Chapter 12

Sound

In this chapter you will

- describe how sounds are produced and how they travel
- measure the speed of sound
- describe how the amplitude and frequency of a sound wave are linked to its loudness and pitch
- state the range of human hearing
- define the term ‘ultrasound’ and describe some of its applications

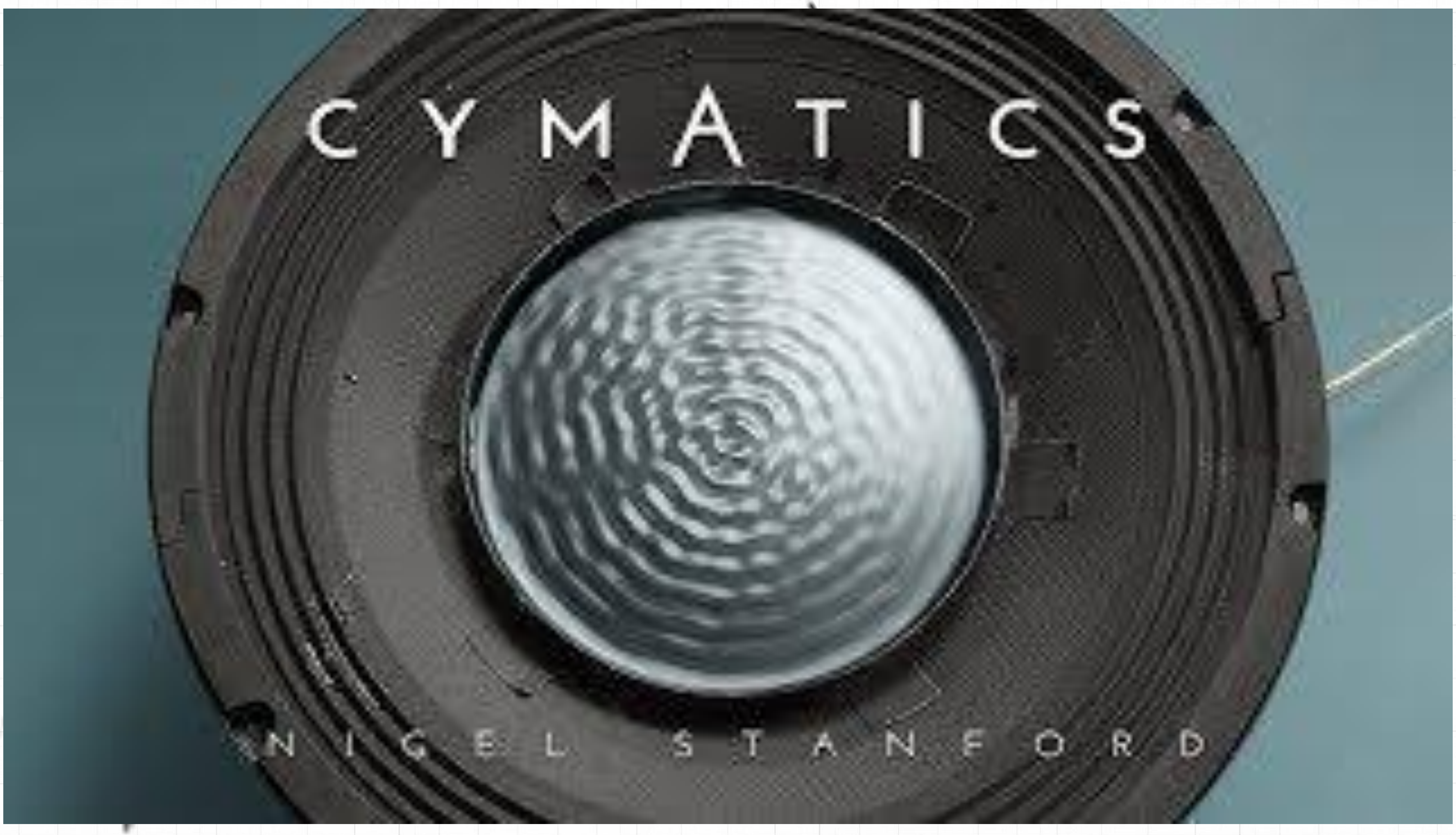
12.1 What is Sound

All sounds are caused by something vibrating.

The vibrations are not always visible because they may be too small or too fast.

Vibrating sources cause the air around them to vibrate.

These vibrations are passed through the air to our ears where they cause the eardrum to vibrate and we hear sound.


CYMATICS
NIGEL STANFORD

Whether from the vibrations in your vocal cords, a violin string or a loudspeaker, all the speech, music and noise we hear around us are transmitted by sound waves

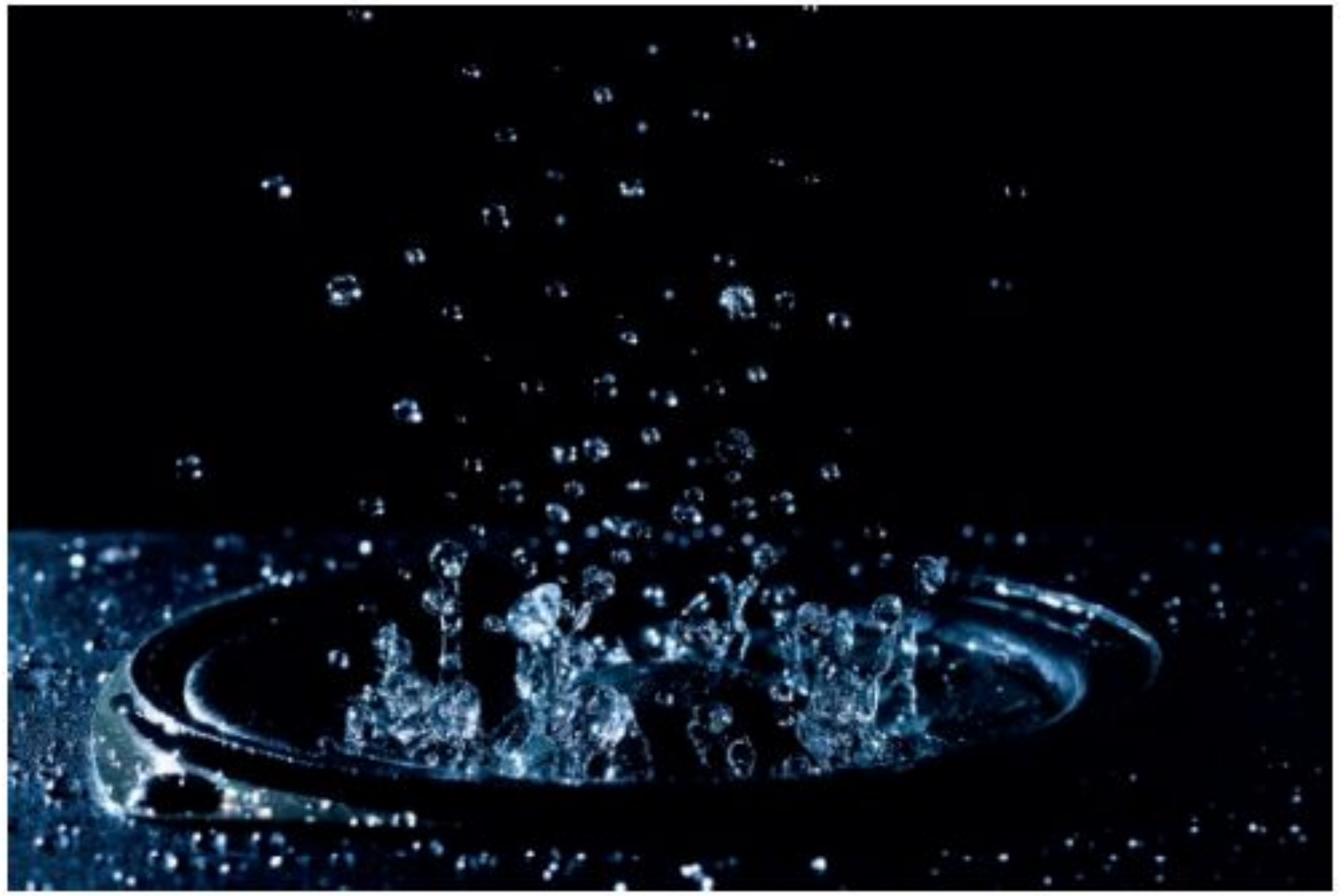


Figure 12.3: The water particles on this speaker are vibrating as the speaker makes a sound. The vibrations of the speaker and the water will change if the pitch or loudness of the sound is changed.

Whether from the vibrations in your vocal cords, a violin string or a loudspeaker, all the speech, music and noise we hear around us are transmitted by sound waves

Figure 12.5: Hitting the gong with a hammer causes it to vibrate.

Whether from the vibrations in your vocal cords, a violin string or a loudspeaker, all the speech, music and noise we hear around us are transmitted by sound waves

Figure 12.7: Vocal folds in the human throat vibrate to create speech.

Musical Sound

The position that you struck or the hole that you blow air will make different sounds. This is the basics of musical instruments

Drums

Figure 12.8: Djembe drums are made in a range of sizes to produce different notes. The skin vibrates when hit and produces sound waves.

Flute

Figure 12.10: The system of holes on a flute allows a range of notes to be played.

Musical Sound

The position that you struck or the hole that you blow air will make different sounds. This is the basics of musical instruments

Guitar

12.2 How does sound travel?

Sound makes air to vibrate

Sound is a series of vibrations passing through air or another material.

Sound makes air to vibrate

The source of the sound vibrates and this makes the air particles around it vibrate back and forward.

Sound makes air to vibrate

These vibrations make a sound wave. This type of wave is called a longitudinal wave.

Sound makes air to vibrate

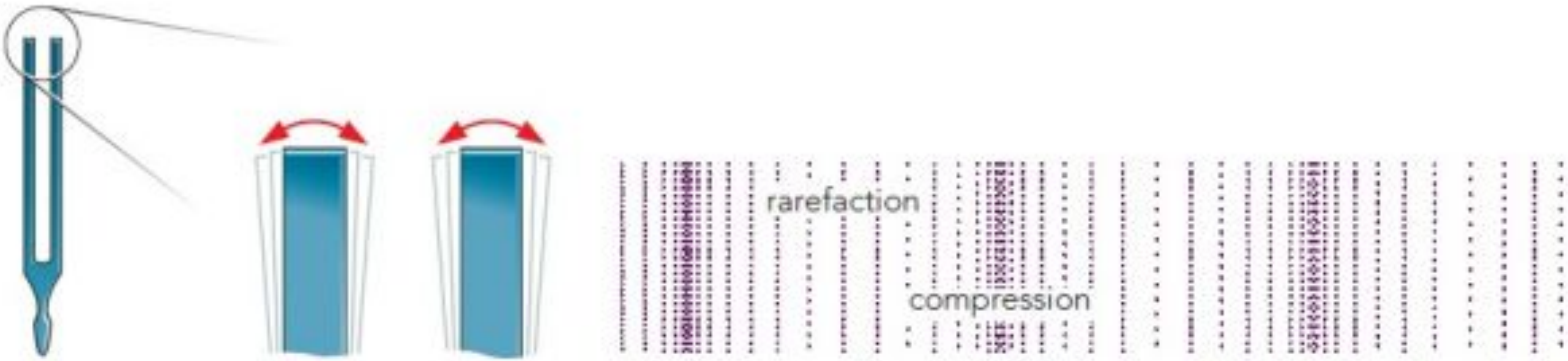
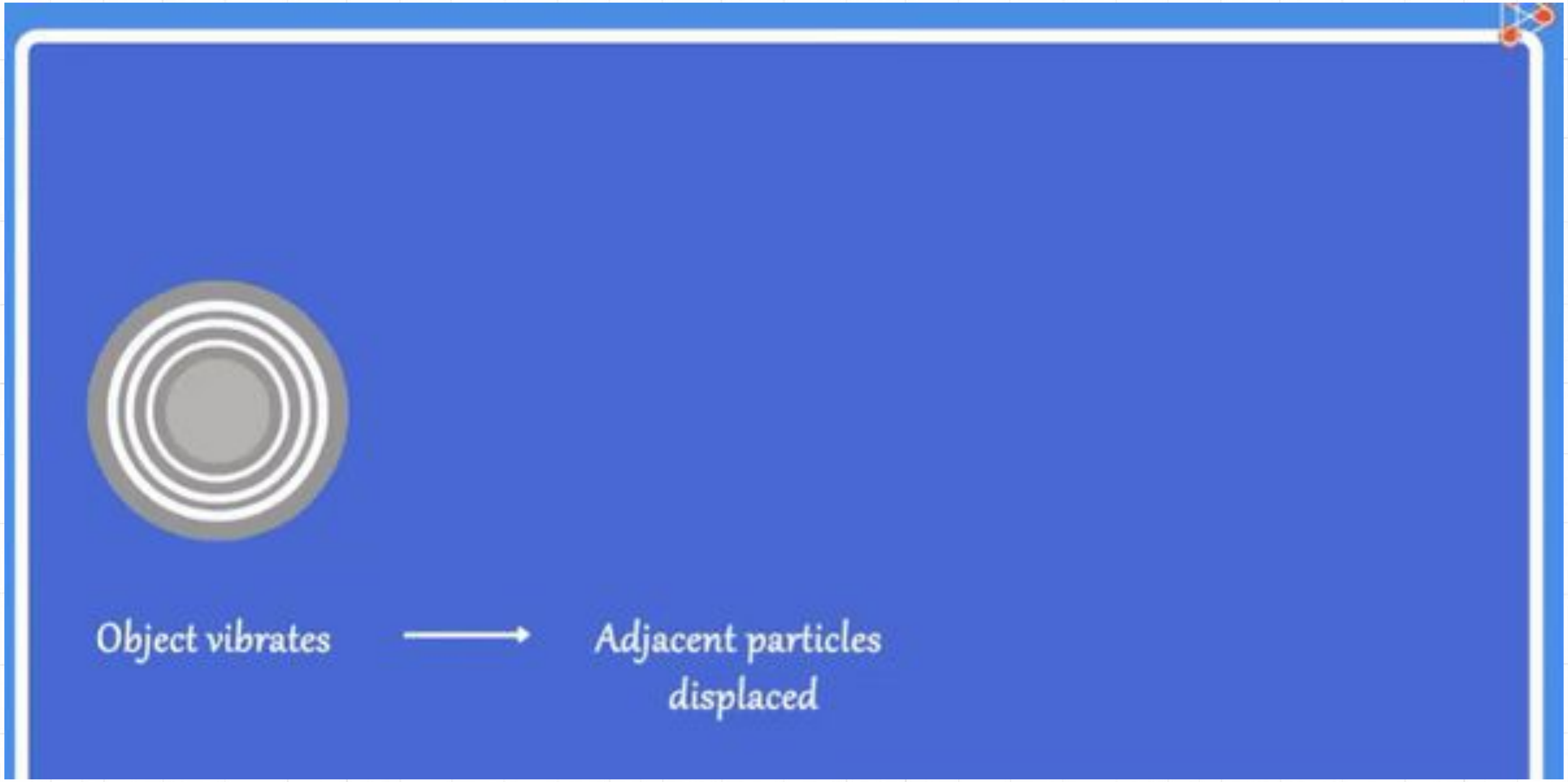


Figure 12.12: The tuning fork's prongs move back and forth creating compressions and rarefactions in the air.

Sound makes air to vibrate



Sound makes air to vibrate

Evidently sound cannot travel in a vacuum as light can.

A medium is needed to transmit sound waves.

Sound makes air to vibrate

In addition to air, solids and liquids are also able to transmit sound waves.3

Sound makes **materials** to vibrate

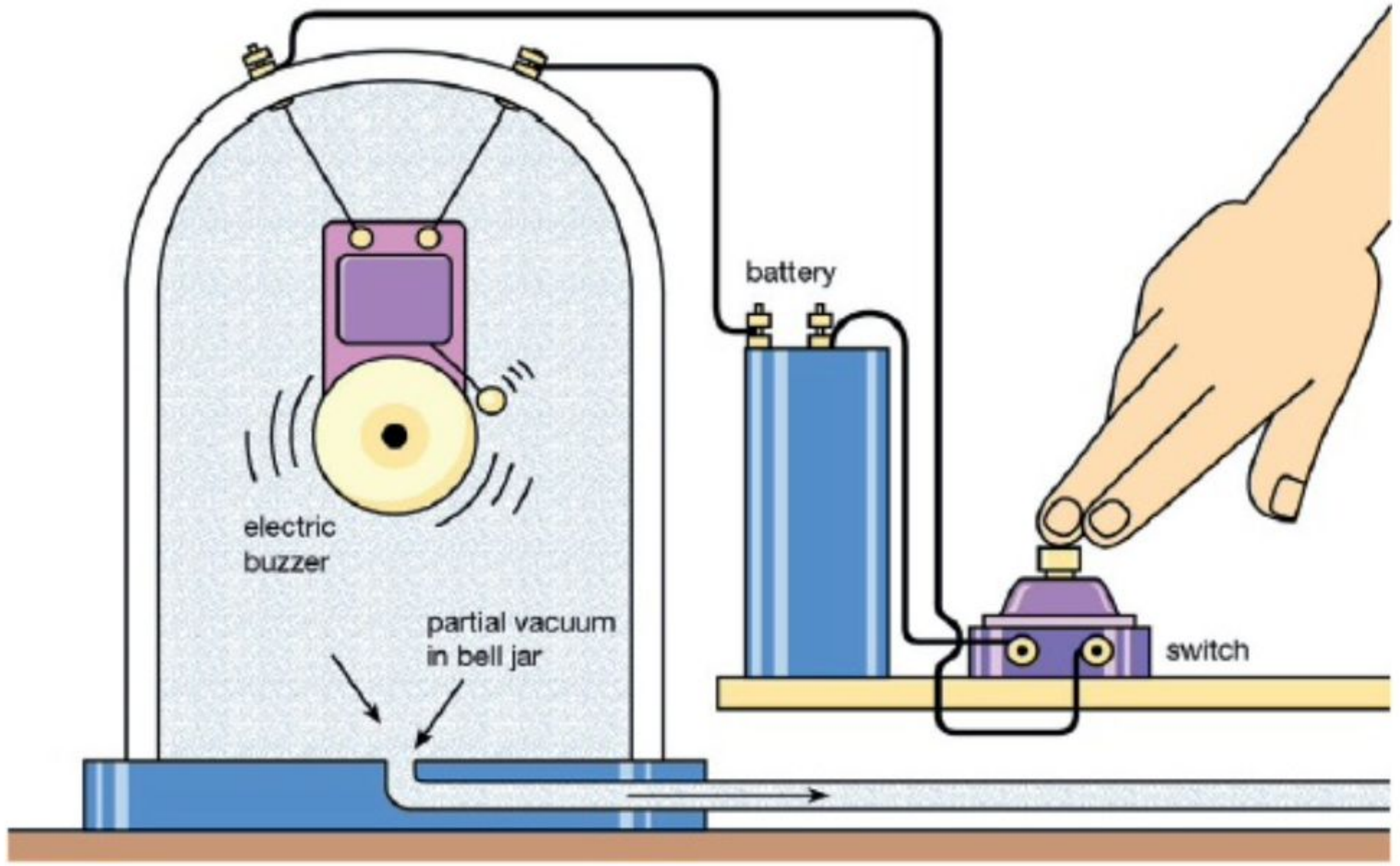


Figure 12.14: When the battery is connected, the bell can be seen and heard. Vibrations from the bell pass through the air in the jar, through the glass and then through the air to your ear. When the pump removes the air from the jar, the bell can still be seen vibrating, but cannot be heard.

The Sun

The Sun is very active and yet we hear no sound from it. This is because there are no particles to carry the huge disturbances caused by explosions and solar flares.

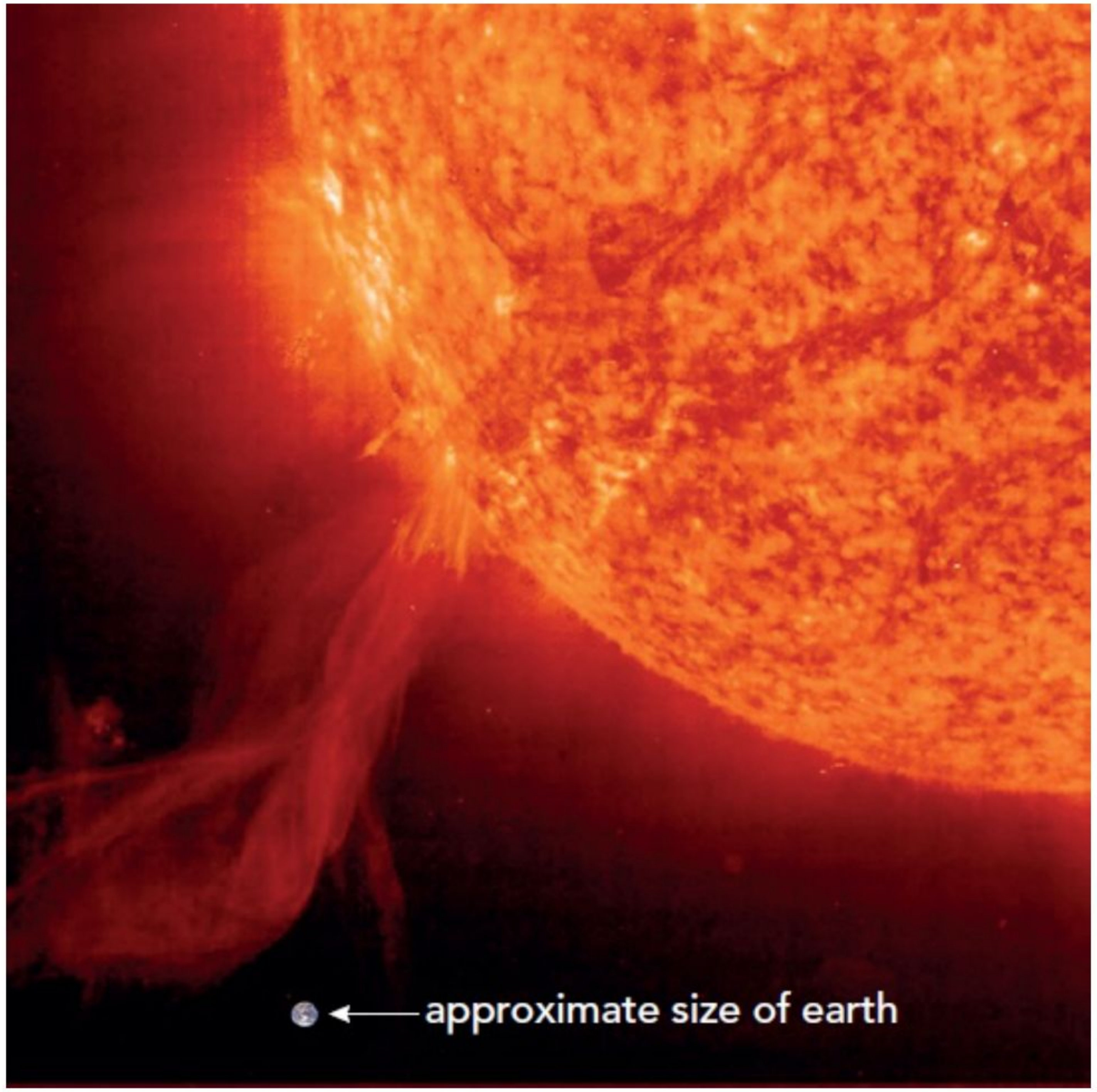


Figure 12.15: This is a solar flare, where a huge amount of matter is emitted by the Sun. An explosion like this on Earth would create a deafening sound.

Question

Which is faster: Light or sound?

Question

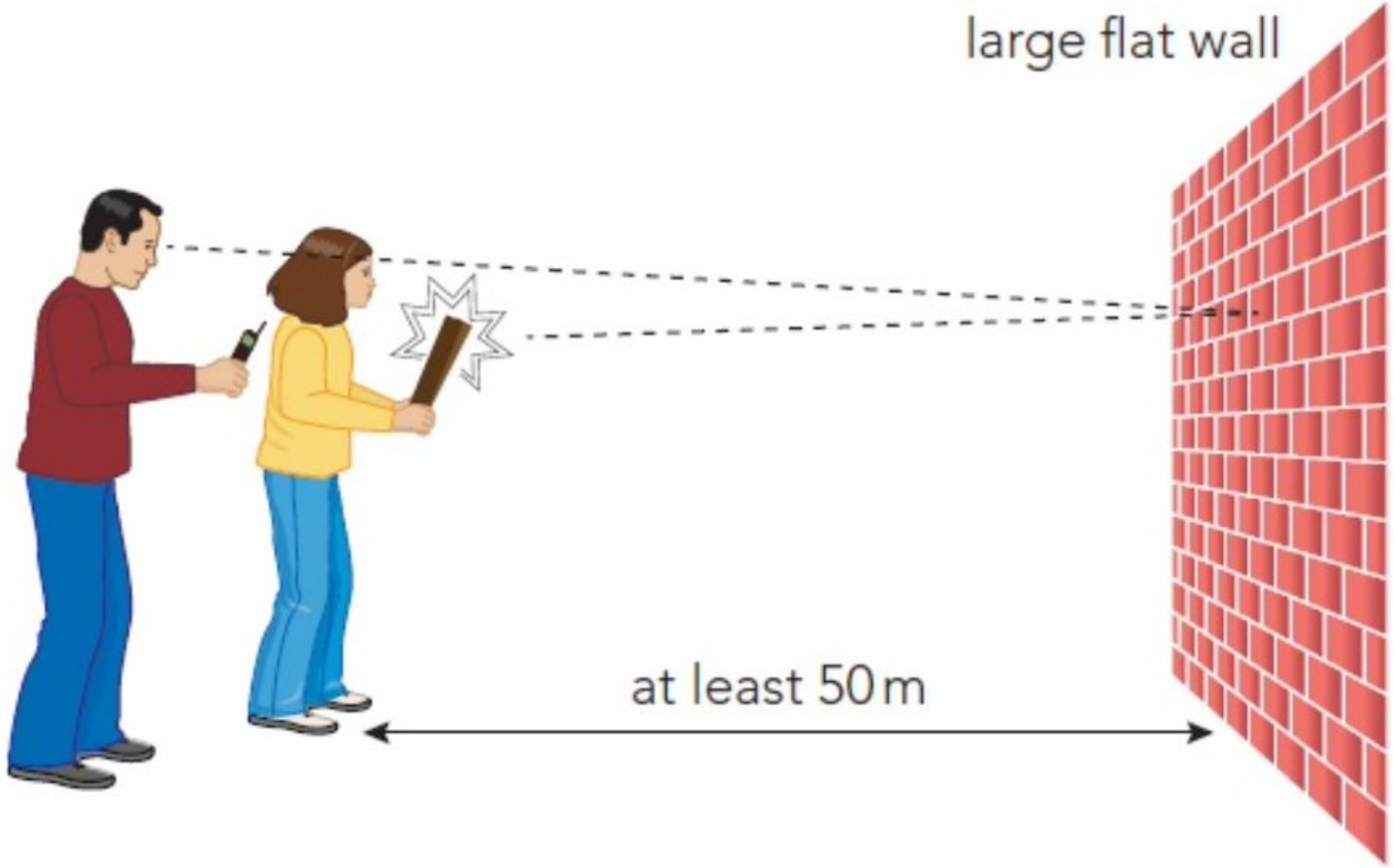
A major difference between sound and light waves is their speed. Light travels at 300 000 000 m/s, about a million times faster than sound. This means we see the lightning almost as it happens but hear the sound later.

12.3 The speed of sound

The speed of sound

Sound travels at between 330 m/s and 350 m/s in air. The speed changes slightly depending on the temperature and humidity of the air. This is much slower than light, but still so fast that we are usually not aware of the time it takes for sounds to reach us, unless the distance it travels is large.

The speed of sound



Question

A man blows a whistle and hears the echo from a rock face after 3.6 seconds. How far away from the rock is he? Assume speed of sound in air = 340 m/s.

Question

A spectator at a match sees the batsman hit the ball, then 1.2 seconds later he hears the strike. How far away is the spectator? The speed of sound in air is 330 m/s.

Question

Sound travels at 1500 m/s in fresh water and at 1530 m/s in salt water.

Explain the difference in speeds.

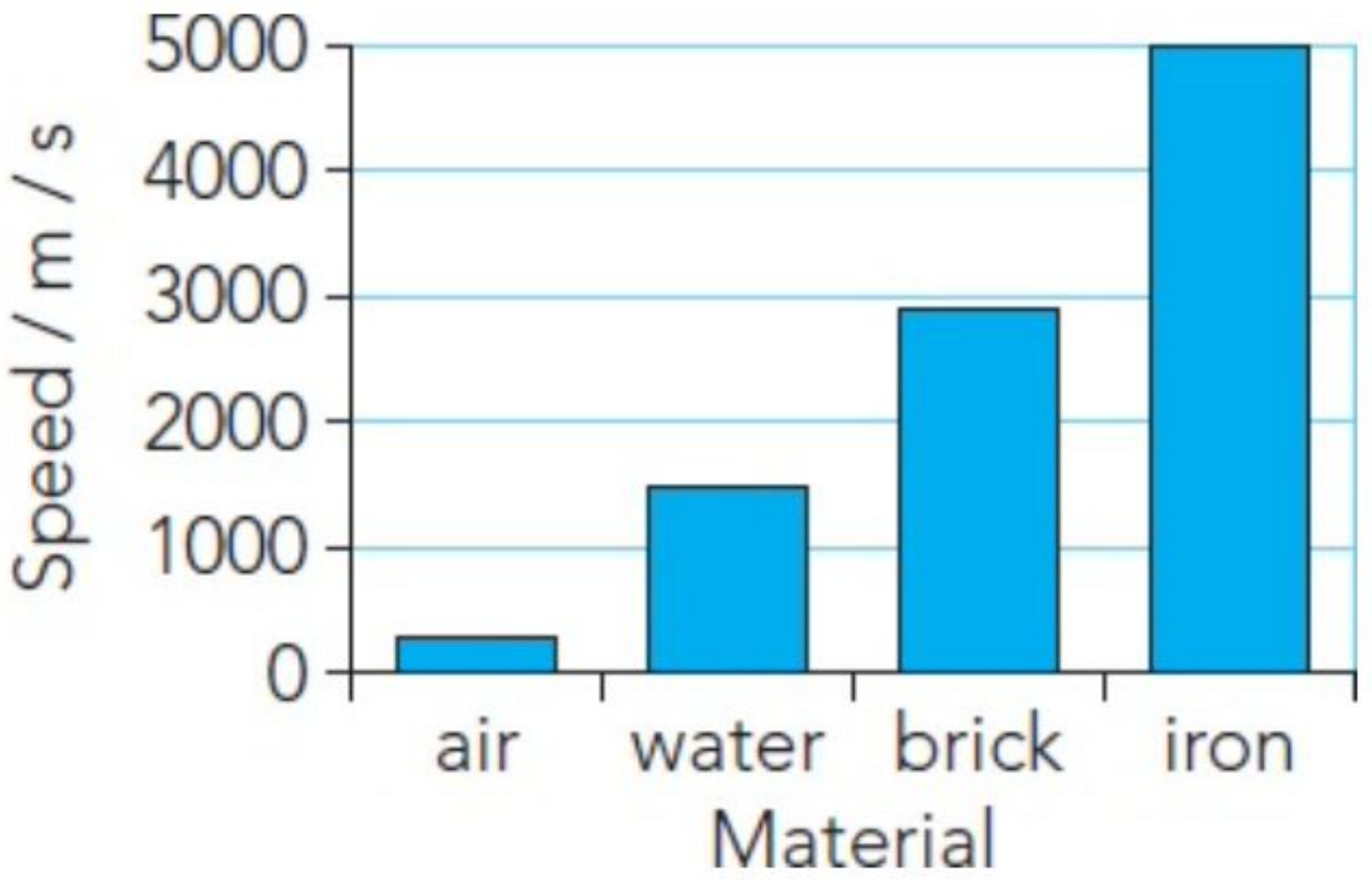


Figure 12.18: The speed of sound in different materials.

Review

Sound is made by

Vibrating objects, which in turn vibrates the air particles

Sound cannot move

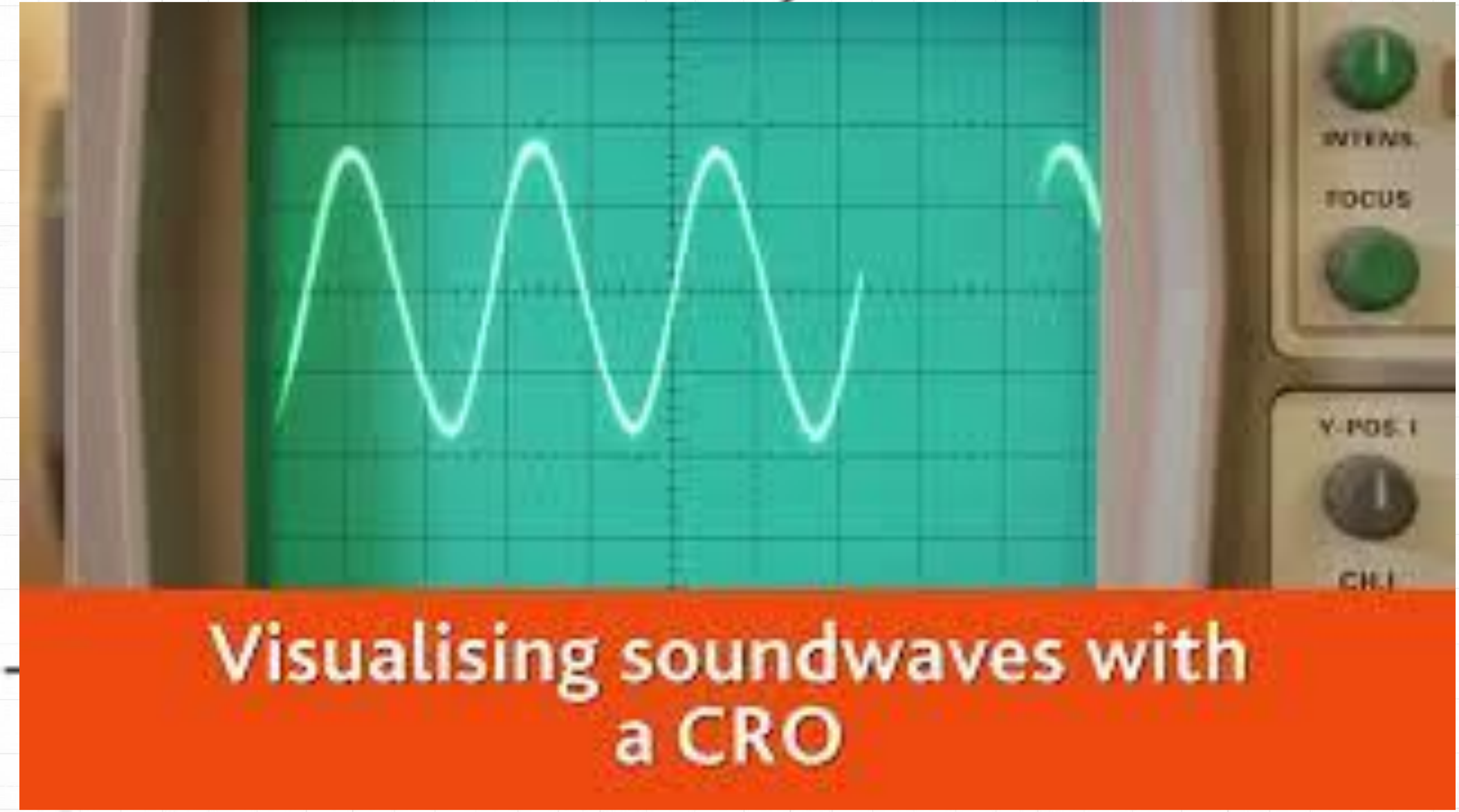
In a vacuum

The speed of sound

In air is between 330m/s and 350 m/s

12.4 Seeing and hearing sound

While seeing other objects vibrate with sound, it is not scientific! In order to find a better way to represent sound, we will use a device that is called a cathode ray oscilloscope and a microphone. The microphone converts the sound into an electrical signal. This oscilloscope converts this to a line which represents the vibration that makes uo the sound wave.


INTENS.
FOCUS
Y-POS. I
Visualising soundwaves with a CRO

The vibration from a musical instrument is complicated because it is produced by vibrations of the air and the instrument itself. A signal generator can be used to produce a pure sound wave. Pure notes are easier to measure, but not so musical.

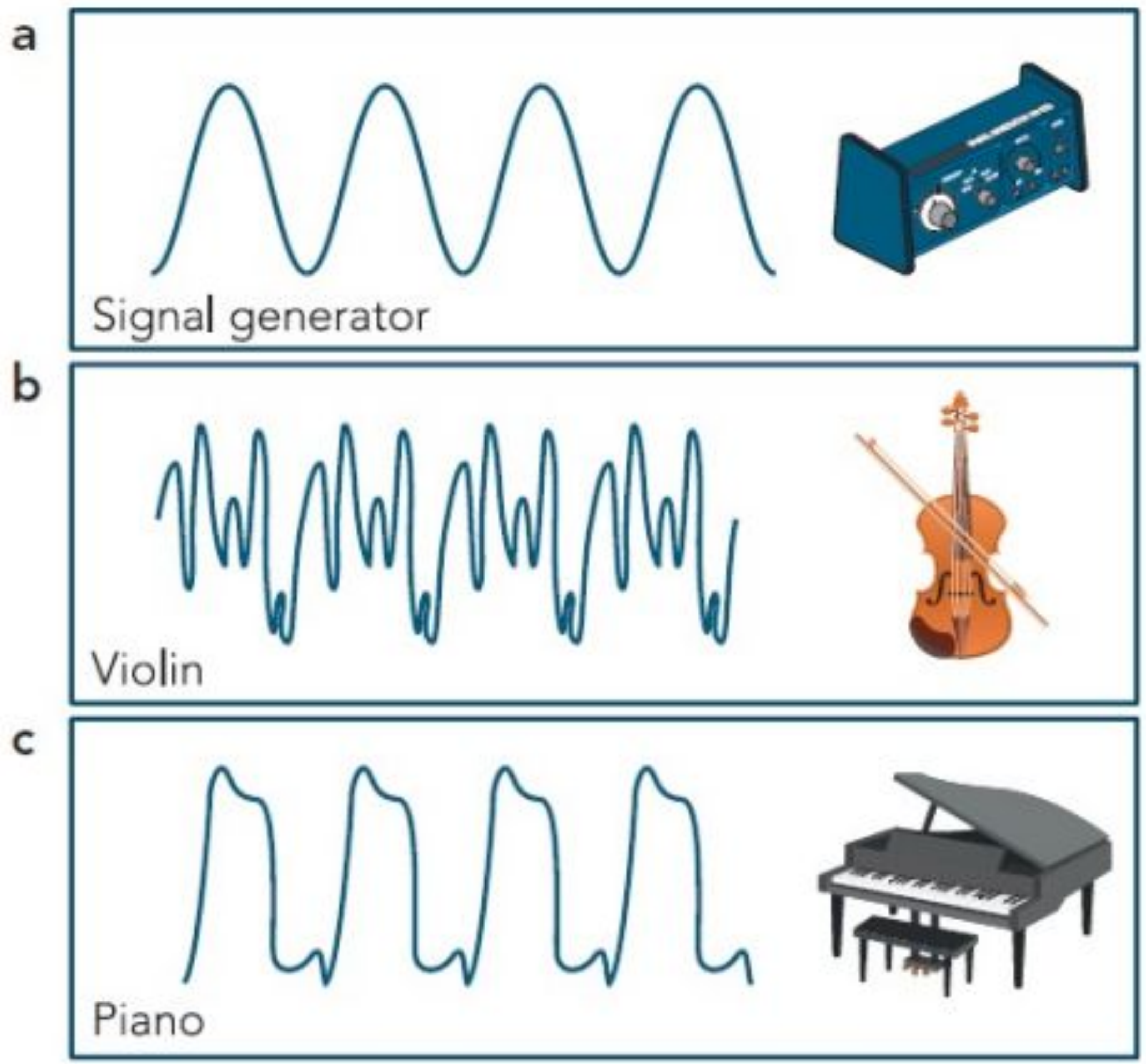


Figure 12.20: The three representations of sound waves shown here are all the same note. Each wave has a repeating pattern. The design of the instrument adds extra vibrations called overtones which give each instrument its distinctive sound. All three waves have four repeats, meaning that they all are the same note.

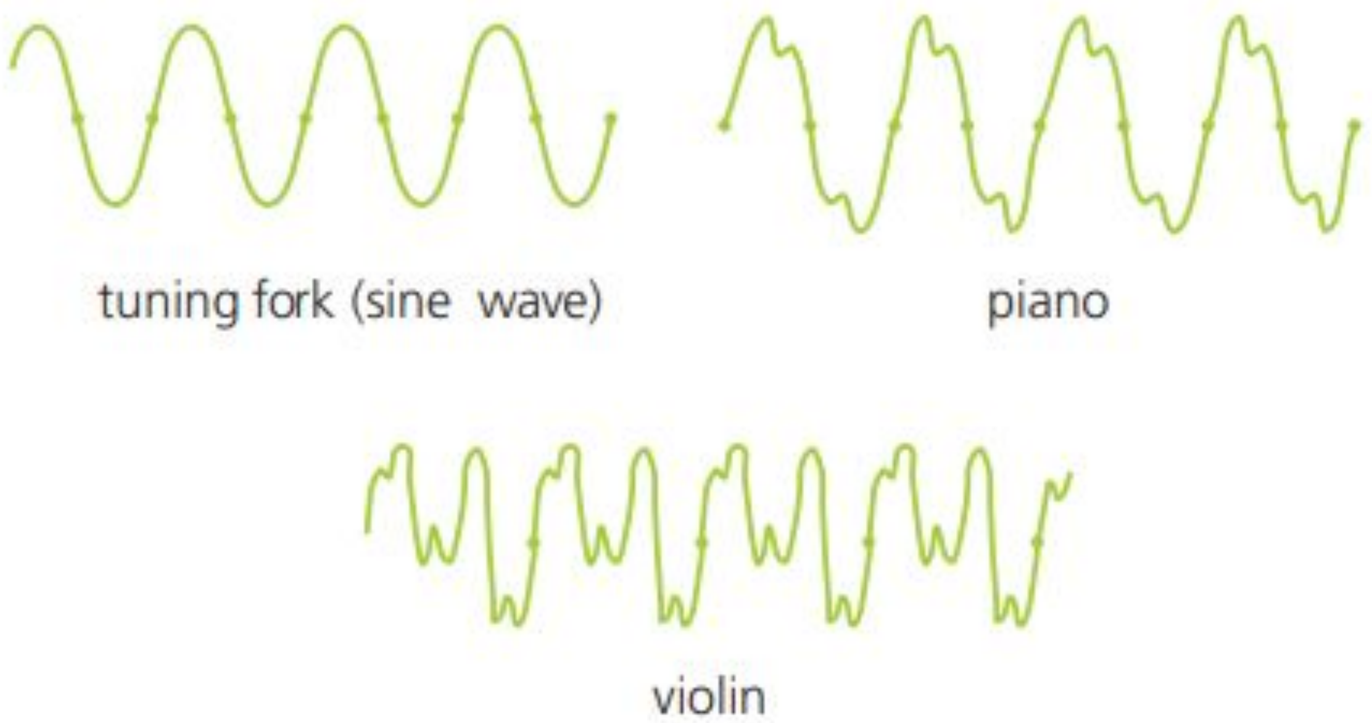
Going further

Quality

The same note on different instruments sounds different; we say the notes differ in *quality* or *timbre*. The difference arises because no instrument (except a tuning fork and a signal generator) emits a 'pure' note, i.e. of one frequency. Notes consist of a main or fundamental frequency mixed with others, called overtones, which are usually weaker and have frequencies that are exact multiples of the fundamental. The number and strength of the overtones decides the quality of a note. A violin has more and stronger higher overtones than a piano. Overtones of 256 Hz (middle C) are 512 Hz, 768 Hz and so on.

The waveform of a note played near a microphone connected to a cathode ray oscilloscope (CRO) can be displayed on the CRO screen. Those for the *same* note on three instruments are shown in Figure 3.4.7. Their different shapes show that while they have the same fundamental frequency, their quality differs. The 'pure' note of a tuning fork has a *sine* waveform and is the simplest kind of sound wave.

Note that although the waveform on the CRO screen is transverse, it represents a longitudinal sound wave.



▲ **Figure 3.4.7** Notes of the same frequency (pitch) but different quality

The oscilloscope can be used to observe two important things:

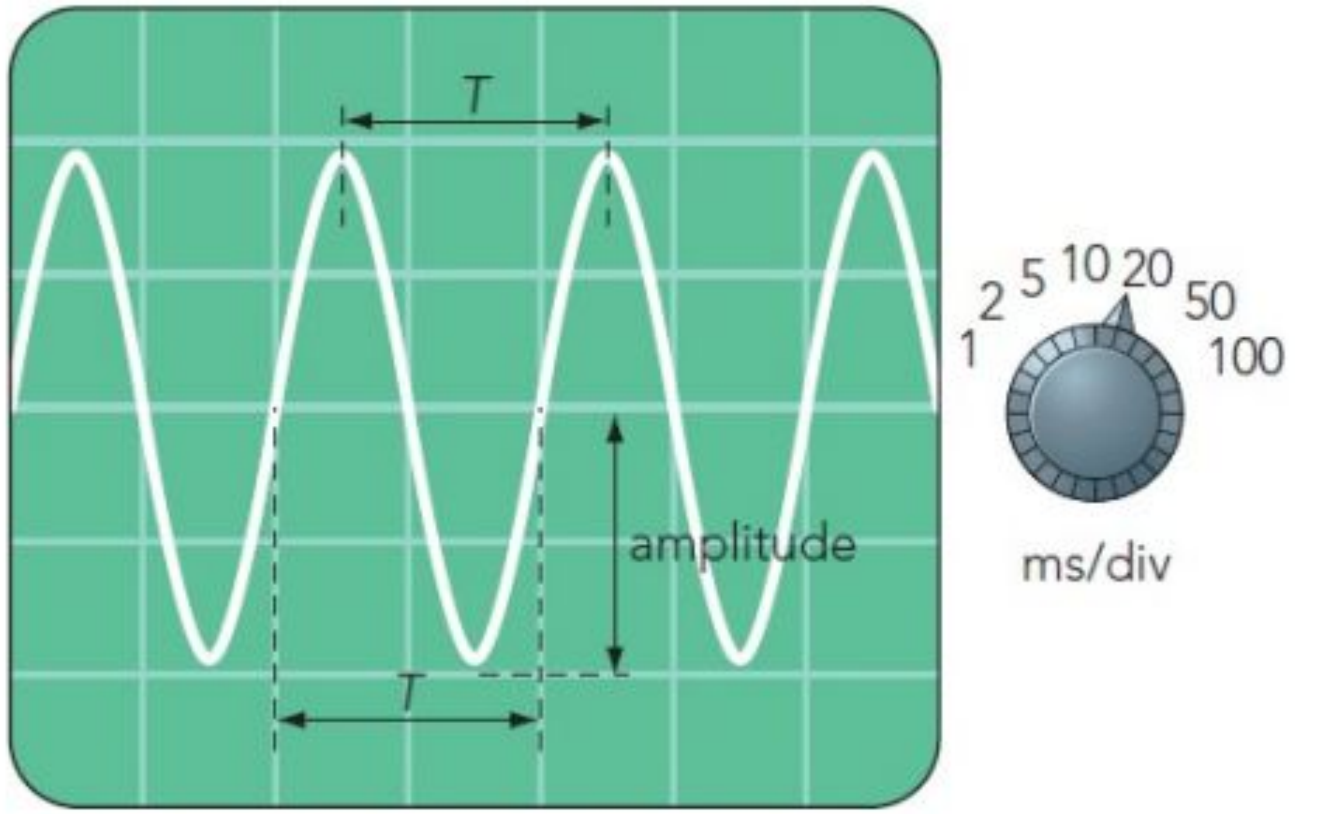
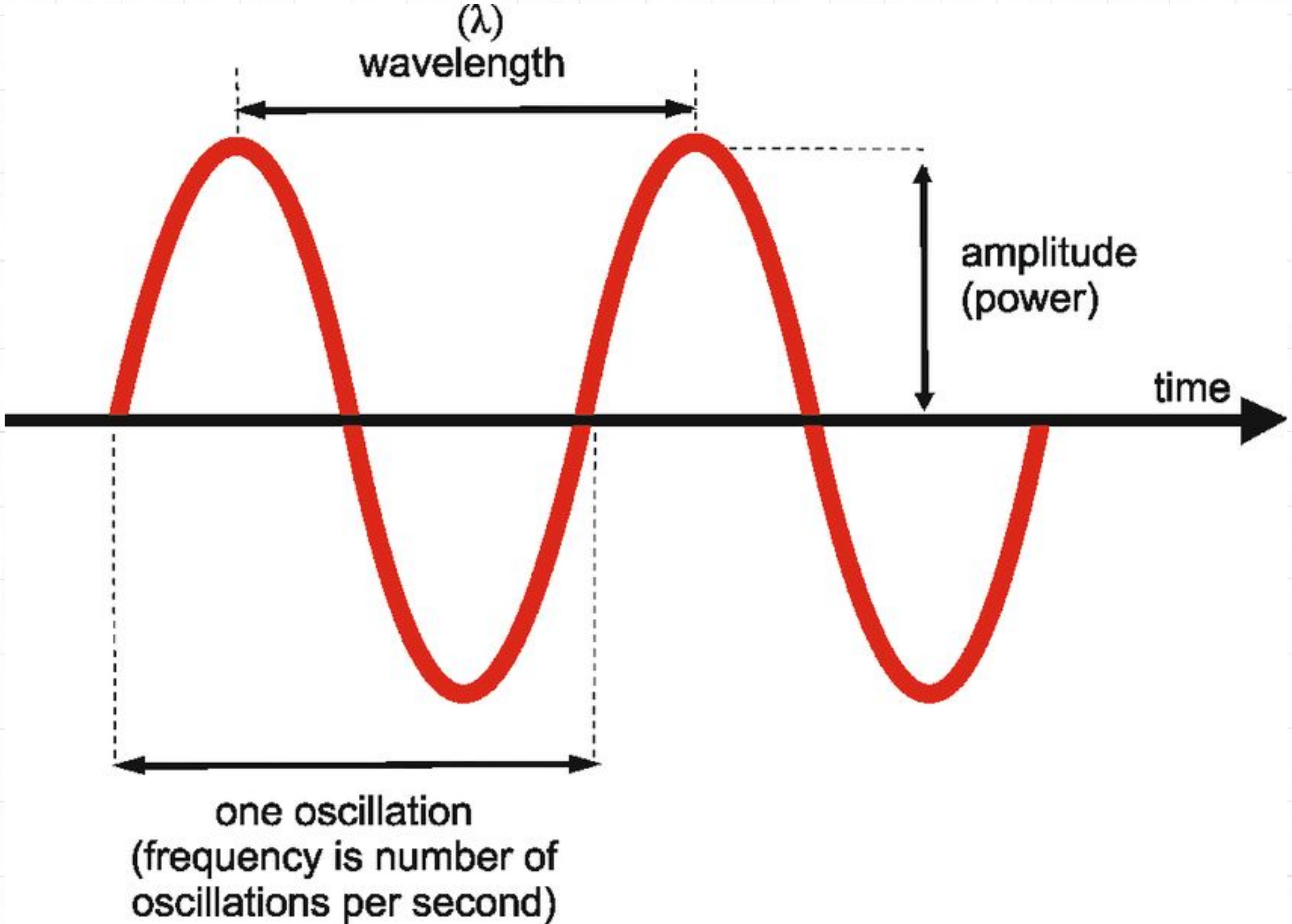


Figure 12.21: The frequency of the note can be calculated from the oscilloscope trace. This oscilloscope is set at 20 ms/div. This means each division on the grid represents 20 ms (0.02 s). The time for one wave (marked as *T*) is two divisions or 0.04 seconds. One wave takes 0.04 seconds, so the number of waves each second is 1 ÷ 0.04 = 25 Hz.

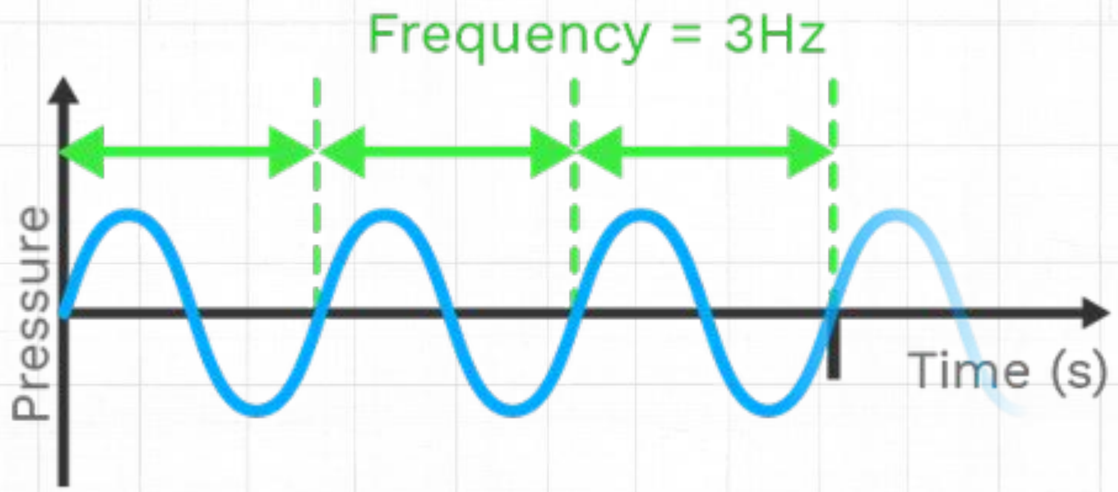
Amplitude and frequency

- The amplitude is the furthest distance the particles move from their undisturbed position. This is shown by the height or depth of the oscilloscope trace.
- The frequency is the number of vibrations each second. The more waves on the screen, the higher the frequency. Frequency is measured in hertz. One hertz means one wave per second.

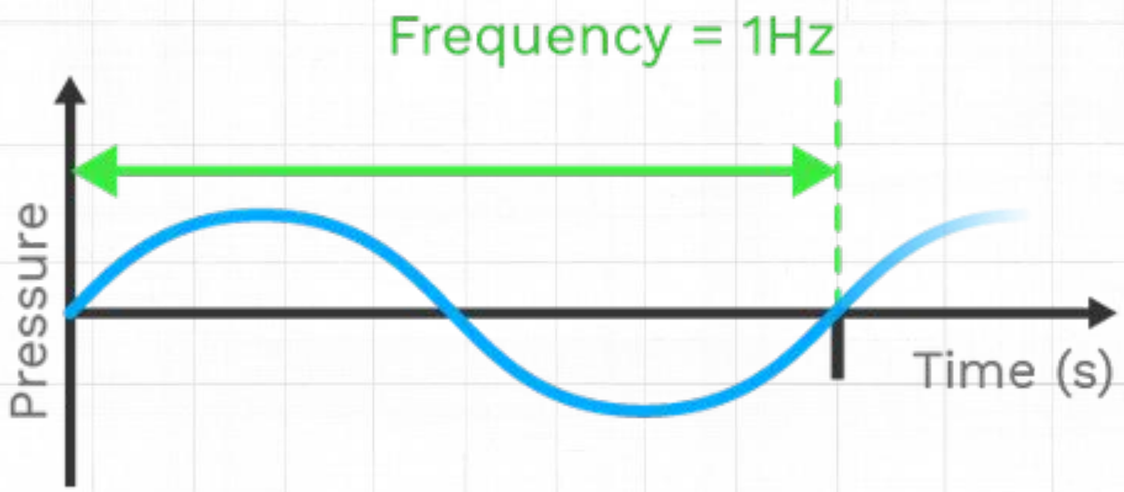
The oscilloscope can be used to observe two important things:



PITCH

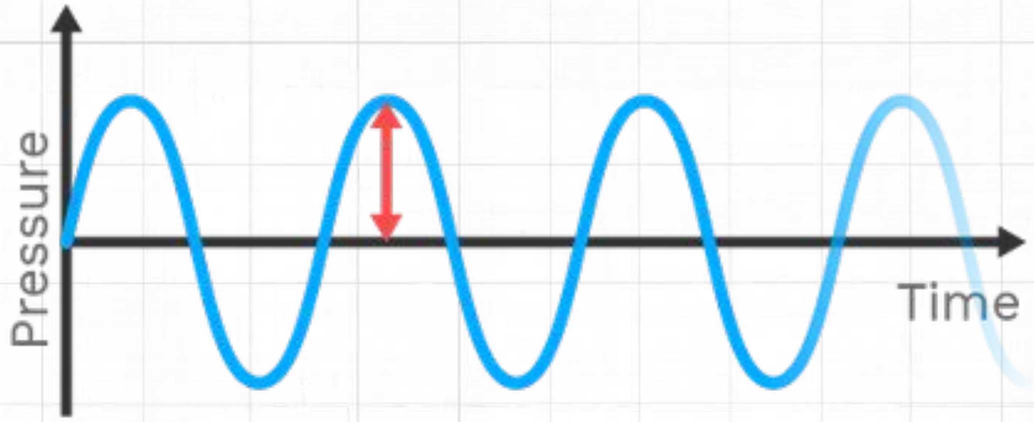


Higher frequency
Higher pitch sound

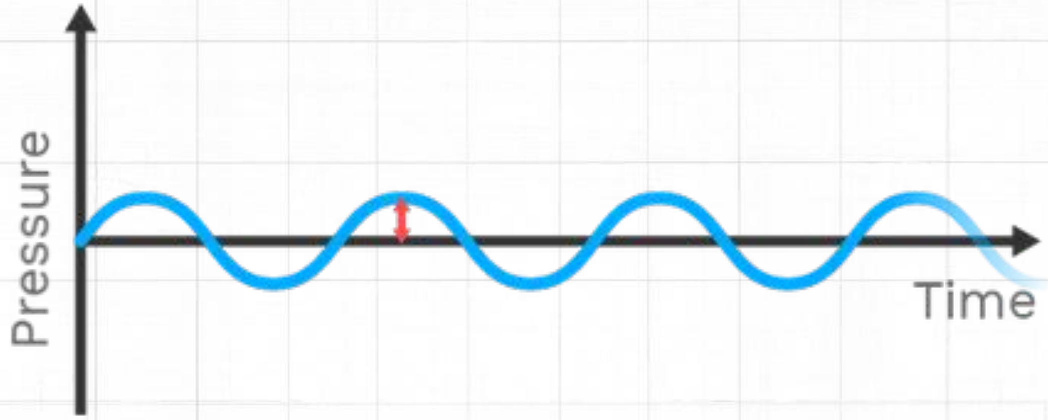


Lower frequency
Lower pitch sound

LOUDNESS



Higher amplitude
Louder sound



Lower amplitude
Quieter sound

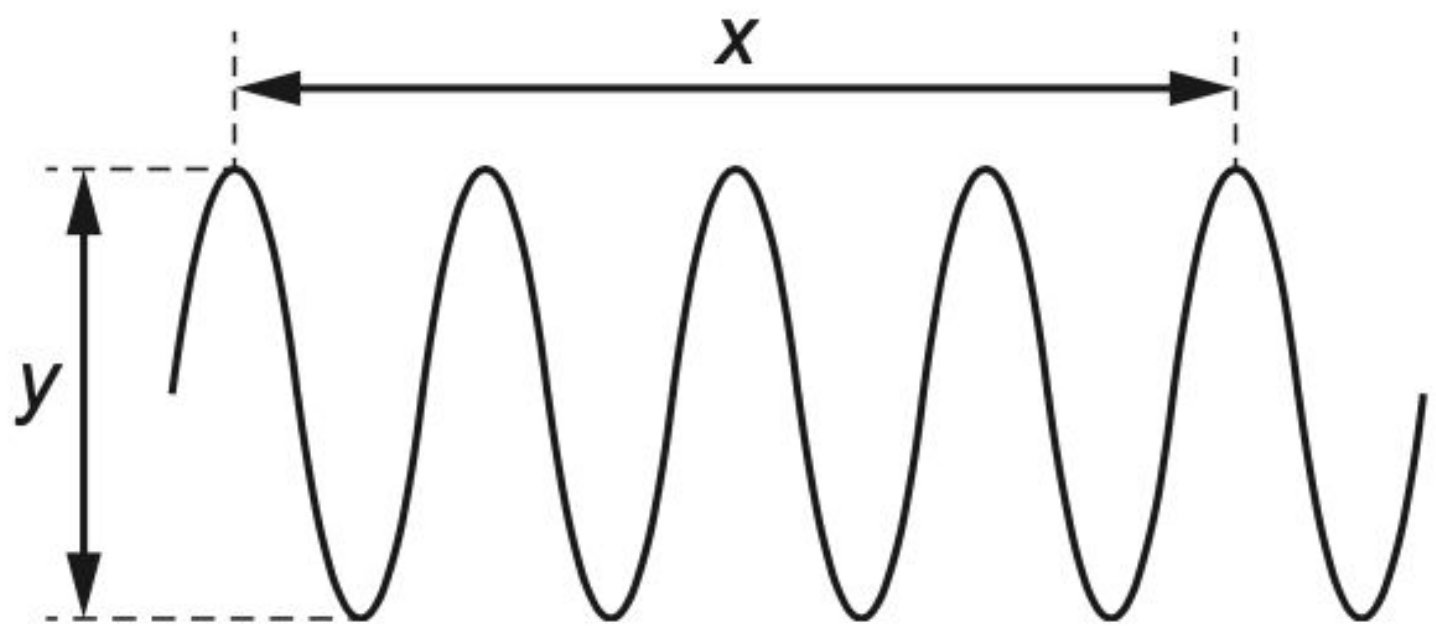
Amplitude and frequency

there is a relationship between the speed of sound, frequency, and wavelength. The speed of sound in a medium can be described by the equation:

$$v = f\lambda$$

v: is the speed of sound in the medium (in metres per second),
f: is the frequency of the sound wave (in hertz),
λ: (lambda) is the wavelength of the sound wave (in metres).

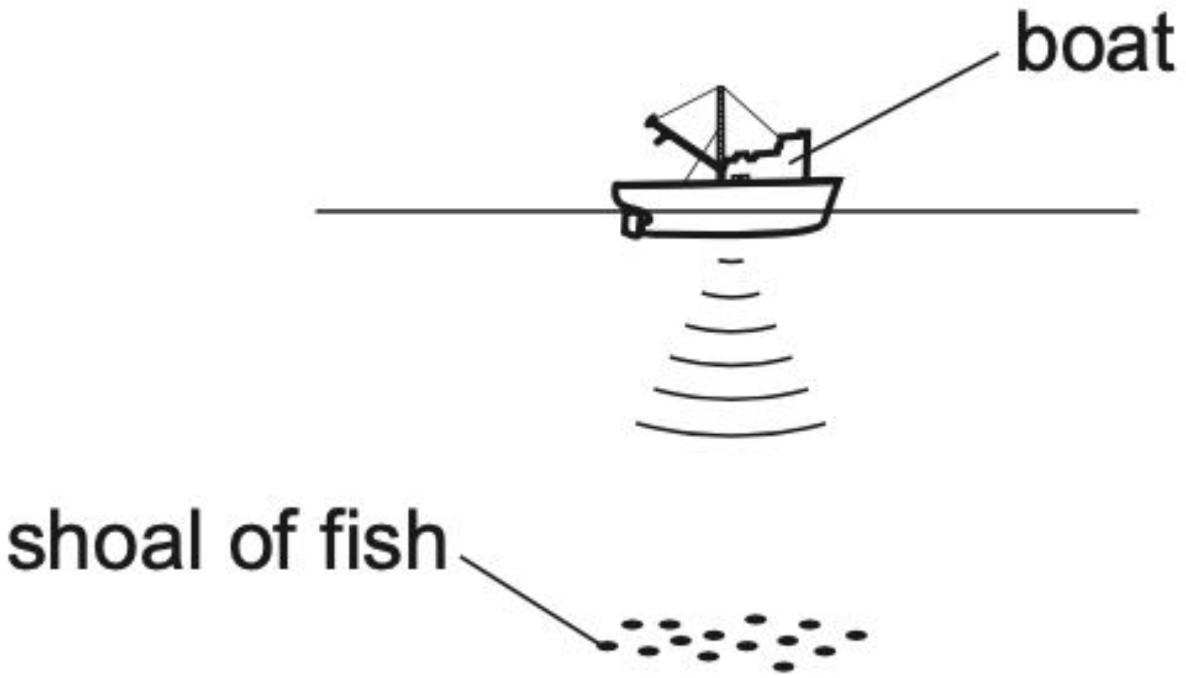
16 The diagram represents a wave.



Which row gives the wavelength and the amplitude of the wave?

	wavelength	amplitude
A	x	y
B	y	x
C	x	$\frac{y}{2}$
D	$\frac{x}{4}$	$\frac{y}{2}$

22 A pulse of sound is produced at the bottom of a boat. The sound travels through the water and is reflected from a shoal of fish. The sound reaches the boat again 1.2 s after it is produced. The speed of sound in the water is 1500 m / s.



How far below the bottom of the boat is the shoal of fish?

A 450 m **B** 900 m **C** 1800 m **D** 3600 m

16 What is the name of the distance from one crest in a transverse wave to the next crest?

A amplitude

B period

C wavefront

D wavelength

23 A student hits two wooden blocks together in front of a wall and calculates the speed of sound to be 340 m / s.

The time between the student hitting the blocks and hearing the echo is 0.59 s.

NOT TO SCALE

What is the distance between the student and the wall?

A 100 m **B** 200 m **C** 290 m **D** 570 m

16 Which statement about waves is correct?

A Waves do not transfer either energy or matter.

B Waves transfer both energy and matter.

C Waves transfer energy without transferring matter.

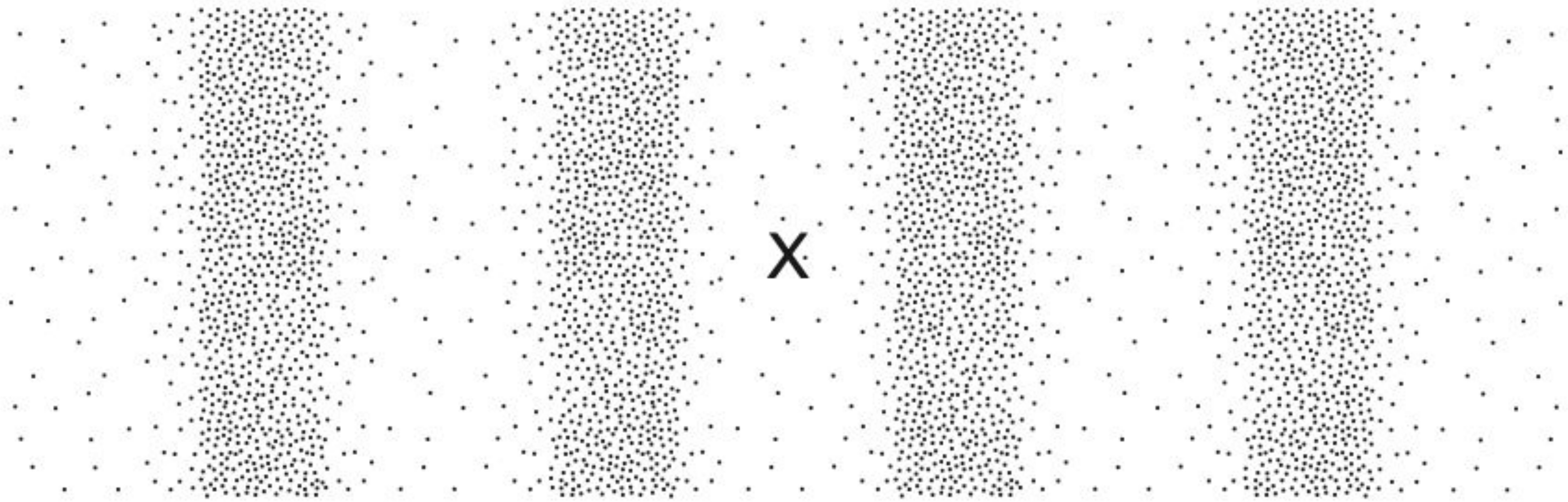
D Waves transfer matter without transferring energy.

22 A sound wave travels at 330 m / s. The distance between the centre of a compression and the centre of the nearest rarefaction in the sound wave is 2.5 cm.

What is the frequency of the sound wave?

A 66 Hz **B** 130 Hz **C** 6600 Hz **D** 13 000 Hz

22 The diagram shows the air molecules in part of a sound wave at a particular moment in time.



Which statement is **not** correct?

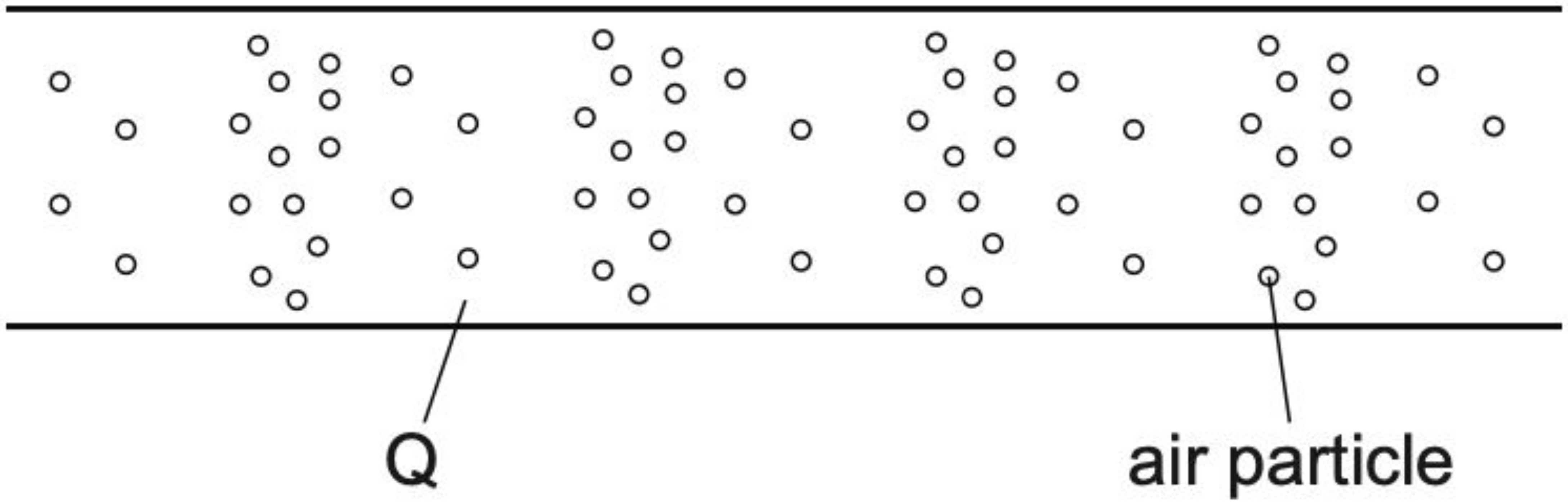
A Earlier, there was compression at X.

B Later, there will be a rarefaction at X.

C This part of the wave is travelling horizontally across the page.

D This part of the wave is travelling towards the top of the page.

26 The diagram shows a model of a sound wave passing through air in an open tube.



What is the region Q?

A a compression which is a region of high pressure

B a compression which is a region of low pressure

C a rarefaction which is a region of high pressure

D a rarefaction which is a region of low pressure

24 Which row gives the typical values of the speed of sound at room temperature in the materials stated?

	speed of sound / m/s		
	air	water	iron
A	340	1500	5100
B	340	5100	1500
C	5100	1500	340
D	3.0×10^8	3.0×10^8	3.0×10^8

17 Which statement about waves is correct?

A All waves can travel through a vacuum.

B All waves travel at the same speed.

C Seismic S-waves can be modelled as longitudinal waves.

D Waves transfer energy without transferring matter.

23 A sound is produced and an echo is heard after the sound reflects off a wall.

How do the properties of the echo compare to the original sound wave?

	amplitude	frequency	speed
A	lower	lower	lower
B	lower	same	same
C	same	lower	lower
D	same	same	same

5 An observer stands at P and looks into a rock quarry. A small explosion takes place at X in the quarry.

Fig. 5.1 shows the situation.

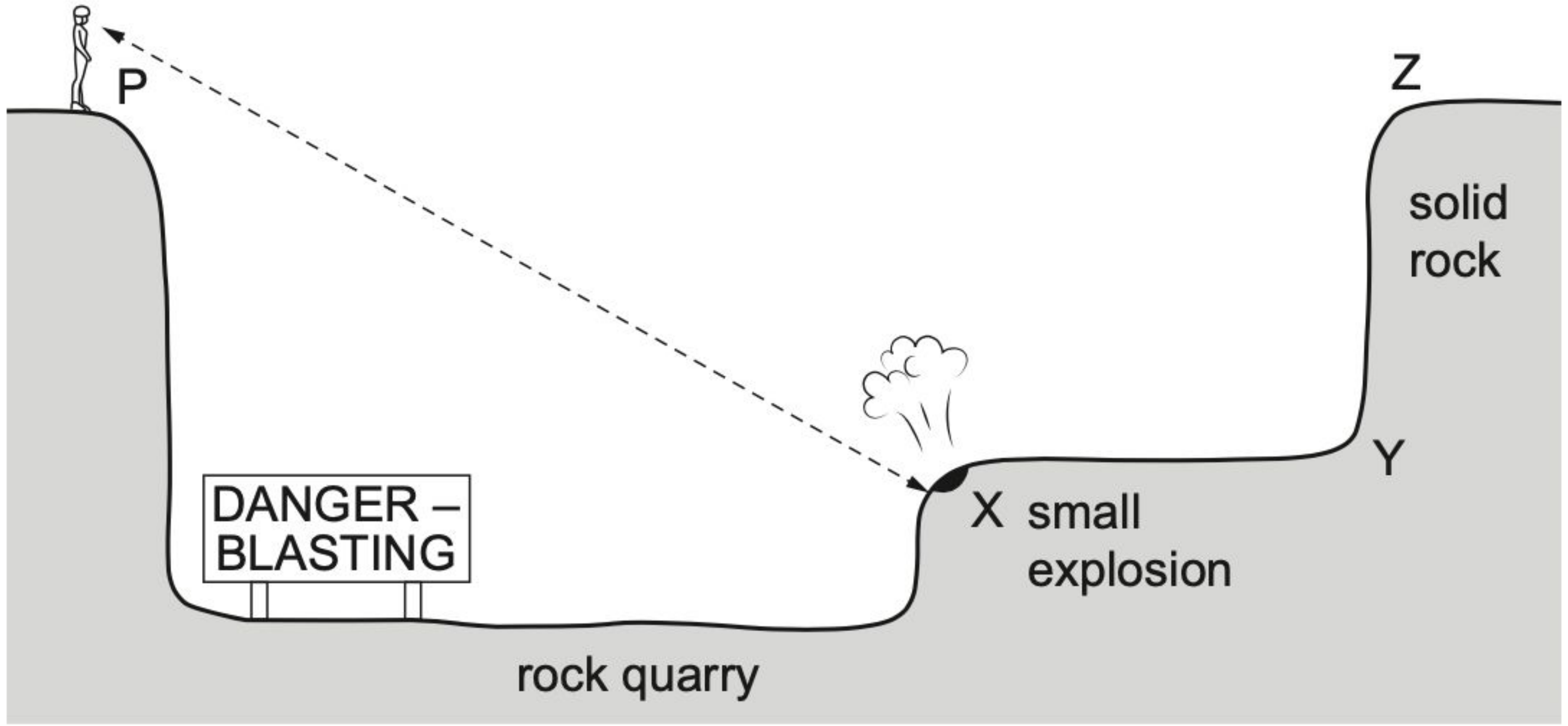


Fig. 5.1 (not to scale)

(a) The observer first hears the sound from the explosion 1.8 s after the explosion occurs. The speed of the sound is 340 m/s.

(i) Calculate the distance XP from the explosion at X to the observer at P.

distance XP = ... m [3]

(ii) The observer then hears a quieter sound from the explosion.

Suggest how the quieter sound waves reach the observer.

....

.... [2]

Fig. 6.1 shows particles of a material in which a sound wave is travelling.

Fig. 6.1 (not to scale)

(a) On Fig. 6.1, mark:

(i) the centre of a compression with the letter C [1]

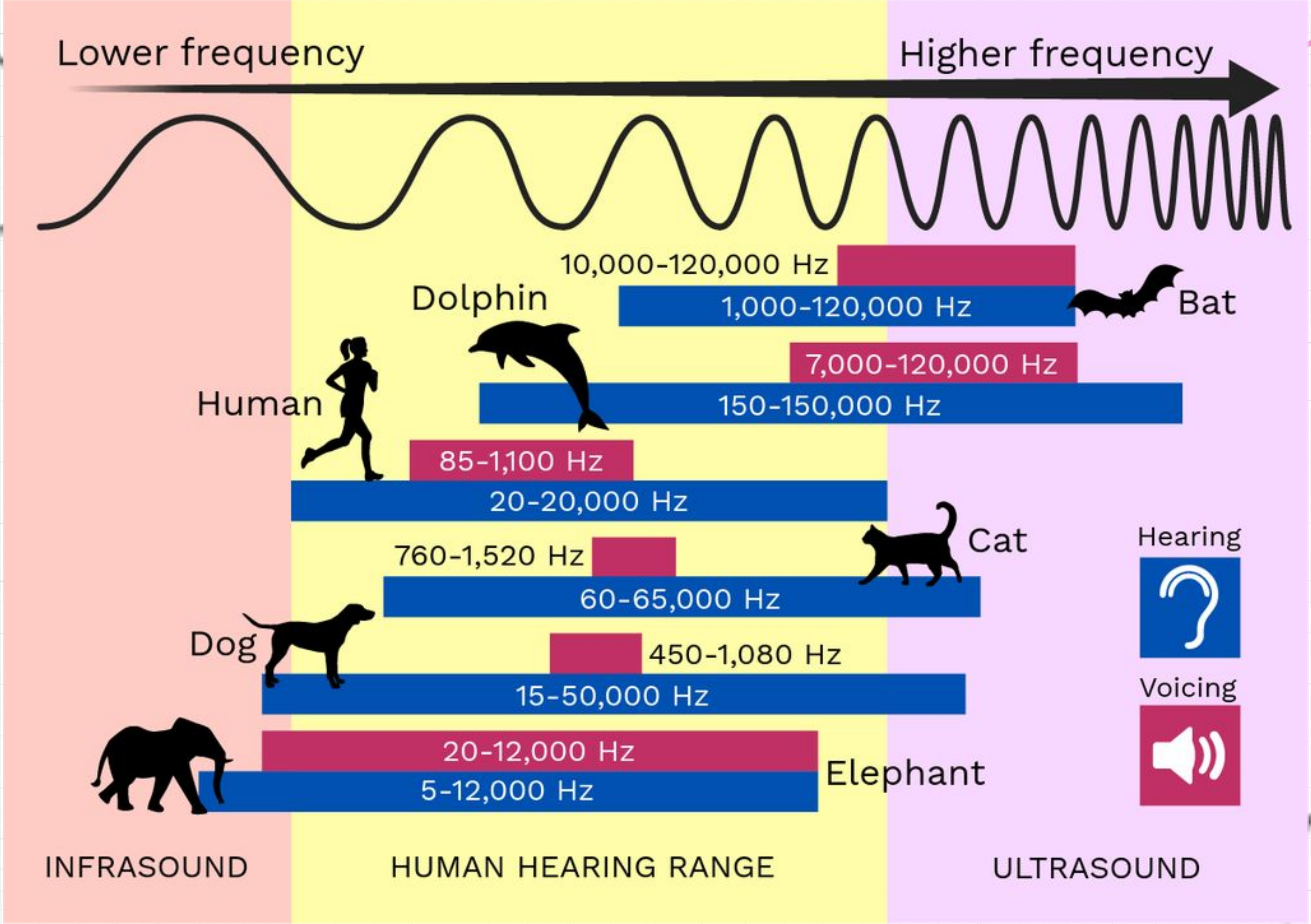
(ii) the centre of a rarefaction with the letter R [1]

(iii) one wavelength with a double-ended arrow. [1]

Hearing sound

Young humans can hear sounds from 20 Hz up to 20 000 Hz.

As we grow older, the sensory cells in the ear which detect vibrations deteriorate. This means that the range of sounds which can be heard decreases with age.



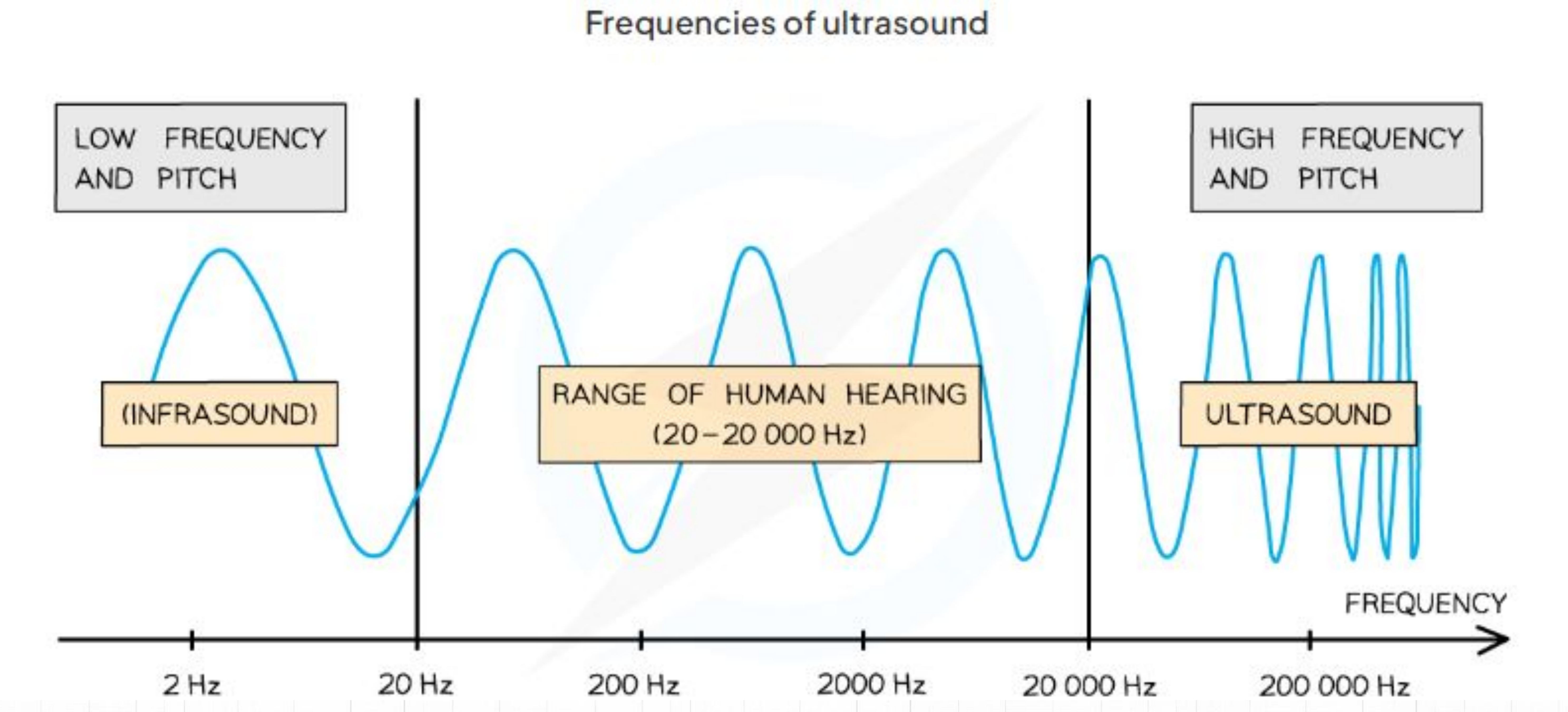
Lower frequency
Higher frequency
10,000-120,000 Hz
Dolphin
1,000-120,000 Hz
Bat
7,000-120,000 Hz
Human
150-150,000 Hz
85-1,100 Hz
20-20,000 Hz
760-1,520 Hz
Cat
60-65,000 Hz
Hearing
Dog
450-1,080 Hz
15-50,000 Hz
Voicing
20-12,000 Hz
Elephant
5-12,000 Hz
INFRASOUND
HUMAN HEARING RANGE
ULTRASOUND

Ultrasound

Sounds which have a higher frequency than 20 000 Hz are too high pitched to be heard by the human ear. These sounds are known as ultrasound.

Ultrasound is defined as sound with a frequency higher than 20kHz. The frequency of ultrasound is too high to be detected by the human ear but can be detected electronically and displayed on a cathode ray oscilloscope (CRO).

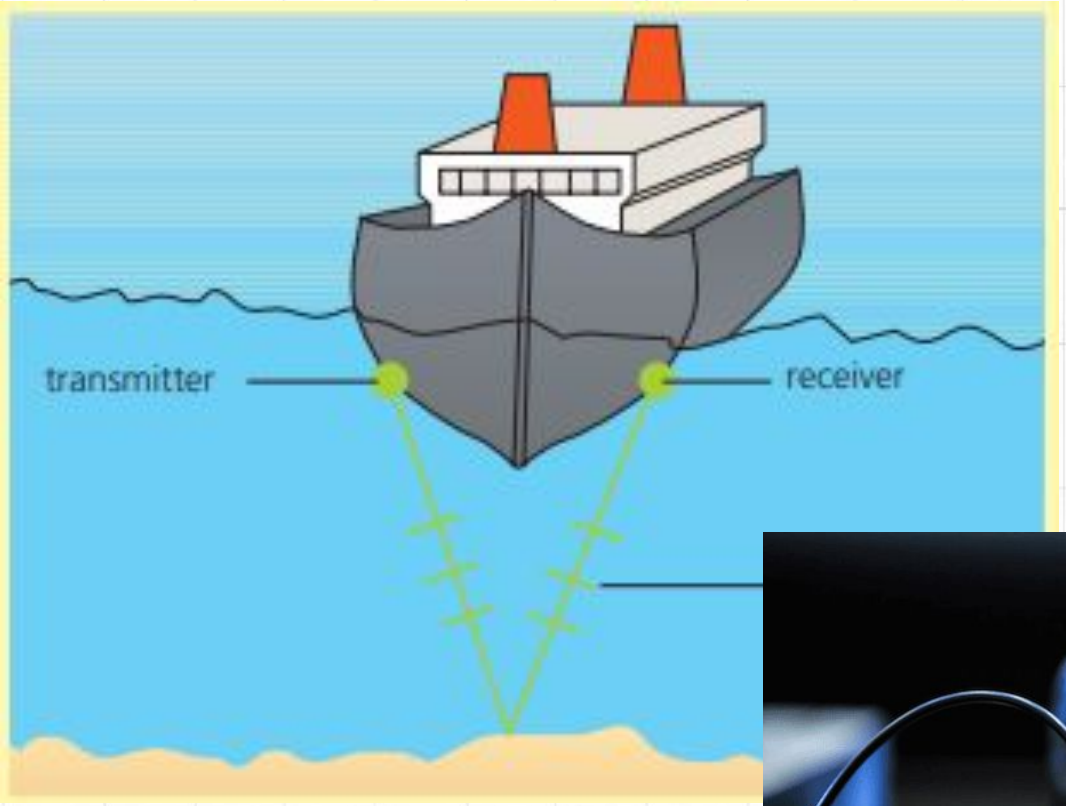
Ultrasound

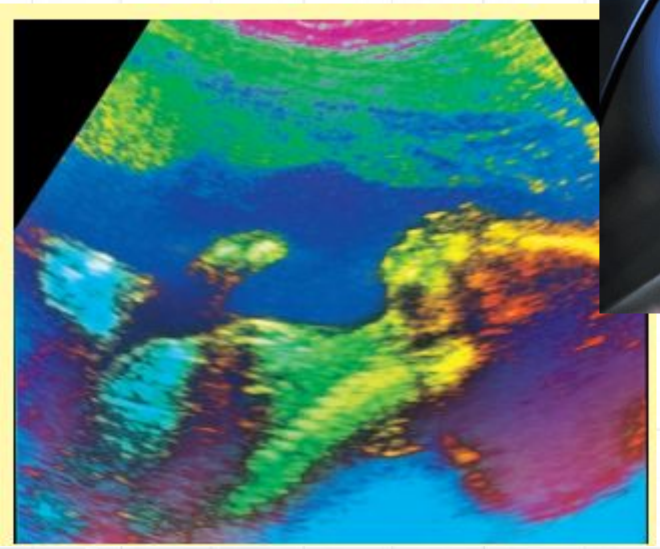


Frequencies of ultrasound
LOW FREQUENCY AND PITCH
HIGH FREQUENCY AND PITCH
(INFRASOUND)
RANGE OF HUMAN HEARING (20 – 20 000 Hz)
ULTRASOUND
FREQUENCY
2 Hz
20 Hz
200 Hz
2000 Hz
20 000 Hz
200 000 Hz

Application of ultrasound

- Sonar
- Material testing
- medical ultrasound imaging
- Ultrasound can be used in ultrasound drills to cut holes in hard materials





Sonar

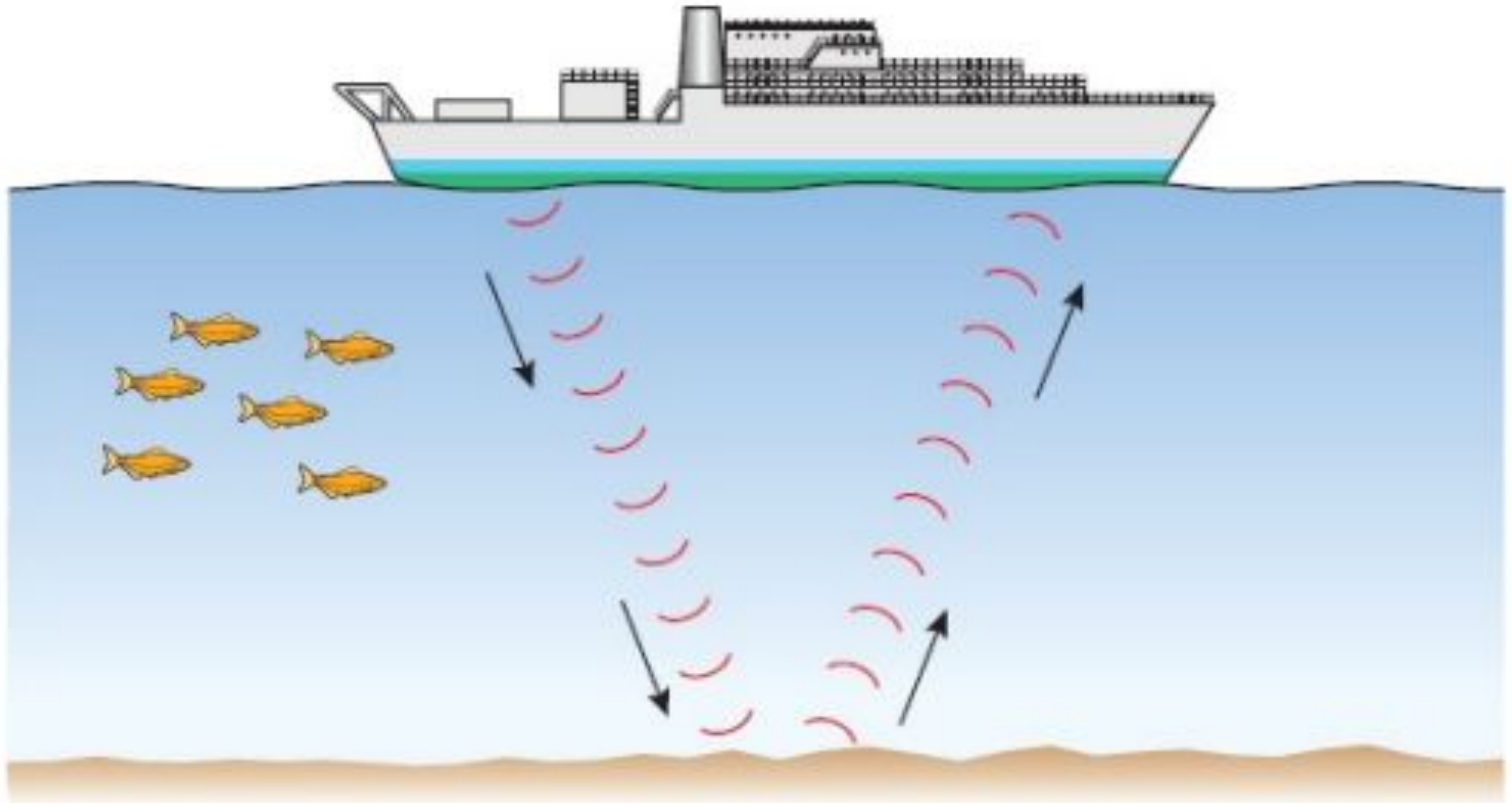
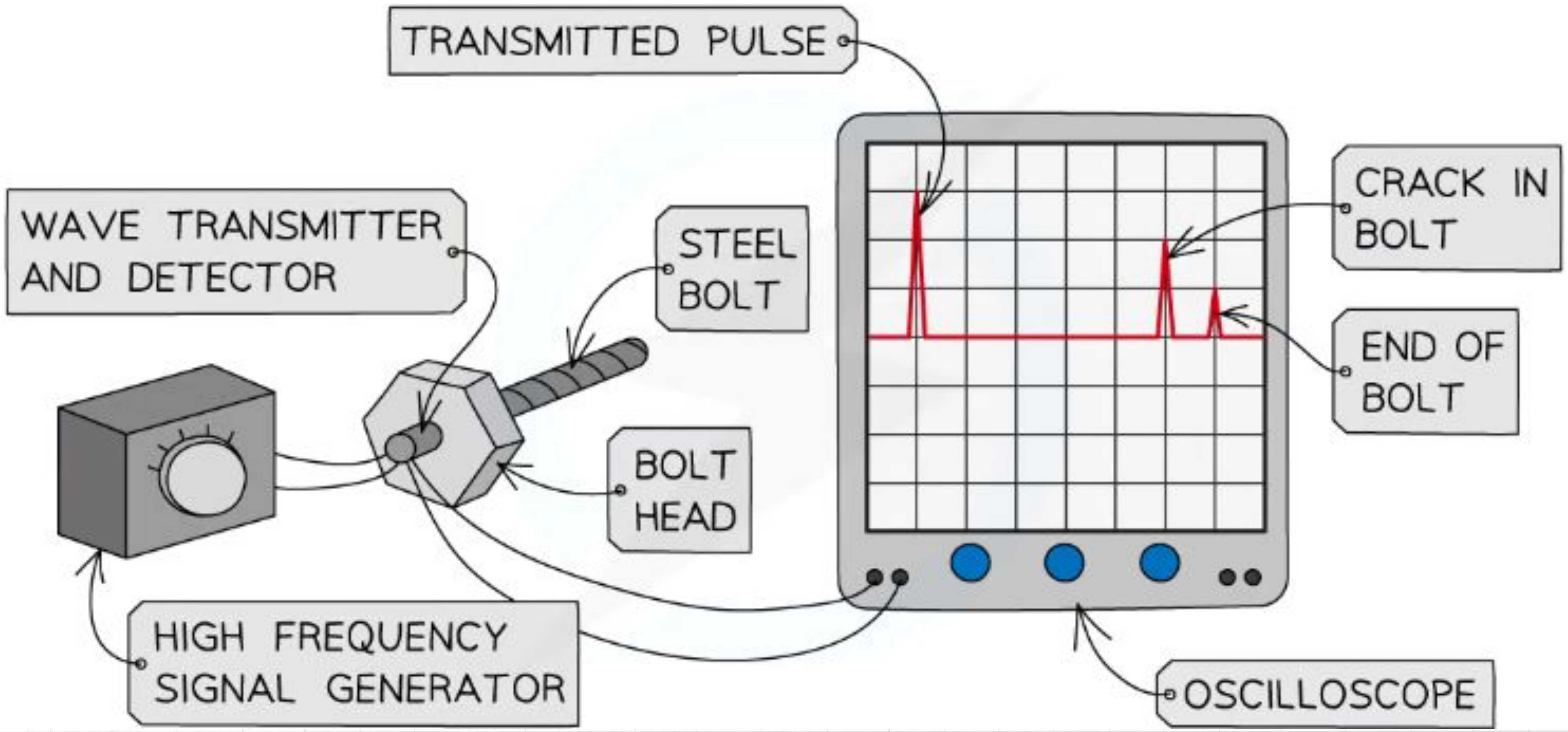


Figure 12.23: Using sonar to measure depth. What effect might the fish have?

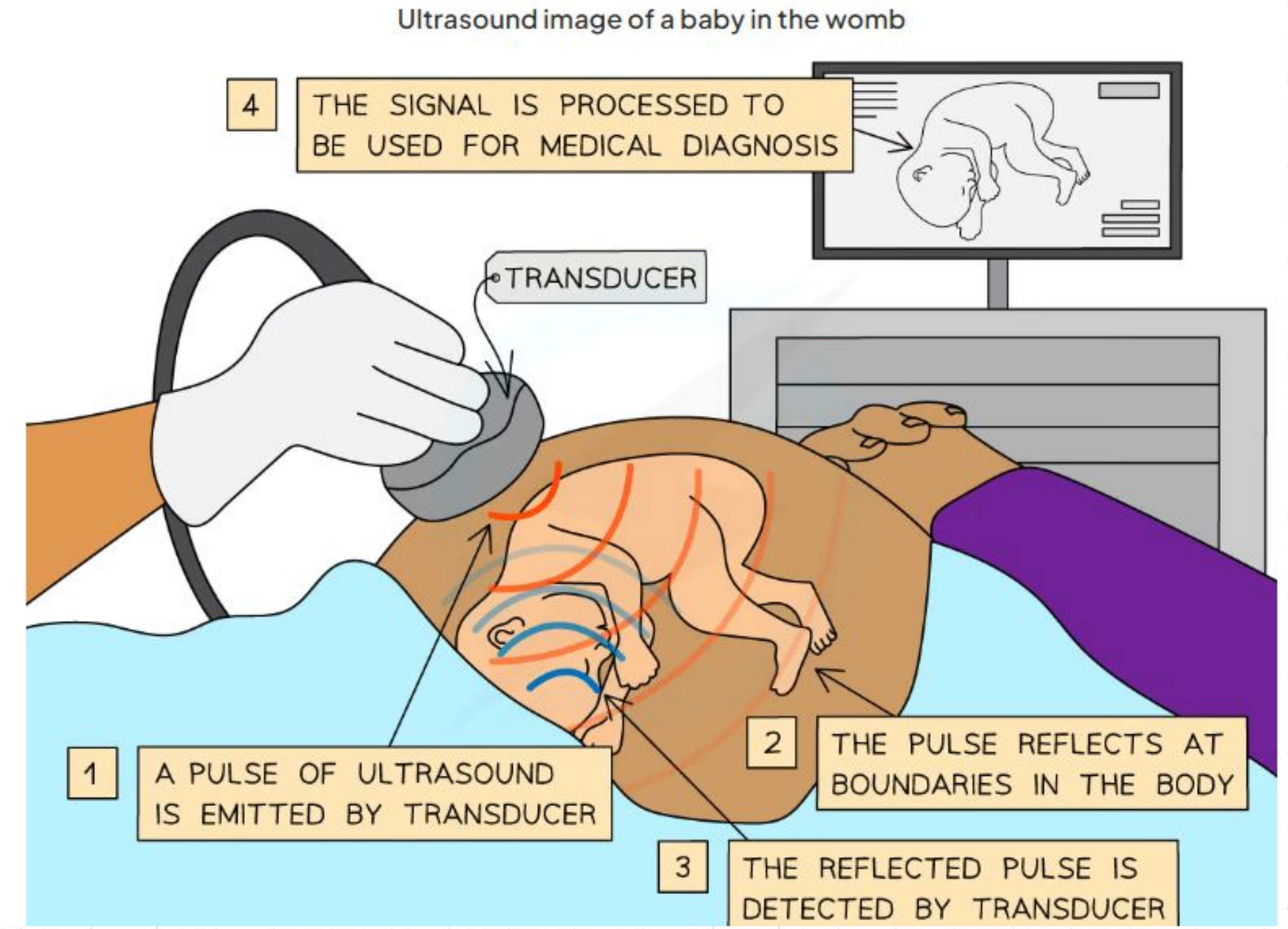
A pulse of ultrasound is sent down from a boat and reflects from the seabed. The time taken for the reflected pulse to be received is measured. This is used, with the speed of sound in water to calculate the depth of the water.

Ultrasonic material testing

Oscilloscope display for material imperfection testing

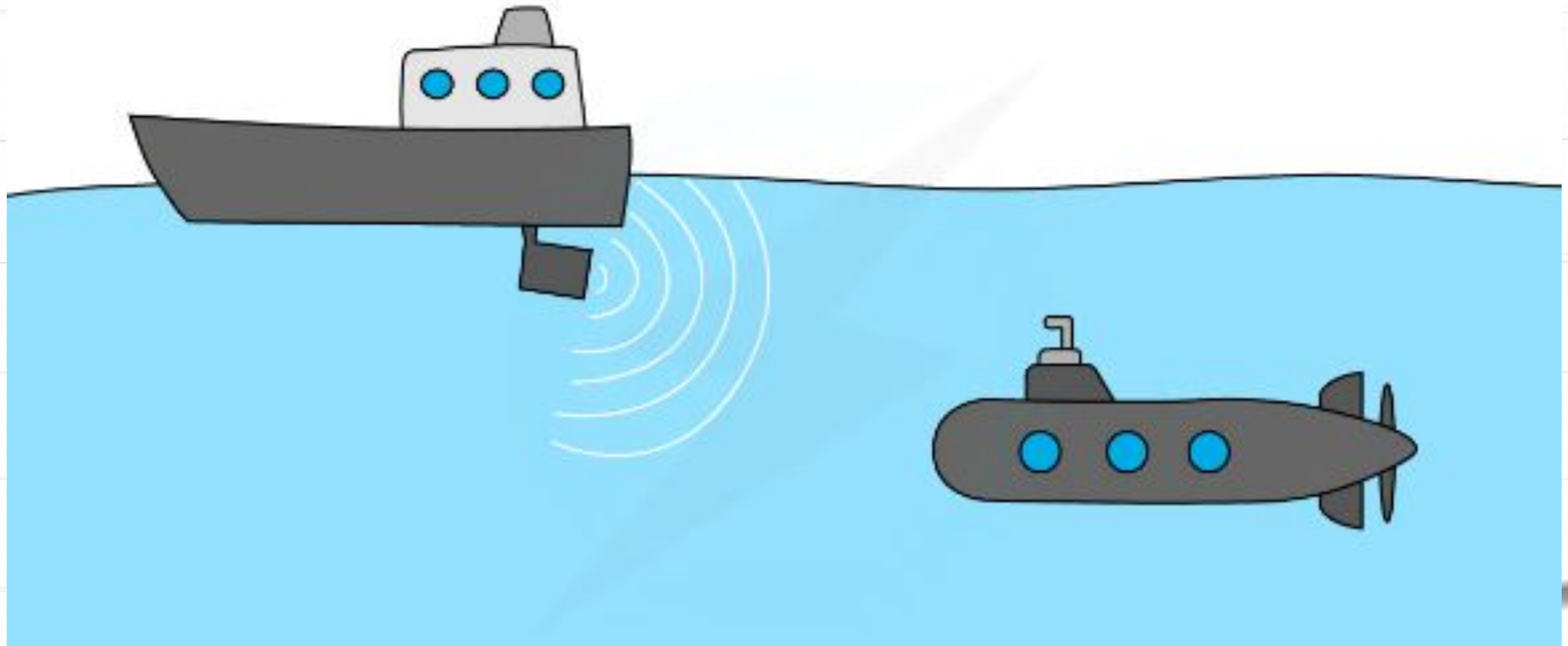


Ultrasound in medicine



Application of ultrasound

Echo sounding can be used to measure depth or to detect objects underwater



Question

State the range of sound a young person can typically hear.

20 Hz to 20 000 Hz

Question

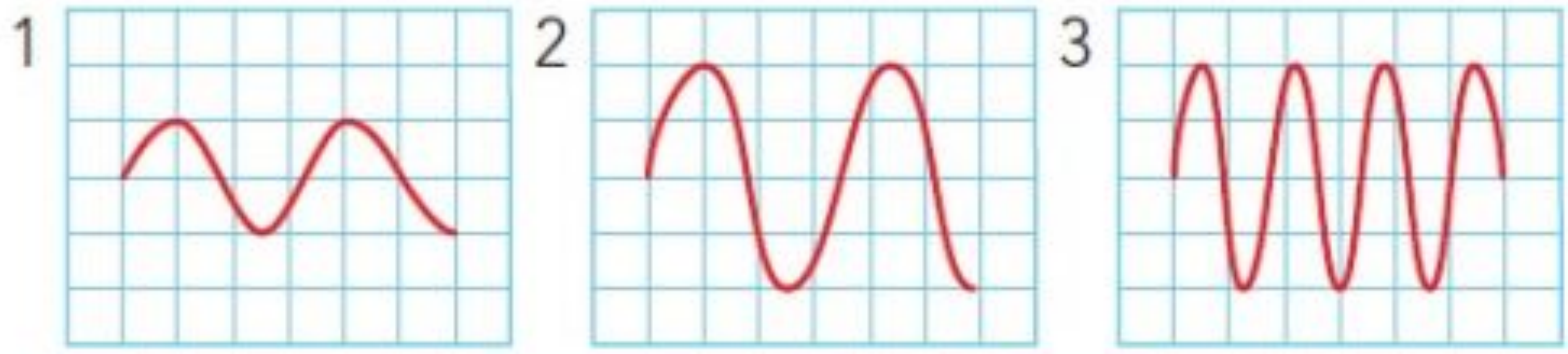
Describe what happens to this range as the person gets older. What else can have this effect on hearing?

The range gets smaller. Exposure to very loud sounds can also have this effect

Question

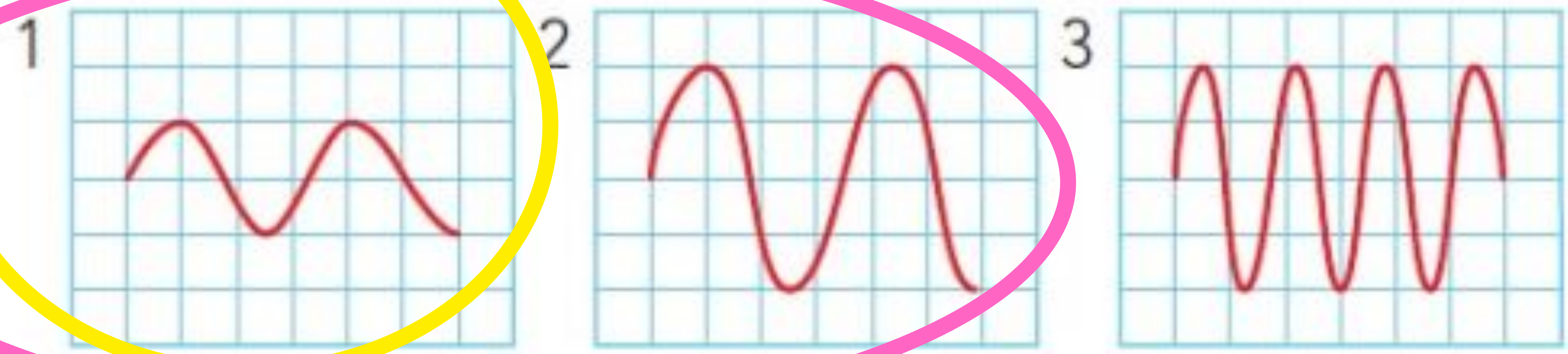
Which sound is quietest? Explain your answer.

Which two sounds have the same pitch? Explain your answer.



1 is the quietest as it has the smallest amplitude

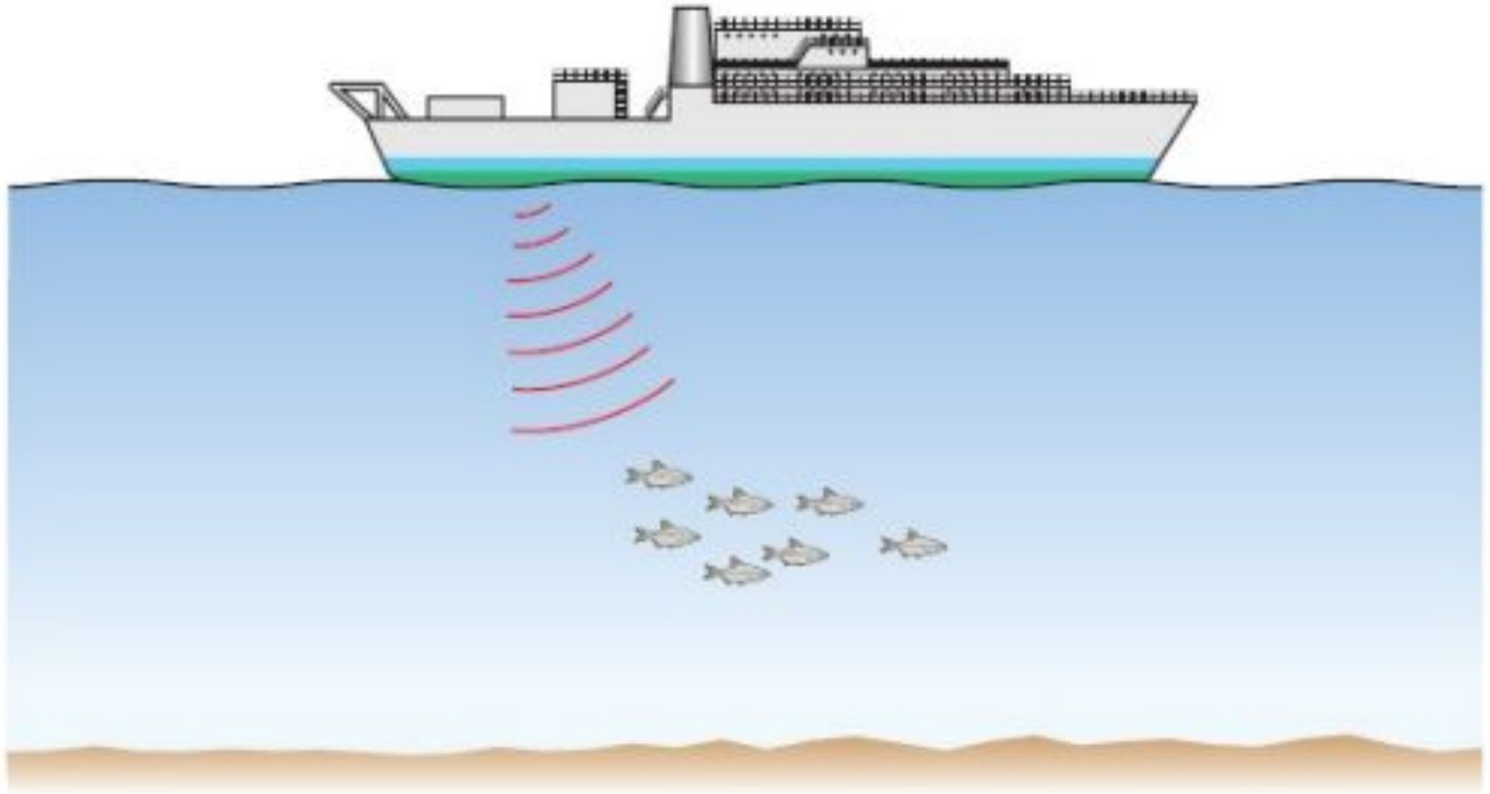
1 and 2. They have the same frequency (the same number of waves can be seen on the screen).



Question

A ship positioned above a shoal of fish sends out an ultrasound pulse and receives two reflected pulses, one after 0.2 seconds and the other after 0.5 seconds. The speed of sound in water is 1500 m/s.

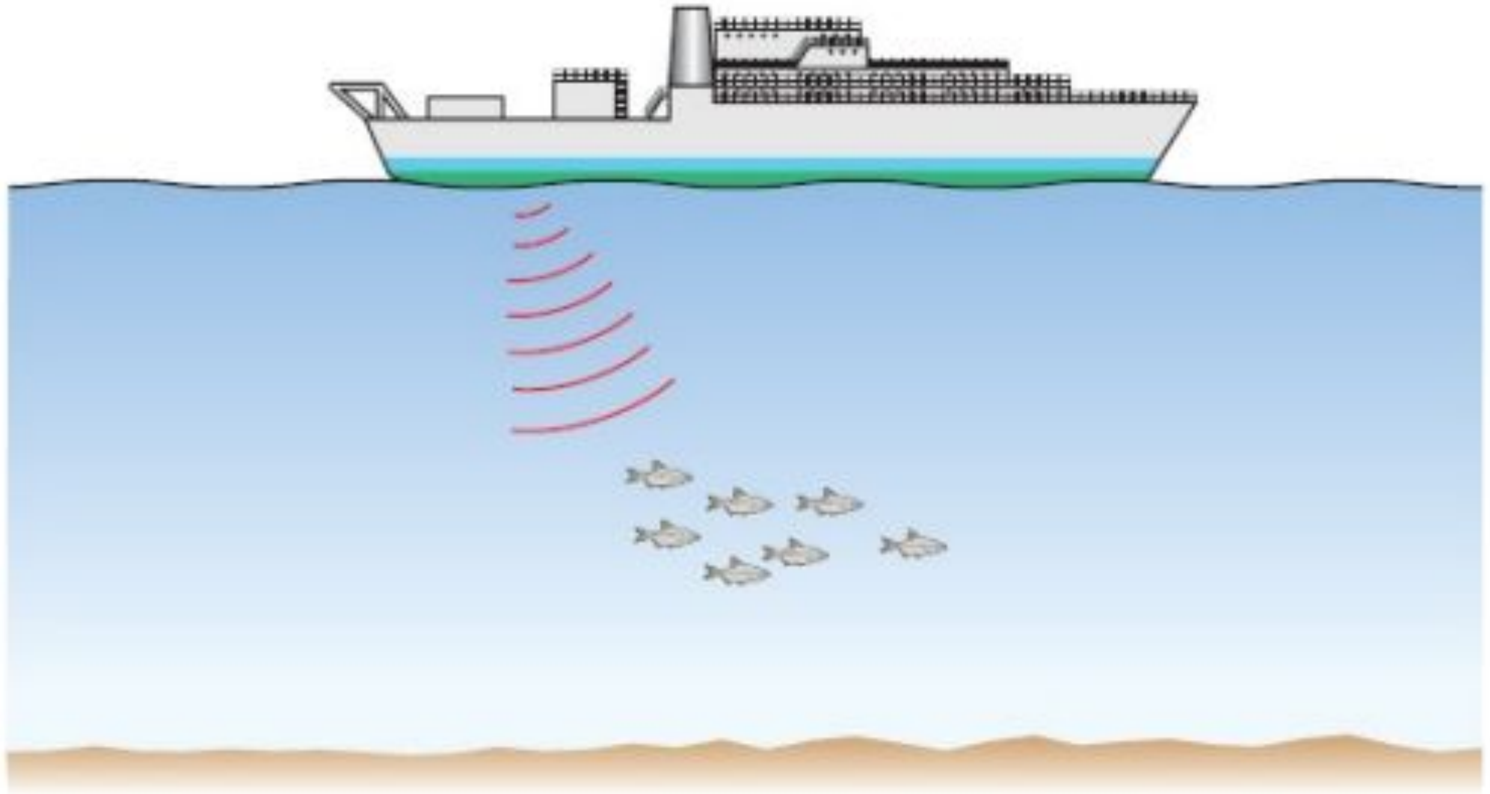
- Calculate the depth of the sea
- Calculate the depth of the shoal of fish
- Explain why the first reflected pulse lasts for longer than the second



Question

A ship positioned above a shoal of fish sends out an ultrasound pulse and receives two reflected pulses, one after 0.2 seconds and the other after 0.5 seconds. The speed of sound in water is 1500 m/s.

- **375 m**
- **150 m**
- **The fish are at different depths so there are lots of small echoes rather than one distinct one.**



Question

A girl stands 160m away from a high wall and claps her hands at a steady rate so that each clap coincides with the echo of the one before. If her clapping rate is 60 per minute, state the value this gives for the speed of sound.

320 m/s

Question

If she moves 40m closer to the wall she finds the clapping rate has to be 80 per minute. Calculate the value these measurements give for the speed of sound.

320 m/s

Question

She moves again and finds the clapping rate becomes 30 per minute. Calculate how far she is from the wall if the wave speed of sound is the value you found the beginning.

Distance of sound traveled = 640 m

Distance of the girl = 320 m

Question

Draw the waveform of

- a loud, low-pitched note
- a soft, high-pitched note

- **High amplitude, stretched frequency**
- **Low amplitude, compacted (high intensity) frequency**

Question

If the speed of sound is 340m/s what is the wavelength of a note of frequency

- 340 Hz
- 170 Hz

- **1m**
- **2m**

Question

Describe how sound waves are used in sonar

Reflection of sound waves can be used to measure depth or to detect objects. A sound wave can be transmitted from source. When the sound wave is reflected, for example of the bottom on an ocean or different materials, the time it takes for the sound wave to return is used to calculate the depth of the objects.

Question

Name the state of matter in which sound waves travel:

- fastest
- slowest

- **Solid**
- **Gas**

Question

Name two uses of ultrasound other than sonar

non-destructive testing of materials

medical scanning of soft tissue

sonar to calculate the depth or distance from time and wave speed

Question

Which of the frequency ranges below is completely audible by a human who has average hearing?

A. 200 Hz to 200 kHz

B. 5 Hz to 50 kHz

C. 50 Hz to 5 kHz

D. 50 kHz to 50 MHz

Question

A tuba player plays a loud note on her tuba.

She then plays a quiet note of the same pitch.

Which property of the sound wave she produced has changed?

A. Frequency

B. Wavelength

C. Amplitude

D. Speed

Question

Extended tier only

Which of the following is **not** a use of ultrasound?

A. Scanning a fetus during pregnancy

B. Non-destructive testing of materials such as to find leaks in copper pipes

C. Mapping with sonar

D. Identifying broken bones

After a lockdown drill at a school, the management team notes that the lockdown siren is too quiet, and its pitch is too low to be heard at a distance.

They call the company that supplied the siren and ask them to make the alarm louder, and to give it a higher pitch.

What effect does the change have on the resulting sound wave produced by the siren?

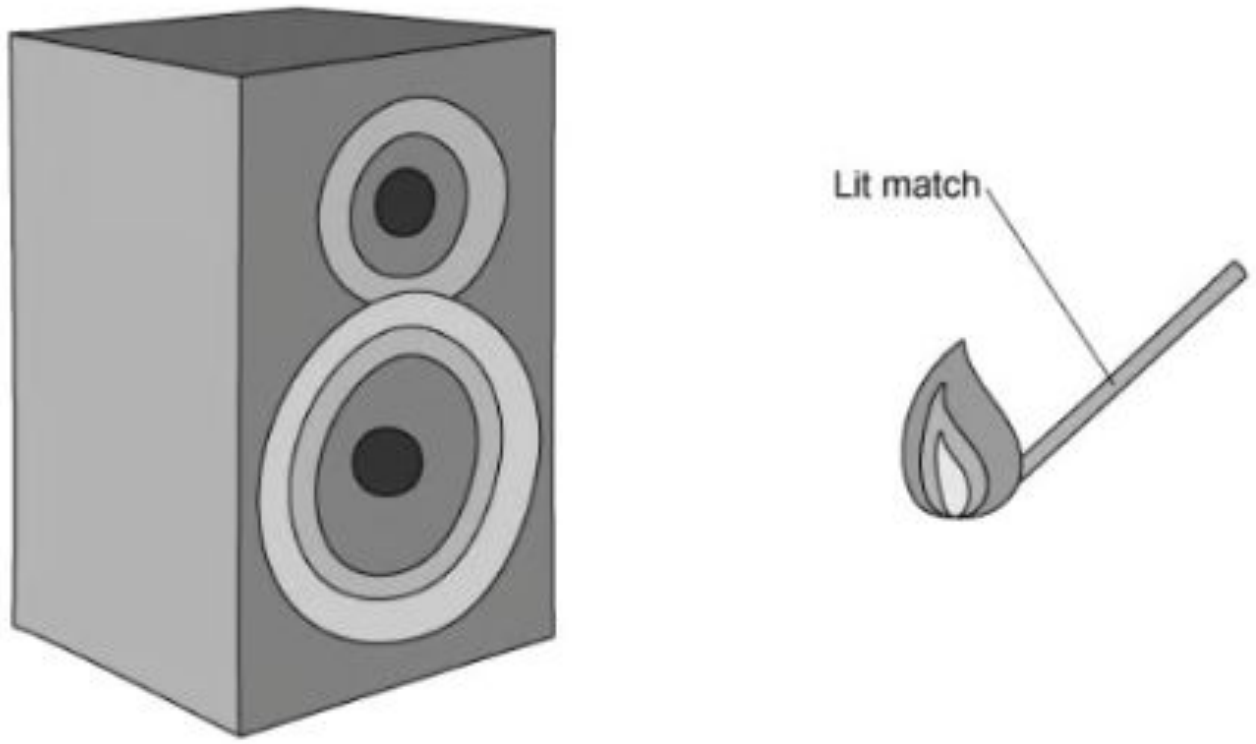
A. It has a larger amplitude and a lower frequency.

B. It has a larger frequency and a lower amplitude.

C. It has a smaller frequency and a larger amplitude.

D. It has a larger frequency and a larger amplitude.

In a common secondary school demonstration, a speaker is placed next to a lighted match.



A loud sound wave is played through the speaker, causing the flame to vibrate.

What type of wave is emitted from the speaker, and in which direction does the flame vibrate?

	wave type	direction of vibration
A	transverse	$\leftrightarrow$
B	longitudinal	$\leftrightarrow$
C	transverse	$\updownarrow$
D	longitudinal	$\updownarrow$

In the olympic 100 m sprint final, a starting pistol is used to tell the sprinters when to start.

A spectator, sitting in the viewing area 300 m away sees the smoke from the pistol 0.86 s before hearing the bang. The spectator has exceptionally keen reactions and a very accurate internal clock.

Using only this information, what is the speed of sound in air?

A. 349 m/s

B. 330 m/s

C. 258 m/s

D. 698 m/s

A walker can see a cliff face some distance away, and wants to estimate how far away it is.

He makes a loud noise, and times how long it takes the echo to come back. It takes 1.8 s.

If the speed of sound is 345 m/s, how far away is the cliff?

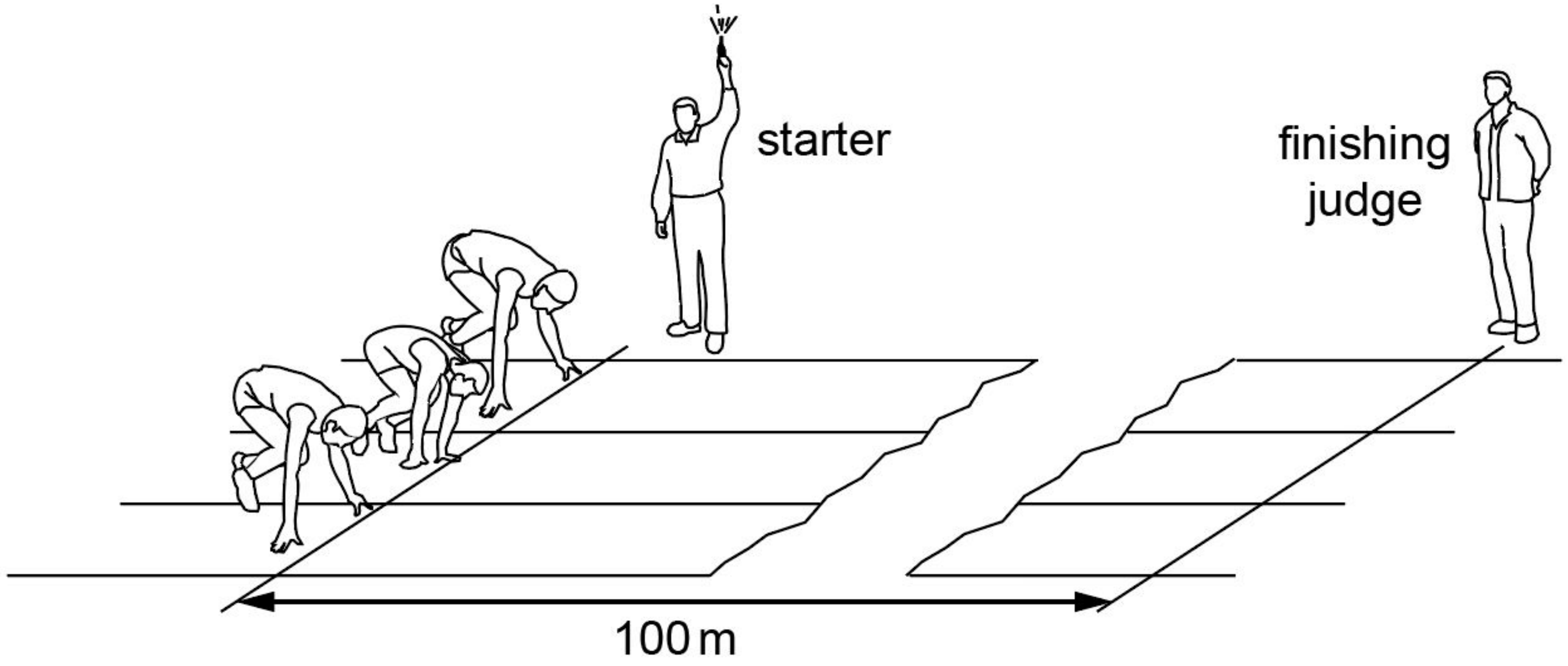
A. 192 m

B. 96 m

C. 621 m

D. 311 m

24 A 100 m race is started by firing a gun. The gun makes a bang and a puff of smoke at the same time.



When does the finishing judge see the smoke and when does he hear the bang?

	sees the smoke	hears the bang
A	almost immediately	almost immediately
B	almost immediately	after about 0.3 s
C	after about 0.3 s	almost immediately
D	after about 0.3 s	after about 0.3 s

24 An observer stands at the finish line of a 100 m race. He wants to time the winner's run. He starts his stop-watch as soon as he sees the smoke from the starting gun instead of when he hears the bang.

What is the reason for doing this?

A Light travels much faster than sound.

B There is a risk he might respond to an echo from a wall.

C Humans react slower to sound than to light.

D Humans react more quickly to sound than to light.

24 What is ultrasound?

A sound waves that are so loud that they damage human hearing

B sound waves that are too high-pitched for humans to hear

C sound waves that are too low-pitched for humans to hear

D sound waves that are too quiet for humans to hear

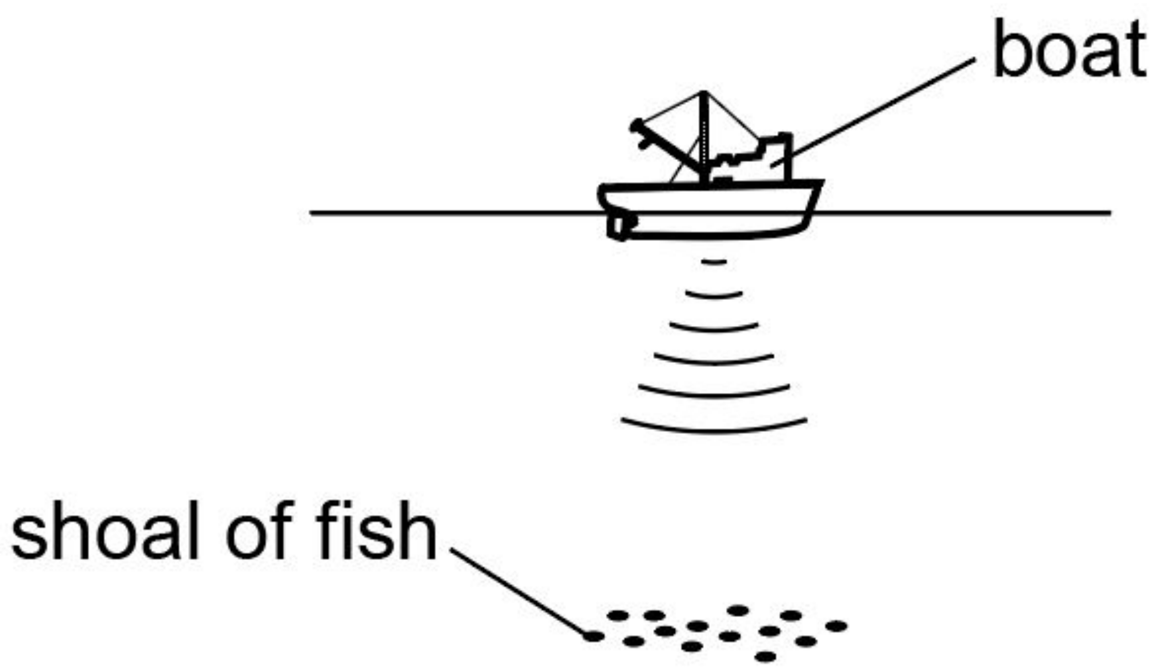
23 A student hits two wooden blocks together in front of a wall and calculates the speed of sound to be 340 m / s.

The time between the student hitting the blocks and hearing the echo is 0.59 s.

What is the distance between the student and the wall?

A 100 m **B** 200 m **C** 290 m **D** 570 m

22 A pulse of sound is produced at the bottom of a boat. The sound travels through the water and is reflected from a shoal of fish. The sound reaches the boat again 1.2 s after it is produced. The speed of sound in the water is 1500 m / s.



How far below the bottom of the boat is the shoal of fish?

A 450 m **B** 900 m **C** 1800 m **D** 3600 m

23 The element mercury exists as a solid, a liquid or a gas.

Which row gives a possible set of values of the speeds of sound through mercury?

	speed of sound in frozen mercury / m/s	speed of sound in liquid mercury / m/s	speed of sound in mercury vapour / m/s
A	250	1500	2500
B	250	2500	1500
C	1500	250	2500
D	2500	1500	250

(a) A sound wave used for a medical examination has a frequency of 1.5 MHz.

(i) State and explain what type of sound wave this is.

....

.... [2]

(ii) The wave travels through soft human tissue at a speed of 1.3 km/s.

Calculate the wavelength of the wave in soft human tissue.

wavelength = 8.7×10^{-4} m .... [3]

23 Dogs can hear sounds in the range from 100 Hz to 45 kHz.

Which statement is correct?

A Any sound a dog can hear can also be heard by a human.

B Any sound a human can hear can also be heard by a dog.

C Dogs can hear some low frequency sounds that are silent for humans.

D Dogs can hear some high frequency sounds that are silent for humans.

Thank You