Waves for detection and exploration

4.6.1.5 · Waves · revision notes

How differences in the speed, absorption and reflection of waves let us find structures we cannot see directly: ultrasound scans, echo sounding, and seismic waves that reveal the Earth's core. Higher tier only, and GCSE Physics only (not in Combined Science). Expect echo-timing calculations and explanations of the seismic evidence for the Earth's structure.

Key facts

- Ultrasound: frequency above 20 kHz
- Ultrasound is partially reflected at a boundary between two different media
- P-waves: longitudinal; travel through solids and liquids; faster than S-waves
- No S-waves on the far side of the Earth → the outer core is liquid
- 1 ms = 10^{-3} s; 1 μs = 10^{-6} s
- Echo: distance = speed × time ÷ 2 (there and back)
- Uses: medical scans (e.g. foetus), finding flaws in metal, echo sounding for water depth
- S-waves: transverse; cannot travel through liquids
- P-waves refract at the core → P-wave shadow zone → size of the core

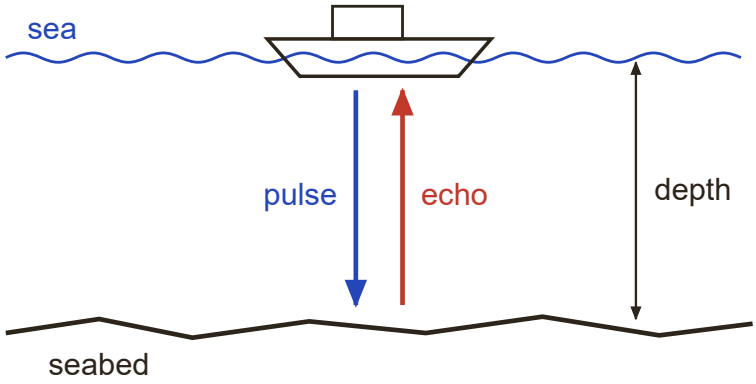
Notes

Using echoes

- When a wave meets a boundary between two different media, part of it is reflected and the rest is transmitted (some may be absorbed).
- If you know the wave speed and time how long an echo takes to return, you can work out how far away the boundary is: **distance = speed × time ÷ 2**, because the wave travels there **and back**.
- Different materials reflect, absorb and transmit waves differently, and waves travel at different speeds in them. This lets us detect and explore structures hidden from direct view.

Ultrasound and echo sounding

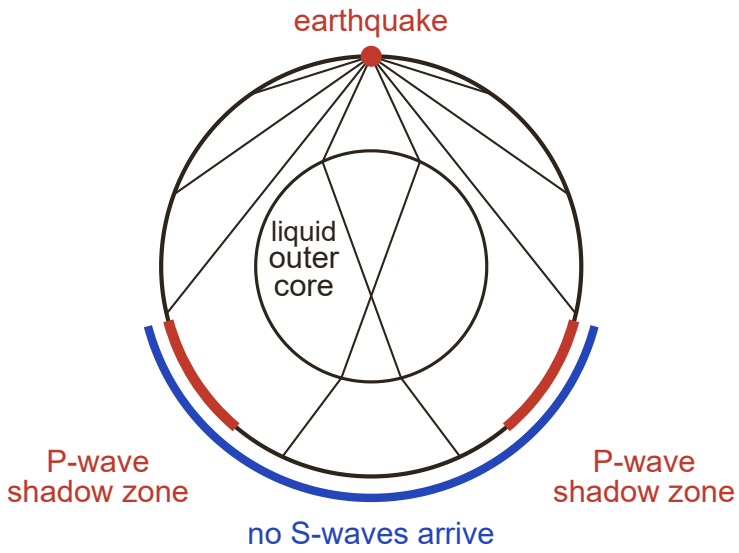
- **Ultrasound** is sound with a frequency above 20 kHz, the upper limit of human hearing.
- A pulse of ultrasound is sent into the body or object. At each boundary between two different media (e.g. two types of tissue, or metal and an air-filled crack) the ultrasound is **partially reflected** and the rest carries on.
- A detector records when each echo returns. The time taken gives the distance to each boundary, and a computer uses these to build up an image.
- **Medical imaging**: e.g. scanning a foetus. Ultrasound is not ionising, so it is much safer than X-rays for this. **Industrial imaging**: finding hidden cracks or flaws in metal parts, pipes and welds.
- **Echo sounding**: ships send pulses of high-frequency sound down through the water and time the echoes. This measures the depth of the water and detects objects in deep water, such as shoals of fish or wrecks.



Echo sounding: depth = speed × time ÷ 2, because the pulse goes down and back.

Seismic waves and the Earth's structure

- Earthquakes produce **seismic waves**, which travel through the Earth and are detected by seismometers around the world.
- **P-waves** are longitudinal. They travel through solids and liquids, at different speeds in each, and are faster than S-waves.
- **S-waves** are transverse. They **cannot travel through a liquid**.
- S-waves are not detected in a large region on the opposite side of the Earth from an earthquake (the S-wave shadow zone). This is evidence that the outer core is **liquid**.
- P-waves change speed, and so refract, as they pass into and out of the core. This leaves a region where no P-waves arrive directly (the P-wave shadow zone). The sizes and positions of the shadow zones show the size of the core.



S-waves cannot cross the liquid outer core (blue zone). P-waves refract as they enter and leave the core, so some still reach the far side, but none reach the P-wave shadow zones (red).

- No one can drill down to the core, so the study of seismic waves gave new evidence about parts of the Earth that cannot be observed directly.

How to answer each type of question

Calculate a depth or distance from an echo time

3 marks | Grade 6

1. Convert the time to seconds (ms or μs to s) if needed.
2. Find the total distance travelled: distance = speed × time.
3. Halve it: the pulse goes to the boundary and back.

Example. A ship uses echo sounding to measure the depth of the sea. A pulse of sound is sent down and the echo from the seabed is detected 0.40 s later. The speed of sound in seawater is 1500 m/s. Calculate the depth of the sea.

Model answer.

distance travelled = 1500 × 0.40 = 600 m (1)

The pulse travels down and back up, so depth = 600 ÷ 2 (1)

depth = 300 m (1)

Compare P-waves and S-waves

2 marks | Grade 5

1. Write about both waves in each difference.
2. Use: longitudinal or transverse; travels through liquids or not; faster or slower.

Example. Give **two** differences between P-waves and S-waves.

Model answer.

P-waves are longitudinal but S-waves are transverse (1).

P-waves can travel through liquids but S-waves cannot / P-waves travel faster than S-waves (1).

Explain how ultrasound is used to produce an image

3 to 4 marks | Grade 7

1. Say pulses of ultrasound are sent in.
2. Say they are partially reflected at each boundary between different media.
3. Say the time for each echo is measured and used to find the distance to each boundary.
4. Say the distances are used to build up an image.

Example. Explain how ultrasound can be used to produce an image of a foetus in the womb.

Model answer. Pulses of ultrasound are sent into the body (1). At each boundary between different tissues, some of the ultrasound is reflected and the rest passes on (1). A detector measures the time taken for each echo to return (1). The times are used to calculate the distance to each boundary, and a computer uses these to build up an image (1).

Explain the seismic evidence for the Earth's structure 3 marks **Grade 8**

1. State the observation (which waves are or are not detected, and where).
2. State the property of the wave (S-waves cannot travel through liquids).
3. Give the conclusion: part of the core (the outer core) is liquid.

Example. After an earthquake, seismometers on the opposite side of the Earth detect P-waves but not S-waves.
Explain what this shows about the structure of the Earth.

Model answer. S-waves are transverse and cannot travel through liquids (1). P-waves are longitudinal and can travel through liquids as well as solids (1). So the S-waves must have been stopped by a liquid layer: part of the Earth's core (the outer core) is liquid (1).

Don't lose marks

- Forgetting to halve the distance in echo calculations.
- Saying S-waves 'cannot travel through the core' without giving the reason: they cannot travel through **liquids**, and the outer core is liquid.
- Mixing up which seismic wave is transverse and which is longitudinal.
- Saying ultrasound is completely reflected at a boundary. It is only partially reflected, which is why echoes return from several boundaries.
- Using the speed of sound in air (about 340 m/s) when the question gives a speed in water, tissue or steel.

More tips

Memory tricks

- Echo = there and back: always divide the distance by 2.
- P-waves: 'Push–Pull', longitudinal, get through solids and liquids. S-waves: 'Side-to-Side', transverse, Solids only.
- Microseconds: 1 μs = 10^{-6} s. Enter it with the $\times 10^{x}$ key.

Exam technique

- Link each piece of evidence to its conclusion using 'so' or 'this shows that'.
- Use the key terms: partially reflected, boundary, different media, echo, time taken.
- Check the unit the answer must be in (m or cm) and convert at the end.

What each grade needs

What you need to be able to do, from the first marks up to the top grade.

Grade 4 **Define ultrasound**
Sound with a frequency higher than 20 kHz, the upper limit of human hearing.

Grade 5 **Give uses of ultrasound and echo sounding**
Medical scans (e.g. of a foetus), finding flaws inside metal, and measuring the depth of water.

Grade 5

Compare P-waves and S-waves

P-waves are longitudinal and travel through solids and liquids; S-waves are transverse and cannot travel through liquids.

Grade 6

Calculate distance from an echo time

Distance = speed × time, then halve it because the pulse travels there and back.

Grade 7

Explain how ultrasound produces an image

Pulses are partially reflected at each boundary between media, and the echo times give the distance to each boundary.

Grade 8

Explain seismic evidence for a liquid outer core

S-waves are not detected on the far side of the Earth from an earthquake, so part of the core must be liquid.

Grade 9

Explain how P-waves reveal the core's size

P-waves change speed and refract at the core boundary, leaving a P-wave shadow zone whose position shows the size of the core.

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