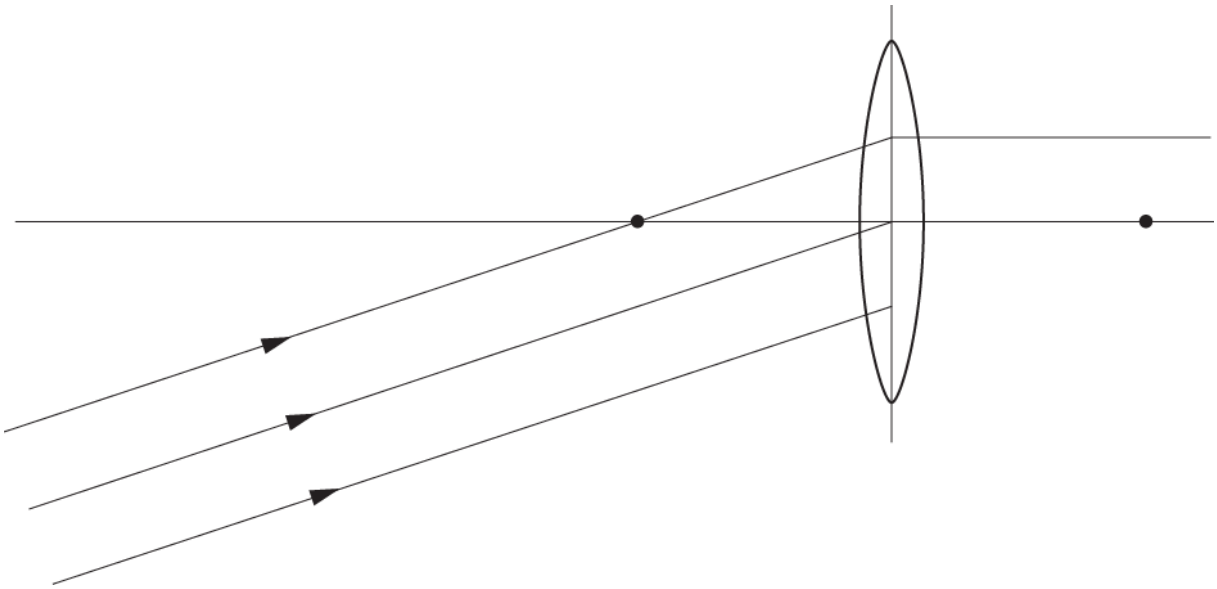
1. A lens refracts light passing through it.

(i) Explain why a light ray can change direction when passing through a lens.

---

[3]

(ii) Complete the diagram to show how a lens can form an image of a distant object.
The dots on the diagram are the focal points of the lens.
Label the position of the image.



[3]

2(a). Alice looks at the Moon.

Alice knows she sees the Moon using light from the Sun.

Explain how Alice sees the Moon.
Use the general model of electromagnetic radiation in your answer.

---

[3]

(b).

(i) The Earth and Moon have the same average distance from the Sun over a year. Therefore on average they receive the same intensity of light.

The diameter of the Moon is approximately 3500 kilometres.
The diameter of the Earth is approximately 13 000 kilometres.

How many times more energy is transferred directly by light from the Sun to the Earth than from the Sun to the Moon?

answer = _____ **[2]**

(ii) This would result in the Earth and the Moon having the same average temperature.
Suggest why the Earth's average temperature is 15°C and the Moon's is −23°C.

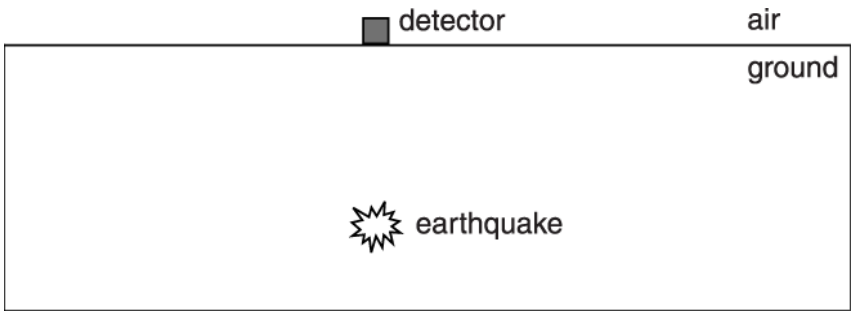
_____

_____

_____ **[1]**

3(a). 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]

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(b). 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). Earthquakes close to the coast often produce dangerous water waves called tsunamis.

The table below gives typical data for a tsunami.

Depth of water (m)	Speed (m/s)	Wavelength (m)
7000	260	282000
4000	200	213000
2000	140	151000
200	45	48000
50	22	23000
10	10	10600

(i) A tsunami crossed the Indian Ocean from the earthquake on the coast of Indonesia to Africa. It took 8 hours and 20 minutes to do so. The speed of this tsunami was 180 m/s.

Calculate the distance in km from the Indonesian earthquake to Africa.

distance = _____ km **[3]**

(ii) Estimate the depth of the Indian Ocean, which you can assume to be the same at all parts.

depth = _____ m

Explain how you decided on this value.

_____

_____ **[1]**

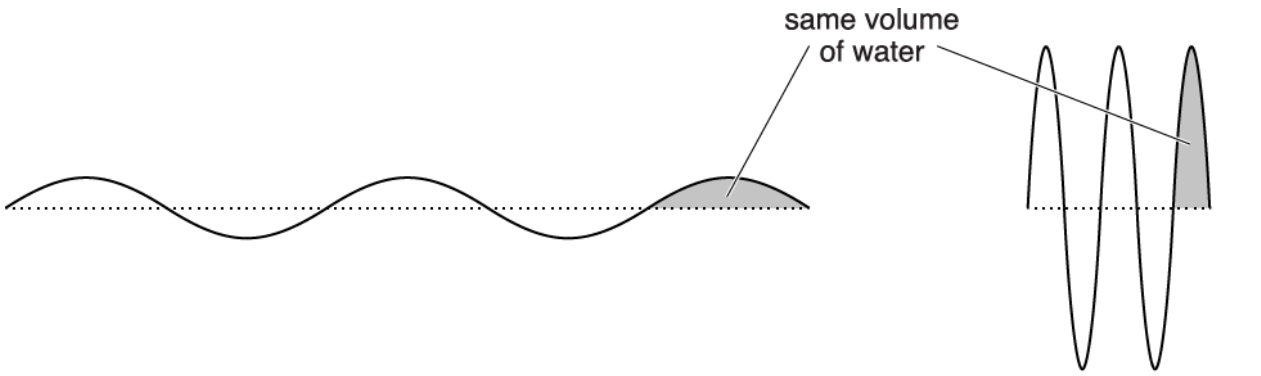
(b). It has been suggested that the speed of a tsunami is directly proportional to the depth of the water.

Explain what **directly proportional** means and use the data in the table below to see if the suggestion is true.

Speed (metres per second)	Depth of water (metres)
45	200
10	10

[2]

(c). The diagram below shows the tsunami waves in mid-ocean and near the land. The volume of water in each 'peak' of the wave stays the same.



Explain why a tsunami may not be noticed by a ship in mid-ocean but can cause terrible damage when it strikes the land.

[2]

5. The following table shows typical frequencies for some parts of the electromagnetic spectrum. The frequencies are measured in GHz, where 1 GHz = 1×10^9Hz.

Type of radiation	Microwave	Infrared	Visible light	Ultraviolet	X-ray
Frequency in GHz	2	1000	550000	30 million	3 thousand million

(a) The speed of light is 3.0×10^8 m/s.

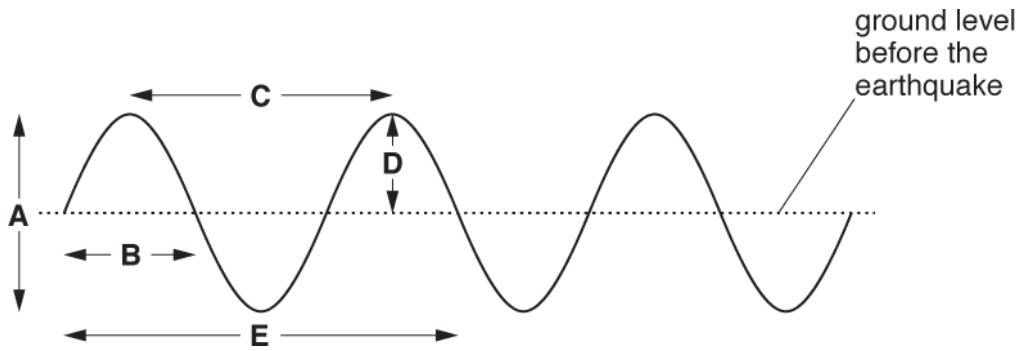
Calculate the typical wavelength of visible light.

Write your answer in nanometres (nm), where 1 nm = 1×10^{-9} m.

Give your answer to **one** significant figure.

wavelength = _____ nm **[3]**

6(a). The diagram below shows the ground moving when an earthquake wave passes. The dotted line shows the ground level before the earthquake arrived.



The wave diagram has five different arrows labelled **A**, **B**, **C**, **D** and **E**.

Which arrow, **A**, **B**, **C**, **D** or **E**, shows the **amplitude** of the wave?

the amplitude is shown by arrow _____ **[1]**

(b). Which arrow, **A**, **B**, **C**, **D** or **E**, shows the **wavelength** of the wave?

the wavelength is shown by arrow _____ **[1]**

(c). The wave in the diagram has a wavelength of 1 km and a frequency of 2 Hz.

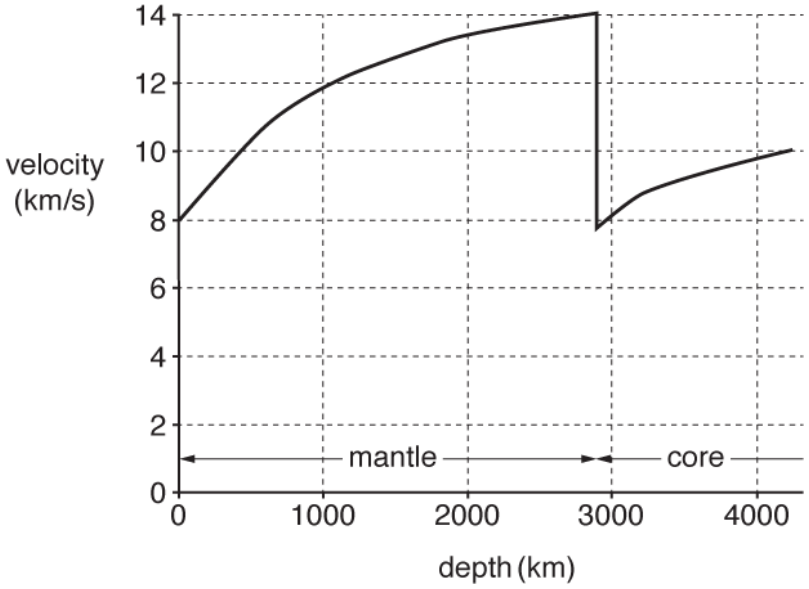
Calculate the speed of the wave in m/s.

Show your working.

speed = _____ m/s **[2]**

[Total: 4]

7. As an earthquake wave travels deeper into the Earth, its speed changes as shown below.



An earthquake wave has a wavelength of 2000 m when it enters the Earth's mantle.

Explain why the graph shows that its wavelength will be 3500 m just before it enters the Earth's core.

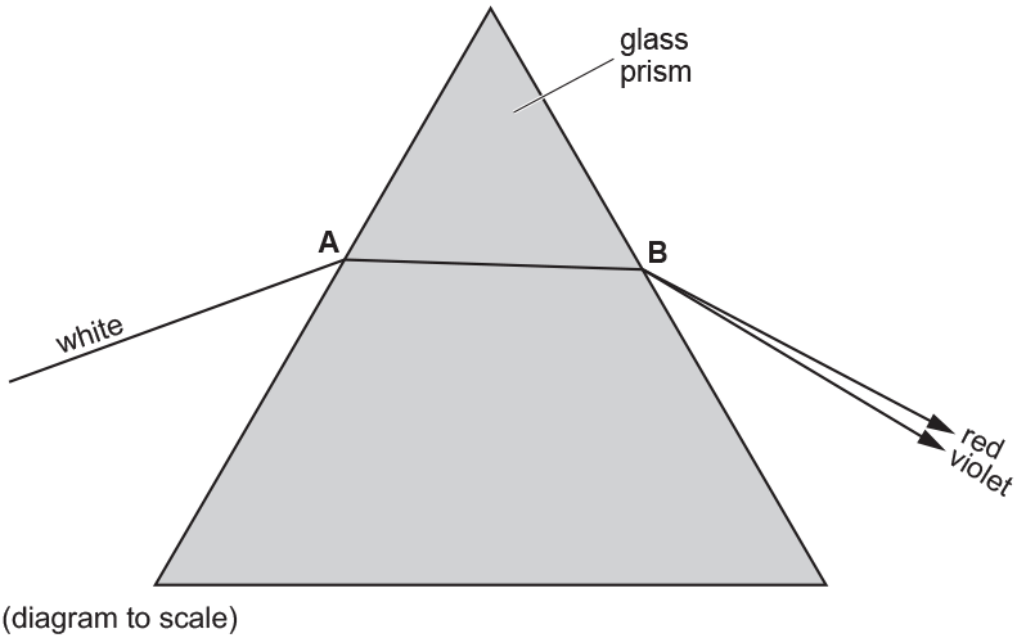
[3]

8(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. ☐

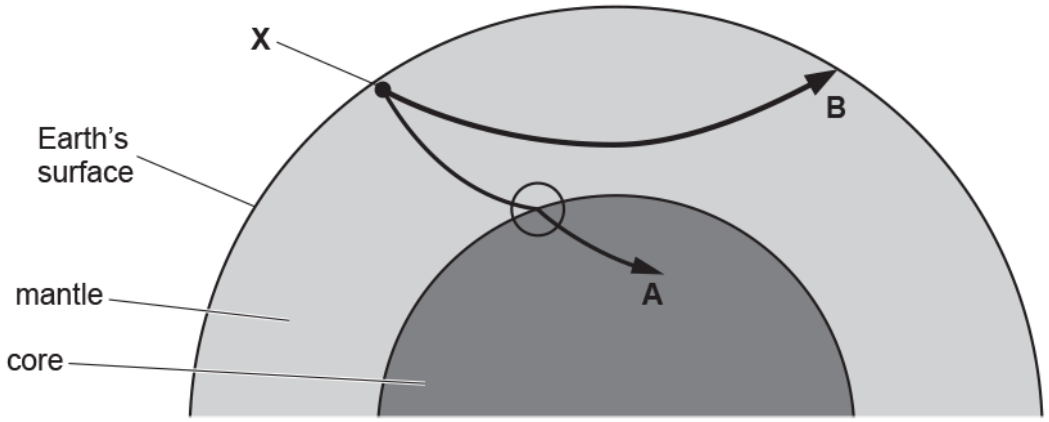
When they go from glass into air, both red light and violet light decrease in wavelength. ☐

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.

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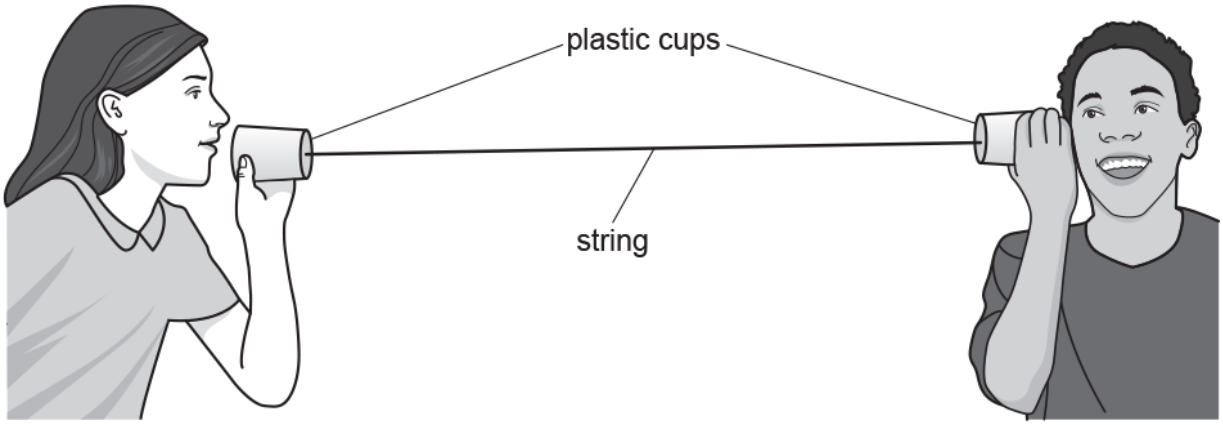
[2]

9. 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.

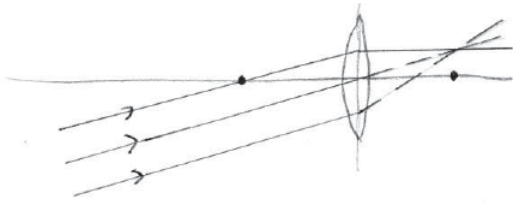
The speed of sound in the string is 600 m / s.

Calculate the frequency of a sound with wavelength 1.2 m in the string.

Frequency = ... Hz **[3]**

END OF QUESTION PAPER

Question			Answer/Indicative content	Marks	Guidance
1		i	EITHER • Light speed slows down (as it enters lens); • (Hence) decrease in wavelength; • Light changes direction towards normal; OR • Light speeds up (as it leaves lens); • (Hence) increase in wavelength; • Light changes direction away from normal; OR • Sides of the lens are not parallel; • Speed in the lens not same as in air; • Wavelength different in lens;	3	Unless specified, assume that light is passing into the lens. **Ignore** colours **Not** frequency changes (negate wavelength marks)
		i			**Allow** wavelength changes and speed changes for 1 mark if no other marks scored **Examiner's Comments** Many candidates were unable to give clear responses to this question. Although the majority of candidates referred to changes in wavelength, speed or direction, many did not state the nature of the change. The most common correct response was 'light slows down' which, due to the nature of the question stem, was taken to mean 'when passing into the lens'. Very few referred to the passage of light into or out of the lens. A small number of candidates incorrectly referred to frequency changes.
		ii	ray through centre of lens continues straight to intersect top ray	1	**Ignore** any additional rays constructed for the top ray.

Question			Answer/Indicative content	Marks	Guidance
		ii	bottom ray bends in lens then continues as straight line to intercept of central and top ray 	1	
		ii	image labelled at intercept of all three rays;	1	**Accept** an extended image to the principal axis **Examiner's Comments** Where attempted, this question was not well answered. Many candidates either ignored the pre-drawn top ray, choosing to replace this with a ray directed towards the principal axis or showed the bottom ray refracting and then running parallel to the principal axis. Many candidates, however, recognised that the centre ray continues in a straight line and the majority were aware that the image is formed where light rays cross albeit not always where all three lines crossed.
			Total	**6**	

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Question			Answer/Indicative content	Marks	Guidance
2	a		any 3 from the sun emits / radiates light the moon reflects light light is transmitted through space / the atmosphere light is absorbed by the eye	3	Examiner's Comments Few candidates were able to use terms from the general model correctly throughout this question. The idea of light reflecting off the moon was the marking point most frequently scored but there were quite a few candidates who, while knowing that the sun emits radiation, thought that it was ultraviolet radiation that allowed us to see the moon. 'Transmitted' was the least used term.
	b	i	either calculates the cross sectional area of **either** the earth **or** the moon OR calculates the square of the ratio of **both** earth and moon 13.8	2	**allow** 3.7 or 4 (use of diameters instead of areas) Moon cross sectional area = 9,621,127.5 km^2 earth cross sectional area = 132,732,289.6 km^2 moon diameter^2 = 12,250,000 km^2 Earth diameter^2 = 169,000,000 km^2 **accept** $130^2/35^2$ or $26^2/7^2$ correct numerical answer gains both marks **accept** 13.5 to 14 **ignore** units Examiner's Comments Only a handful of candidates recognised that the ratio of cross-sectional areas was key here. A number of candidates did recognise that a ratio was needed but simply calculated the ratio of the two diameters. Some candidates tried to use energy transferred = power x time.

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Question			Answer/Indicative content	Marks	Guidance
		ii	the Earth has an atmosphere **and** this increases the temperature / keeps it warm / OR the greenhouse effect raises temperature	1	**ignore** references to ozone layer **accept** consistent albedo argument – the earth reflects less energy back into space and the moon reflects more energy **Examiner's Comments** Less than half of candidates correctly identified the role of Earth's atmosphere in retaining heat there were a range of incorrect answers e.g. the core of the earth, the ozone layer, that the moon was further away, in the shadow of the earth or that human activity was to blame.
			Total	6	

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Question			Answer/Indicative content	Marks	Guidance
3	a	i	longitudinal associated with up and down motion / p-wave OR transverse associated with side to side motion motion / s-wave	1	
		i	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	1	**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.
		ii	buildings are less stable against side-to side motion / s-waves transfer more energy / power / s-waves have a larger amplitude	1	**ignore** s-waves are stronger **Examiner's Comments** The few marks awarded here were mainly for stating that s-waves transfer more energy.
	b		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	6	

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Question			Answer/Indicative content	Marks	Guidance
4	a	i	time = ((8 × 60) + 20) × 60 = 30 000 (s) (1) distance = 180 m/s × 30 000 s = 5 400 000 (m) (1) = 5400 (km) (1)	3	bald correct answer 5400 gets all 3 marks omitting min to s gives 500 ecf own time mark for (correctly) dividing own distance/m by 1000 1 error (e.g. min/s or km/m) would give 90 km or 5 400 000 km and either would get 2 marks; both factors wrong gives 90 000 km which is one mark (for method) Examiner's Comments Candidates were required to convert the given time into seconds, calculate the distance travelled at 180 m/s in the time they had deduced, and then convert the answer into km. Few managed all three steps with no errors, and the commonest mark awarded was the second one, with 'error-carried forward', i.e. getting the wrong time but then correctly using that value to find a distance, which was often then not converted from m to km.
		ii	Reason: must be between 2000 m and 4000 m	1	no mark for the value (although it may indicate that the method is reasonable); give a mark for the reasoning. Examiner's Comments About half the candidates could estimate a depth which required a simple interpolation between two values in the table. Unsuccessful candidates here went for the greatest possible depth, or averaged the six values in the table.

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Question			Answer/Indicative content	Marks	Guidance
	b		If you divide the speed by the depth (or vice versa) you get the same value / you plot a graph, it's a straight line though the origin / speed = constant × depth (1) use of data to show that it is not true (1)	2	proposing a test (which includes attempting to perform it) e.g. dividing one variable by the other, or sketching a graph, gets the first mark. 2nd mark needs application of the test (which could be an annotated sketch graph or 45/10 is not 200/10) Examiner's Comments Very, very few candidates could explain what direct proportion meant or demonstrate that the given data did not display it.
	c		The amplitude is bigger on the shore / smaller in mid-ocean (1) Wavelength gets smaller / waves bunch more / waves slow down as they approach land (1) Large amplitude means more (potential) energy (to cause damage) (1) Waves go further inland / can get over barriers (1)	2	any two points large amplitude could be 'taller / higher wave' but **ignore** 'bigger waves'; could describe vertical motion of e.g. ship ignore "frequency change" ignore kinetic energy e.g. can cause flooding inland Examiner's Comments Candidates who applied the appropriate terminology of wavelength and amplitude to the diagrams usually earned both marks, but weaker responses referred to 'bigger waves' or 'more powerful waves' in a vague way.
			Total	8	

Question			Answer/Indicative content	Marks	Guidance
5			f = 550 000 × (1 × 10^9 Hz) = 5.5 × 10^{14} Hz ✓ $\lambda = v / f$ = (3.0 × 10^8 m/s)/(5.5 × 10^{14} Hz) = 5.45.. × 10^{-7} m / 545 × 10^{-9} m ✓ = (5.45.. × 10^{-7} m)/ (1 × 10^{-9}) nm = 500 (nm) to 1 s.f. ✓	3	m.p.1 is for conversion GHz ➔ Hz. Allow this for expression such as 550 000 × 10^9 (Hz) m.p.2 is for calculation f ➔ λ with e.c.f. from m.p.1 m.p.3 is for conversion m ➔ nm AND rounding to 1.s.f Beware awarding m.p.1. and m.p.3 for two unit conversions cancelling, e.g. 3.0 × 10^8 m/s / 550 000Hz = 545.454 = 500 nm gets only m.p.2 and should be annotated with two carets ^ Bald '500' and no working gains all 3 marks – must assume that the calculation has been done correctly Bald '545' and no working gains 2 marks – no rounding
			Total	3	
6	a		D	1	
	b		C	1	
	c		FIRST CHECK THE ANSWER ON THE ANSWER LINE If answer = 2000 (m / s) award 2 marks if answer = 2 (m / s) award 1 mark 1 km = 1000 m (1); speed (= frequency × wavelength) = 2 (Hz) × 1000 (m) = 2000 (m/s) (1)	2	Needs use of equation & evaluation of own values of f and λ for this mark, e.g. λ = 100 m and speed = 200 m/s would get m.p.2 (e.c.f) only as m.p.1 has a conversion error.
			Total	4	

Question			Answer/Indicative content	Marks	Guidance
7			Any three points from: *v* increases with depth / density (1); *f* is constant (1); *v* ↑ means *λ* ↑ (in proportion) (1); scaling up e.g. *v* goes up 1¾ times so *λ* increases to 1¾ × 2000 m = 3500 m (1)	3	ignore consistent omission to convert km to m [*f* = (8000 m/s)/2000 m = 4 Hz] Calculation of *λ* = 3500 m using ratios / direct proportion means candidate also gets m.p.3
			Total	3	

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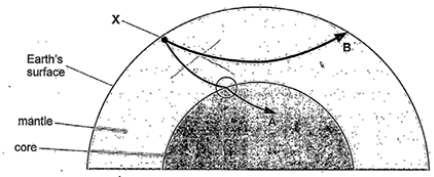
Question			Answer/Indicative content	Marks	Guidance
8	a		Red light and violet light both slow down when going from air into glass. ✓ When they go from glass into air, violet light speeds up more than red light. ✓	2 (AO 2.1 x 2)	Top and bottom boxes
	b	i	Refraction/bending (towards normal) ✓ waves slower 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'.

Question			Answer/Indicative content	Marks	Guidance
					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]
			Total	6	
9			FIRST CHECK THE ANSWER ON ANSWER LINE If answer = 500 (Hz) award 3 marks select **and** rearrange: f = *v* / *λ* ✓ = 600 / 1.2 ✓ = 500 (Hz) ✓	3 (AO 1.2) (AO 2.2) (AO 2.1)	Correct substitution also gains m.p. 1 <u>Examiner's Comments</u> By contrast with part (a), most candidates made correct use of the wave equation to calculate the frequency of 500 Hz.
			Total	3	