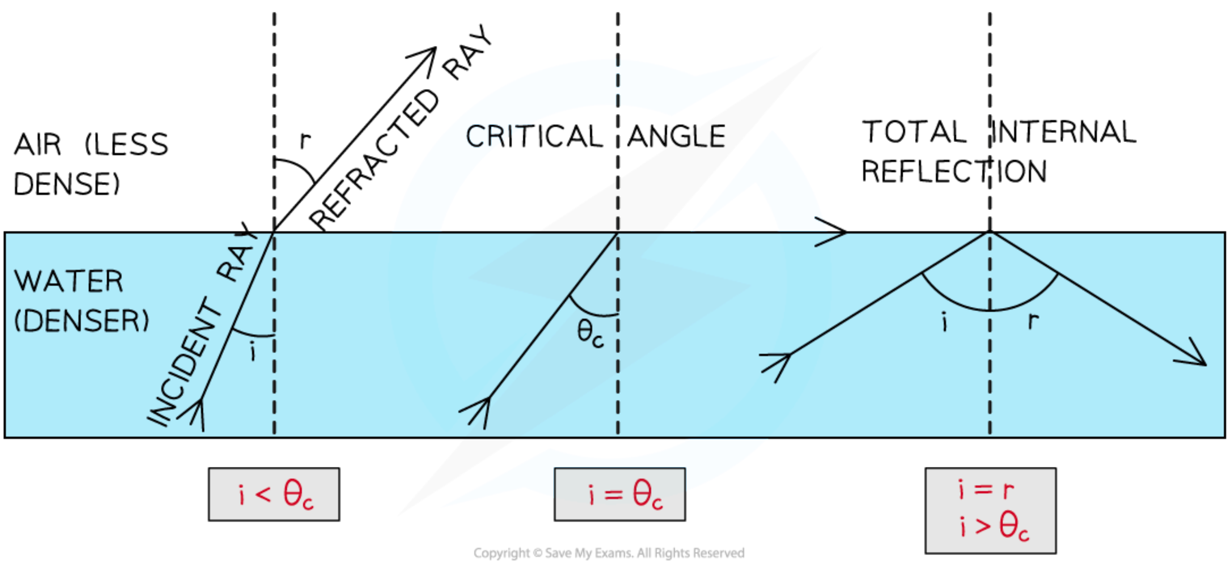
$$n = \sin i / \sin r$$

- Where:
  - n = the refractive index of the material
  - i = angle of incidence of the light (°)
  - r = angle of refraction of the light (°)
- 'Sin' is the trigonometric function 'sine' which is on a scientific calculator

Total Internal Reflection

- Sometimes, when light is moving from a denser medium towards a less dense one, instead of being refracted, all of the light is reflected
    - This phenomenon is called total internal reflection
- Total internal reflection (TIR) occurs when:
  The angle of incidence is greater than the critical angle and the incident material is denser than the second material
- Therefore, the two conditions for total internal reflection are:
    - The angle of incidence > the critical angle
    - The incident material is denser than the second material

Critical Angle and TIR



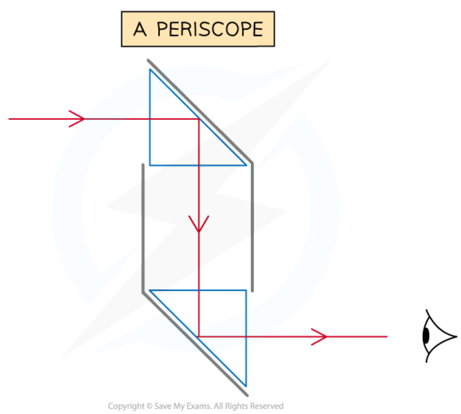
TIR occurs when the angle of incidence is greater than the angle of reflection

- Total internal reflection is utilised in:
    - Optical fibres e.g. endoscopes
    - Prisms e.g. periscopes

Prisms

- Prisms are used in a variety of optical instruments, including:
    - Periscopes
    - Binoculars
    - Telescopes
    - Cameras
-
- They are also used in safety reflectors for bicycles and cars, as well as posts marking the side or edge of roads

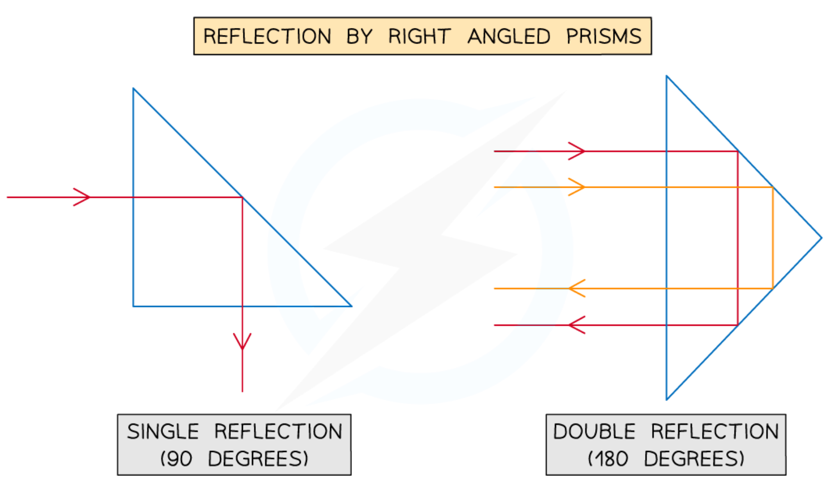
- A periscope is a device that can be used to see over tall objects
    - It consists of two right-angled prisms



Reflection of light through a periscope

- The light totally internally reflects in both prisms

Internal Reflection in Prisms



Refractive Index & Critical Angle Equation

- The critical angle, *c*, of a material is related to its refractive index, *n*
- The relationship between the two quantities is given by the equation:

$$\sin c = 1/n$$

- This can also be rearranged to calculate the refractive index, *n*:

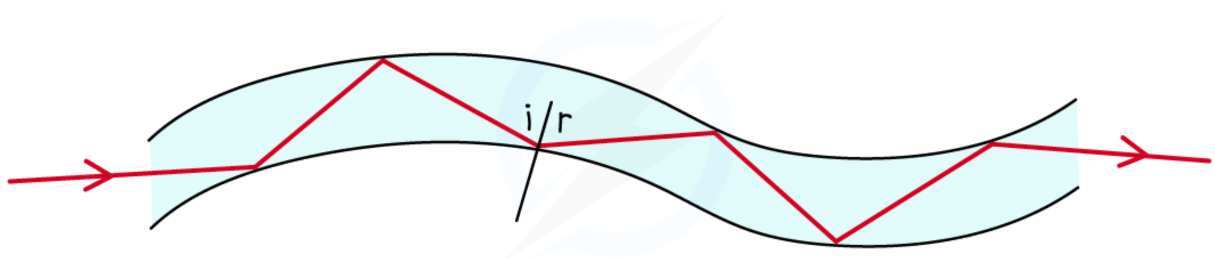
$$n = 1/\sin c$$

- This equation shows that:
  - The larger the refractive index of a material, the smaller the critical angle
  - Light rays inside a material with a high refractive index are more likely to be totally internally reflected

Optical Fibres

- Total internal reflection is used to reflect light along optical fibres, meaning they can be used for
  - Communications
  - Endoscopes
  - Decorative lamps
- Light travelling down an optical fibre is totally internally reflected each time it hits the edge of the fibre
- This means information can be transmitted over long distances with minimal loss

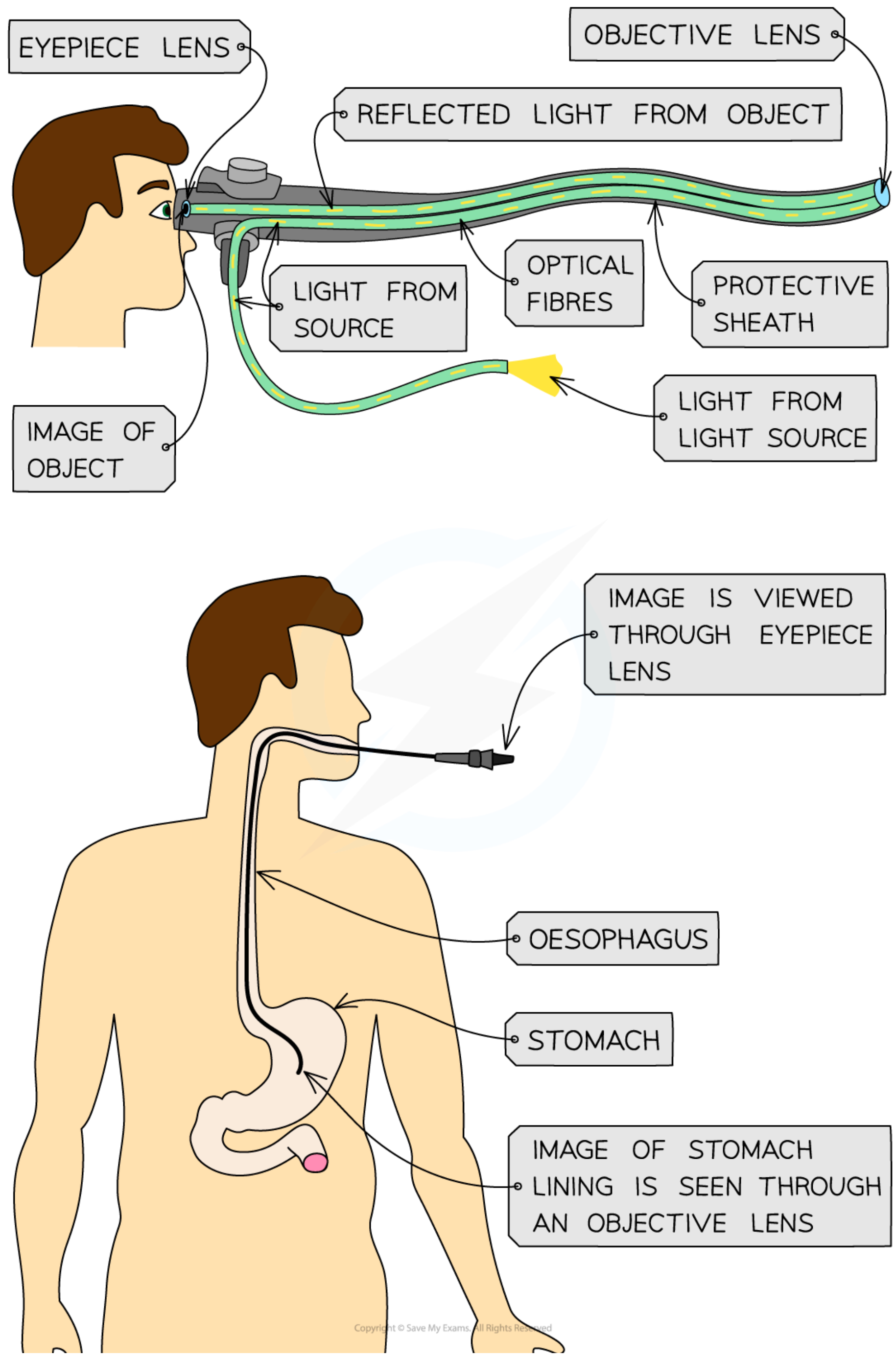
Total Internal Reflection in an Optical Fibre



Optical fibres utilise total internal reflection for communications

- Optical fibres are also used in medicine in order to see within the human body

Optical Fibres in Medicine



Endoscopes utilise total internal reflection to see inside a patient's body

Features of Lens Diagrams

- Lens diagrams can be described using the following terms:
  - Principal axis
  - Principal focus, or focal point
  - Focal length
- The principal axis is defined as:
  A line which passes through the centre of a lens
- The principal focus, or focal point, is defined as:
  The point at which rays of light travelling parallel to the principal axis intersect the principal axis and converge or the point at which diverging rays appear to proceed
- Focal length is defined as:
  The distance between the centre of the lens and the principal focus

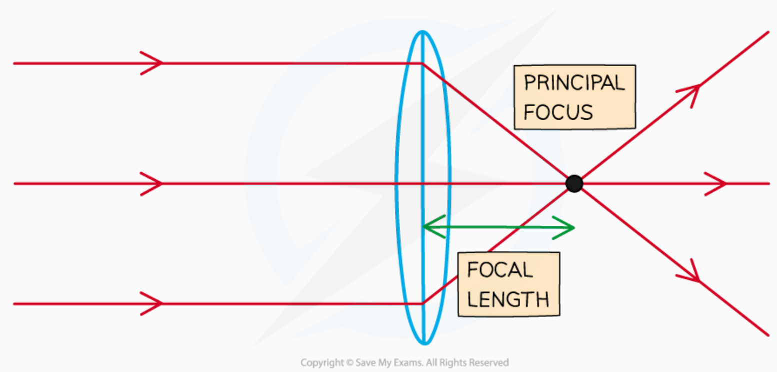
Converging & Diverging Lenses

- A lens is a piece of equipment that forms an image by refracting light
- There are two types of lens:
  - Converging
  - Diverging

Converging Lenses

- In a converging lens, parallel rays of light are brought to a focus
  - This point is called the principal focus
- This lens is sometimes referred to as a convex lens
- The distance from the lens to the principal focus is called the focal length
  - This depends on how curved the lens is
  - The more curved the lens, the shorter the focal length

Converging Lens

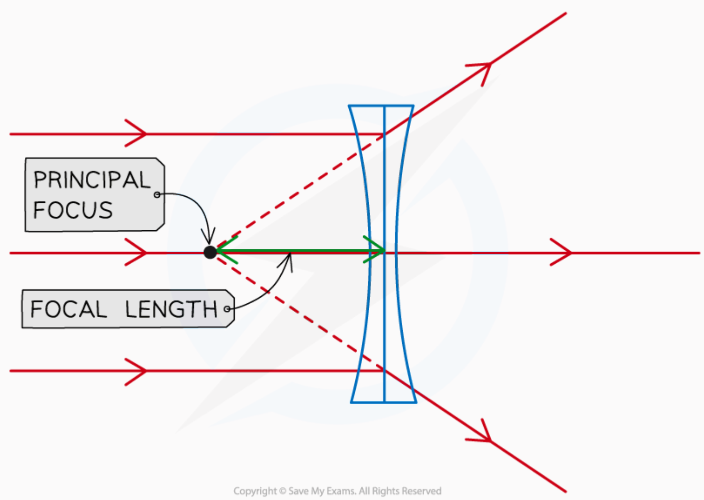


The focal length is the distance from the lens to the principal focus. In a converging lens, parallel light rays converge on the principal focus.

Diverging Lenses

- In a diverging lens, parallel rays of light are made to diverge (spread out) from a point
    - This lens is sometimes referred to as a concave lens
- The principal focus is now the point from which the rays appear to diverge from

Diverging Lens

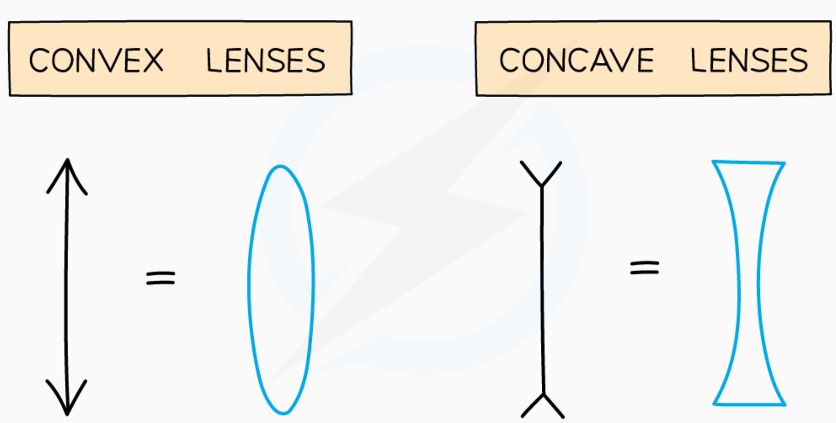


Parallel rays from a diverging lens appear to diverge from the principal focus

Representing Lenses

- In diagrams, the following symbols are often used to represent each type of lens:

Symbols for Lenses



Real & Virtual Images

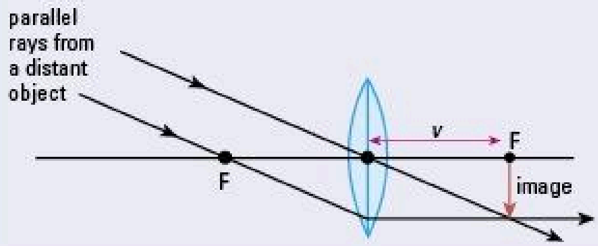
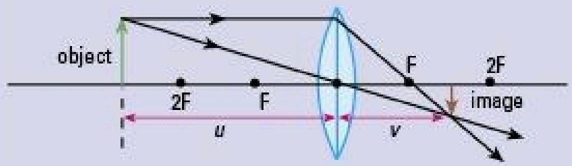
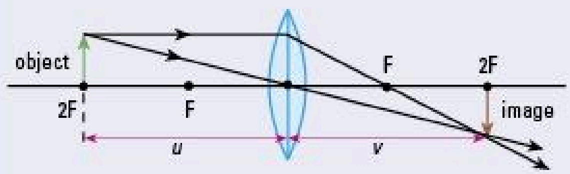
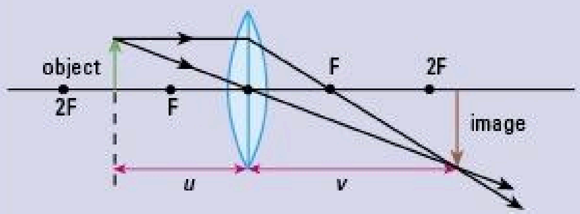
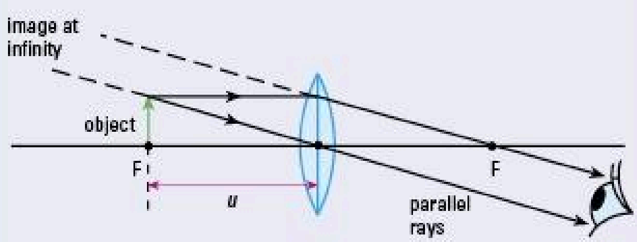
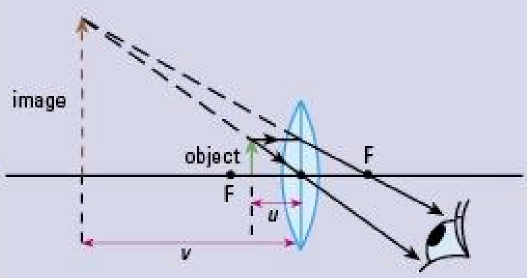
- Images produced by lenses can be one of two types:
    - A real image
    - A virtual image

Real Images

- A real image is defined as:
  An image that is formed when the light rays from an object converge and meet each other and can be projected onto a screen
- A real image is one produced by the convergence of light towards a focus
- Real images are always inverted
- Real images can be projected onto pieces of paper or screens
    - An example of a real image is the image formed on a cinema screen

Virtual Images

- A virtual image is defined as:
  An image that is formed when the light rays from an object do not meet but appear to meet behind the lens and cannot be projected onto a screen
- A virtual image is formed by the divergence of light away from a point
- Virtual images are always upright
- Virtual images cannot be projected onto a piece of paper or a screen
    - An example of a virtual image is a person's reflection in a mirror

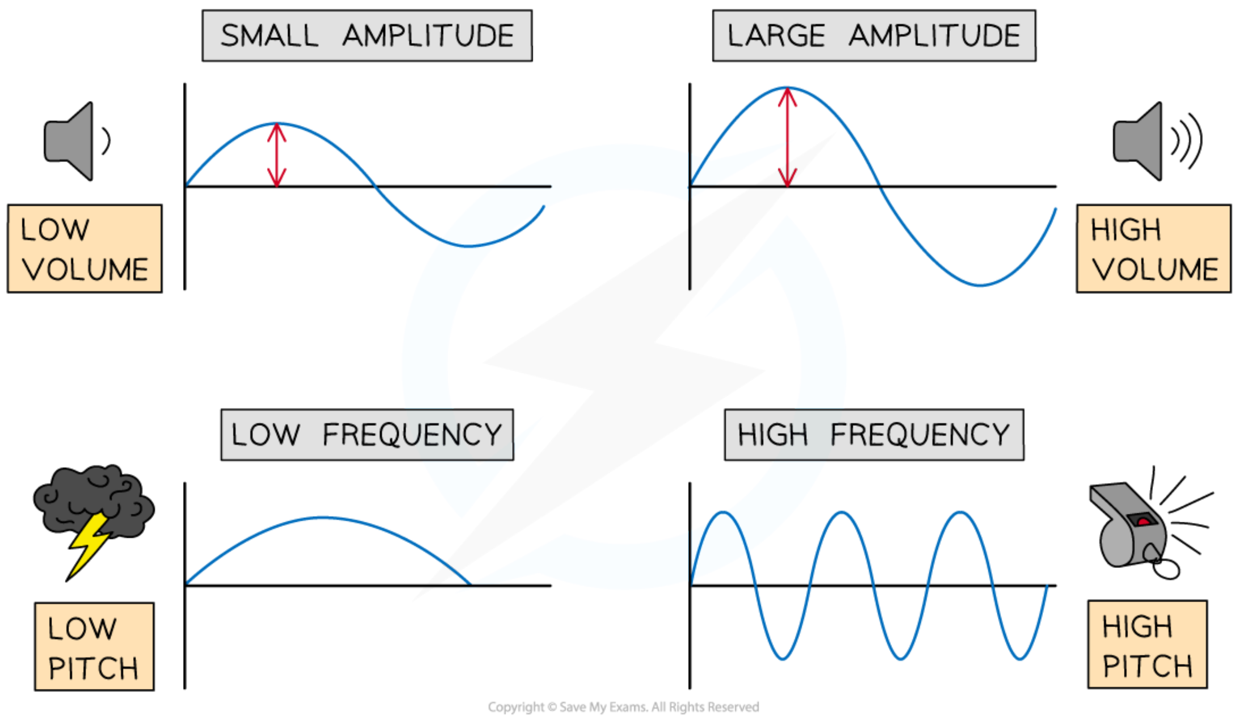
Object distance (u)	Ray diagram	Type of image	Image distance (v)	Uses
$u = \infty$		- inverted - real - diminished	$v = f$ - opposite side of the lens	- object lens of a telescope
$u > 2f$		- inverted - real - diminished	$f < v < 2f$ - opposite side of the lens	- camera - eye
$u = 2f$		- inverted - real - same size	$v = 2f$ - opposite side of the lens	- photocopier making same-sized copy
$f < u < 2f$		- inverted - real - magnified	$v > 2f$ - opposite side of the lens	- projector - photograph enlarger
$u = f$		- upright - virtual - magnified	- image at infinity - same side of the lens	- to produce a parallel beam of light, e.g. a spotlight
$u < f$		- upright - virtual - magnified	- image is behind the object - same side of the lens	- magnifying glass

Sound

Pitch & Loudness

- The frequency of a sound wave is related to its pitch
  - Sounds with a high pitch have a high frequency (or short wavelength)
  - Sounds with a low pitch have a low frequency (or long wavelength)
- Sounds with a large amplitude have a high volume
  - Sounds with a small amplitude have a low volume The amplitude of a sound wave is related to its volume

Graphs of Different Amplitudes & Frequencies



The amplitude of a wave determines the volume of the sound and the frequency determines the pitch

Investigating Sound in a Vacuum

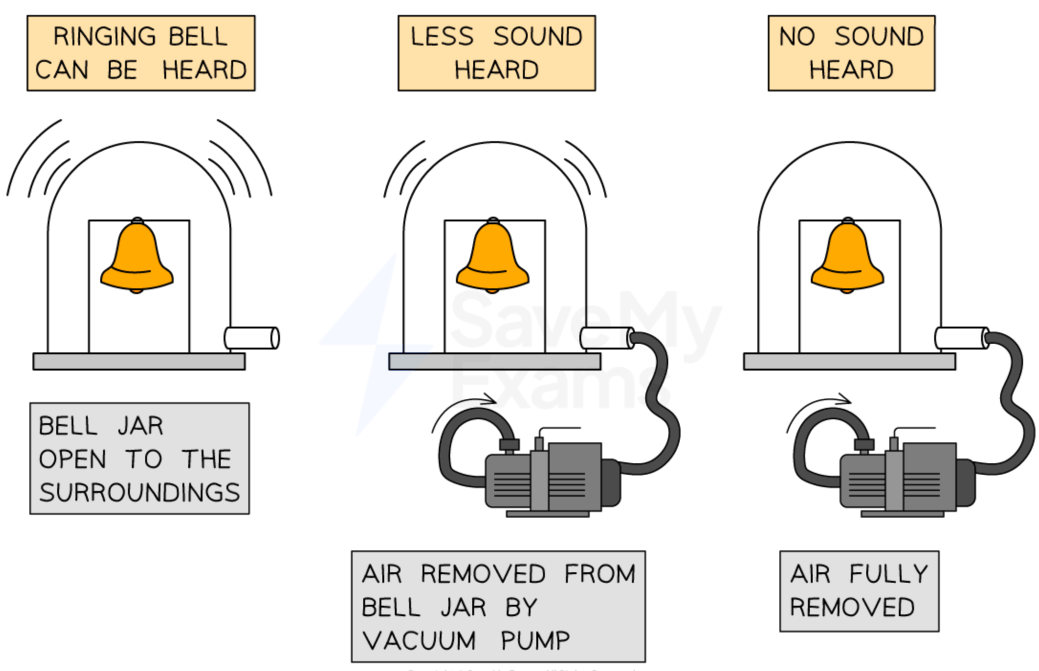
Sound Waves in a Vacuum

- Sound waves are **longitudinal** waves
  - All longitudinal waves require a **medium** through which to travel
- A vacuum is a region of space that does not contain air (or any other matter)
  - This means that, in a vacuum, there is no medium for sound waves
  - So sound waves **cannot** travel in a **vacuum**

Using a Bell Jar

- This can be easily demonstrated using a piece of equipment called a **bell jar**
  - This is a glass container from which air can be pumped out, creating a vacuum (or nearly a vacuum)
- A sound-emitting object is used, such as a battery-operated ringing bell or alarm
- This is placed in a bell jar, which still contains air
  - The ringing bell can be heard despite the bell jar's glass walls
- However, as the air begins being pumped out, the volume of the sound heard starts decreasing
- When the air is completely removed from the bell jar, the ringing bell cannot be heard at all

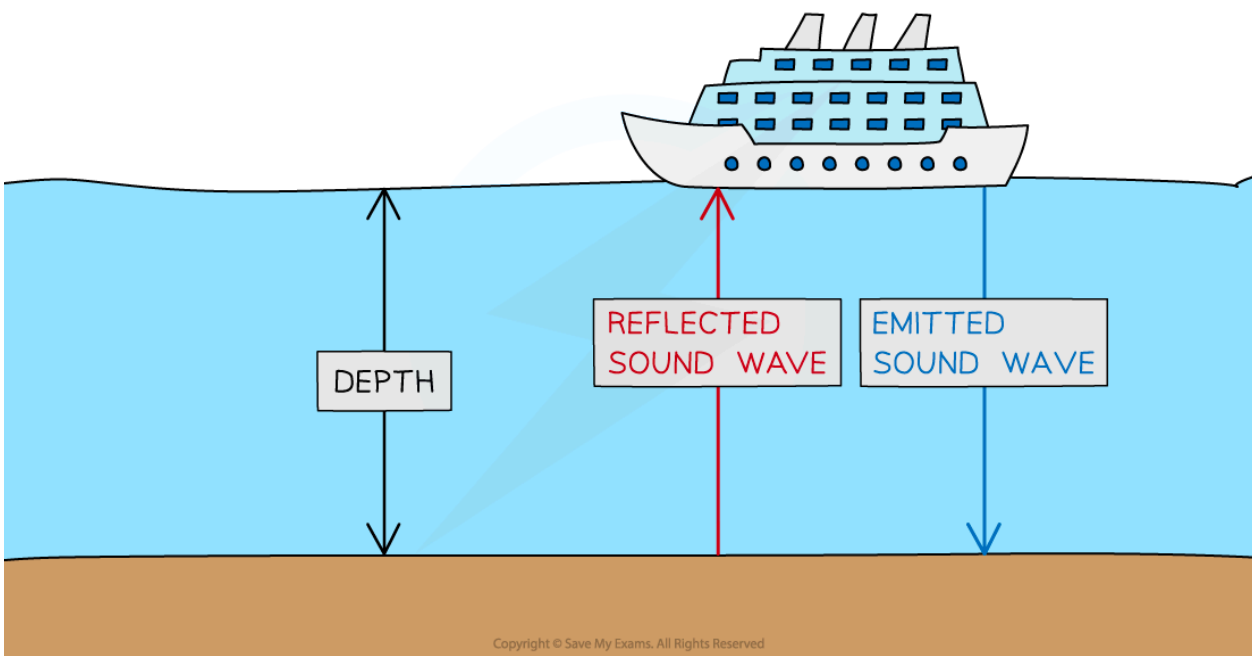
Sound in a Bell Jar Demonstration



Echoes

- Sound waves **reflect** off hard surfaces
    - The reflection of a sound wave is called an **echo**
- Echo sounding can be used to measure depth or to detect objects underwater
    - A sound wave can be transmitted from the surface of the water
    - The sound wave is reflected off the bottom of the ocean
- The time it takes for the sound wave to return is used to calculate the depth of the water
    - This is the distance to the ocean floor plus the distance for the wave to return
    - The distance the wave travels is twice the depth of the ocean

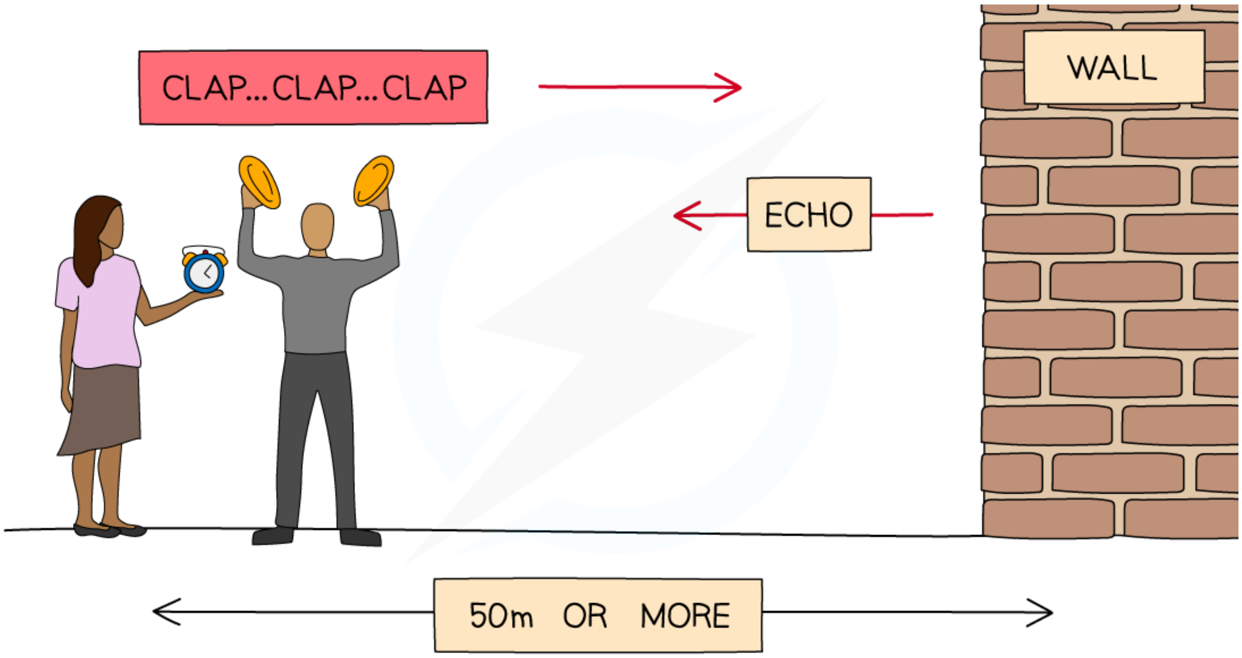
Ship using Radar



Echo sounding is used to determine water depth

Investigating the Reflection of Sound Waves

Using Echoes to Measure the Speed of Sound

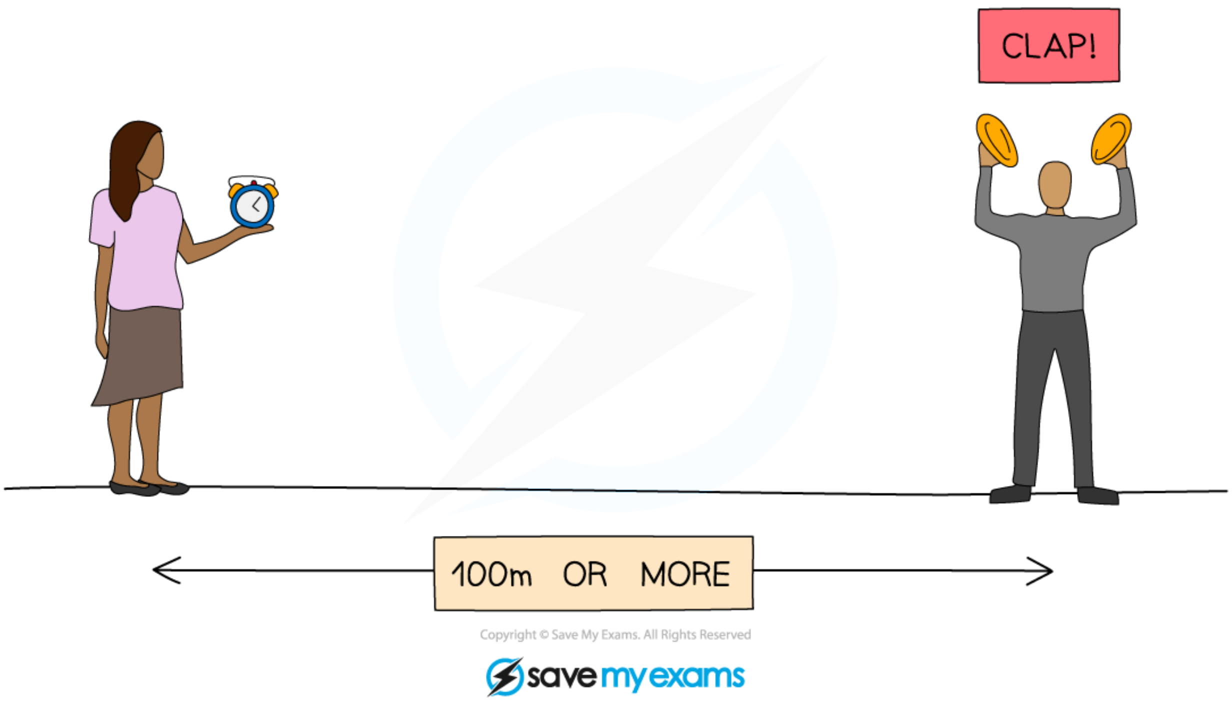


Measuring the speed of sound using echoes

1. A person stands about 50 m away from a wall (or cliff) using a **trundle wheel** to measure this distance
2. The person claps **two wooden blocks** together and listens for the echo
3. A second person has a **stopwatch** and starts timing when they hear one of the claps and stops timing when they hear the echo
4. The process is then repeated 20 times and an average time calculated
5. The distance travelled by the sound between each clap and echo will be (2 × 50) m
6. The speed of sound can be calculated from this distance and the time using the equation:

Speed of sound = 2 x distance / time

Measuring the Speed of Sound Using a Loud Noise



Measuring the speed of sound directly between two points

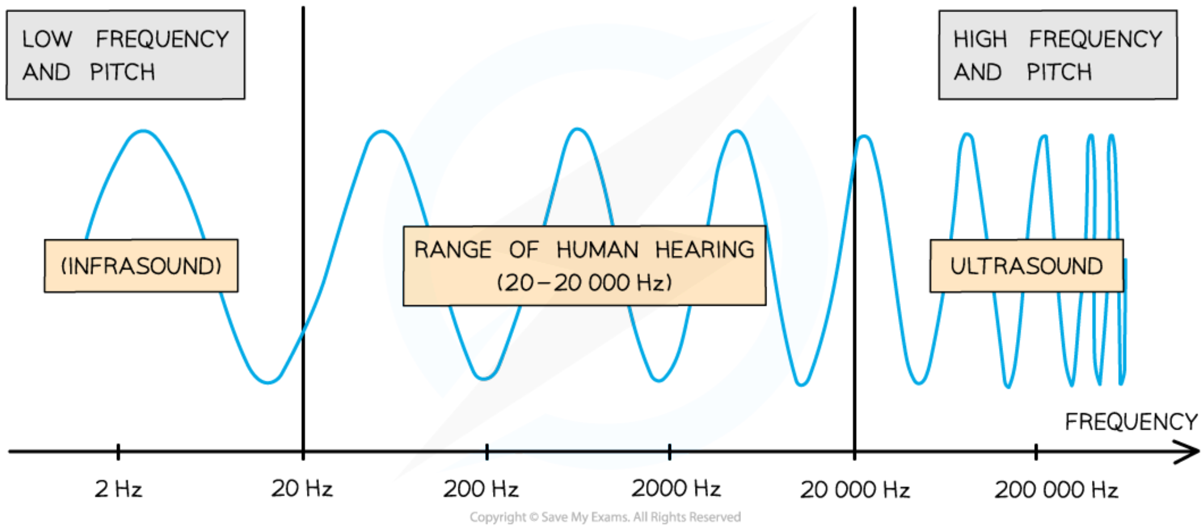
1. Two people stand a distance of around 100 m apart
2. The distance between them is measured using a **trundle wheel**
3. One person has **two wooden blocks**, which they bang together above their head
4. The second person has a **stopwatch** which they start when they see the first person banging the blocks together and stops when they hear the sound
5. This is then repeated several times and an average value is taken for the time
6. The speed of sound can then be calculated using the equation:

Speed = distance/time

Ultrasound

- Humans can hear sounds between about 20 Hz and 20 000 Hz in frequency (although this range decreases with age)

Infrasound & Ultrasound



Humans can hear sounds between 20 and 20 000 Hz

- **Ultrasound** is the name given to sound waves with a frequency greater than 20000 Hz

Uses of Ultrasound

- When ultrasound reaches a boundary between two media, some of the waves are partially reflected
- The remainder of the waves continue through the material and are transmitted
- Ultrasound transducers are able to:
    - **Emit** ultrasound
    - **Receive** ultrasound
- The time taken for the reflections to reach a detector can be used to determine how far away a boundary is
    - This is because ultrasound travels at different speeds through different media
- This is by using the speed, distance, time equation

S = d/t

- Where:
    - v = speed in metres per second (m/s)
    - s = distance in metres (m)
    - t = time in seconds (s)
- This allows ultrasound waves to be used for both **medical** and **industrial** imaging

Ultrasound in Medicine

- In medicine, ultrasound can be used:
    - To construct images of a **foetus** in the womb
    - To generate 2D images of **organs** and other internal structures (as long as they are **not** surrounded by bone)
    - As a medical **treatment** such as removing kidney stones
- An ultrasound detector is made up of a **transducer** that produces and detects a beam of ultrasound waves into the body
- The ultrasound waves are reflected back to the transducer by **boundaries** between tissues in the path of the beam
    - For example, the boundary between fluid and soft tissue or tissue and bone
- When these echoes hit the transducer, they generate electrical signals that are sent to the ultrasound scanner
- Using the speed of sound and the time of each echo's return, the detector calculates the distance from the transducer to the tissue boundary
- By taking a series of ultrasound measurements, sweeping across an area, the time measurements may be used to build up an **image**
- Unlike many other medical imaging techniques, ultrasound is **non-invasive** and is believed to be **harmless**

Ultrasound in Industry

- In industry, ultrasound can be used to:
    - Check for cracks inside metal objects
    - Generate images beneath surfaces
- A crack in a metal block will cause some waves to reflect earlier than the rest, so will show up as pulses on an oscilloscope trace
    - Each pulse represents each time the wave crosses a boundary
- The speed of the waves is constant, so measuring the time between emission and detection can allow the distance from the source to be calculated