

THEME C · WAVE BEHAVIOUR

SL & HL ≈ 30 min read

IB Physics C.2 Wave Model — Notes (SL & HL)

Written by Evan Kotronis for the IB Diploma Physics course (first assessment 2025). C.2 is identical for SL and HL: the guide lists no additional higher level content, so everything on this page is examinable at both levels.

 SL C.2 questions HL C.2 questions Flashcards Waves changing medium simulation

What this page covers

- ✓ What a travelling wave is, and why it transfers energy without carrying the medium along with it
- ✓ Transverse and longitudinal waves, and how the particles of the medium move in each
- ✓ Wavelength, frequency, period, amplitude and wave speed, linked by
$$v = f\lambda = \frac{\lambda}{T}$$
- ✓ Reading λ , T and A from displacement–distance and displacement–time graphs
- ✓ Finding the direction in which a particle of the medium is moving, and locating compressions and rarefactions
- ✓ What happens to the wavelength when the frequency or the medium changes
- ✓ The nature of sound waves
- ✓ The nature of electromagnetic waves and the orders of magnitude of their wavelengths
- ✓ How mechanical waves and electromagnetic waves differ

In one minute

- A travelling wave is a disturbance that moves through a medium (or through space) and **transfers energy**. Each particle of the medium only oscillates about its own equilibrium position.
- **Transverse**: oscillations perpendicular to the direction of energy transfer (rope, string, all electromagnetic waves). **Longitudinal**: oscillations parallel to it, forming compressions and rarefactions (sound).
- $v = f\lambda = \lambda/T$. The **source** sets the frequency; the **medium** sets the speed; the wavelength follows from $\lambda = v/f$.
- A displacement–*distance* graph gives λ and A ; a displacement–*time* graph gives T and A . Always read the axis label first.
- Sound is a longitudinal mechanical wave that needs a medium. Electromagnetic waves are transverse oscillations of electric and magnetic fields that travel through a vacuum at $c = 3.00 \times 10^8 \text{ m s}^{-1}$.

Contents

- | | |
|---|---|
| 1. What a travelling wave is | 8. Changing the frequency or the medium |
| 2. Transverse and longitudinal waves | 9. Mechanical vs electromagnetic waves |
| 3. λ , f , T , v and $v = f\lambda$ | 10. Exam tips |
| 4. Displacement–distance and displacement–time graphs | 11. Common misconceptions |
| 5. How the particles move | 12. How this topic connects |
| 6. The nature of sound waves | 13. Key equations |
| 7. The nature of electromagnetic waves | 14. Check your understanding |

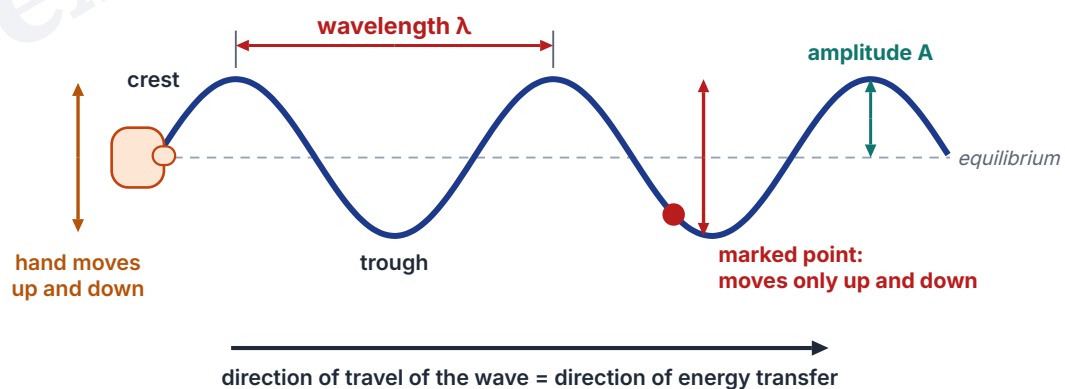
What is a travelling wave?

In C.1 you met a single oscillator. A wave appears when many oscillators are **coupled**: each part of the medium pulls or pushes on its neighbours, so a local

disturbance at the source is passed on, one particle to the next, slightly later each time. That passing-on is the wave.

A travelling (progressive) wave is a disturbance that moves through a medium, or through space, and transfers energy from one place to another without any net transfer of the medium itself.

- Every particle of the medium oscillates about its own **equilibrium position** and ends up where it started. What travels is the *pattern* of the disturbance and the **energy**.
- A single flick of a rope sends a **pulse**; a source that keeps oscillating sends a **continuous** wave. Every particle then oscillates with the frequency of the source.
- Each particle repeats the motion of the particle next to it on the source side, with a short delay. Particles further from the source are further behind in their cycle.
- **Mechanical waves** (waves on ropes and springs, water waves, sound) need a material medium. **Electromagnetic waves** do not: what oscillates is an electric and a magnetic field.



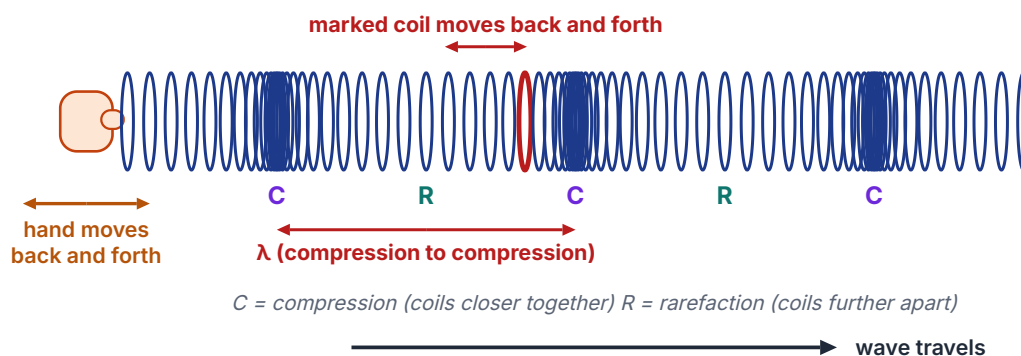
A transverse wave on a rope. The hand moves up and down; the wave pattern and the energy travel to the right, but the marked point on the rope only moves up and down about the equilibrium position.

What is the difference between transverse and longitudinal waves?

In a transverse wave the particles of the medium oscillate perpendicular to the direction of energy transfer. In a longitudinal wave the particles oscillate parallel to the direction of energy transfer.

	Transverse	Longitudinal
Direction of oscillation	perpendicular to the direction of travel	parallel to the direction of travel
Features	crests (peaks) and troughs	compressions (particles closer together, higher pressure and density) and rarefactions (particles further apart, lower pressure and density)
Wavelength measured	crest to crest, or between any two adjacent points oscillating in phase	compression to compression, or between any two adjacent points oscillating in phase
Examples	waves on a rope or a string, a slinky shaken sideways, all electromagnetic waves (light, radio, X-rays...)	sound and ultrasound, a slinky pushed and pulled along its length

- The same slinky can carry either type: shake the end sideways for a transverse wave, push and pull it along its axis for a longitudinal wave. The type depends on the direction of the oscillation, not on the medium.
- "Perpendicular to the direction of travel" is the clean wording. Avoid "perpendicular to the wave", which does not say which direction you mean.



A longitudinal wave on a slinky. Each coil oscillates back and forth along the spring. Where the coils bunch up there is a compression (C); where they spread out there is a rarefaction (R). One wavelength is the distance between the centres of two adjacent compressions.

What are wavelength, frequency, period and wave speed?

Quantity	Symbol and unit	Meaning
Displacement	y or x (m)	distance and direction of a particle from its equilibrium position
Amplitude	A (m)	maximum displacement of a particle from its equilibrium position
Wavelength	λ (m)	the distance between two adjacent points on the wave that oscillate in phase, e.g. crest to crest or compression to compression
Period	T (s)	the time for one complete oscillation of a particle of the medium
Frequency	f (Hz = s^{-1})	the number of complete oscillations per second; $f = 1/T$
Wave speed	v (m s^{-1})	the speed at which the energy (the wave pattern) travels through the medium

In one period the source completes one oscillation and the wave travels forward by exactly one wavelength. So the wave speed is $v = \frac{\lambda}{T} = f\lambda$.

$$v = f\lambda = \frac{\lambda}{T}$$

- v = wave speed (m s^{-1}), f = frequency (Hz), λ = wavelength (m), T = period (s). In the data booklet under C.2; $T = 1/f$ is in the data booklet under C.1.
- The equation applies to **every** wave: ropes, sound, water waves and electromagnetic waves. For electromagnetic waves in a vacuum it becomes $c = f\lambda$.
- Do not confuse the **wave speed** (constant in a given medium) with the **speed of a particle** of the medium, which changes continuously during each oscillation (C.1): zero at maximum displacement, maximum at the equilibrium position.
- Watch prefixes: kHz (10^3), MHz (10^6), GHz (10^9); mm, μm (10^{-6}), nm (10^{-9}).

WORKED EXAMPLE 1 Easy · Calculate

A student holds one end of a long rope and moves her hand up and down three times every second. A crest is observed to move 4.5 m along the rope in 1.5 s.

Calculate (a) the frequency and the period of the wave, (b) the wave speed, (c) the wavelength.

(a) Three oscillations per second: $f = 3.0 \text{ Hz}$; $T = \frac{1}{f} = \frac{1}{3.0} = 0.33 \text{ s}$

(b) The crest moves with the wave: $v = \frac{\text{distance}}{\text{time}} = \frac{4.5}{1.5} = 3.0 \text{ m s}^{-1}$

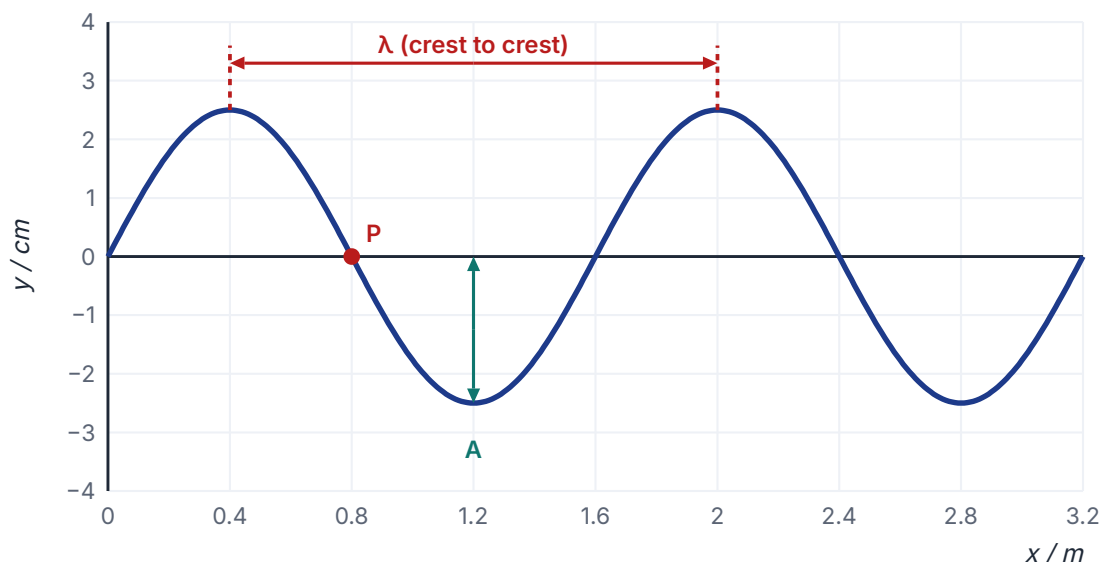
(c) $\lambda = \frac{v}{f} = \frac{3.0}{3.0} = 1.0 \text{ m}$

How do you read λ , T and A from wave graphs?

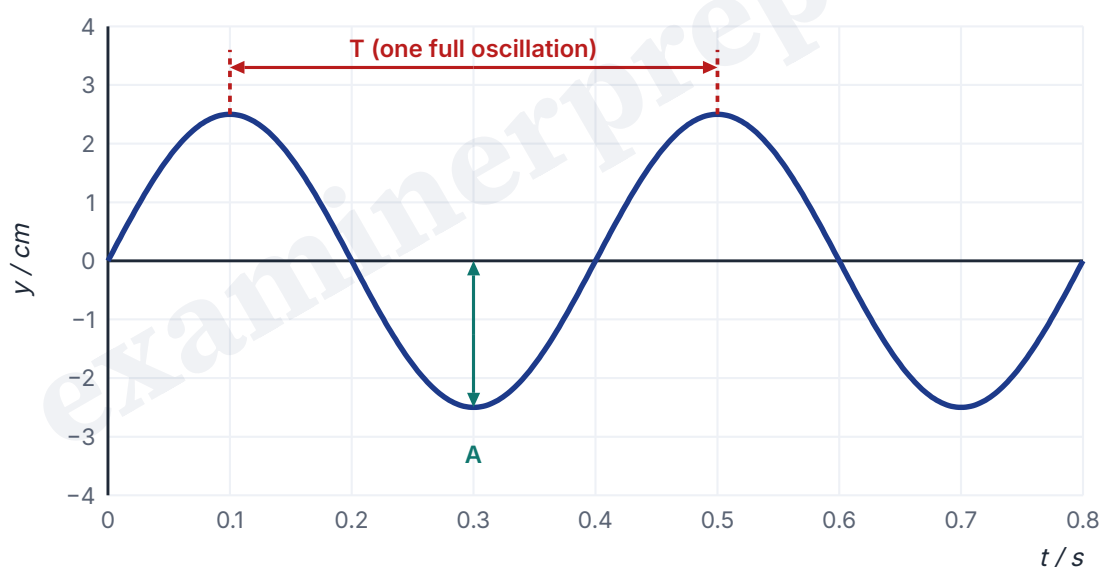
Exam questions describe the motion of the medium in two ways: how the displacement varies with **position along the wave** at one instant, and how the displacement of **one particle** varies with time. The two graphs look alike, so the axis label decides what you can read from them.

	Displacement–distance graph	Displacement–time graph
What it shows	a “snapshot” of the whole wave at one instant	the history of one particle at a fixed position
Horizontal axis	distance x along the wave (m)	time t (s)
Repeat length gives	wavelength λ	period T (then $f = 1/T$)
Height of peak gives	amplitude A	amplitude A
Cannot give on its own	T or f (you need v as well)	λ (you need v as well)

- Measure a repeat length across **several** cycles and divide, to reduce the reading uncertainty.
- The amplitude is measured from the equilibrium line ($y = 0$) to a peak — not from a trough to a crest, which is $2A$.
- For a longitudinal wave the vertical axis still shows displacement, but the displacement is *along* the direction of travel (positive = one way, negative = the other). The graph is not a picture of the wave.



Displacement–distance graph for a transverse wave on a long spring at $t = 0$ (worked example 2). The wavelength is read crest to crest and the amplitude from the equilibrium line. P is the particle at $x = 0.80$ m.



Displacement–time graph for particle P of the same wave. The same sine shape, but now the repeat length along the axis is the period, not the wavelength.

WORKED EXAMPLE 2 Medium · Determine (graphs)

The two graphs above describe the same transverse wave travelling along a long spring. The first shows the displacement y against distance x at $t = 0$; the second shows the displacement of particle P (at $x = 0.80$ m) against time.

(a) State the amplitude, the wavelength and the period. (b) Determine the frequency and the speed of the wave. (c) Determine the distance moved by

the wave, and the total distance travelled by P, in 3.0 s. (d) Deduce, using both graphs, the direction in which the wave is travelling.

(a) $A = 2.5 \text{ cm}$; from the first graph $\lambda = 1.6 \text{ m}$ (crests at 0.40 m and 2.0 m); from the second graph $T = 0.40 \text{ s}$ (crests at 0.10 s and 0.50 s).

(b) $f = \frac{1}{T} = \frac{1}{0.40} = 2.5 \text{ Hz}$; $v = f\lambda = 2.5 \times 1.6 = 4.0 \text{ m s}^{-1}$

(c) Wave: $4.0 \times 3.0 = 12 \text{ m}$.

P: in 3.0 s it makes $3.0/0.40 = 7.5$ oscillations, and in each oscillation it travels $4A = 10 \text{ cm}$. Total distance = $7.5 \times 10 = 75 \text{ cm (0.75 m)}$ — up and down, while staying at $x = 0.80 \text{ m}$.

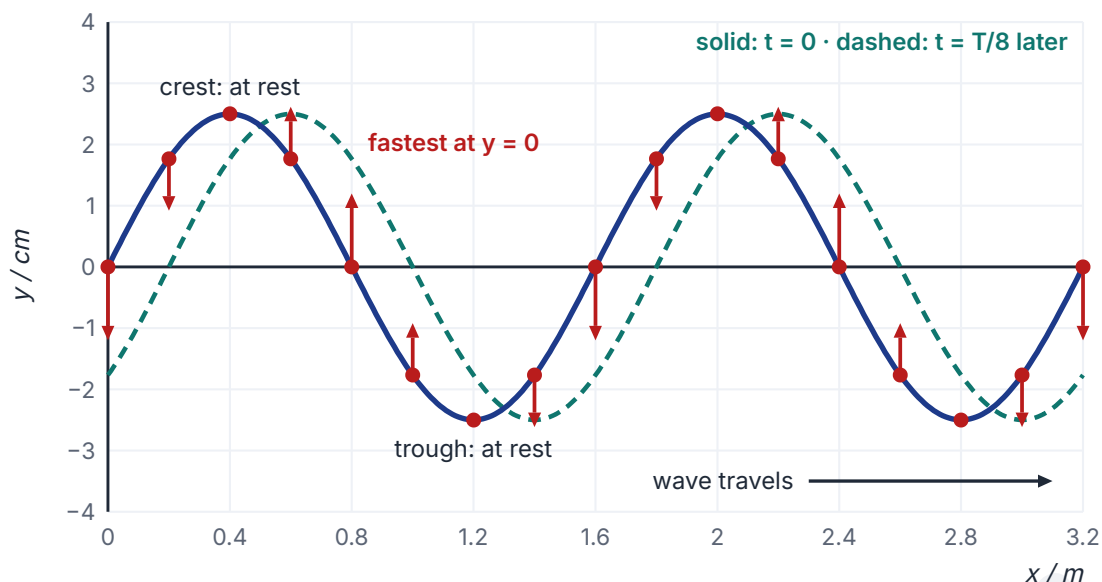
(d) The second graph shows P moving **upwards** at $t = 0$ (its displacement becomes positive). On the first graph, the particles just to the *left* of P are displaced upwards. P copies the particles on the source side, so the source side is to the left: the wave travels **in the +x direction (to the right)**.

How do the particles of the medium move when a wave passes?

Transverse waves: which way is a particle moving?

Each particle repeats the motion of its neighbour on the source side a moment later. To find a particle's direction of motion, sketch the wave shifted slightly in the direction of travel and see whether the particle's displacement increases or decreases.

- Particles at a crest or a trough are momentarily **at rest** (maximum displacement).
- Particles at the equilibrium position ($y = 0$) move with their **maximum speed**.
- For a wave travelling to the right, the particles just ahead of a crest (on its right) are moving up, the particles just behind it (on its left) are moving down. Reverse the wave direction and every particle's velocity reverses.

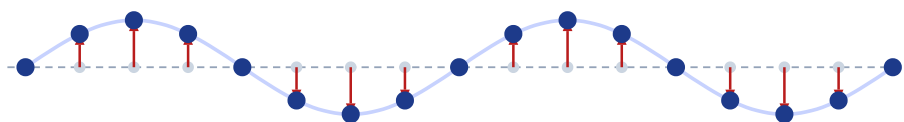


The wave of worked example 2 at $t = 0$ (solid) and $T/8 = 0.050$ s later (dashed, shifted 0.20 m to the right). The red arrows show the velocity of each particle at $t = 0$, drawn to scale: zero at crests and troughs, largest at $y = 0$.

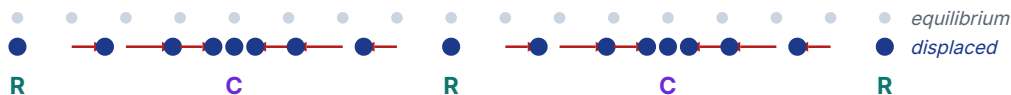
Longitudinal waves: locating compressions and rarefactions

For a longitudinal wave, the displacement–distance graph has the same shape, but a positive displacement means “displaced in the direction of travel” (or whichever direction the question defines as positive). To find the compressions, ask where neighbouring particles move **towards** each other.

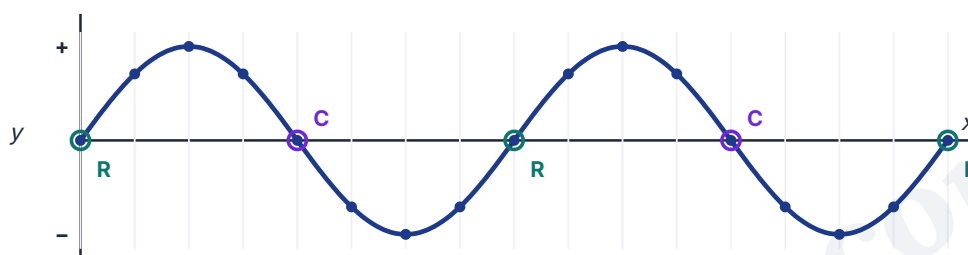
(a) transverse: particles displaced perpendicular to the direction of travel



(b) longitudinal: the same displacements, but along the direction of travel



(c) one graph describes both: displacement against distance at this instant



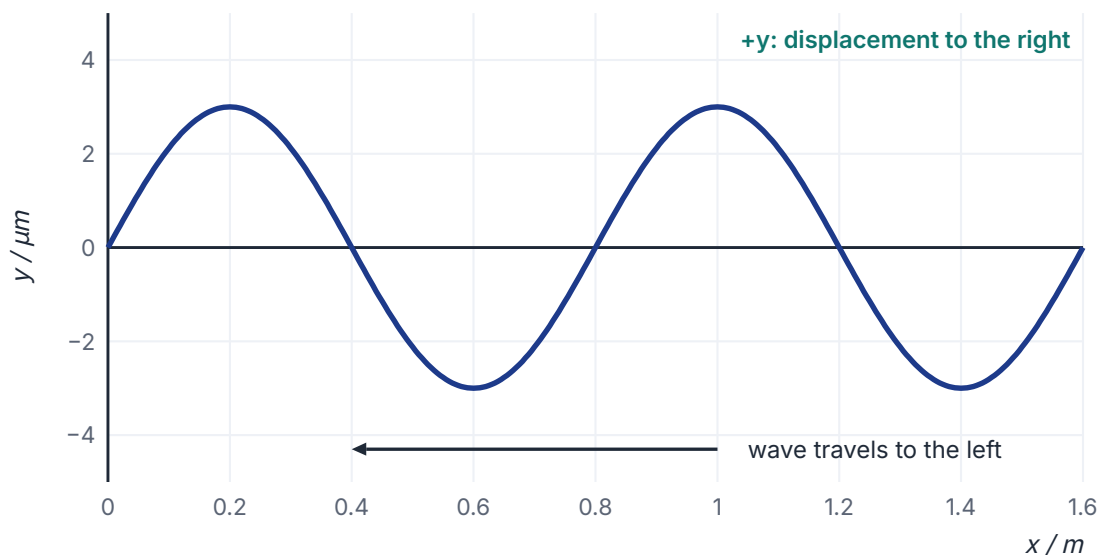
Longitudinal wave: + means displaced to the right (in the direction of travel), - to the left.

A compression is where $y = 0$ and the graph slopes DOWN (particles on both sides are displaced towards it);

a rarefaction is where $y = 0$ and the graph slopes UP (particles on both sides are displaced away).

Seventeen particles, equally spaced at equilibrium, given the same displacements (a) perpendicular to and (b) along the direction of travel. In (b) the particles crowd together at C and spread out at R. Both cases are described by graph (c): compressions and rarefactions sit where the displacement is zero, not at the peaks.

- With "positive = to the right": at a **compression** the graph crosses zero going **down** (particles on the left are displaced right, particles on the right are displaced left — both towards the point).
- At a **rarefaction** the graph crosses zero going **up** (particles on both sides are displaced away).
- The particle at the centre of a compression or rarefaction has zero displacement, but it is moving at its maximum speed.
- Adjacent compressions are one wavelength apart; a compression and the next rarefaction are half a wavelength apart.



Displacement of air molecules against position for a sound wave of frequency 425 Hz at $t = 0$ (worked example 3). Positive displacement is to the right; the wave travels to the left.

WORKED EXAMPLE 3 Hard · Identify / Deduce / Determine

A sound wave of frequency 425 Hz travels to the **left** through air. The graph above shows the displacement y of the air molecules against position x at $t = 0$; a positive displacement is to the right. Take the speed of sound in air as 340 m s^{-1} .

- Show that the graph is consistent with the speed and frequency given.
- Identify the positions of the centres of the compressions at $t = 0$.
- Deduce the direction of motion of the molecule whose equilibrium position is at $x = 0.40 \text{ m}$, at $t = 0$.
- Determine the shortest time after $t = 0$ at which there is a compression at $x = 0$.
- A student says the molecule at $x = 0.40 \text{ m}$ will reach $x = 0$ at that time. Comment.

(a) From the graph $\lambda = 0.80 \text{ m}$. $\lambda = \frac{v}{f} = \frac{340}{425} = \mathbf{0.800 \text{ m}}$ ✓

(b) The displacement is zero and the graph slopes downwards (molecules on the left displaced right, on the right displaced left) at $\mathbf{x = 0.40 \text{ m}}$ and $\mathbf{x = 1.20 \text{ m}}$. (At 0, 0.80 m and 1.60 m there are rarefactions.)

(c) The wave travels to the left, so the source side is to the *right*. A moment later, the molecule at 0.40 m has the displacement that the molecules just to

its right hand now, which is negative. So it is moving **to the left** — at its maximum speed, since $y = 0$.

(d) The nearest compression to the right of $x = 0$ is at 0.40 m and the pattern moves left at 340 m s^{-1} : $t = \frac{0.40}{340} = 1.2 \times 10^{-3} \text{ s}$ (1.18 ms).

Check: $T = \frac{1}{425} = 2.35 \text{ ms}$, and a compression replaces a rarefaction after half a period, 1.18 ms. ✓

(e) Wrong. The *compression* (the pattern) moves 0.40 m; the molecule does not. It oscillates about $x = 0.40 \text{ m}$ with an amplitude of only $3.0 \mu\text{m}$. The wave transfers energy, not air.

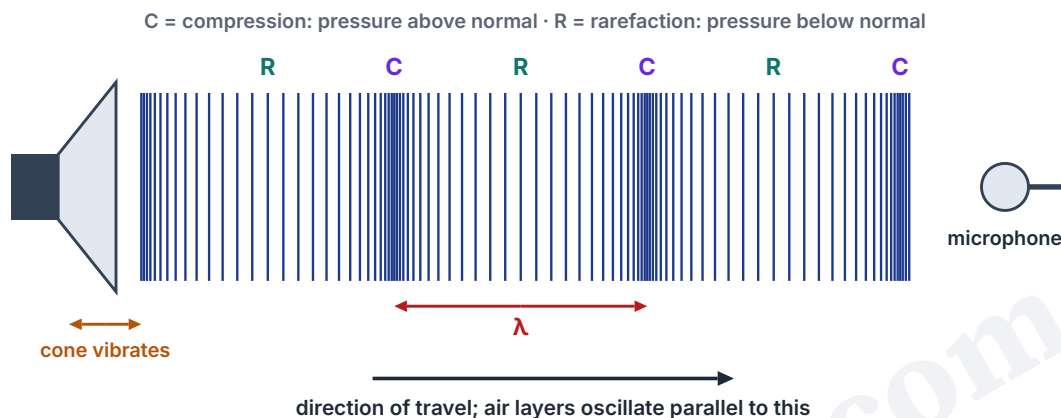
What is the nature of sound waves?

Sound is a longitudinal mechanical wave: the particles of the medium oscillate parallel to the direction of energy transfer, producing a travelling pattern of compressions and rarefactions.

- Sound is produced by a vibrating object (a loudspeaker cone, a string, vocal folds). As the object moves forward it pushes the neighbouring layer of air together (compression); as it moves back it leaves a region of lower pressure (rarefaction).
- The pressure and density of the medium vary along the wave: higher than normal at compressions, lower at rarefactions.
- Sound **needs a medium**. It cannot travel through a vacuum: in the classic bell-in-a-jar demonstration the ringing fades as the air is pumped out, although the bell can still be seen (light needs no medium).
- The speed of sound depends on the medium: roughly 340 m s^{-1} in air at room temperature (larger in warmer air), about 1500 m s^{-1} in water and several thousand m s^{-1} in solids such as steel. Values are given in questions; they are not in the data booklet.
- Humans hear frequencies from about 20 Hz to 20 kHz; in air this is wavelengths from about 17 m down to 1.7 cm. Sound above 20 kHz is

ultrasound — still a longitudinal mechanical wave.

- Qualitatively, a higher frequency is heard as a higher pitch, and a larger amplitude as a louder sound. Neither changes the speed of sound in a given medium.



Sound in air from a loudspeaker. Each vertical line represents a layer of air; the layers oscillate back and forth about their equilibrium positions and the pattern of compressions (C) and rarefactions (R) travels to the microphone. The wavelength is the distance between adjacent compressions.

WORKED EXAMPLE 4 Medium · Show that / Suggest

To measure the speed of sound, a student stands 102 m in front of a tall wall and strikes two wooden blocks together. A microphone next to her, connected to a data logger, records 0.598 s between the sound of the strike and the arrival of the echo.

(a) Show that the speed of sound in air is about 340 m s^{-1} . (b) A tuning fork emits a note of frequency 440 Hz. Calculate the wavelength of this sound in air. (c) Suggest why the student stands far from the wall rather than close to it.

(a) The sound travels to the wall and back: distance = $2 \times 102 = 204 \text{ m}$.

$$v = \frac{204}{0.598} = 341 \text{ m s}^{-1} \approx 340 \text{ m s}^{-1}$$

(b) $\lambda = \frac{v}{f} = \frac{340}{440} = 0.77 \text{ m}$ (using 341 m s^{-1} gives 0.78 m; either is accepted)

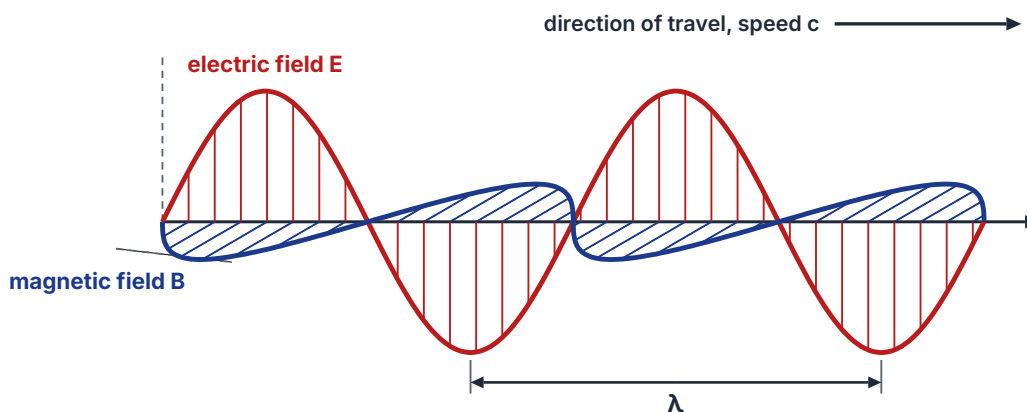
(c) A longer distance gives a longer time interval, so the same absolute uncertainty in the time (for example ± 0.01 s) is a smaller **percentage** uncertainty: here about 2 %. Close to the wall the echo would also overlap with the original sound.

Forgetting the factor of 2 for the return journey is the classic error: it would give 171 m s^{-1} .

What is the nature of electromagnetic waves?

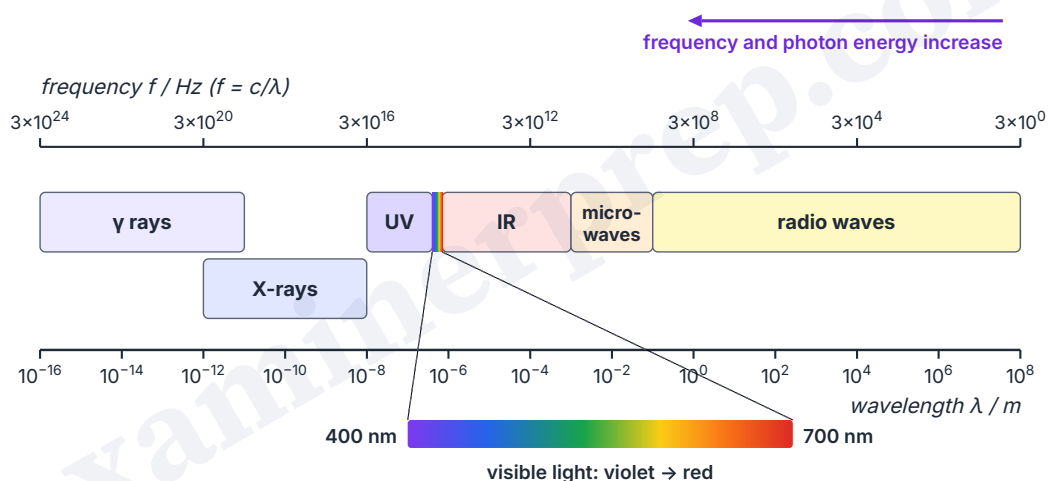
An electromagnetic wave is a transverse wave of oscillating electric and magnetic fields, perpendicular to each other and to the direction of energy transfer, which travels through a vacuum at $c = 3.00 \times 10^8 \text{ m s}^{-1}$.

- Electromagnetic waves are produced by **accelerating charges** (for example electrons oscillating in a radio aerial). Nothing material oscillates — only the fields — so **no medium is needed**.
- All electromagnetic waves travel at the same speed c in a vacuum, whatever their frequency. In air the speed is almost exactly c ; in glass or water it is smaller (C.3).
- They are transverse, they carry energy (sunlight warming the Earth, B.2) and they obey $c = f\lambda$.
- Visible light is one small part of a continuous **electromagnetic spectrum**. The data booklet chart gives a rough order of magnitude for the wavelength range of each region — learn to use it, not the exact boundaries, which overlap.



$E \perp B$, and both $\perp$ direction of travel: a transverse wave that needs no medium

An electromagnetic wave at one instant. The electric field (red) and magnetic field (blue) oscillate in phase, at right angles to each other and to the direction of travel.



The electromagnetic spectrum on a logarithmic scale of wavelength, as in the data booklet. Frequency, $f = c/\lambda$, increases to the left. Region boundaries are approximate; γ rays and X-rays overlap and are distinguished by how they are produced.

Region	Order of magnitude of λ / m	Typical source or use
γ rays	$10^{-16} - 10^{-11}$	radioactive nuclei (E.3); sterilising, cancer treatment
X-rays	$10^{-12} - 10^{-8}$	fast electrons hitting a metal target; medical imaging
Ultraviolet	$10^{-8} - 4 \times 10^{-7}$	the Sun; causes sunburn, makes some materials fluoresce
Visible	$4 \times 10^{-7} - 7 \times 10^{-7}$ (400–700 nm)	hot objects such as the Sun and lamps; sight, optical fibres
Infrared	$7 \times 10^{-7} - 10^{-3}$	all warm bodies (B.1, B.2); remote controls, thermal imaging
Microwaves	$10^{-3} - 10^{-1}$	radar, mobile phone and wireless networks, microwave ovens
Radio waves	10^{-1} and longer	oscillating currents in aerials; broadcasting, communication

WORKED EXAMPLE 5 Medium · Calculate / State

An airport radar emits electromagnetic waves of wavelength 3.2 cm. Take the speed of the waves in air to be c .

(a) Calculate the frequency of the waves. (b) State, with a reason, the region of the electromagnetic spectrum to which they belong. (c) A pulse reflected from an aircraft returns to the radar 0.12 ms after it was emitted. Calculate the distance to the aircraft.

$$\text{(a) } f = \frac{c}{\lambda} = \frac{3.00 \times 10^8}{3.2 \times 10^{-2}} = \mathbf{9.4 \times 10^9 \text{ Hz}} \text{ (9.4 GHz)}$$

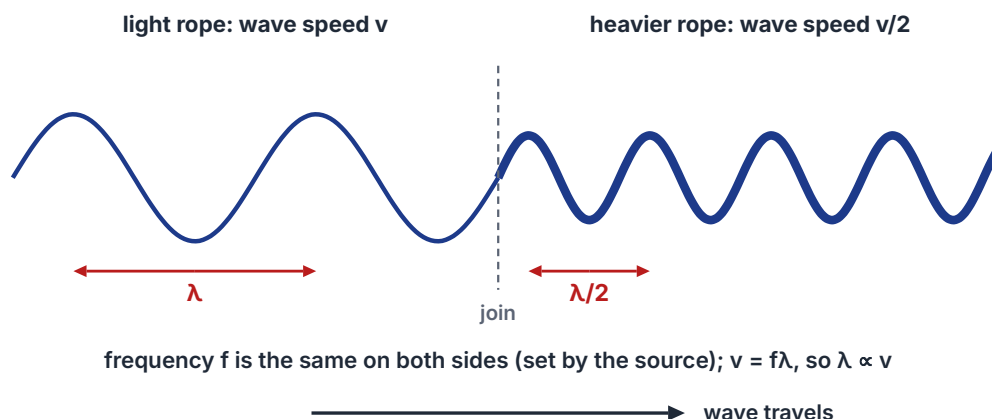
(b) $\lambda = 3.2 \times 10^{-2}$ m lies between about 10^{-3} m and 10^{-1} m, so the waves are **microwaves**.

(c) The pulse travels there and back: $2d = ct \Rightarrow d = \frac{3.00 \times 10^8 \times 0.12 \times 10^{-3}}{2} = 1.8 \times 10^4 \text{ m (18 km)}$

What happens to the wavelength when the frequency or the medium changes?

The frequency of a wave is set by its source; the speed is set by the medium. When a wave passes into a different medium its frequency stays the same, so its wavelength changes in proportion to its speed, $\lambda = v/f$.

- **Change the source frequency, same medium:** the speed is unchanged, so $\lambda \propto \frac{1}{f}$. Doubling the frequency halves the wavelength.
- **Same source, new medium:** the particles at the boundary are driven at the rate at which the waves arrive, so the number of oscillations per second cannot change. If the speed falls, the wavelength falls in the same ratio.
- The speed depends on the properties of the medium — for a rope, how taut and how heavy it is; for sound, the material and its temperature. In the situations met in IB questions it does **not** depend on the frequency or the amplitude.
- Light entering glass from air slows down, so its wavelength decreases while its frequency (and colour) stays the same. Sound entering water from air speeds up, so its wavelength increases. The change of direction that can accompany this, refraction, is studied in C.3.



A wave passing from a light rope into a heavier rope in which the wave speed is half as large. The same number of crests passes the join every second, so the wavelength halves. The transmitted wave also has a smaller amplitude, because part of the energy is reflected at the join (the reflected wave is not shown).

TRY IT YOURSELF

C.2 Refraction & Snell's law simulation: send waves into a slower medium and watch the wavefronts bunch up — the wavelength shrinks while the frequency stays fixed. (The angles and Snell's law come in C.3.)

WORKED EXAMPLE 6 Hard · Determine / Explain

A medical ultrasound probe emits pulses of frequency 3.0 MHz into soft tissue, where the speed of sound is 1540 m s^{-1} . The pulses then pass into bone, where the speed of sound is 3500 m s^{-1} .

(a) Calculate the wavelength in soft tissue. (b) Explain what happens to the frequency, the speed and the wavelength as the ultrasound passes from tissue into bone, and determine the wavelength in bone. (c) Each pulse lasts for four complete oscillations. Determine the duration of a pulse and its length in soft tissue. (d) The probe is switched to 6.0 MHz. State the effect on the speed and on the wavelength in soft tissue.

$$\text{(a)} \quad \lambda_t = \frac{v}{f} = \frac{1540}{3.0 \times 10^6} = 5.1 \times 10^{-4} \text{ m (0.51 mm)}$$

(b) The frequency is set by the probe and is **unchanged** at 3.0 MHz: the bone at the boundary is made to oscillate at the rate the tissue drives it. The

speed **increases** because bone is a different medium. Since $\lambda = v/f$ with f constant, the wavelength increases in the same ratio ($3500/1540 = 2.27$):

$$\lambda_b = \frac{3500}{3.0 \times 10^6} = 1.2 \times 10^{-3} \text{ m (1.17 mm)}$$

(c) Duration = $4T = \frac{4}{3.0 \times 10^6} = 1.3 \times 10^{-6} \text{ s}$; length in tissue = $4\lambda_t = 4 \times 0.513 \text{ mm} = 2.1 \text{ mm}$

(d) The speed is unchanged (same medium, 1540 m s^{-1}); the wavelength halves to **0.26 mm**.

How do mechanical waves differ from electromagnetic waves?

The wave model — oscillation, wavelength, frequency, speed, $v = f\lambda$, energy transfer — applies to both families. What differs is *what* oscillates and what the wave needs in order to travel.

	Mechanical waves	Electromagnetic waves
What oscillates	particles of a material medium	electric and magnetic fields
Medium	needed — cannot cross a vacuum	not needed — travel through a vacuum
Type	transverse (rope, string) or longitudinal (sound)	always transverse
Speed	depends on the medium; from about 1 m s^{-1} (water waves) to several thousand m s^{-1} (sound in solids)	$c = 3.00 \times 10^8 \text{ m s}^{-1}$ in a vacuum for every frequency; less in matter
Produced by	a vibrating object in contact with the medium	accelerating (e.g. oscillating) charges
Examples	sound, ultrasound, water waves, seismic waves, waves on strings	radio, microwaves, IR, light, UV, X-rays, γ rays

Exam tips for C.2

EXAM TIP 1 — COMPRESSIONS ARE NOT AT THE PEAKS

On a displacement–position graph for a sound wave, the centre of a compression is where the displacement is **zero** and neighbouring particles are displaced **towards** it. With “positive = displaced in the +x direction”, that is where the graph crosses the axis going down. Choosing a crest is the most common wrong answer in multiple-choice questions on this.

EXAM TIP 2 — FREQUENCY IS THE INVARIANT

When asked how the wavelength changes as a wave enters a new medium, the marks go to two ideas: the **frequency stays the same** *and* the **speed changes**, so by $v = f\lambda$ the wavelength changes in the same direction as the speed. Stating only “the wavelength decreases” earns at most one mark.

EXAM TIP 3 — READ THE AXIS BEFORE THE CURVE

A repeat length on a y – x graph is λ ; on a y – t graph it is T . Students who read “0.40” off a time axis and call it a wavelength lose every subsequent mark. Write down which graph you are using next to each value you read.

EXAM TIP 4 — DESCRIBE THE MEDIUM PRECISELY

When asked to describe how the particles move, say that they **oscillate about fixed equilibrium positions, parallel** (longitudinal) or **perpendicular** (transverse) to the direction of energy transfer, and that there is no net movement of the medium. “The particles move with the wave” is a contradiction of the wave model and scores zero.

EXAM TIP 5 — POWERS OF TEN AND THE DATA BOOKLET

Most lost marks in electromagnetic-spectrum calculations are prefix errors: nm is 10^{-9} m, MHz is 10^6 Hz. After calculating a wavelength, check its region against the data booklet chart — a “radio wave” of wavelength 10^{-7} m tells you a power of ten has gone wrong.

Common misconceptions

Misconception	Why it is wrong	Correct idea
The particles of the medium travel along with the wave.	Each particle returns to its equilibrium position after every oscillation.	Energy and the wave pattern travel; the medium only oscillates.
A higher frequency makes a wave travel faster.	In a given medium v is fixed; increasing f reduces λ instead.	The medium sets v ; the source sets f ; $\lambda = v/f$.
A larger amplitude makes a wave travel faster.	Amplitude affects the energy carried, not the speed.	Louder sound and quieter sound reach you at the same time.
The frequency changes when a wave enters a new medium.	The boundary oscillates at the rate the waves arrive; oscillations cannot pile up or disappear there.	Frequency is constant; speed and wavelength change together.
Sound can travel through space, and radio waves are a kind of sound.	Sound needs particles to oscillate; radio waves are electromagnetic.	Sound is mechanical and longitudinal; radio is electromagnetic and transverse.
A displacement–time graph shows the shape of the wave.	It shows one particle's motion over time, not the wave in space.	Only a displacement–distance graph is a “snapshot”, and only for a transverse wave does it look like the wave.

How this topic connects

Wavelength from distance = speed $\times$ time

A wave pattern moves through a uniform medium at constant speed, so distance = speed $\times$ time applies (A.1). In one period T the source completes one oscillation and the disturbance it started has moved forward by vT . That distance is, by definition, one wavelength: $\lambda = vT$, which is $v = f\lambda$. The same kinematic idea measures v itself: time an echo or a pulse over a known distance, as in worked examples 4 and 5.

No medium needed: how electromagnetic waves cross empty space

A mechanical wave is passed on by forces between neighbouring particles, so it needs a medium. In an electromagnetic wave the oscillating quantities are fields: a changing electric field is accompanied by a changing magnetic field and vice versa (Maxwell's theory, which is not required in detail; the link between changing magnetic fields and induced emf is met in D.4, HL only). The two fields sustain each other as they travel, so no particles are needed. Light from the Sun and from distant stars crosses the vacuum of space this way.

Spreading power over a sphere: the inverse square law for radiation

A point source radiates energy equally in all directions. At distance d the power L is spread over a sphere of area $4\pi d^2$, so the power per unit area is $b = \frac{L}{4\pi d^2}$ (data booklet, B.1). Doubling the distance spreads the same power over four times the area, so the intensity falls to one quarter. This assumes no energy is absorbed on the way — true in a vacuum, approximately true in clear air.

Tools & inquiry — measuring waves (NOS: models, evidence and serendipity)

- **Speed of sound by echo or two microphones:** time a sharp sound over a measured path with a data logger. Two microphones a metre or more apart, triggered by the same clap, remove the human reaction time. Reduce background noise — work in a quiet space, use sound-absorbing

material around the microphones and set a trigger threshold above the noise level.

- **Waves in a ripple tank or on a string:** freeze the pattern with a stroboscope or slow-motion video and measure several wavelengths at once; read f from the signal generator; compare $f\lambda$ with a direct timing of a pulse.
- **Sound on an oscilloscope:** a microphone turns the pressure variations into a voltage–time trace. The trace is a displacement–*time* graph, so the horizontal repeat gives T , not λ .
- **NOS — how were X-rays discovered?** In 1895 Wilhelm Röntgen noticed that a fluorescent screen glowed near a covered cathode-ray tube. He did not ignore the anomaly: he tested it systematically and showed that an unknown, penetrating radiation was responsible. Only later were X-rays shown to be electromagnetic waves of very short wavelength.

Key equations

Equation	Use	In data booklet?
$v = f\lambda = \frac{\lambda}{T}$	wave speed, for every type of wave	yes (C.2)
$T = \frac{1}{f}$	period and frequency	yes (C.1)
$c = f\lambda, c = 3.00 \times 10^8 \text{ m s}^{-1}$	electromagnetic waves in a vacuum	c is in the constants; the equation is $v = f\lambda$ with $v = c$
distance = speed $\times$ time; echo: $2d = vt$	pulse and echo timing	no — kinematics; remember the factor of 2
$b = \frac{L}{4\pi d^2}$	inverse square fall-off of intensity from a point source	yes (B.1)
electromagnetic spectrum chart	orders of magnitude of λ for each region	yes

Check your understanding

1. Water-wave crests 1.2 m apart pass a floating buoy once every 2.0 s. Calculate the wave speed and describe the motion of the buoy.

$v = \frac{\lambda}{T} = \frac{1.2}{2.0} = 0.60 \text{ m s}^{-1}$. The buoy bobs up and down about the same position with a period of 2.0 s; it is not carried along by the wave (ignoring any current or wind).

2. Classify each as transverse or longitudinal, and as mechanical or electromagnetic: sound along a steel rail; starlight; a wave on a guitar string; ultrasound in tissue; X-rays.

Sound in steel: longitudinal, mechanical. Starlight: transverse, electromagnetic. Guitar string: transverse, mechanical. Ultrasound: longitudinal, mechanical. X-rays: transverse, electromagnetic.

3. Visible light has wavelengths from 400 nm to 700 nm in a vacuum. Calculate the corresponding range of frequencies.

$$f = \frac{c}{\lambda}: \frac{3.00 \times 10^8}{400 \times 10^{-9}} = 7.5 \times 10^{14} \text{ Hz (violet) to } \frac{3.00 \times 10^8}{700 \times 10^{-9}} = 4.3 \times 10^{14} \text{ Hz (red).}$$

4. A displacement–time graph for one point on a string shows 15 complete oscillations in 6.0 s. The wave speed on the string is 2.4 m s^{-1} . Determine the wavelength.

$$f = \frac{15}{6.0} = 2.5 \text{ Hz, so } \lambda = \frac{v}{f} = \frac{2.4}{2.5} = 0.96 \text{ m. The time graph alone gives only } f; \text{ you need } v \text{ to get } \lambda.$$

5. Thunder is heard 4.5 s after the lightning flash is seen. The speed of sound is 340 m s^{-1} . Estimate the distance to the lightning and explain why the travel time of the light can be ignored.

$$d = vt = 340 \times 4.5 = 1.5 \times 10^3 \text{ m (1530 m). The light takes } \frac{1530}{3.00 \times 10^8} = 5.1 \times 10^{-6} \text{ s — about a millionth of the sound's travel time, far smaller than the uncertainty in timing 4.5 s.}$$

Practise C.2 with exam-style questions

Original Paper 1A, 1B and 2 questions on wave types, wave graphs, $v = f\lambda$, sound and electromagnetic waves, with full mark schemes. Tick the questions you want and print them as your own test.

SL C.2 questions

HL C.2 questions

Revise and explore

- [Flashcards](#) — choose IB Physics and filter to C.2 Wave model. Free, no sign-up.

- [C.2 Refraction & Snell's law simulation](#) — see the wavelength change as waves enter a new medium
- [Full IB Physics question bank \(all sub-topics, SL & HL\)](#)

[← Previous: C.1 Simple harmonic motion](#) · [Next: C.3 Wave phenomena →](#)

© ExaminerPrep · examinerprep.com · Original material by Evan Kotronis. ExaminerPrep is an independent tutoring service. It has been developed independently from and is not endorsed by the International Baccalaureate Organization. "International Baccalaureate", "IB" and "IB Diploma Programme" are registered trademarks of the IBO, used here for descriptive purposes only. Pearson Edexcel and Cambridge are trademarks of their owners; ExaminerPrep is not affiliated with any exam board.

examinerprep.com