Cambridge (CIE) IGCSE Physics

Your notes

Sound

Contents

- Sound Waves
- Measuring the Speed of Sound
- Effects of Sound Waves
- Ultrasound

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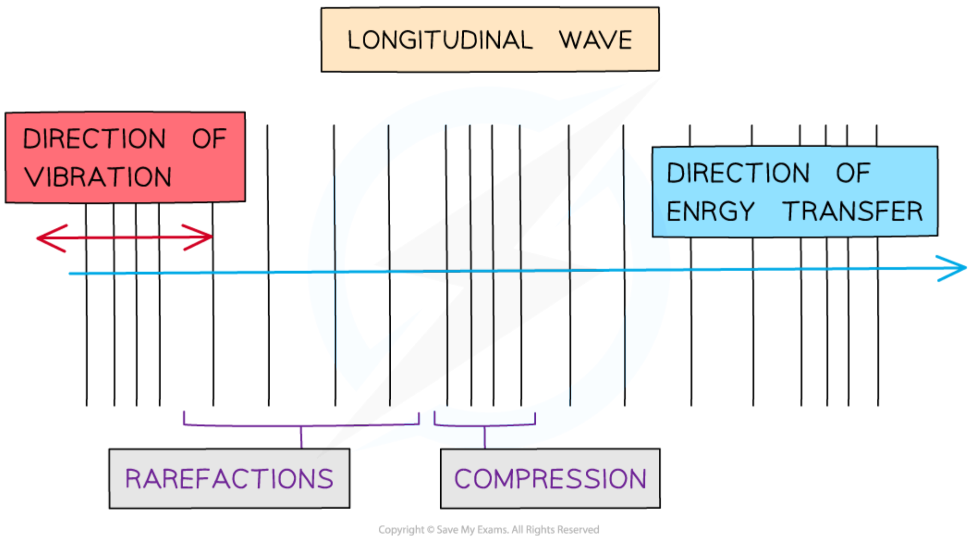
Describing sound

- Sound waves are produced by **vibrating** sources
- Sound waves are Longitudinal
  - So a **medium** is needed to transmit sound waves
  - This means if there are no molecules, such as in a **vacuum**, then the sound can't travel through it
- When a sound wave comes into contact with a solid, the longitudinal wave vibrations are **transferred** to the solid
  - For example, sound waves can cause a drinking glass to vibrate
  - If the glass vibrates too much the movement causes the glass to shatter

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**

Representing a longitudinal wave with compression and rarefaction



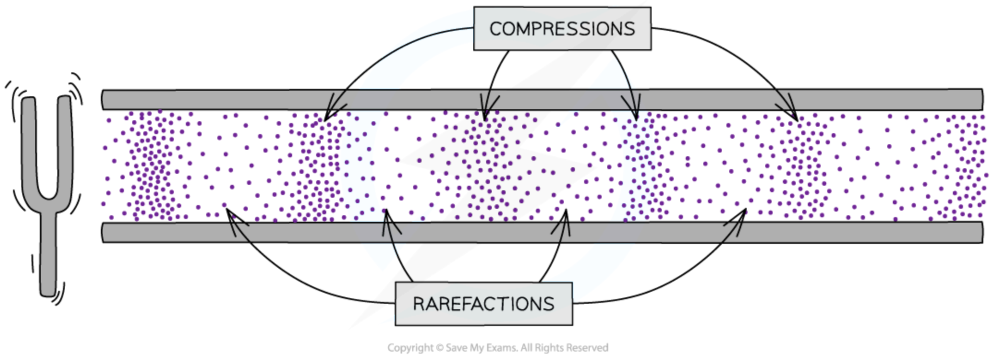
Longitudinal waves are represented as sets of lines with rarefactions and compressions

Compression & rarefaction

Extended tier only

- Longitudinal waves consist of compressions and **rarefactions**:
  - A **compression** is a region of higher density i.e. a place where the molecules are bunched together
  - A **rarefaction** is a region of lower density i.e. a place where the molecules are spread out

Compression and rarefaction



Sound is a longitudinal wave consisting of compressions and rarefactions – these are areas where the pressure of the air in the pipe varies with the wave

- These compressions and rarefactions cause changes in pressure, which vary in time with the wave
  - Therefore, sound is a type of **pressure wave**
- When the waves hit a solid, the variations in pressure cause the surface of the solid to **vibrate** in sync with the sound wave

Compression and rarefaction in contact with a solid

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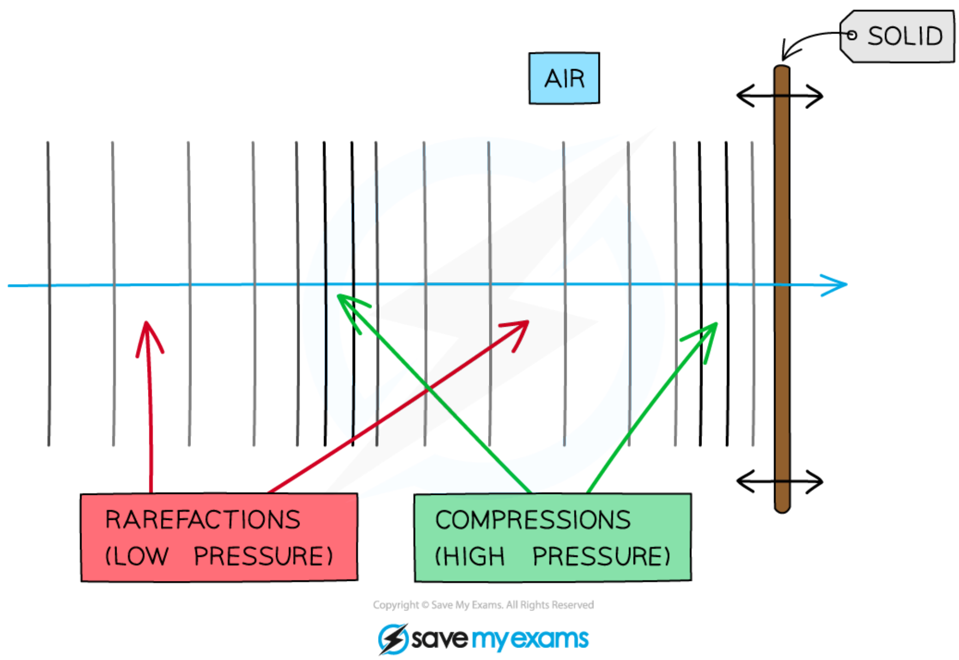

When sound waves hit a solid, the fluctuating pressure causes the solid to vibrate

Examiner Tips and Tricks

When describing compressions and rarefactions, make sure to use the correct terms. It is best to refer to them as regions of high and low densities of particles instead of the particles are more 'bunched up' or 'far apart', as this is too vague and not very scientific!

Your notes

Measuring the Speed of Sound

Your notes

Speed of sound in air

- The speed of sound in air varies from **330 – 350 m/s**
  - The **higher** the air **temperature**, the **greater** the **speed** of sound

Speed of sound in materials

Extended tier only

- Sound travels at different speeds in different media:
  - Sound travels **fastest in solids**
  - Sound travels **slowest in gases**
- Sound travels at:
  - Around 1500 m/s in liquids
  - Around 5000 m/s in solids

Measuring the speed of sound

Equipment

Equipment list

Equipment	Purpose
Trundle Wheel	To measure the distance travelled by the sound waves
Wooden Blocks	To create a sound when banged together
Stopwatch	To time how long it takes the sound waves to travel
Oscilloscope	To display the sound wave electronically
Microphones x2	To detect sound waves and turn them into an electrical signal
Tape Measure	To measure the distance between microphones

- **Resolution** of measuring equipment:
  - Trundle wheel = 0.01 m
  - Tape measure = 0.1 cm

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- Stopwatch = 0.01 s

Experiment 1: measuring the speed of sound between two points

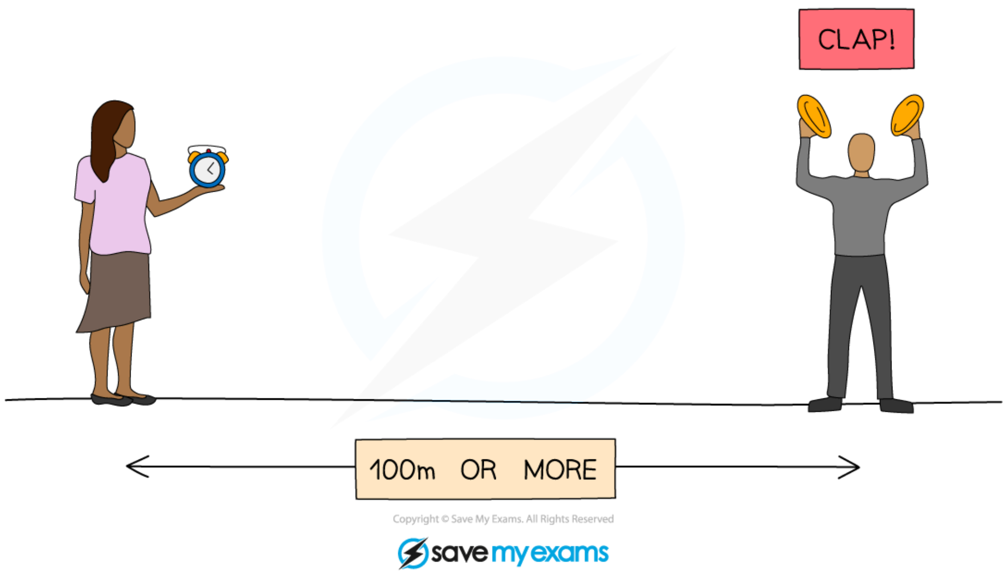
- This experiment aims to measure the speed of sound in air between two points

Variables

- **Independent variable** = Distance
- **Dependent variable** = Time
- Control variables:
  - Same location to carry out the experiment

Method

Measuring the speed of sound in air



Measuring the speed of sound directly between two points

1. Use the trundle wheel to measure a distance of 100 m between two people
2. One of the people should have two wooden blocks, which they will bang together above their head to generate sound waves
3. The second person should have a stopwatch which they start when they see the first person banging the blocks together and stop when they hear the sound
4. This should be repeated several times and an average taken for the time travelled by the sound waves
5. Repeat this experiment for various distances, e.g. 120 m, 140 m, 160 m, 180 m

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Results

An example results table for the speed of sound in air

Distance / m	Time 1 / s	Time 2 / s	Time 3 / s	Average time / s
100				
120				
140				
160				
180				

Analysis of results

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

$$\text{average speed} = \frac{\text{distance moved}}{\text{time taken}}$$

- The speed of sound in the air should work out to be about 340 m/s

Experiment 2: measuring the speed of sound with oscilloscopes

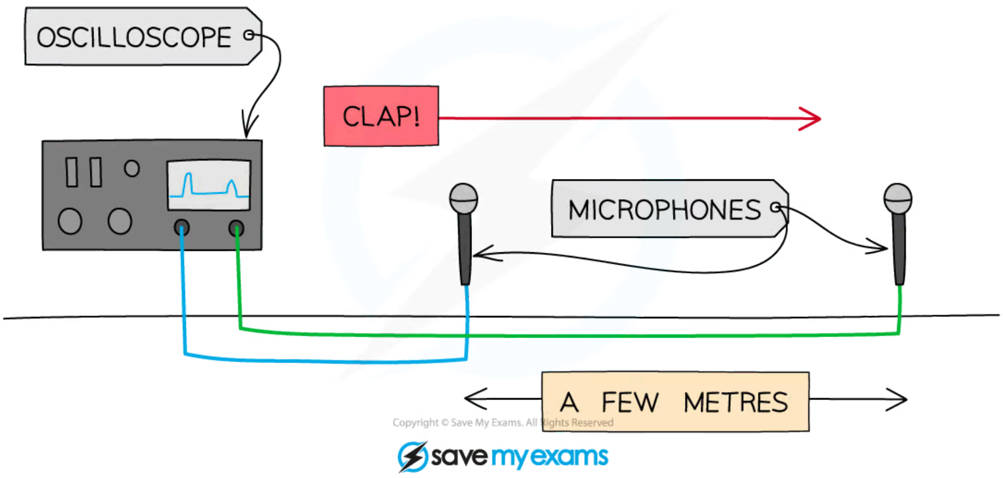
- This experiment aims to measure the speed of sound in air between two points using an oscilloscope

Variables

- **Independent variable** = Distance
- **Dependent variable** = Time
- Control variables:
  - Same location to carry out the experiment
  - Same set of microphones for each trial

Method

Measuring the speed of sound with an oscilloscope



Measuring the speed of sound using an oscilloscope

1. Connect two microphones to an oscilloscope
2. Place them about 2 m apart using a tape measure to measure the distance between them
3. Set up the oscilloscope so that it triggers when the first microphone detects a sound, and adjust the time base so that the sound arriving at both microphones can be seen on the screen
4. Make a large clap using the two wooden blocks next to the first microphone
5. Use the oscilloscope to determine the time at which the clap reaches each microphone and the time difference between them
6. Repeat this experiment for several distances, e.g. 2 m, 2.5 m, 3 m, 3.5 m

Results

An example results table for obtaining the speed of sound using an oscilloscope

Distance / m	Time 1 / s	Time 2 / s	Time 3 / s	Average time / s
2.0				
2.5				
3.0				
3.5				

4.0				

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Analysis of results

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

$$\text{average speed} = \frac{\text{distance moved}}{\text{time taken}}$$

- The speed of sound in the air should work out to be about 340 m/s

Evaluating the experiments

Systematic Errors:

- In experiment 2, ensure the scale of the time base is accounted for correctly
  - The scale is likely to be small (e.g. milliseconds) so ensure this is taken into account when calculating speed

Random errors:

- The main cause of error in experiment 1 is the measurement of time
  - Ensure to take repeat readings when timing intervals and calculate an average to keep this error to a minimum
  - Maximise the distance between the two people where possible. This will reduce the error in measurements of time because the time taken by the sound waves to travel will be greater

Examiner Tips and Tricks

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

In the case of measuring the speed of sound:

- Experiment 2 is the **most** accurate because the timing is done automatically
- Experiment 1 is the **least** accurate because the time interval is very short

Whilst this may not be too important when giving a method, you should be able to explain why each method is accurate or inaccurate and suggest ways of making them better (use bigger distances)

- For example, if a manual stopwatch is being used there could be variation in the time measured which can be up to 0.2 seconds due to a person's reaction time
- The time interval could be as little as 0.3 seconds for sound travelling in the air
- This means that the variation due to the stopwatch readings has a big influence on the results and they may not be reliable

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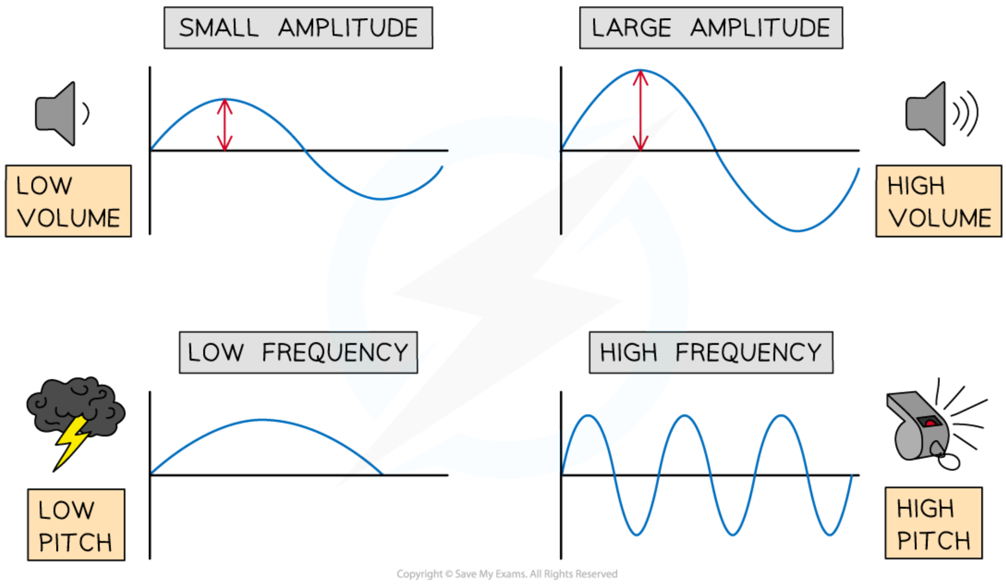
Pitch & loudness

- Changes in **amplitude** and **frequency** affect the **loudness** and **pitch** of sound waves
- 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)
- The **amplitude** of a sound wave is related to its **volume**
  - Sounds with a **large** amplitude have a **high** volume
  - Sounds with a **small** amplitude have a **low** volume

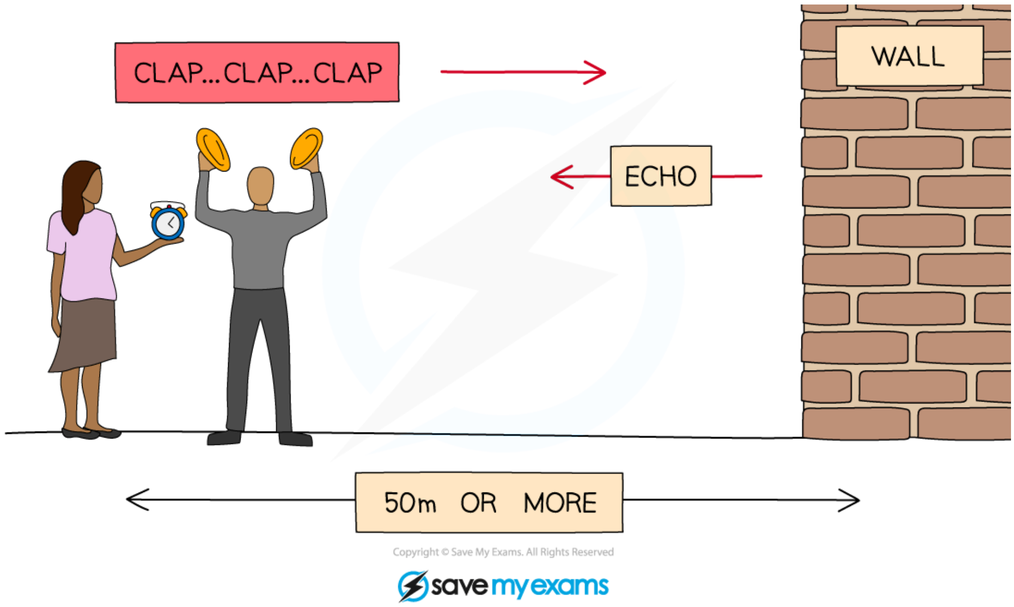


Pitch and amplitude of sound

Echoes

- Sound waves **reflect** off hard surfaces
  - The reflection of a sound wave is called an **echo**

An example of an echo



A clap sound is reflected off a wall. When the reflected sound is heard, this is the echo

- The distance to the surface where the echo reflects can be calculated using the equation:

$$\text{distance} = \frac{1}{2} \times \text{speed} \times \text{time}$$

- Where:
  - distance = half the total distance travelled by the sound wave, measured in metres (m)
  - speed = speed of sound in air, measured in metres per second (330 - 350 m/s)
  - time = total time for sound wave to travel to the surface and back, measured in seconds (s)

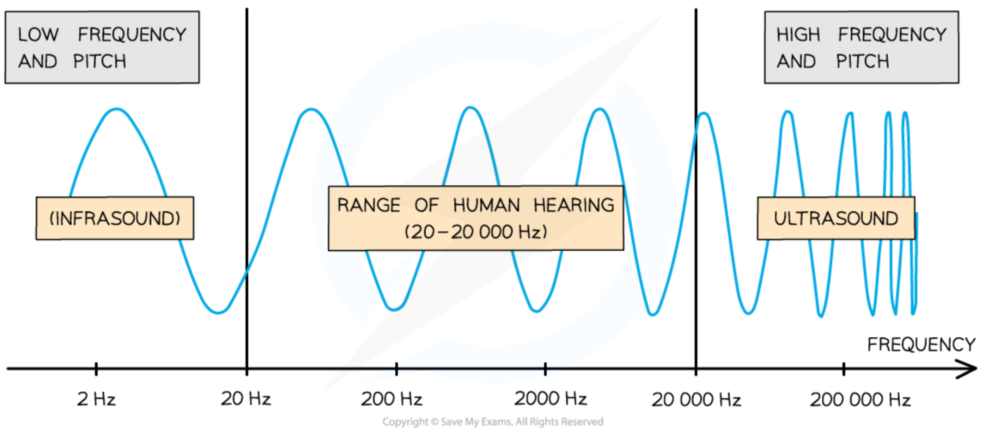
Your notes

Your notes

Ultrasound

- The approximate range of frequencies audible to humans is 20 Hz to 20 000 Hz in frequency
  - The human hearing range decreases with age

Frequencies of ultrasound



Humans can hear sounds between 20 and 20 000 Hz

- **Ultrasound** is defined as

sound with a frequency higher than 20 kHz

Uses of ultrasound

Extended tier only

- Ultrasound is used in:
  - non-destructive **testing of materials**
  - **medical scanning** of soft tissue
  - **sonar** to calculate the depth or distance from time and wave speed

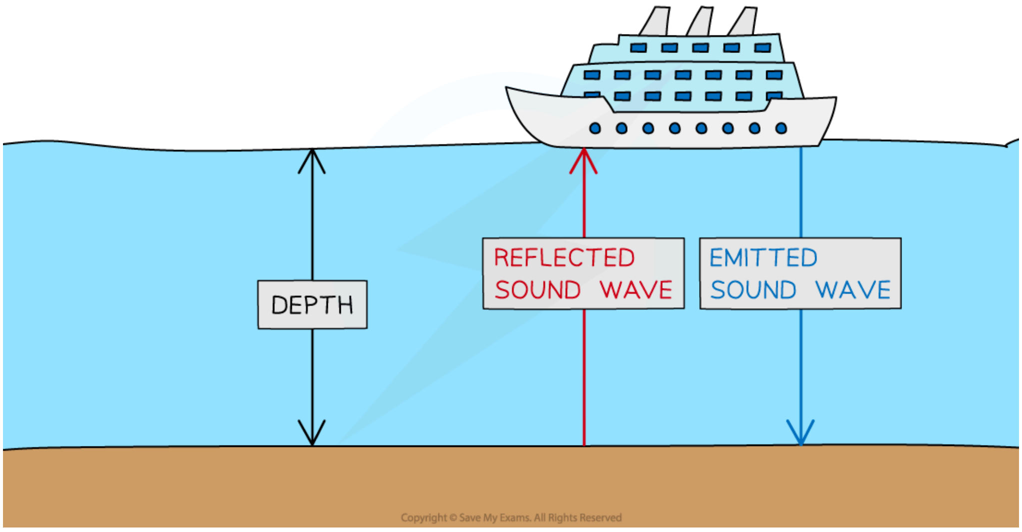
Measuring the speed of ultrasound

- When ultrasound signals reach a **boundary** between two media, some of the waves are **partially reflected**
  - The remainder of the waves are **transmitted** through the material
- Ultrasound transducers:

- **emit** and **receive** ultrasound
- **display** the received signal on an **oscilloscope screen**

- The depth of the boundary can be determined using:
  - **Time taken** between the ultrasound being emitted and received
  - Knowing the **speed** of the ultrasound through the material

Measuring the depth of a boundary



The depth of a boundary is measured using the difference between emitted and received ultrasound pulses

- The depth of the boundary is calculated using the equation:

$$\text{depth} = \frac{1}{2} \times \text{speed} \times \text{time}$$

- Where:
  - depth = half the total distance travelled by the ultrasound, measured in metres (m)
  - speed = speed of the ultrasound in the medium, measured in metres per second (m/s)
  - time = total time from ultrasound emission to receipt, measured in seconds (s)

Ultrasound in material testing

- In industry, ultrasound can be used to:
  - Check for cracks inside metal objects
  - Generate images from beneath surfaces
- Ultrasound waves that reach a **crack** in an object, such as a metal bar, are reflected back from the crack earlier than the waves that continue to be absorbed through the object

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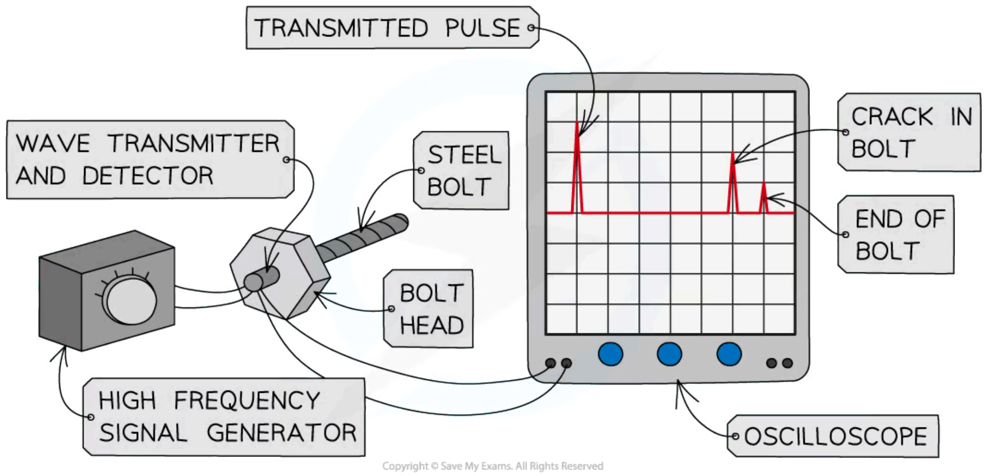
- The reflected waves are displayed as pulses on an oscilloscope trace
- This allows engineers to **assess** the structure of an object

Oscilloscope display for material imperfection testing



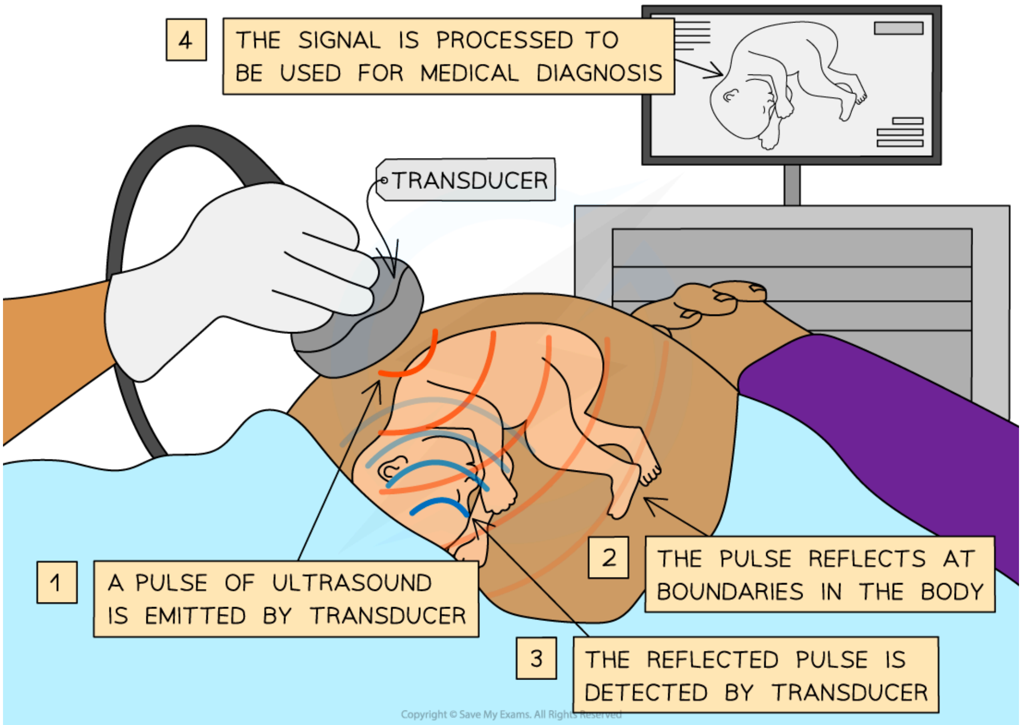
Ultrasound is partially reflected at boundaries, so in a bolt with no internal cracks, there should only be two pulses (at the start and end of the bolt)

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
- The ultrasound waves are reflected back to the transducer by **boundaries** between tissues in the path of the beam
  - Examples of boundaries are between fluid and soft tissue or tissue and bone
- 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 image of a baby in the womb

Your notes



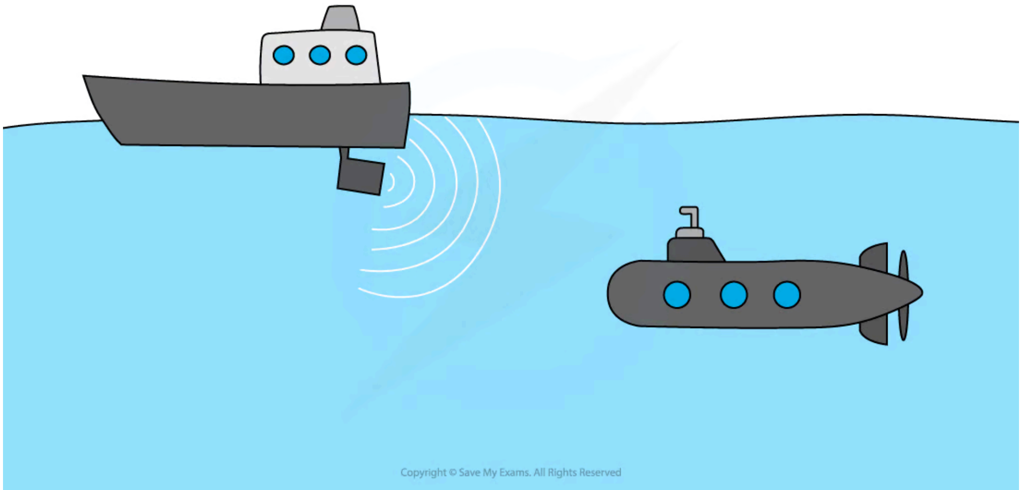
Ultrasound can be used to construct an image of a foetus in the womb

Sonar

- 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
- The **distance** the wave travels is **twice the depth** of the ocean
  - This is the distance to the ocean floor plus the distance for the wave to return

Echo sounding

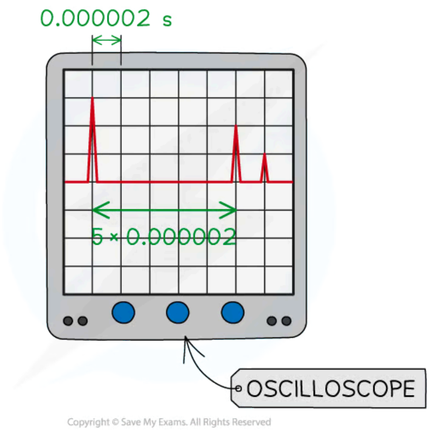
Your notes



Echo sounding is used to determine water depth

Your notes

Worked Example



In the diagram above, a very high-frequency sound wave is used to check for internal cracks in a large steel bolt. The oscilloscope trace shows that the bolt does have an internal crack. Each division on the oscilloscope represents a time of 0.000002 s. The speed of sound through steel is 6000 m/s.

Calculate the distance, in cm, from the head of the bolt to the internal crack.

Answer:

Step 1: List the known quantities

- Speed of ultrasound, v = 6000 m/s

- Time taken between emission and detection, $t = 5 \times 0.000002 = 0.00001$ s

Step 2: Write down the equation relating speed, distance and time

$$\text{distance} = \text{speed} \times \text{time}$$

Step 3: Calculate the total distance travelled by the sound wave

$$\text{total distance} = 6000 \times 0.00001 = 0.06 \text{ m}$$

Step 4: Calculate the distance travelled by the sound wave to the crack

$$\text{distance to the crack} = 0.06 / 2 = 0.03 \text{ m}$$

Step 5: Convert the distance to cm

$$\text{distance to the crack} = 3 \text{ cm}$$

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