

Sound ultrasound and seismic exploration

AQA GCSE Separate Physics 8463 | Higher tier only | Paper 2

Worked answers | Separate Physics Higher only | 28 parts | 50 marks

Specification points covered

4.6.1.2: wave speed, frequency and wavelength; sound crossing between media

4.6.1.4: sound, vibrations in solids and limits of human hearing

4.6.1.5: ultrasound, echo sounding and P/S-wave evidence for hidden structures

A coastal-tunnel team checks a flooded access shaft, steel inspection plates and hidden geological layers. You will interpret echoes and choose suitable wave methods. The team also compares its layered model with the evidence used to study the Earth's core.

Original PhysicsUK practice, not an official AQA resource. 28 parts, 50 marks. Separate Physics Higher only throughout. Distinguish elapsed echo time from an absolute display reading and total path length from one-way depth. The normal-incidence layer diagram is a model, not a scale drawing of the Earth. Timing is estimated and untrials.

1 Hearing sound during the inspection

The workers use an audible warning and a high-frequency inspection probe. The probe can detect waves that a person cannot hear.

1(a) State the approximate frequency range of normal human hearing. **[1 mark]**

Answer / mark points: 20 Hz to 20000 Hz / 20 kHz. [1] Both limits are required. Ultrasound is above the upper limit, not below 20 Hz.

1(b) The probe emits 38 kHz waves. Explain why a person with normal hearing cannot hear this signal, even though a detector records it. **[2 marks]**

Answer / mark points: 38 kHz is above the normal upper hearing limit of 20 kHz. [1]
The ear's conversion of sound waves to vibrations producing hearing works over a limited frequency range, so this frequency does not produce normal hearing. [1] Inaudible does not mean no wave exists.

1(c) A worker taps a steel plate and another worker hears the sound through air. Describe the two vibration stages that lead to hearing. **[2 marks]**

Answer / mark points: The vibrating solid plate produces sound / pressure disturbances in the air. [1]
Those sound waves make the ear drum and other parts of the ear vibrate, producing the sensation of sound. [1] Sound can also propagate as vibrations through solid steel.



2 Accounting for the return journey

The team uses echoes in air, in water and in steel. Figure 1 is a cross-section of the steel plate used later; d is the internal-gap depth and H is the plate thickness. It is not to scale. Assume straight out-and-back paths and ignore instrument delays in this section.

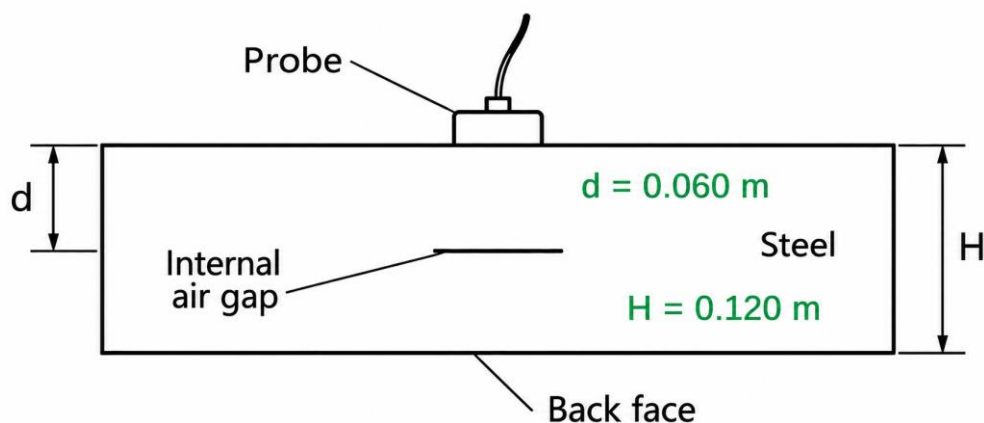


Figure 1

2(a) An audible pulse returns from a flat tunnel wall 0.20 s after it is sent. The sound speed is 340 m s^{-1} . Calculate the one-way distance to the wall. **[2 marks]**

Answer / mark points: Total path = $340 \times 0.20 = 68 \text{ m}$. [1]
One-way wall distance = $68 / 2 = 34 \text{ m}$. [1] Accept $340 \times (0.20 / 2)$.

2(b) An underwater sound pulse returns from the shaft floor after 0.016 s. Speed in the water is 1500 m s^{-1} . Calculate the water depth below the probe. **[2 marks]**

Answer / mark points: Total path = $1500 \times 0.016 = 24 \text{ m}$. [1]
Depth = $24 / 2 = 12 \text{ m}$. [1] The reflection is at the water–floor boundary.

2(c) At another position the water depth below the probe is 9.0 m. Calculate the time between sending a pulse and receiving its floor echo. Use 1500 m s^{-1} . **[2 marks]**

Answer / mark points: Out-and-back path = $2 \times 9.0 = 18 \text{ m}$. [1]
Time = $18 / 1500 = 0.012 \text{ s}$. [1] Using $9.0 / 1500$ gives only the outward travel time.

2(d) The plate in Figure 1 has $H = 0.120 \text{ m}$. Calculate the out-and-back time to its back face, in microseconds. Speed in steel is 6000 m s^{-1} . **[2 marks]**

Answer / mark points: Time = $2 \times 0.120 / 6000 = 0.000040 \text{ s}$. [1]
 $0.000040 \text{ s} = 40 \mu\text{s}$. [1] The boundary is the steel back face, not the internal gap.



3 Interpreting the plate echo trace

Figure 2 shows the Figure 1 plate: S is the sent pulse, C the internal steel–air boundary echo, and B the back-face echo. The display has an offset: use peak-time differences. Speed in steel is 6000 m s^{-1} . Ignore multiple echoes. Pulse shapes are schematic; width and height must not be used to infer flaw size.

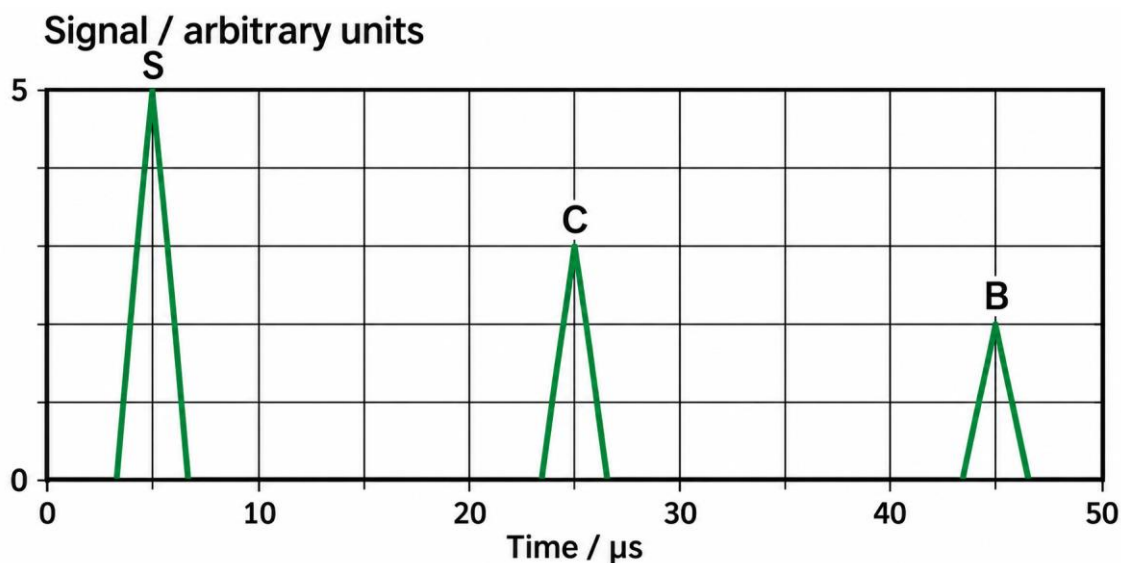


Figure 2

3(a) Read the peak times of S and C, then determine the elapsed time for the internal-gap echo. **[1 mark]**

Answer / mark points: S at $5 \mu\text{s}$, C at $25 \mu\text{s}$; elapsed time = $25 - 5 = 20 \mu\text{s}$. [1] Do not use the absolute $25 \mu\text{s}$ display reading as the travel time.

3(b) Convert that elapsed time into seconds. **[1 mark]**

Answer / mark points: $20 \mu\text{s} = 0.000020 \text{ s} = 2.0 \times 10^{-5} \text{ s}$. [1] Accept an equivalent correct form.

3(c) Calculate d , the depth of the internal reflecting boundary below the probe face. **[2 marks]**

Answer / mark points: Total path = $6000 \times 0.000020 = 0.120 \text{ m}$. [1]
 $d = 0.120 / 2 = 0.060 \text{ m}$ (60 mm). [1] Allow correct follow-through from their elapsed time; do not reward a full path as a one-way depth.

3(d) Use the B echo to check the plate thickness H . Show how you account for the display offset. **[2 marks]**

Answer / mark points: Elapsed time = $45 - 5 = 40 \mu\text{s} = 0.000040 \text{ s}$. [1]
 $H = 6000 \times 0.000040 / 2 = 0.120 \text{ m}$. [1] Use the same sent-pulse reference for both echoes.

3(e) Explain how a back-face echo can still be received when some ultrasound is reflected at the internal boundary. **[1 mark]**

Answer / mark points: Only some wave energy is reflected there; some continues through the steel / past the localised gap, reflects at the back face and returns to the probe. [1] Partial reflection does not mean the entire beam stops.



4 Choosing the inspection probe

Table 1 gives stated performance limits for two probes in this steel. These are supplied test data, not universal resolution rules. Speed is 6000 m s^{-1} . Minimum separation means the smallest gap between two reflecting boundaries that gives distinguishable echoes. Higher-frequency waves are more strongly absorbed in this test material.

Table 1

Probe	Frequency / MHz	Minimum separation / mm	Maximum usable depth / mm
P	2.0	3.0	200
Q	4.0	1.5	100

4(a) Convert Probe P's frequency to hertz. [1 mark]

Answer / mark points: $2.0 \text{ MHz} = 2000000 \text{ Hz} = 2.0 \times 10^6 \text{ Hz}$. [1]

4(b) Calculate the wavelength in steel for Probe P, in metres. [1 mark]

Answer / mark points: $\lambda = v / f = 6000 / 2000000 = 0.0030 \text{ m}$. [1] Allow correct follow-through from (a).

4(c) Calculate the wavelength in steel for Probe Q. Give the answer in millimetres. [2 marks]

Answer / mark points: $\lambda = 6000 / 4000000 = 0.0015 \text{ m}$. [1]
 $0.0015 \text{ m} = 1.5 \text{ mm}$. [1] A higher frequency gives a shorter wavelength at the same wave speed.

4(d) Two reflecting boundaries are 2.0 mm apart at a depth of 80 mm. Which probe meets both stated requirements? Justify using Table 1. [2 marks]

Answer / mark points: Q. Its minimum distinguishable separation of 1.5 mm is smaller than 2.0 mm. [1]
 Its 100 mm maximum usable depth also includes 80 mm. [1] P reaches this depth but cannot distinguish a 2.0 mm separation under the stated limits.

4(e) The same 2.0 mm separation occurs at a depth of 160 mm. Explain why neither listed probe meets both requirements. [2 marks]

Answer / mark points: P reaches 160 mm but its 3.0 mm minimum separation is too large to resolve the pair. [1]
 Q resolves 2.0 mm separation but 160 mm exceeds its 100 mm usable depth. [1] One suitable performance figure is not enough.

4(f) A sound wave passes from water into steel. Its frequency is unchanged and its speed increases. Explain how its wavelength changes. [2 marks]

Answer / mark points: Its wavelength increases. [1]
 Since $v = f\lambda$ and f stays constant, the greater speed requires a greater wavelength. [1] Frequency does not automatically increase on entering a faster medium.



5 Interpreting P and S waves

Figure 3 shows only transmitted paths through a layered model; reflected paths are omitted. Both waves approach the boundaries normally. Measurements reliably show P transmitted through X but no S transmitted through X. For (b), assume detector failure and excessive absorption have been ruled out. This is not a literal map of the Earth.

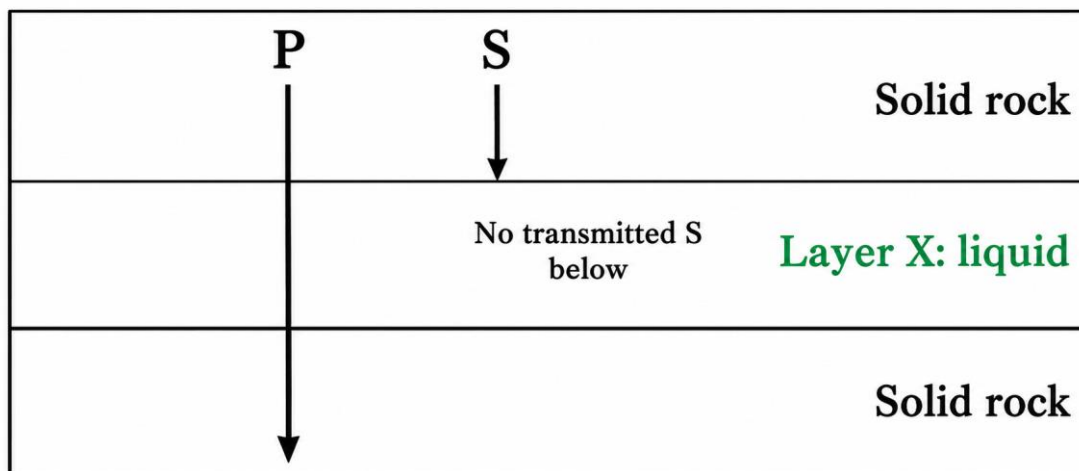


Figure 3

5(a) State the wave type of P-waves and the wave type of S-waves. [2 marks]

Answer / mark points: P-waves are longitudinal. [1]

S-waves are transverse. [1] These are seismic waves; do not reverse the two names.

5(b) Infer whether Layer X is solid or liquid in this model. Explain using the transmitted-wave evidence. [2 marks]

Answer / mark points: Liquid. [1]

S-waves cannot travel through liquids, whereas P-waves can pass through them; the observed transmission pattern fits a liquid layer. [1] P transmission also rules out an empty vacuum gap in this model.

5(c) A P-wave in a different test meets a boundary at an angle to the normal and changes speed. Name the effect on its path and explain the cause. [2 marks]

Answer / mark points: Refraction / a change in propagation direction. [1]

It occurs because the P-wave speed changes on entering the other medium. [1] Figure 3 uses normal incidence, so its straight paths do not show every possible seismic ray path.

5(d) Explain how S-wave records provide evidence that the Earth's outer core is liquid. [2 marks]

Answer / mark points: S-waves cannot propagate through a liquid. [1]

The absence of transmitted S-waves along paths that would cross the outer core is consistent with a liquid outer core. [1] This concerns the outer core, not a claim that the whole core is liquid.

5(e) A trainee says neither P-waves nor S-waves can pass through the outer core. Correct the claim and explain what can happen to P-wave paths. [2 marks]

Answer / mark points: P-waves can propagate through the liquid outer core, unlike S-waves. [1]

Their speed changes between materials, so their paths can refract / bend; some surface regions may receive no direct P-wave without all P-waves being stopped at the core. [1]



6 Evaluating hidden-structure evidence

The team must explain what its records establish and what still needs checking. Consider the stated wave behaviour, not just whether a single signal appears on a screen.

6(a) A plate test gives no identified flaw echo. Give two reasons, other than the plate having no flaw, why this could happen. **[2 marks]**

Answer / mark points: Any two: strong absorption / attenuation makes the returning signal too weak; flaw orientation reflects the wave away from the receiver; poor probe contact; flaw outside the beam / usable depth; detector or timing settings unsuitable. [1 each, max 2]
Do not accept that ultrasound cannot travel through any solid.

6(b) Describe how the team could use an ultrasound probe and its time display to determine the depth of a hidden steel boundary. The wave speed in the steel is known. **[3 marks]**

Answer / mark points: Send a short pulse from the known surface and detect the reflected pulse from the boundary. [1]
Identify the sent and corresponding echo peaks, and subtract their display times to obtain the out-and-back travel time. [1]
Convert time to seconds and use $\text{depth} = \text{speed} \times \text{elapsed time} / 2$ for the normal out-and-back path. [1] Repeat / check calibration and position to strengthen the evidence.

6(c) Use the supplied probe information to explain one advantage and one limitation of increasing inspection frequency. **[2 marks]**

Answer / mark points: The shorter wavelength / higher-frequency probe can distinguish more closely spaced boundaries under the supplied test limits. [1]
It is more strongly absorbed in this steel, so echoes become too weak at a smaller usable depth. [1]
The table's limits apply to this material / test, not every ultrasound system.

6(d) At one geological detector, no S signal is recorded. A trainee immediately claims a liquid layer has been proved. Explain why more evidence is needed. **[2 marks]**

Answer / mark points: A missing signal could instead follow detector failure, excessive absorption, an unsuitable path or a weak source; absence at one site is not uniquely diagnostic. [1]
Use checked detectors, repeat events and compare P / S arrivals at several known positions / paths before judging which structural model fits. [1] The simplified Figure 3 inference had these alternatives explicitly ruled out.

6(e) Why is a worldwide network of seismic records more useful than one detector when estimating the extent of the Earth's core? **[1 mark]**

Answer / mark points: Arrival and absence patterns across many positions constrain the possible core-boundary position / extent when compared with wave-path models. [1] This is indirect evidence for regions that cannot be observed directly; no numerical core-radius calculation is required.

Review and improve

Require precise boundaries and wave types. S-waves cannot propagate through liquids; P-waves can, with changes in speed and path. One missing signal is not a complete structural diagnosis.

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