Cambridge IGCSE · Physics 0625 · Notes

Sound

Read online at **pastopic.com/cambridge/physics-0625/notes/sound**

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Read first: **General properties of waves**

What you need to know

This topic is about what sound is, how fast it travels, what we can hear, and how echoes and ultrasound are used. The parts marked **Extended only** are tested on Papers 2 and 4 only. By the end of it you should be able to:

1. **Describe how sound is made:** every sound comes from something vibrating.
2. **Describe sound as a longitudinal wave:** the particles of the medium vibrate backwards and forwards along the direction the sound travels.
3. **State the range of frequencies humans can hear:** about 20 Hz to $20\,000$ Hz.
4. **Know that sound needs a medium** (a solid, liquid or gas) to travel through, so it cannot cross a vacuum.
5. **Know that the speed of sound in air is about 330–350 m/s.**
6. **Describe a method for measuring the speed of sound in air** by measuring a distance and a time.
7. **Describe how amplitude and frequency affect a sound:** a larger amplitude gives a louder sound; a higher frequency gives a higher pitch.
8. **Describe an echo** as sound that has been reflected.
9. **Define ultrasound** as sound with a frequency higher than 20 kHz.
10. **Extended only:** describe compressions and rarefactions.
11. **Extended only:** know that sound generally travels faster in solids than in liquids, and faster in liquids than in gases.
12. **Extended only:** describe how ultrasound is used in non-destructive testing of materials, medical scanning of soft tissue and sonar, including calculating a depth or distance from a time and the wave speed.

Understand it

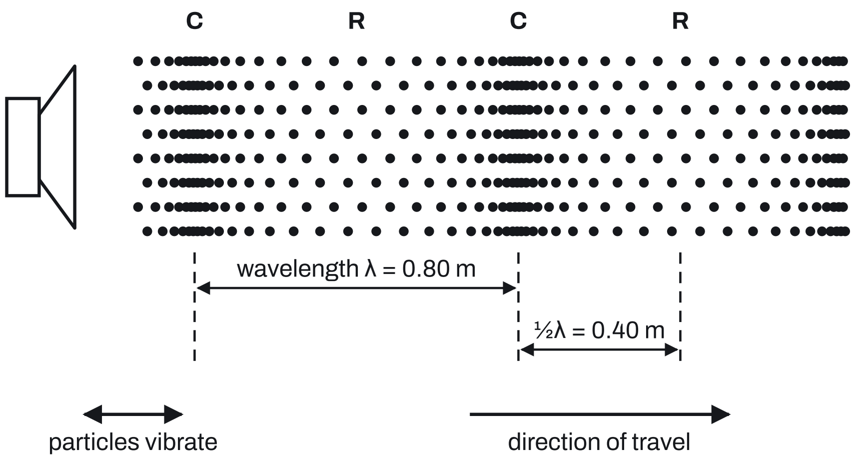
Sound comes from vibrations

Pluck a guitar string, strike a tuning fork or switch on a loudspeaker, and something **vibrates**: it moves quickly backwards and forwards. Each time the loudspeaker cone moves forwards it pushes the air particles in front of it closer together; each time it moves back it leaves a region where the particles are more spread out. The particles push on their neighbours, and these squashed and stretched regions travel outwards through the air. That travelling pattern is a **sound wave**. It carries **energy** from the source to your ear; the air itself does not flow from the loudspeaker to you. Each particle only vibrates about its own fixed position.

Sound is a longitudinal wave

In a **longitudinal** wave the particles vibrate **parallel** to the direction the wave travels (along the same line). In a transverse wave, such as light or a wave on a rope, the vibrations are at right angles to the direction of travel. Sound is longitudinal in every medium, and so is ultrasound.

A candle flame in front of a loudspeaker shows this: the flame flickers backwards and forwards, towards and away from the loudspeaker, not up and down.



Extended only: compressions and rarefactions

- A **compression** is a region where the particles are **closer together** than normal: the air there has a **higher pressure** and **higher density**.
- A **rarefaction** is a region where the particles are **further apart** than normal: **lower pressure** and **lower density**.

One **wavelength** is the distance from the centre of one compression to the centre of the next (or from one rarefaction to the next). From a compression to the **neighbouring rarefaction** is only **half** a wavelength. In the diagram the sound has frequency 425 Hz and speed 340 m/s, so its wavelength is $\frac{340}{425} = 0.80$ m.

If you plot the air pressure at **one place** against **time**, a compression is a peak (above atmospheric pressure) and a rarefaction is a trough (below it). The gap between two peaks on that graph is the **period** T, not the wavelength, because the horizontal axis is time, not distance.

Sound needs a medium

Sound is passed on by particles bumping into their neighbours, so it needs particles: a solid, a liquid or a gas. In a **vacuum** there are no particles, so sound cannot travel. If an electric bell rings inside a sealed jar and the air is pumped out, the sound gets quieter and quieter until you hear nothing, even though you can still see the hammer hitting the bell. Light still gets through the vacuum, because light is an electromagnetic wave. That is also why we see the Sun but never hear it.

The speed of sound

In air, sound travels at about 330 **to** 350 **m/s** (it is a little faster on a warm day). Light travels at 3.0×10^8 m/s, almost a million times faster. So when a distant event makes a flash and a bang at the same moment (lightning, fireworks, a starting pistol), you **see it first and hear it later**. Over short distances the light arrives almost instantly, and the delay is just the time the sound takes.

Extended only: in general, sound travels **fastest in solids, slower in liquids and slowest in gases**, because the particles are closer together and more strongly linked. Typical values:

Material	Typical speed of sound
Air (gas)	330–350 m/s
Water (liquid)	about 1500 m/s
Iron or steel (solid)	about 5000 m/s

The same holds for one substance in its three states: sound is faster in ice than in water, and faster in water than in steam.

Extended only: when sound passes from one material into another, its **frequency does not change** (the source sets it). Since $v = f\lambda$, where the speed goes up the **wavelength goes up** in the same proportion. A 500 Hz sound has $\lambda = \frac{340}{500} = 0.68$ m in air, and $\lambda = \frac{5000}{500} = 10$ m in steel.

What we can hear

A healthy young human ear hears frequencies from about 20 **Hz to** $20\,000$ **Hz** (20 kHz). Many animals hear different ranges; cats, for example, hear up to about 64 kHz. To find what both a human and an animal can hear, take the **overlap** of the two ranges: for a cat hearing 50 Hz to 64 kHz, the overlap with humans is 50 Hz to 20 kHz.

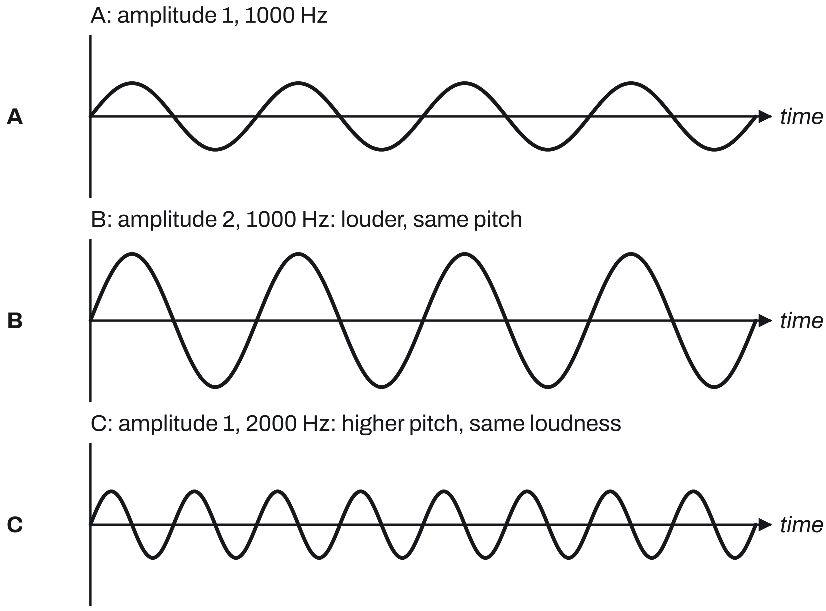
Sound above 20 kHz is **ultrasound**: it is still sound (a longitudinal wave that needs a medium), just too high-pitched for humans to hear.

Loudness and pitch

Two separate properties of the wave control what you hear:

- **Amplitude → loudness.** A larger amplitude (the particles vibrate further, a bigger pressure change) gives a **louder** sound. Hitting a drum harder increases the amplitude only.
- **Frequency → pitch.** A higher frequency (more vibrations every second) gives a **higher pitch**. A short, tight guitar string vibrates faster and gives a higher note.

They change independently: a siren can keep the same loudness while its pitch rises and falls (constant amplitude, varying frequency).



On traces drawn to the same scales, the **tallest** wave is the loudest, and the one with the **most cycles in the same time** has the highest frequency and pitch.

Echoes

An **echo** is a sound that has been **reflected** from a surface, such as a wall, a cliff or the seabed. Hard, flat, large surfaces reflect sound well. Compared with the original sound, an echo has:

- the **same** speed, frequency (so same pitch) and wavelength, and it is still longitudinal;
- a **smaller** amplitude, so it is **quieter**, because some energy is absorbed or spread out.

Because an echo goes **to the surface and back**, the sound travels **twice** the distance to the surface:

$$2d = v \times t \qquad \Rightarrow \qquad d = \frac{v \times t}{2}$$

Measuring the speed of sound in air

All methods measure a **distance** the sound travels and the **time** it takes, then use $\text{speed} = \dfrac{\text{distance}}{\text{time}}$.

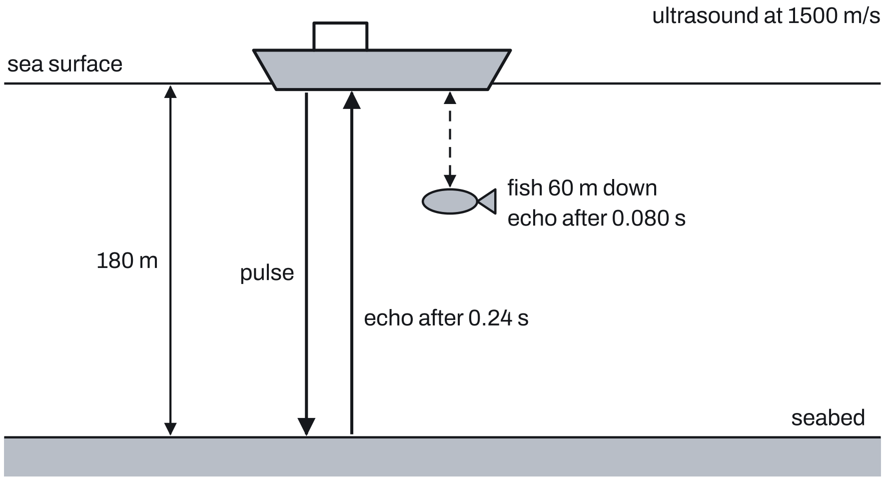
- **Direct method.** Two people stand a long way apart (at least 100 m), measured with a tape measure or trundle wheel. One makes a short, loud sound that can also be seen, such as banging two blocks of wood together or firing a starting pistol. The other starts a stopwatch on **seeing** it and stops it on **hearing** it. Speed $=$ distance $\div$ time.
- **Echo method.** Stand at least 50 m from a large wall and measure the distance. Clap (or bang blocks) and time until the echo is heard. Speed $= \dfrac{2 \times \text{distance}}{\text{time}}$. A better version: clap in time with the echoes (clap, echo, clap, echo...), time 20 claps, and divide.
- **Two-microphone method.** Two microphones a measured distance apart (a metre ruler is enough) are connected to a fast digital timer that starts when the sound reaches the first microphone and stops when it reaches the second.

Human **reaction time** (about 0.2 s) is the main error with a stopwatch. Over 50 m the sound takes only $\frac{50}{340} = 0.15$ s, about the same as the reaction time, so the result could be badly wrong. To reduce the error: use a **longer distance** (so the time is much larger than the reaction time), **repeat** and take the **average** time, and use the same person for starting and stopping.

Extended only: uses of ultrasound

Ultrasound is sent out in short **pulses**. A pulse travels through the material, **reflects** off a boundary (the seabed, a fish, a crack, an organ), and the **time for the echo to return** is measured. The distance to the boundary is then

$$d = \frac{v \times t}{2}.$$



- **Sonar (echo sounding):** a ship finds the depth of the sea, or finds shoals of fish, from the echo time. In the diagram, the echo from the seabed returns after 0.24 s, so the depth is $\frac{1500 \times 0.24}{2} = 180$ m. The fish echo returns sooner (0.080 s, so 60 m) and is weaker.
- **Medical scanning of soft tissue:** a probe on the skin sends ultrasound into the body. Echoes from the boundaries between tissues are used to build up an image, for example of a fetus. Ultrasound is **not ionising**, so it is safe for an unborn baby, unlike X-rays.

- **Non-destructive testing:** ultrasound sent into a metal part or a weld reflects from any hidden crack or flaw. An echo that returns earlier than expected shows where the flaw is, without cutting the part open.

The uses above are Extended only, but the echo calculation $d = \frac{vt}{2}$ is not: Core papers also ask for the depth of the sea or of a shoal of fish, giving the speed of sound in water.

Key facts and formulas

The 0625 papers have no formula sheet, so learn everything here.

Formula	Status
speed $=$ distance $\div$ time, $v = \dfrac{d}{t}$	Learn it
Echo (there and back): $2d = vt$, so $d = \dfrac{vt}{2}$	Learn it
Wave equation $v = f\lambda$, so $\lambda = \dfrac{v}{f}$ and $f = \dfrac{v}{\lambda}$	Learn it
$f = \dfrac{1}{T}$ (frequency from the period)	Learn it
Human hearing: about 20 Hz to $20\,000$ Hz	Learn it
Ultrasound: sound above 20 kHz ($20\,000$ Hz)	Learn it
Speed of sound in air: 330–350 m/s	Learn it
Extended only: speed in water about 1500 m/s; solids faster than liquids, liquids faster than gases	Learn it
Amplitude ↑ ⇒ louder; frequency ↑ ⇒ higher pitch	Learn it
Extended only: compression → wavelength: $\lambda = 2\times$ (compression-to-rarefaction distance)	Learn it
Prefixes: k $= 10^3$, M $= 10^6$; 1 cm $= 0.01$ m; per minute ÷ 60 = per second	Learn it

How to do it

We have tagged 112 questions for this topic across Papers 1–4, 2021–2025; 22 are repeats on other papers, leaving 90 different questions. The table counts those 90 different questions; 32 of them mix two or more types, so the counts add up to more than 90.

Question type	Questions
Calculate distance, time or speed from an echo or a sight–sound delay	25
State the human hearing range; decide whether a sound is audible	18
Extended: state or compare the speed of sound in solids, liquids and gases	18
Extended: identify, label or explain compressions and rarefactions	15
Define or identify ultrasound	14

Question type	Questions
Sound is longitudinal; particle motion and how sound is made	13
Use $v = f\lambda$ for sound	13
Link loudness to amplitude and pitch to frequency	12
Compare sound with light and other e-m waves	12
Describe an experiment to measure the speed of sound in air	8
Echo: name it, say it is reflection, compare it with the original	8
Extended: uses of ultrasound	6
Extended: diffraction of sound through a gap	4

1. Calculate distance, time or speed from an echo or a delay (25 questions)

1. **Decide which kind it is.**
    - **Echo** (a wall, cliff, building, seabed, fish): the sound goes **there and back**, so the distance travelled is $2d$.
    - **Direct delay** (thunder, a starting pistol, fireworks, a whistle seen being blown): the sound travels the distance **once**, and the light arrives instantly.
2. **Write the equation**: speed $=$ distance $\div$ time (a mark on its own), with $2d$ for an echo.
3. **Substitute and rearrange**, then give the answer with a unit.

For example, a driver sounds a car horn and hears it echo from a tall building after 2.6 s, with sound at 340 m/s: the sound travels $340 \times 2.6 = 884$ m there and back, so the building is $\frac{884}{2} = 442$ m away. A timekeeper 150 m from a starting pistol hears the bang $\frac{150}{340} = 0.44$ s after it is fired.

Variations you will meet:

- **Find the time for an echo**: $t = \dfrac{2d}{v}$. A student 120 m from a wall hears the echo after $\frac{2\times120}{340} = 0.71$ s.
- **Find the speed from an echo**: $v = \dfrac{2d}{t}$. A wall 200 m away and an echo after 1.2 s gives $\frac{400}{1.2} = 333 \approx 330$ m/s.
- **Choose the expression** in multiple choice: the distance to the wall is $\dfrac{v \times t}{2}$. The options without the 2, or with $\times 2$, are traps.
- **Echoes in water** (Core as well as Extended; the speed is given): the same working with $v \approx 1500$ m/s. A pulse that returns after 2.8 s means a depth of $\frac{1500\times2.8}{2} = 2100$ m.
- **Two routes for one sound**: a listener hears a sound directly and again after it reflects off a wall. Work out both path lengths from the diagram; the time between the two sounds is $\dfrac{\text{difference in path lengths}}{v}$.
- **Timing a race**: a timekeeper at the finish should start the stopwatch on **seeing the smoke**, not hearing the bang. Starting on the sound makes the recorded time too short by the time the sound takes (0.44 s over 150 m).

2. The human hearing range; is it audible? (18 questions)

1. **State the range with units**: 20 Hz to $20\,000$ Hz (or 20 kHz).
2. **To decide if a sound is audible**, get its frequency in Hz (convert kHz, or use $f = \frac{v}{\lambda}$ first), compare it with the range, and give the reason: "yes, because 3400 Hz is between 20 Hz and $20\,000$ Hz".

Variations you will meet:

- **An animal's range**: sounds both can hear lie in the **overlap** of the two ranges. A sound the animal hears but a human cannot lies outside 20 Hz–20 kHz. An animal hears every sound a human can only if its range starts at or below 20 Hz **and** ends at or above 20 kHz.
- **Which animal is most like a human?** The one whose range is closest to 20–$20\,000$ Hz.
- **A $28\,000$ Hz sound cannot be heard**: its frequency is **too high** (not its speed or its amplitude). To make it audible, **lower the frequency** below 20 kHz.
- **A sound rises from 36 kHz to 38 kHz**: both are ultrasound, so a human hears nothing either way.
- **Lowest audible frequency to a wavelength**: in air at 340 m/s, $\lambda = \frac{340}{20} = 17$ m.

3. Extended only: the speed of sound in different materials (18 questions)

1. **Air**: give a value between 330 and 350 m/s, with the unit.
2. **Order**: solids > liquids > gases. Water about 1500 m/s, metals about 5000 m/s.
3. **Frequency is fixed** when sound passes into a new material; the wavelength changes in step with the speed.

Variations you will meet:

- **Pick the row of typical values**: air about 340, water about 1500, a metal about 5000 m/s. Check the **order**, not just one number.
- **One substance in three states** (mercury, ice/water/steam): the solid value is largest, the gas value smallest.
- **Sound from air into steel or water**: speed increases, frequency stays the same, so the **wavelength increases**. From water into air, the speed and the wavelength both decrease, and the frequency still stays the same.
- **Materials between a loudspeaker and a microphone**: the shortest time comes from the fastest materials (solids).
- **The light trap**: 3.0×10^8 m/s is the speed of light, never of sound.

4. Extended only: compressions and rarefactions (15 questions)

1. **Define both**: a compression is where the particles are close together (high pressure); a rarefaction is where they are far apart (low pressure).
2. **On a particle diagram**, mark C at the centre of a crowded region and R at the centre of a spread-out region. For a wavelength, mark from the **centre of one compression to the centre of the next**.

3. **On a pressure–time graph**, C is at a peak (above atmospheric pressure) and R at a trough.

Variations you will meet:

- **Compression to the neighbouring rarefaction** is **half** a wavelength: a gap of 0.15 m means $\lambda = 0.30$ m. A gap of 4.0 cm means $\lambda = 8.0$ cm $= 0.080$ m.
- **"Why can't this graph give the wavelength?"** Its horizontal axis is time, so it shows the period, not a distance.
- **Fill in the sentence**: sound is made of vibrating **particles**; a compression is a region of **high pressure**; a rarefaction a region of **low pressure**; the particles vibrate **parallel** to the direction the wave travels.
- **Earlier and later**: the pattern moves in the direction of travel, so a compression now at one place becomes a rarefaction there half a period later.
- **Density**: a compression has a **greater** density than a rarefaction. The wavelength belongs to the whole wave, so options saying it is longer or shorter in a compression are wrong.

5. Define or identify ultrasound (14 questions)

1. **Definition**: ultrasound is **sound with a frequency higher than 20 kHz**. The mark needs both "sound" and "20 kHz" (or $20\,000$ Hz); "a high frequency" alone is not enough.
2. **It is still sound**: longitudinal, needs a medium, too high-pitched for humans to hear.

Variations you will meet:

- **Given a frequency** (3.0 MHz, 22 kHz, 16 kHz): say whether it is ultrasound and why. 3.0 MHz $= 3\,000\,000$ Hz, far above $20\,000$ Hz, so yes; 16 kHz is below 20 kHz, so no.
- **Multiple choice**: "sound waves too high-pitched for humans to hear" and "longitudinal waves above $20\,000$ Hz" are right; "transverse", "too loud" and "below 20 Hz" are wrong.

6. Sound is longitudinal; how sound is made (13 questions)

1. **How sound is made**: a source **vibrates**; the vibrations push on the particles of the medium, making compressions and rarefactions that travel outwards.
2. **Longitudinal**: the particles (vibrations) move **parallel** to the direction the wave travels. The word "vibrations" or "oscillations" must be in the definition.
3. **Energy, not matter**: the wave transfers energy; the particles stay about their own positions.

Variations you will meet:

- **A tuning fork**: its prongs vibrate and push the air particles next to them backwards and forwards.
- **A candle flame by a loudspeaker**: the flame moves backwards and forwards along the line from the loudspeaker.
- **"Describe the motion that a sound wave gives air particles"**: they vibrate backwards and forwards, parallel to the direction the sound travels (not up and down, and not along with the wave).

7. Use $v = f\lambda$ for sound (13 questions)

1. **Write the equation** $v = f\lambda$ (**C1**).
2. **Convert** to Hz, m and m/s: kHz $\times 10^3$; cm $\div 100$; vibrations per minute $\div 60$.
3. **Rearrange and substitute** (**C1**): $\lambda = \dfrac{v}{f}$ or $f = \dfrac{v}{\lambda}$. Use the speed given, or 340 m/s in air if you have to recall it.
4. **Answer with a unit** (**A1**).

For example, a note of 440 Hz in air at 340 m/s: $\lambda = \dfrac{340}{440} = 0.77$ m.

Variations you will meet:

- **Vibrations per minute**: a loudspeaker vibrating $75\,000$ times per minute has $f = \frac{75\,000}{60} = 1250$ Hz, so at 340 m/s, $\lambda = \frac{340}{1250} = 0.27$ m.
- **From a compression–rarefaction distance** (Extended): double it to get λ first, then $f = \frac{v}{\lambda}$.
- **Measure λ on a full-scale diagram** (Extended): measure across several wavelengths with a ruler and divide, to reduce the error; don't take the whole diagram as one wavelength.
- **Sound in water**: use the speed given, about 1500 m/s. 6.0 kHz in water gives $\lambda = \frac{1500}{6000} = 0.25$ m.
- **Then "is it audible?"**: compare the frequency you found with 20 Hz–20 kHz.

8. Loudness and amplitude, pitch and frequency (12 questions)

1. **Louder or quieter** → the **amplitude** is bigger or smaller.
2. **Higher or lower pitch** → the **frequency** is higher or lower.
3. Treat the two separately; one can change without the other.

Variations you will meet:

- **Both change**: "quieter and lower" means amplitude and frequency both decrease.
- **Fill a table**: large amplitude → loud; small amplitude → quiet (soft); high frequency → high pitch; low frequency → low pitch.
- **Choose from a box** (amplitude, frequency, speed, wavelength): loudness goes with amplitude, pitch with frequency. Speed is not changed by the source.
- **Traces on the same scales**: the tallest is loudest; the one with the most complete waves across the screen has the highest pitch.

9. Compare sound with light and other e-m waves (12 questions)

Give any of these differences (usually three are asked for):

- sound **needs a medium** and **cannot travel through a vacuum**; light and other e-m waves can;
- sound is **longitudinal**; light is **transverse**;
- light is an **electromagnetic** wave; sound is not;

- light is **much faster** (3.0×10^8 m/s against about 340 m/s in air).

Variations you will meet:

- **A bell or noisy toy in a jar with the air pumped out**: you see it working but cannot hear it, because sound cannot cross the vacuum and light can.
- **Which jar makes no sound?** The one containing a vacuum (sound travels through air, carbon dioxide and water).
- **A tick table** of properties: sound ticks only "longitudinal"; microwaves (or light) tick "transverse", "electromagnetic" and "travels in a vacuum".
- **Why we see before we hear**: light is far faster, so the smoke from a pistol or a lightning flash arrives almost instantly.

10. Describe an experiment to measure the speed of sound in air (8 questions)

Write it as a method with the apparatus, the measurements and the calculation. For the direct method:

1. Two students stand **at least 100 m apart** on open ground; **measure the distance** with a tape measure or trundle wheel.
2. One makes a **short, loud sound that can be seen** (banging wooden blocks, a starting pistol).
3. The other **starts a stopwatch on seeing** the action and **stops it on hearing** the sound.
4. **Repeat** several times and find the **average** time.
5. **Speed $=$ distance $\div$ average time.**

Variations you will meet:

- **Echo method**: stand at least 50 m from a large wall; time from the clap to the echo; speed $= \frac{2 \times \text{distance}}{\text{time}}$. Clapping in time with the echoes for 20 claps and dividing gives a better time.
- **Two microphones and a digital timer**: the timer starts when the sound reaches the first microphone and stops at the second; speed $=$ separation $\div$ time.
- **Why is their value wrong?** Over a short distance (say 50 m) the time is only about 0.15 s, about the same as the reaction time, so the reaction time makes a big error. **Improvements**: a longer distance, repeats with an average, or electronic timing.
- **Name the apparatus**: a stopwatch (or stop-clock) for the time; a tape measure or trundle wheel for the distance.

11. Echo: name it and compare it with the original (8 questions)

1. **Name it**: an echo.
2. **What causes it**: **reflection** of sound (not refraction, diffraction or dispersion).
3. **Compare with the original**: same speed, frequency, wavelength and pitch, still longitudinal; smaller amplitude, so quieter.

Variations you will meet:

- **A second, quieter bang** heard in a quarry, near cliffs or by tall buildings is the echo from the rock or walls.
- **A same/different tick table**: only **loudness** and **amplitude** are "different".

12. Extended only: uses of ultrasound (6 questions)

1. **Name the use**: sonar (depth of the sea, finding fish), medical scanning of soft tissue, or non-destructive testing of materials.
2. **Describe the method**: a pulse of ultrasound is sent out; it **reflects** from the boundary (seabed, object, organ, crack); the **time** for the pulse to go there and back is measured; **distance** $= \dfrac{\text{speed} \times \text{time}}{2}$.
3. **Calculate** if asked, using the speed given (about 1500 m/s in water).

Variations you will meet:

- **Seabed and fish**: the fish echo comes back **sooner** (the fish is nearer) and is **weaker** (the fish is small and reflects only part of the pulse).
- **Ultrasound scan compared with an X-ray**: ultrasound is not ionising, so it is safe for a fetus and images soft tissue; X-rays are ionising and show bones.
- **"State one other use"**: give a different one from the list, for example "medical scanning" after sonar.

13. Extended only: diffraction of sound through a gap (4 questions)

This comes from General properties of waves. Diffraction (spreading as a wave passes through a gap) is greatest when the **gap is about the same size as the wavelength**.

1. **Compare the gap and the wavelength**: most sounds have wavelengths of centimetres to metres, similar to a doorway, so sound spreads round the doorway and can be heard at points to the side. Light's wavelength is far smaller than a doorway, so light hardly spreads, and you hear someone round a corner without seeing them.
2. **Higher frequency** means a **shorter wavelength** and **less** spreading.
3. **On a diagram**: behind the gap draw wavefronts with the **same spacing** as before (the wavelength doesn't change), curving round at the edges; for a higher frequency draw them **closer together** and less curved.

Worked examples

The bold codes show where marks are earned, as in Cambridge mark schemes. The number is how many marks.

- **A1** accuracy mark: for a correct answer; it needs the M mark before it.
- **B1** mark for a correct result on its own, with no method needed.
- **C1** compensatory mark: earned for working even though the final answer is wrong.

Example 1

A boy stands 102 m from a tall wall. He claps his hands once and hears a second, quieter sound a short time later.

(a) State the name of the second sound and what causes it. **[2]**

(b) The speed of sound in air is 340 m/s. Calculate the time between the clap and the second sound. **[3]**

(c) The boy claps louder, keeping the same pitch. State what happens to the amplitude and to the frequency of the sound. **[2]**

(d) A bat can hear sounds from 1.5 kHz to 110 kHz. State the range of frequencies that both the bat and the boy can hear. **[1]**

(a) An echo **B1**, caused by reflection of the sound from the wall **B1**.

(b) The sound goes to the wall and back: distance $= 2 \times 102 = 204$ m. time $= \dfrac{\text{distance}}{\text{speed}}$ **C1** $= \dfrac{204}{340}$ **C1** $=$ 0.60 s **A1**.

(c) The amplitude increases **B1**; the frequency stays the same **B1**.

(d) 1.5 kHz to 20 kHz (1500 Hz to $20\,000$ Hz) **B1**. (Humans hear 20 Hz to 20 kHz; the overlap starts where the bat's range starts and ends where the human range ends.)

Example 2

Two students measure the speed of sound in air on a playing field.

(a) Describe how they should do it, naming the apparatus. **[4]**

(b) They stand 240 m apart. Their times are 0.68 s, 0.74 s and 0.70 s. Calculate the speed of sound. **[3]**

(c) Explain why they get a less reliable value if they stand only 40 m apart. **[2]**

(a) Any four of: measure the distance between them with a tape measure or trundle wheel **B1**; one bangs two wooden blocks together (a loud sound that can be seen) **B1**; the other starts a stopwatch on seeing the blocks hit and stops it on hearing the sound **B1**; repeat and find the average time **B1**; speed $=$ distance $\div$ time **B1**.

(b) Average time $= \dfrac{0.68 + 0.74 + 0.70}{3} = 0.707$ s **C1**. speed $= \dfrac{240}{0.707}$ **C1** $= 340$ m/s (2 s.f.) **A1**.

(c) Over 40 m the sound takes only about $\frac{40}{340} = 0.12$ s **B1**, which is less than a typical reaction time of about 0.2 s, so the reaction time makes a large part of the measured time **B1**.

Example 3

Extended only. A tuning fork is struck and gives a steady note. At one instant, in the air in front of it, the middle of a crowded region of particles is 17 cm from the middle of the spread-out region next to it. Sound travels at 340 m/s in the room.

(a) Describe what is meant by a compression and a rarefaction. **[2]**

(b) Calculate the frequency of the sound, and state whether a human with normal hearing can hear it. **[4]**

(c) The same sound passes into water, where its speed is 1500 m/s. Calculate its wavelength in water. **[2]**

(a) A compression is a region where the particles are close together, at high pressure **B1**; a rarefaction is a region where they are spread out, at low pressure **B1**.

(b) Compression to rarefaction is half a wavelength, so $\lambda = 2 \times 17$ cm $= 34$ cm $= 0.34$ m **B1**. $f = \frac{v}{\lambda}$ **C1** $= \frac{340}{0.34} = 1000$ Hz **A1**. Yes, it is audible, because 1000 Hz lies between 20 Hz and $20\,000$ Hz **B1**.

(c) The frequency does not change: 1000 Hz **C1**. $\lambda = \frac{1500}{1000} = 1.5$ m **A1**. (The wavelength is longer in water because the speed is greater.)

Example 4

Extended only. A fishing boat uses pulses of ultrasound of frequency 40 kHz to find the depth of the sea. The speed of ultrasound in sea water is 1500 m/s.

(a) Define ultrasound. **[1]**

(b) Calculate the wavelength of the ultrasound in sea water. **[2]**

(c) The echo from the seabed returns 0.32 s after the pulse is sent. Calculate the depth of the sea. **[3]**

(d) A shoal of fish swims under the boat. Describe how the echo from the fish differs from the echo from the seabed. **[2]**

(a) Sound with a frequency higher than 20 kHz **B1**.

(b) $\lambda = \frac{v}{f} = \frac{1500}{40\,000}$ **C1** $= 0.0375$ m **A1**.

(c) The pulse goes down and back, so depth $= \frac{v \times t}{2}$ **C1** $= \frac{1500 \times 0.32}{2}$ **C1** $= 240$ m **A1**.

(d) It arrives sooner, because the fish are nearer than the seabed **B1**; it is weaker (smaller amplitude), because the fish reflect only part of the pulse **B1**.

Common mistakes

- **Forgetting to double (or halve) for an echo.** Examiners see it every year, and multiple-choice options are built from it. Write "there and back: $2d$" before substituting.
- **Using an echo method on a direct-delay question.** For thunder or a starting pistol the sound travels the distance only once. Reports note candidates bringing echo or sonar ideas into questions that don't need them.
- **Getting the hearing range wrong or leaving off the unit.** It is 20 Hz to $20\,000$ Hz; "20 to $20\,000$" with no unit loses the mark.
- **A vague definition of ultrasound.** "High-frequency sound" or "sound we can't hear" is not enough; say "sound with a frequency above 20 kHz". Some candidates also describe ultrasound as transverse or confuse it with infrasound.
- **Defining longitudinal without vibrations.** Say "the vibrations are parallel to the direction the wave travels", not just "it moves forwards".
- **Mixing up rarefaction, refraction and reflection.** They are different words: rarefaction is part of a sound wave, refraction is a change of direction when speed changes, reflection causes an echo. Write them clearly.
- **Marking compressions badly**: mark the centre of a crowded region, and take the wavelength from one compression centre to the next, not across the whole diagram.
- **Quoting the wrong speed.** 3.0×10^8 m/s is light; sound in water is about 1500 m/s, not the 340 m/s of air.
- **Ignoring reaction time.** When asked why a speed-of-sound result is wrong over a short distance, the answer is that the time is similar to human reaction time, not "the wind" or "the stopwatch was broken".
- **Thinking the frequency changes** when sound enters a new material. The frequency stays the same; the speed and wavelength change.

How to get the marks

- **"State the speed of sound in air"**: one value from 330 to 350 m/s, with the unit.
- **Calculations** (usually 3 marks): the equation (**C1**), the numbers substituted, with the 2 for echoes and units converted (**C1**), the answer with its unit (**A1**). Write the equation even if you are unsure of the rest.
- **"Describe an experiment"** (usually 4 marks): name the apparatus for distance and time, say how a short, loud sound is made, say exactly when the timer starts and stops, and give the equation. A suitable distance (100 m or more, or 50 m from a wall) and "repeat and average" are worth writing. A labelled sketch helps.
- **"Explain whether it is audible"**: a yes/no **and** a reason that compares the frequency with 20 Hz to 20 kHz.
- **"Define"** (ultrasound, longitudinal): use the key words: "sound", "20 kHz", "vibrations", "parallel", "direction of travel" (or propagation).
- **"Describe how ultrasound is used"**: three steps: sent into the material, reflects from the object, time there and back measured, then distance $=$ speed $\times$ time $\div 2$.

- **Differences between light and sound**: each point must say which wave does what ("sound cannot travel through a vacuum but light can").
- **Tick tables and gap-fills**: one tick per row; use the exact words (compression, rarefaction, high pressure, low pressure, parallel).
- **Round sensibly**: give answers to 2 or 3 significant figures, matching the data.

Quick check

1. State the range of frequencies a human with normal hearing can hear. Can a human hear a sound of 30 kHz? What is such a sound called?
2. During a storm, a girl sees a lightning flash and hears the thunder 6.2 s later. The speed of sound is 340 m/s. How far away was the lightning?
3. A hiker in a canyon shouts towards a rock face 255 m away. Sound travels at 340 m/s in the canyon. Calculate the time between her shout and the echo reaching her.
4. **Extended only.** A sound wave in air has a wavelength of 0.0125 m. The speed of sound is 340 m/s. Calculate its frequency and say whether a human can hear it.
5. **Extended only.** A 400 Hz sound travels from air (speed 340 m/s) into a steel rail (speed 5000 m/s). State its frequency in the steel, and calculate its wavelength in air and in steel.

Answers

1. 20 Hz to $20\,000$ Hz. No: 30 kHz $= 30\,000$ Hz, which is above $20\,000$ Hz. It is ultrasound.
2. The light arrives almost instantly, so the sound took 6.2 s: distance $= 340 \times 6.2 = 2108$ m, about 2.1 km.
3. The sound goes there and back: $2 \times 255 = 510$ m, so $t = \dfrac{510}{340} = 1.5$ s.
4. $f = \dfrac{v}{\lambda} = \dfrac{340}{0.0125} = 27\,200$ Hz. No: this is above $20\,000$ Hz, so it is ultrasound.
5. The frequency is still 400 Hz. In air, $\lambda = \dfrac{340}{400} = 0.85$ m; in steel, $\lambda = \dfrac{5000}{400} = 12.5$ m.

Past questions to try

- **0625/33/O/N/22 Q7**: echoes compared with the original sound, and the speed of sound from an echo (Core).
- **0625/32/F/M/25 Q8**: how a tuning fork makes sound, the hearing range and reaction-time error (Core).
- **0625/41/O/N/24 Q5**: wavelength from a compression–rarefaction distance, frequency, audibility and diffraction (Extended).
- **0625/42/M/J/24 Q6**: compressions and rarefactions on a pressure–time graph, and $v = f\lambda$ in water (Extended).