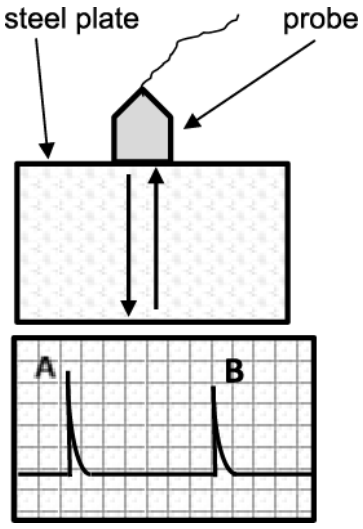
1. Ultrasonic testing is a technique widely used in industry to detect defects or flaws in many materials including metals and plastics.



The probe sends out a sound wave into a sample of steel plate.

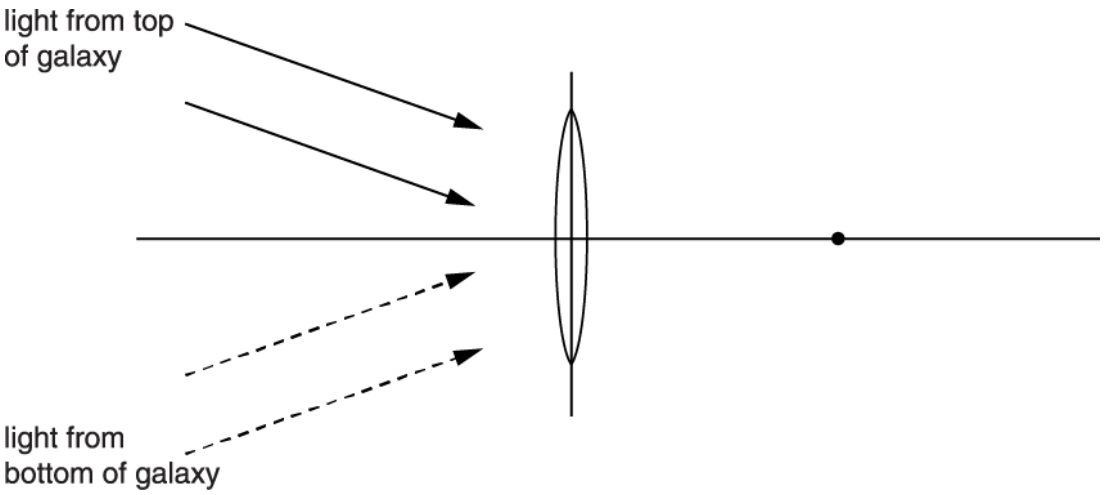
There are two signals displayed. One from the outgoing pulse (**A**) and the second due to the echo from the bottom surface (**B**).

The frequency of a sound wave is 100 kHz.

Calculate the wavelength of these waves given that their speed is 330 m/s.

_____ m **[4]**

2. Complete the ray diagram to show how an image of a distant galaxy is formed.
The point to the right of the lens is the focal point.
Label the image.

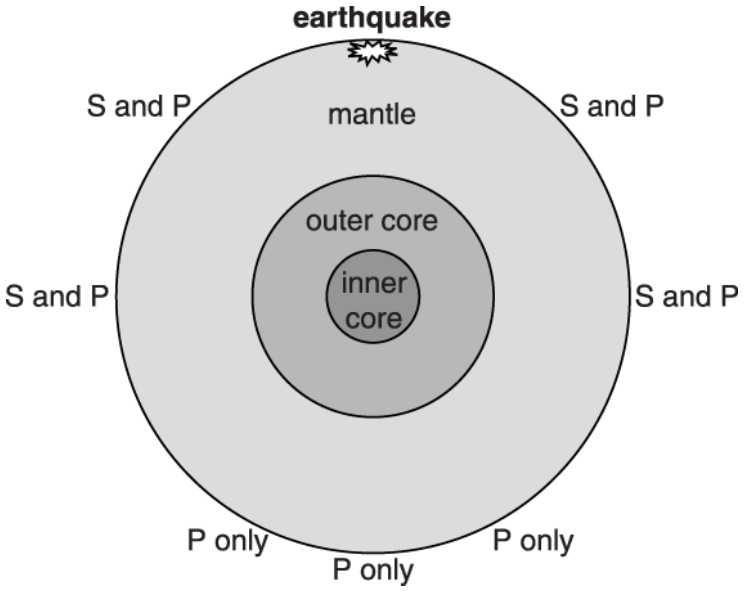


[4]

3(a). Information from earthquake waves can be used to find out about the structure of the Earth.

- S-waves can only travel through solids.
- P-waves can travel through both solids and liquids.

The diagram shows which waves are detected at different points on the Earth from an earthquake.



This evidence can be used to make some conclusions about the structure of the Earth.

Complete the table to show which conclusions can be made from **this evidence.**

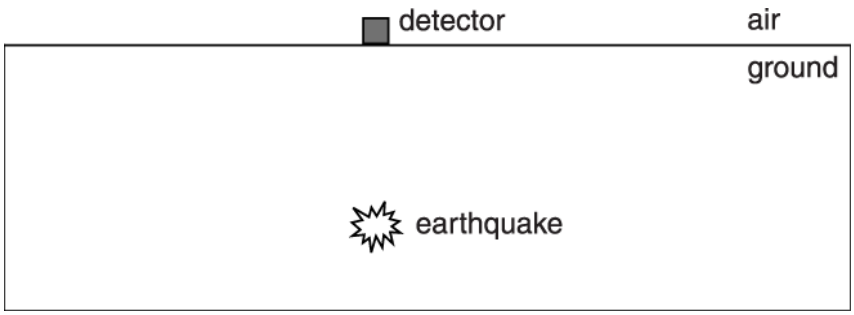
Put one tick (✓) in each row.

	is liquid	**is solid**	**cannot tell**
crust			
mantle			
outer core			
inner core			

[3]

(b). The centre of most earthquakes is deep underground.

An earthquake happens directly below a detector.



When the P-wave arrives the ground moves up and down.
When the S-wave arrives the ground moves from side to side.

(i) By using the properties of the waves, explain the different movement of the ground when each wave arrives.

---[2]

(ii) Suggest why S-waves usually do more damage to buildings than P-waves.

---[1]

(c). The P-waves and S-waves are produced at the same time, however the first P-wave arrives at the detector before the first S-wave.

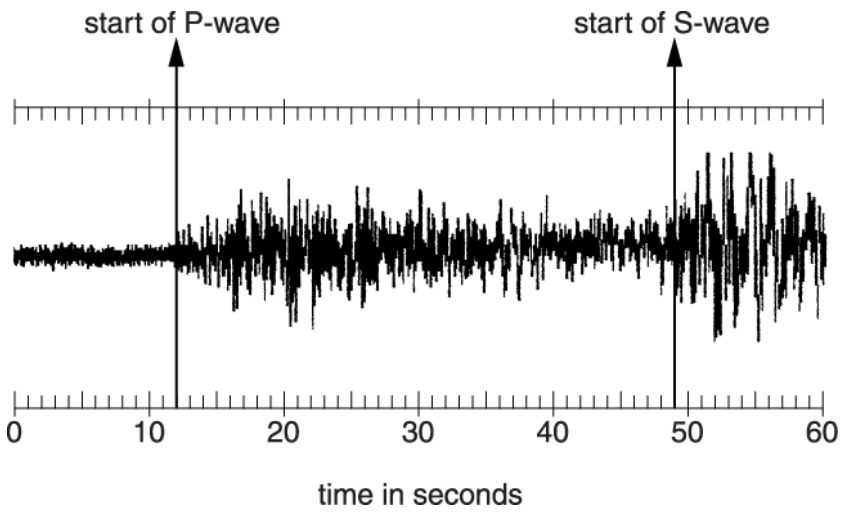
The depth of the earthquake is 30 km.
The average speed of the P-wave is 6 km/s.
The average speed of the S-wave is 4 km/s.

Calculate the time difference between the arrival of the P and S-waves.

Time difference = _____ s **[3]**

4(a). This question is about earthquakes.

The diagram shows the record at a detector of an earthquake.



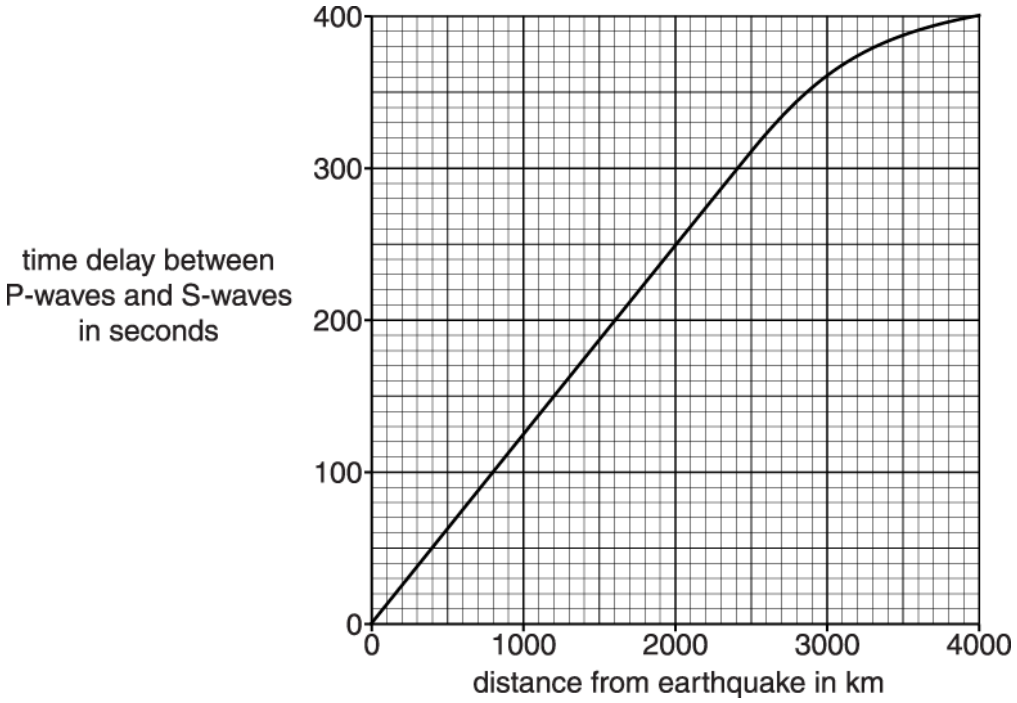
Earth scientists estimate the distance from an earthquake to the detector using the rule:

1 second of time delay between the arrival of the P-waves and the arrival of the S-waves corresponds to a distance of 8 km.

(i) Use the diagram to find the distance between the earthquake and the detector.

answer = _____ **[2]**

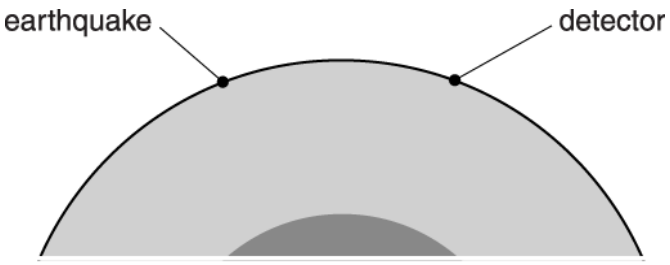
(ii) The graph shows the actual time delay for different distances from the earthquake.



Use the graph to show that the '8 km for every second of delay' rule works much better at a distance of 2000 km than at a distance of 4000 km.

--- [2]

(b). The line on the graph curves because the S-waves and P-waves are both changing in speed as they pass through the Earth.

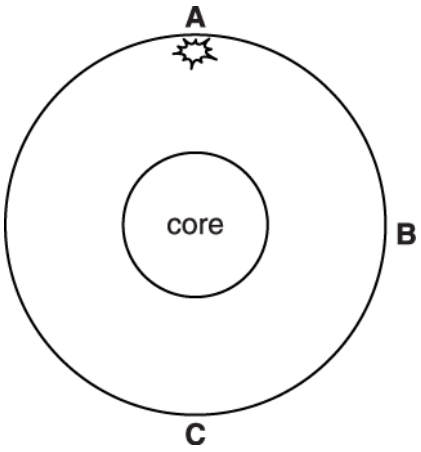


Use your knowledge of the structure of the Earth to suggest and explain why the graph in **(a)(ii)** curves.

---

[2]

5(a). Earthquake waves travel through the Earth from **A** to **B** and from **A** to **C**.



(i) On the diagram draw the complete paths of S-waves travelling from **A** to **B** and from **A** to **C**.

[1]

(ii) Which of the following statements about P-waves are correct?

Put a tick (✓) in the box next to each correct statement.

P-waves cannot be detected at **C**. ☐

The distance from **A** to **B** can be calculated just using P-waves. ☐

At **B**, P-waves are detected before S-waves. ☐

P-waves transfer energy and matter from **A** to **B**. ☐

P-wave vibrations are perpendicular to their direction of motion. ☐

P-wave frequencies are inversely proportional to their wavelength for a constant speed. ☐

[2]

(b). Describe how tectonic plates could cause a **P-wave**.

---

[2]

6. Both analogue and digital signals can be sent through the atmosphere or along optical fibres.

The statements below are about these different ways of sending a signal.
Some of them are true for sending through the atmosphere, some are true for using optical fibres, and some are true for both.

Put a tick (✓) in **each** correct box after each statement. The first statement has been completed for you.

Statement	True for sending through the atmosphere	True for optical fibres
The signals can be digital or analogue	✓	✓
Microwaves can carry the signal.		
Not much of the signal is absorbed by the material it passes through.		
The signal uses photons of less energy than X-ray photons.		
The signal travels at a speed of hundreds of thousands of kilometres each second.		

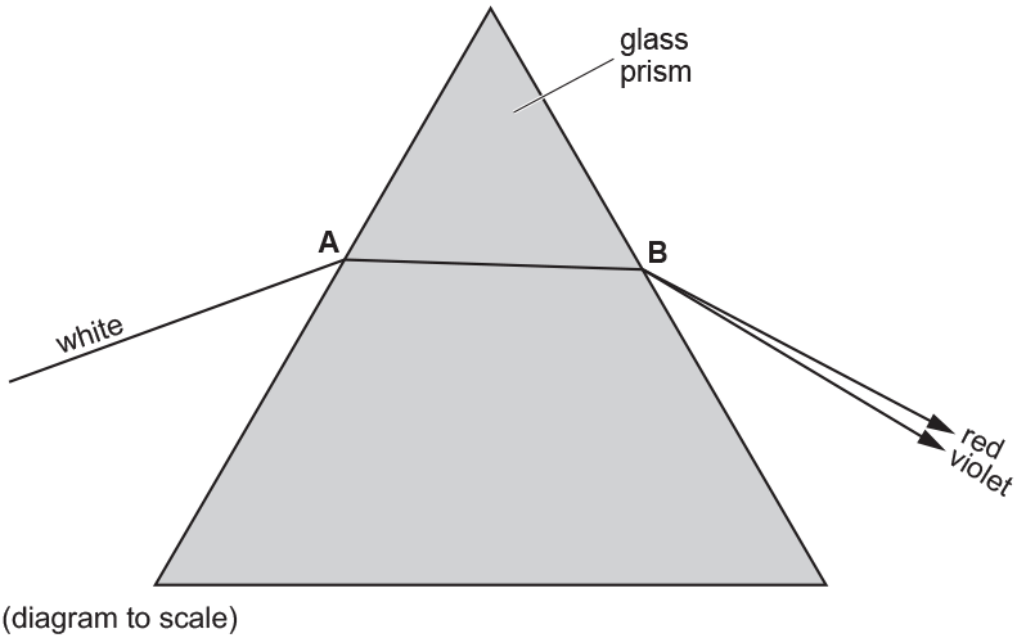
[2]

7(a). This question is about the refraction of waves.

Layla uses a ray-box to send a ray of white light into a triangular glass prism at point **A**.

She cannot see clearly what happens inside the prism, but she sees a spectrum of colours coming out at point **B**.

The diagram shows the paths taken by the colours at the two ends of the spectrum.



(diagram to scale)

Which statements about the physics of this refraction are correct?

Tick **(✓) two** boxes.

Red light and violet light both slow down when going from air into glass. ☐

Red light travels slower than violet light in air. ☐

Violet light travels faster than red light in glass. ☐

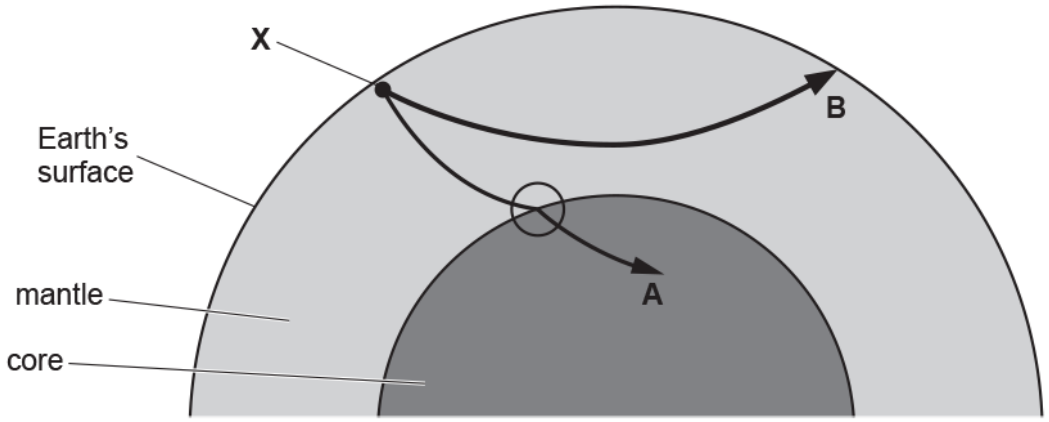
When they go from glass into air, both red light and violet light decrease in wavelength. ☐

When they go from glass into air, violet light speeds up more than red light.

[2]

(b). The diagram below is a section through part of the Earth.

Following an earthquake at **X**, earthquake waves travel through the Earth.
Two wave paths, **A** and **B**, are shown on the diagram.



(i) Look at path **A**.

The wave direction changes suddenly at the place ringed.

Explain what this shows about the speed of the earthquake wave as it moves from the mantle into the core.

---

[2]

(ii) Look at path **B**.

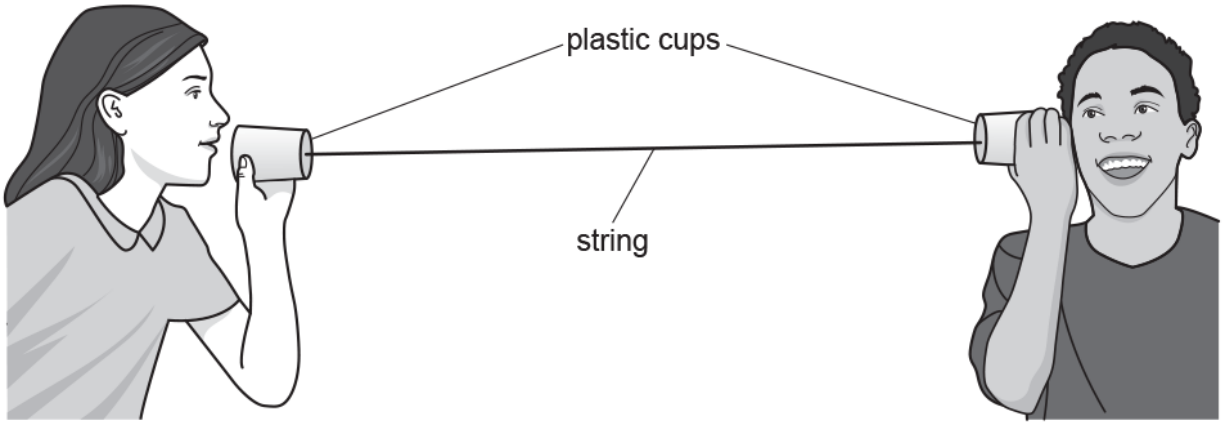
The wave direction changes continuously.

Explain what this shows about the speed of the earthquake waves in the mantle at different depths below the Earth's surface.

---

[2]

8. Eve and Amir make a toy telephone out of plastic cups and string.



Sound waves in the air change when they become sound waves in the string.

How do the **speed**, **frequency** and **wavelength** of the sound waves change when they leave the air and enter the string?

Put one tick (✓) in each row. One has been done for you.

	Increase	Decrease	Stay the same
Speed	✓		
Frequency			
Wavelength			

[2]

9(a). James and Mia investigate their hearing.

James uses an app on his phone to make sounds with different frequencies.

For each frequency, he starts with the volume on his phone set at zero.

Then he turns the volume up step by step until Mia can just hear the sound.

The results show the volume setting needed before Mia can hear the noise for each frequency.

Frequency (Hz)	Volume setting
55	13
110	11
220	7
440	1
880	1
1760	1

Explain why Mia finds it easier to hear some of these frequencies.

--- [2]

(b). They repeat the experiment.

This time there is a wall between the phone and Mia. They want to see what effect the wall has on the results.

(i) Suggest **one** variable that should be controlled to make this new experiment a fair comparison with the first experiment.

---

[1]

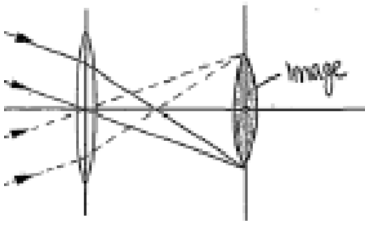
(ii) The volume setting needed for each frequency is higher in the new experiment.

Describe how the sound waves reach Mia and why they sound more faint.

---

[2]

END OF QUESTION PAPER

Question			Answer/Indicative content	Marks	Guidance
1			FIRST CHECK THE ANSWER ON ANSWER LINE **If answer = 3.3×10^{-3} (m) award 4 marks** Recall and apply $v = f \times \lambda$ (1) Rearrange to get $\lambda = v \div f$ (1) Convert kHz to Hz 100 kHz = 100000 Hz (1) 330 m/s ÷ 100000 Hz = 3.3×10^{-3} (m) (1)	4	
			Total	**4**	
2			**for either pair of rays** (the continuous or dotty): ray passes undeviated through centre of lens (1) second ray bends at lens (only) towards the principal axis and crosses the principal axis before the focal point (1) the pair of rays cross in the focal plane (1) **for all rays** labelled extended image based on all 4 correct rays (1)	4	choose the pair of rays to the benefit of the candidate **ignore** gaps to the left of the lens  for 4 marks <u>Examiner's Comments</u> Many candidates had little understanding of ray diagrams. Detailed ray diagrams, resulting in the correct image formation in the focal plane, were rarely seen. Candidates need to know the way in which rays are refracted as they enter the lens. Candidates often continued top ray without refraction and bent central ray along principal axis. In the high scoring responses, a poorly labelled or shrunken image were the most common reasons for only scoring 3 marks. In the weakest responses it was common to see rays bending in mid-air.
			Total	**4**	

<table>
<tr><th colspan="3">Question</th><th>Answer/Indicative content</th><th>Marks</th><th>Guidance</th></tr>
<tr><td>3</td><td>a</td><td></td><td>
<table>
<tr><th></th><th>liquid</th><th>solid</th><th>cannot tell</th></tr>
<tr><td>crust</td><td></td><td>✓</td><td></td></tr>
<tr><td>mantle</td><td></td><td>✓</td><td></td></tr>
<tr><td>outer core</td><td>✓</td><td></td><td></td></tr>
<tr><td>inner core</td><td></td><td></td><td>✓</td></tr>
</table>
</td><td>3</td><td>all 4 correct = 3 marks
3 correct = 2 marks
1 or 2 correct = 1 mark

Examiner's Comments

Most candidates appeared to answer from their previous knowledge rather than responding to the information in the question. This was seen when most 2 mark answers lost the inner core/cannot tell mark.</td></tr>
<tr><td></td><td>b</td><td>i</td><td>longitudinal associated with up and down motion / p-wave
OR
transverse associated with side to side motion motion / s-wave</td><td>1</td><td></td></tr>
<tr><td></td><td></td><td>i</td><td>in a P / longitudinal wave the particles / medium / ground move in same direction as the wave
OR
in an S / transverse wave the particles / medium / ground move at right angles to the direction of the waves</td><td>1</td><td>ignore the wave moving up and down

ignore the wave moving side to side

Examiner's Comments

A reasonable number of candidates identified P and S waves as longitudinal and transverse respectively but their communication skills let them down when trying to explain the different movement of the ground in each situation. Many weaker candidates simply repeated information given in the question.</td></tr>
<tr><td></td><td></td><td>ii</td><td>buildings are less stable against side-to side motion / s-waves transfer more energy / power / s-waves have a larger amplitude</td><td>1</td><td>ignore s-waves are stronger

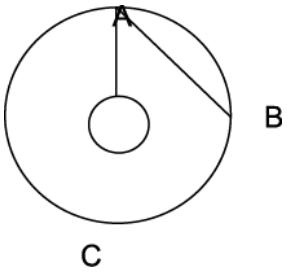
Examiner's Comments

The few marks awarded here were mainly for stating that s-waves transfer more energy.</td></tr>
</table>

Question			Answer/Indicative content	Marks	Guidance
	c		uses idea of distance = wave speed × time calculates time for **either** p-wave = 5 s **or** s-wave = 7.5 s 2.5 (seconds)	3	correct numerical answer gains all marks **Examiner's Comments** Most candidates successfully completed the calculation. A common error was confusion in manipulating the equation 'wave speed x time'.
			Total	**9**	

Question			Answer/Indicative content	Marks	Guidance
4	a	i	(time delay = 49 ? 12 =) 37 (s) (1) (distance = 8 × 37 =) 296 (km) (1)	2	**ignore** incorrect or missing units **allow** ± 1 s on difference, i.e. 36, 37 or 38 gets the first mark ecf own time delay: 2nd mark is for 8 × (whatever) = result 36 s gives 288 km & 38 s gives 304 km correct answer with no working gets both marks Examiner's Comments Most candidates tackled (i) well but some failed to negotiate the different stages needed to get to the answer.
		ii	A calculation from data for 2000 km confirming the rule (1) Shows that data for 4000 km does not confirm the rule (1)	2	calculation needed e.g. 250 × 8 = 2000 (km), 2000/8 = 250 (s) or 2000/250 = 8 (km/s) – **working must be shown** e.g. (4000/400 =) 10 (km/s), (4000/8 =) 500 (s)or (400 × 8 =) 3200 (km). Accept any of the three answers linked to 4000 km as evidence of equation not working Allow 2nd mark for reference to graph curving / levelling out after 2000 km but not just ‘graph curves over’ with no reference to when Examiner's Comments In (ii), many did not justify their answer by calculation: many who had the right idea ended up with 1/2 after a paragraph of continuous prose, while others had gained both marks after two simple calculations followed by brief comments.

Question			Answer/Indicative content	Marks	Guidance
	b		Density / state changes (with depth) (1) Idea that s–waves **and** p–waves change speed with depth (differently) (1)	2	e.g. becomes more liquid e.g. 'the waves go faster' **ignore** reference to core the speed change must be linked to the change in the mantle e.g. the speed of p–**and** s–waves changes with depth / density / state **Examiner's Comments** The stimulus diagram was meant to indicate to candidates that the path from earthquake to detector went nowhere near the core, just visible at the bottom, but unfortunately the sight of the core led many to discuss the behaviour of P- and S-waves on reaching the core.
			Total	8	

<table>
<tr><th colspan="3">Question</th><th>Answer/Indicative content</th><th>Marks</th><th>Guidance</th></tr>
<tr><td>5</td><td>a</td><td>i</td><td>line from surface near A to surface near B and line starting near A going towards C, but stopping at the edge of the core near A.
 
</td><td>1</td><td>both lines needed for the mark

accept wavy lines

ignore correct additional lines

Examiner's Comments

This was generally very poorly answered. Most candidates correctly drew from A to B but failed to show that the wave stopped by the liquid core. Common errors were the wave going through the core, curving around the core or reflecting from the surface.</td></tr>
<tr><td></td><td></td><td>ii</td><td><table><tr><td>P-waves cannot be detected at C.</td><td></td></tr><tr><td>The distance from A to B can be calculated just using P waves.</td><td></td></tr><tr><td>At B,P-waves are detected before S waves.</td><td>✓</td></tr><tr><td>P-waves transfer energy and transmit matter from A to B.</td><td></td></tr><tr><td>P-wave vibrations are perpendicular to their direction of motion.</td><td></td></tr><tr><td>P-wave frequencies are inversely proportional to their wavelength .</td><td>✓</td></tr></table></td><td>2</td><td>Examiner's Comments

Most candidates ticked the correct number of boxes – but often the wrong ones. There was no noticeable pattern to the errors.</td></tr>
<tr><td></td><td>b</td><td></td><td>plates (causes rocks to) move / rub against each other / release of stress in / between plates (1)

Shows awareness of the longitudinal motion (of a P-wave) e.g. involve compression / forwards and backwards movement / pressure wave (1)</td><td>2</td><td>must be an interaction between plates

Examiner's Comments

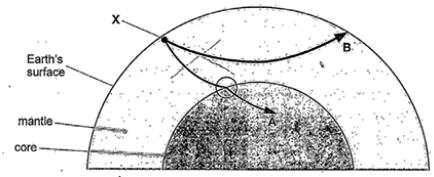
Many candidates got the idea of plate interaction (although a small number just referred to plates moving). A very small number recognised the need for longitudinal motion.</td></tr>
<tr><td></td><td></td><td></td><td>Total</td><td>5</td><td></td></tr>
</table>

<table>
<tr><th colspan="3">Question</th><th>Answer/Indicative content</th><th>Marks</th><th>Guidance</th></tr>
<tr><td>6</td><td></td><td></td><td>
<table>
<tr><td></td><td>atmos</td><td>opt fibre</td></tr>
<tr><td>microwaves</td><td>?</td><td></td></tr>
<tr><td>not much absorbed</td><td>?</td><td>?</td></tr>
<tr><td>photons</td><td>?</td><td>?</td></tr>
<tr><td>speed</td><td>?</td><td>?</td></tr>
</table>
</td><td>2</td><td>all correct = (2)
three rows correct = (1)

<u>Examiner's Comments</u>

<u>?</u>?The objective part (b) was surprisingly poorly answered, quite possibly because candidates found it hard to put ticks in almost all of the boxes.</td></tr>
<tr><td></td><td></td><td></td><td>Total</td><td>2</td><td></td></tr>
</table>

Question			Answer/Indicative content	Marks	Guidance
7	a		Red light and violet light both slow down when going from air into glass. ✓ When they go from glass into air, violet light speeds up more than red light. ✓	2 (AO 2.1 x 2)	Top and bottom boxes
	b	i	Refraction/bending (towards normal) ✓ waves slower in core than in mantle ✓	(AO 1 x 1) 2 (AO 2 x 1)	ALLOW 'change direction' for refracted here
		ii	Refracted other way from (b)(i) ✓ Wave speed faster lower in the mantle ✓	(AO 1 x 2) 2 (AO 2 x 1)	ECF mp2 reversed in (b)(i) Examiner's Comments This question was an example where many candidates did not see the linking 'story' in the question and treated each item as a standalone question. Part (a) was well done, but fewer candidates gained any credit for part (b). Only a handful of candidates were credited with all six marks for Q9. Exemplar 22 In this exemplar the candidate has clearly understood that the diagrams in parts (a) and (b) are meant to be compared. The candidate explains in a clear and precise way that the seismic wave is refracted as it goes from mantle to core in (b), just like the light in (a), and so it must be slowing down. They note that wave in the mantle is refracting in the opposite direction, and so this must indicate that the wave speed is greater the deeper you go into the mantle. This candidate is able to express themselves using appropriate scientific language such as 'normal' and the 'speed must be changing continuously'.

<table>
<tr><th colspan="3">Question</th><th>Answer/Indicative content</th><th>Marks</th><th>Guidance</th></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td>
Tick (✓) two boxes.
Red light and violet light both slow down when going from air into glass. ✓
Red light travels slower than violet light in air.
Violet light travels faster than red light in glass.
When they go from glass into air, both red light and violet light decrease in wavelength.
When they go from glass into air, violet light speeds up more than red light. ✓
[2]


(i) Look at path A.
The wave direction changes suddenly at the place ringed.
Explain what this shows about the speed of the earthquake wave as it moves from the mantle into the core.
As the wave bends towards the normal as it enters the core this shows that the wave is slowing down / the speed of the wave has decreased. [2]
The changing direction of the wave shows that its speed must be changing continuously too. The curve shows that as the wave travels deeper it must increase in speed as it bends away from the normal (s) and back up to the surface. [2]
</td></tr>
<tr><td></td><td></td><td></td><td>Total</td><td>6</td><td></td></tr>
<tr><td>8</td><td></td><td></td><td>
<table>
<tr><th></th><th>Increase</th><th>Decrease</th><th>Stay the same</th></tr>
<tr><td>speed</td><td>(✓)</td><td></td><td></td></tr>
<tr><td>frequency</td><td></td><td></td><td>✓</td></tr>
<tr><td>wavelength</td><td>✓</td><td></td><td></td></tr>
</table>
</td><td>2
(AO 1.1 ×2)</td><td><u>Examiner's Comments</u>

Most candidates appreciate that the frequency of the sound does not change, however a very common error was to indicate that wavelength would decrease.</td></tr>
<tr><td></td><td></td><td></td><td>Total</td><td>2</td><td></td></tr>
</table>

Question			Answer/Indicative content	Marks	Guidance
9	a		sound is transmitted/vibrations pass through bones in ear ✓ this works best/more sensitive over a limited range of frequencies/between 1000 to 3000 Hz ✓	2 (AO 1.1 ×2)	IGNORE ear drum IGNORE pick up / detect ALLOW low frequency produce smaller vibrations (in our ears) ORA ALLOW e.g. low frequencies produce smaller vibrations in the bones (=2 mks) ALLOW higher frequencies are more within our hearing range / lower frequencies are on the edge of our hearing range / we are more/less sensitive to certain frequencies DO NOT ALLOW just 'higher frequencies are easier to hear' DO NOT ALLOW just 'we are sensitive to certain frequencies' <u>Examiner's Comments</u> This question is aimed at assessing specification statement 1.4.7. Candidates should be able to explain that the transmission of sound through the bones of the ear works over a limited frequency range. Although many candidates made reference to the ear drum, very few candidates referred to the bones. Candidates who were able to identify that humans have a hearing range often found it difficult to use the data to conclude that we are less sensitive to frequencies at the lower limit of that range.

Question			Answer/Indicative content	Marks	Guidance
	b	i	Any one from: distance between phone/James and Mia ✓ background noise ✓ time to listen to each sound ✓ same frequency/ies	1 (AO 3.3a)	IGNORE distance between Mia and wall IGNORE the same phone/speaker/app <u>Examiner's Comments</u> Most candidates gained credit for identifying a continuous variable such as the distance between the phone and Mia or using the same frequency values from the first experiment. Discrete variables such as 'use the same wall' did not gain credit.
		ii	waves are transmitted / pass through the wall ✓ but some waves are absorbed / reflected by the wall ✓	2 (AO 1.1 ×2)	ALLOW as vibrations / as longitudinal waves / as compressions and rarefactions ALLOW a description of absorption e.g. the wave loses energy by vibrating the particles in the wall ALLOW a description of reflection e.g. the wave echoes off the wall/bounces back from the wall <u>Examiner's Comments</u> Most candidates were able to express the idea that waves are transmitted through the wall but only a few of the most able candidates were able to explain the faintness of the sound in terms of absorption or reflection of the sound waves. A common response was simply to state that the waves had lost energy with no attempt to explain the cause of the energy loss.
			Total	5	