

## 3.4 Sound

### Sound Waves

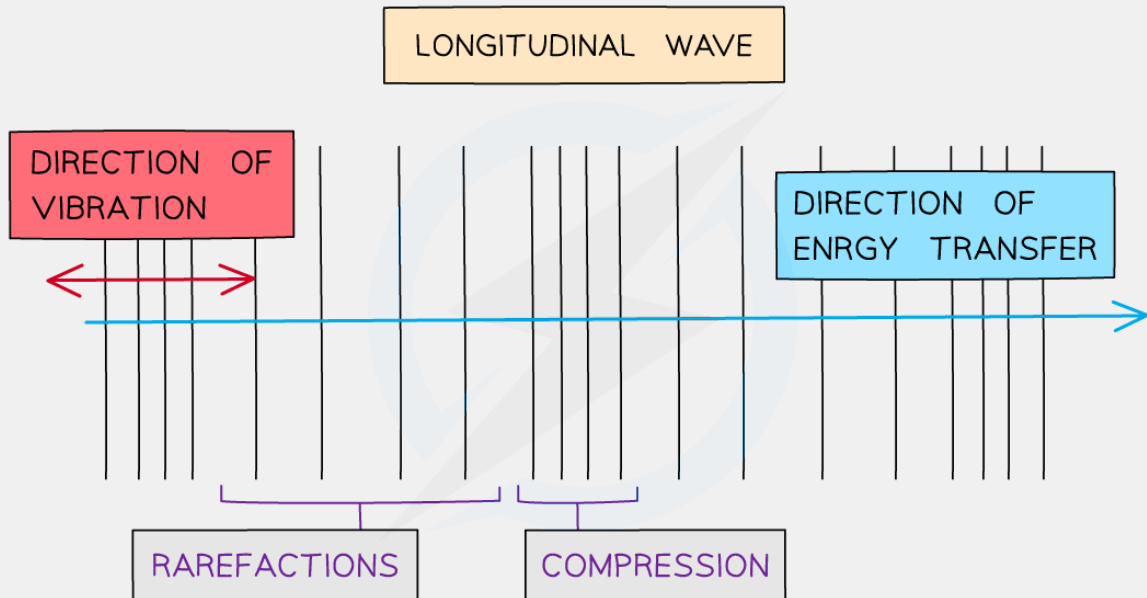
#### Describing sound

- 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



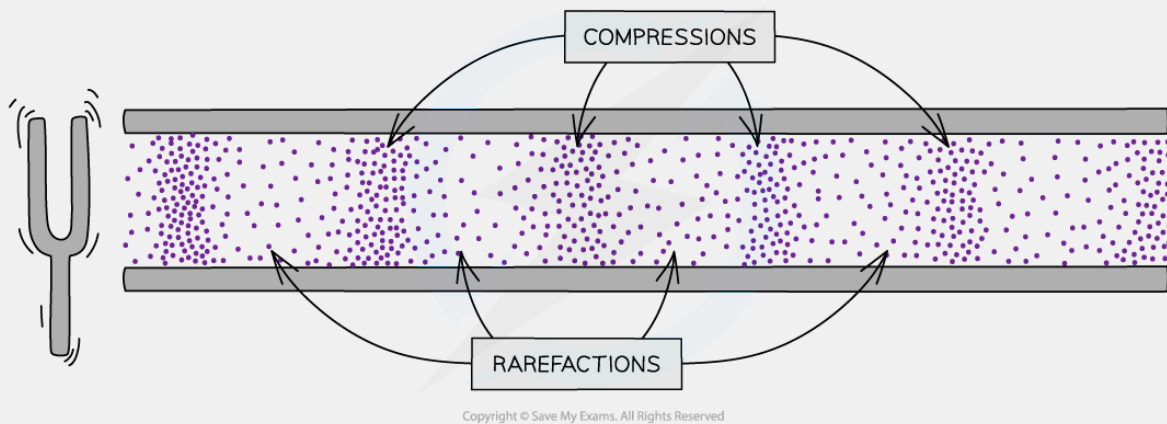
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*Longitudinal waves are represented as sets of lines with rarefactions and compressions*

## Compression & rarefaction

- 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

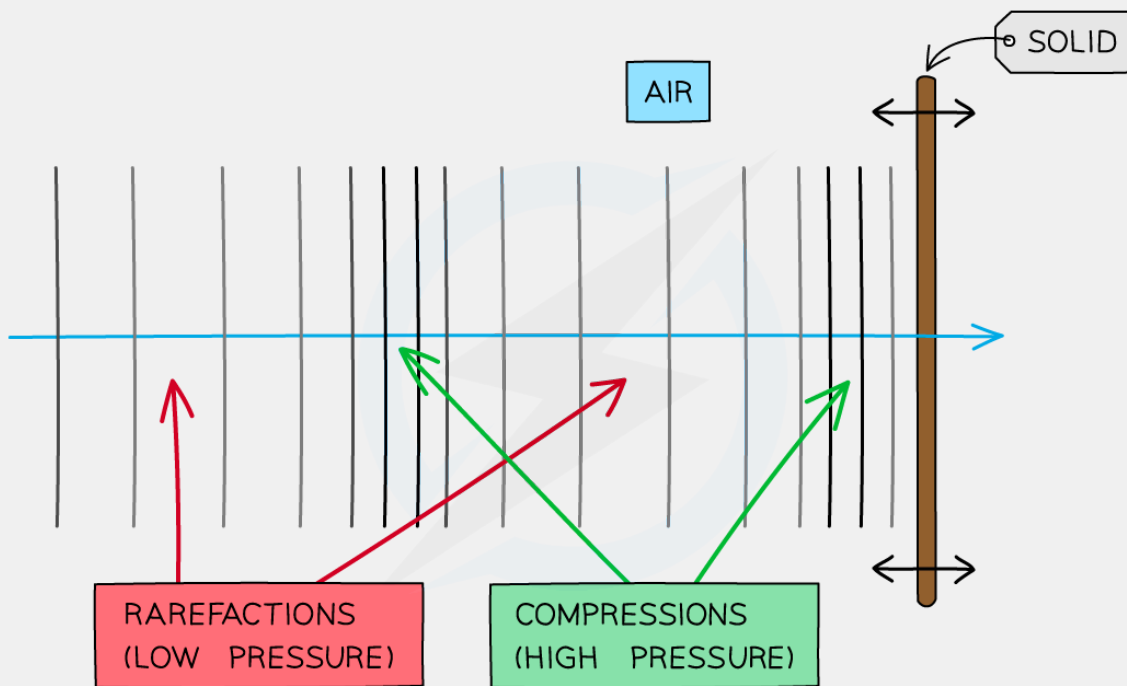
## Compression and rarefaction



***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



*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!

### 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

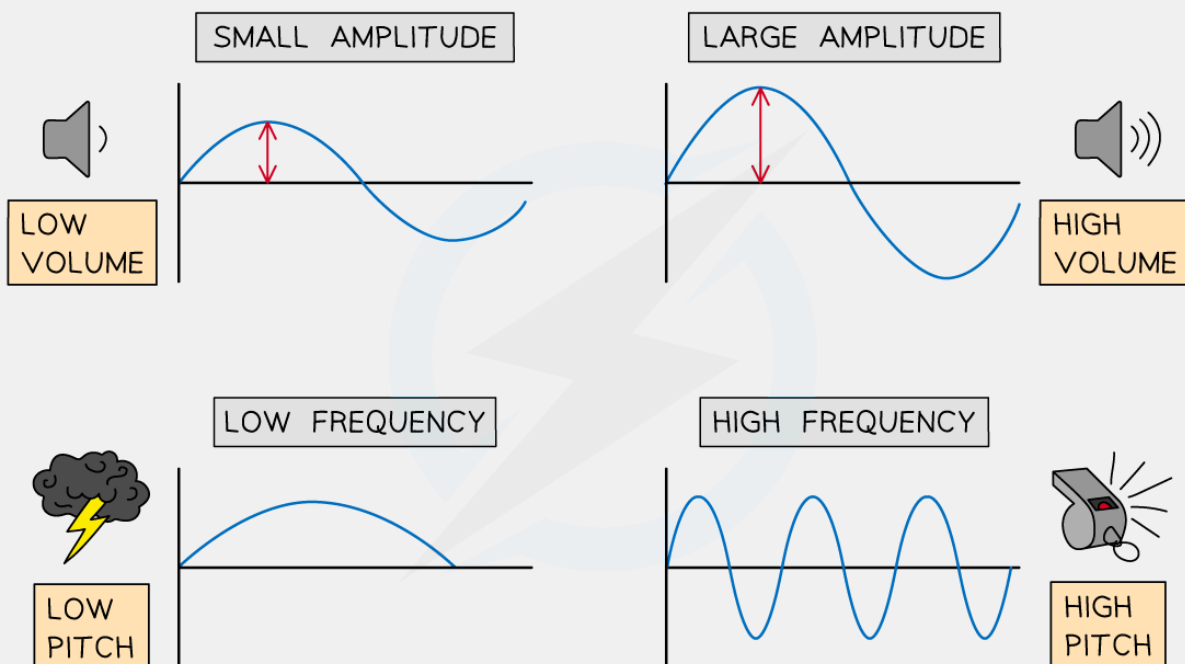
## Speed of sound in materials

- 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
- Sound waves are caused by particles **transferring its vibration** to its **surrounding particles** by collisions.
- As particles are packed **closest** in solids, the vibrations are transferred the **fastest**, hence sound travels fastest in solids.

# Effects of Sound Waves

## 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



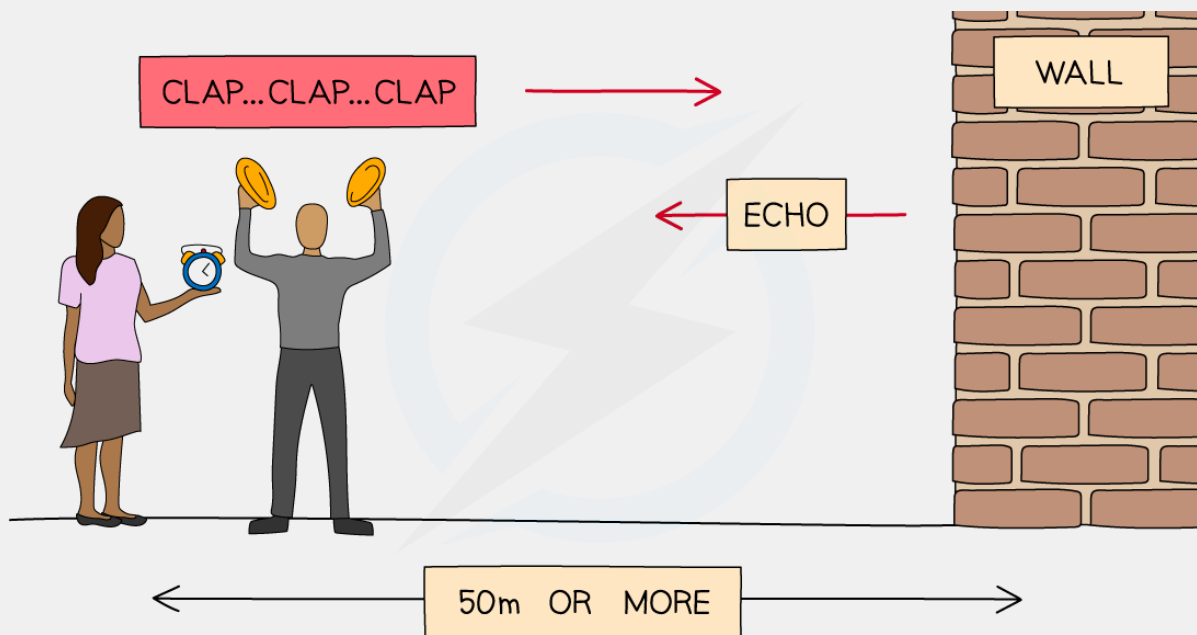
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*Pitch and amplitude of sound*

## Echoes

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

### An example of an echo



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*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:

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

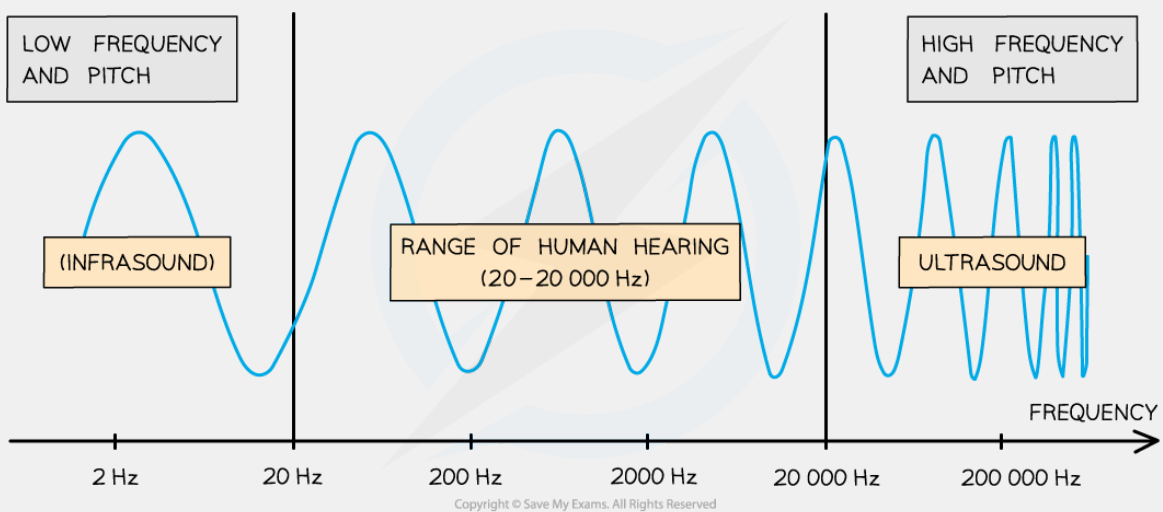
- Where:
  - distance = half the total distance travelled by the sound wave, measured in metres (m)
  - speed = speed of sound in air, measured in metres per second (330 - 350 m/s)
  - time = total time for sound wave to travel to the surface and back, measured in seconds (s)

- The  $\frac{1}{2}$  is there in the equation because the sound wave must travel to the wall, and then back to the observer

## 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*

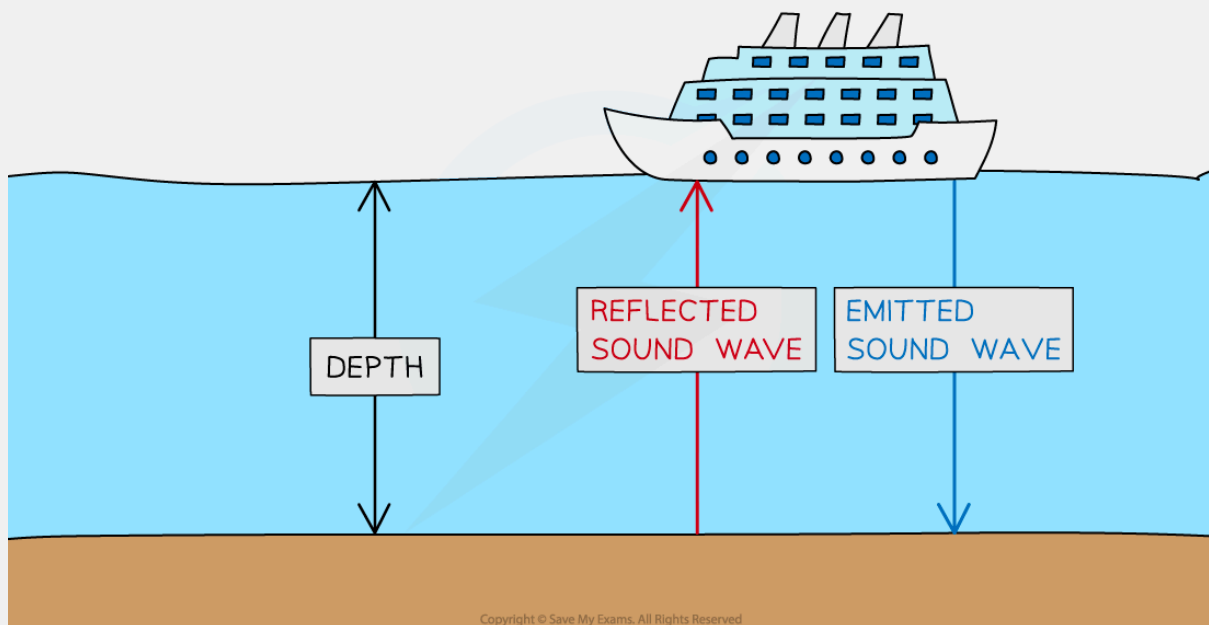
- **Ultrasound** is defined as  
**sound with a frequency higher than 20 kHz**

## Uses of ultrasound

- 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
- 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:

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

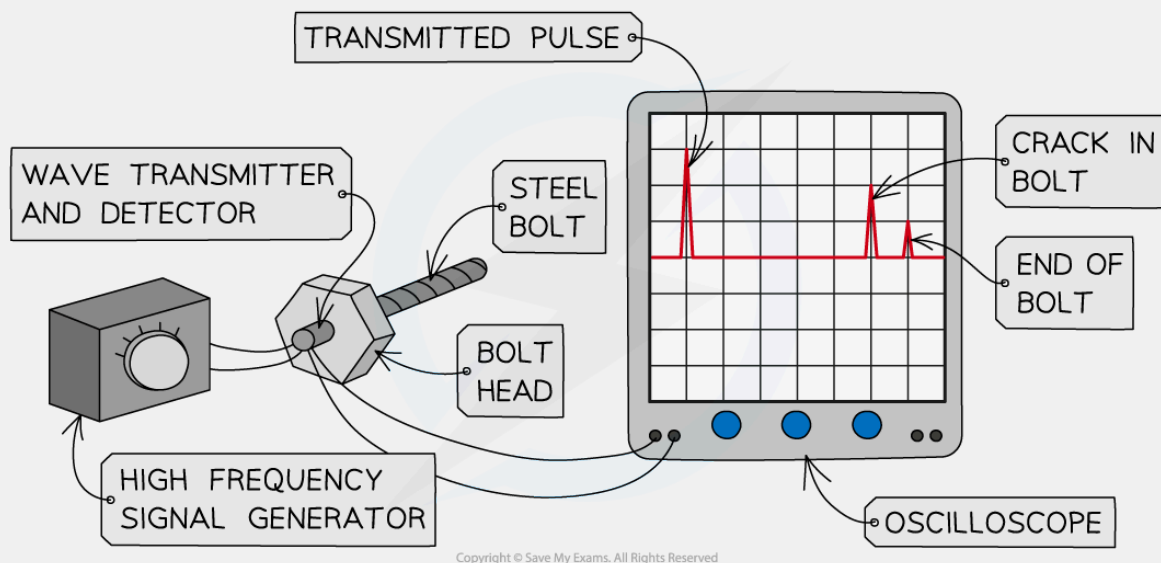
- Where:
  - depth = half the total distance travelled by the ultrasound, measured in metres (m)
  - speed = speed of the ultrasound in the medium, measured in metres per second (m/s)

- 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
  - 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)*

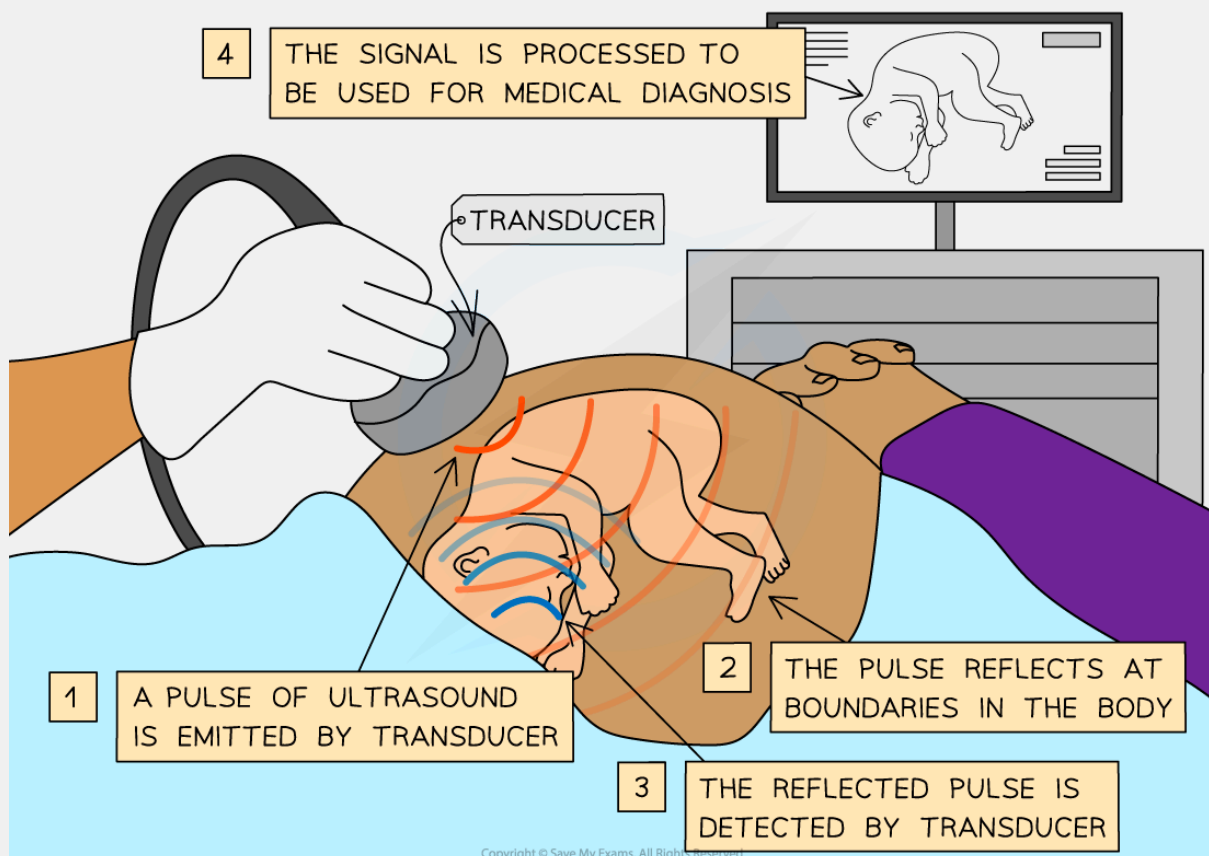
## Ultrasound in medicine

- 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

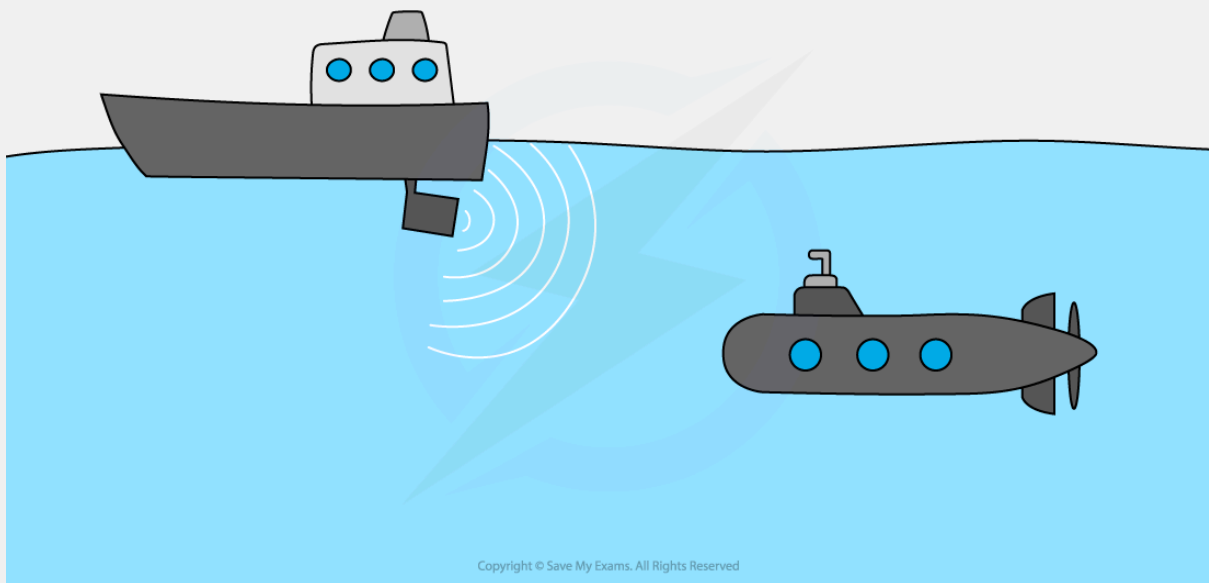


*Ultrasound can be used to construct an image of a foetus in the womb*

## Sonar

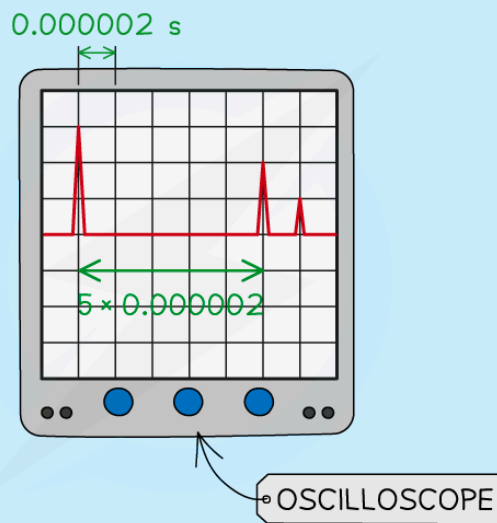
- Echo sounding can be used to measure **depth** or to **detect objects underwater**
  - A sound wave can be transmitted from the surface of the water
    - The sound wave is reflected off the bottom of the ocean
  - The time it takes for the sound wave to return is used to calculate the depth of the 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



*Echo sounding is used to determine water depth*

## Worked Example



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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,  $v = 6000 \text{ m/s}$
- Time taken between emission and detection,  $t = 5 \times 0.000002 = 0.00001 \text{ s}$

**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**

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