Chapter 15 – Sound

Subject content

Content
- Sound waves
- Speed of sound
- Echo
- Ultrasound

Learning outcomes
(a) Describe the production of sound by vibrating sources
(b) Describe the longitudinal nature of sound waves in terms of the processes of compression and rarefaction
(c) Explain that a medium is required in order to transmit sound waves and that the speed of sound differs in air, liquids and solids
(d) Describe a direct method for the determination of the speed of sound in air and make the necessary calculation
(e) Relate loudness of a sound wave to its amplitude and pitch to its frequency
(f) Describe how the reflection of sound may produce an echo, and how this may be used for measuring distances
(g) Define ultrasound and describe one use of ultrasound, e.g. quality control and pre-natal scanning

Definitions

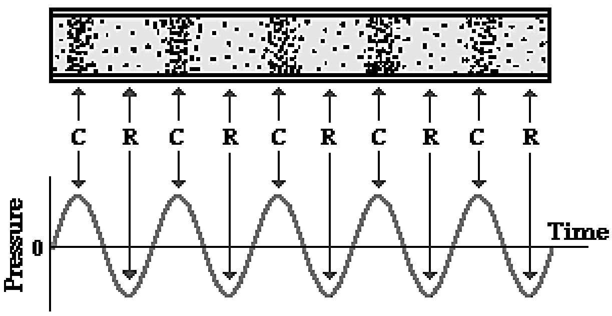
Phrase	Definition
Sound	A form of energy that is transferred from one point to another as a longitudinal wave
Compression	region where air pressure is higher than surrounding air pressure
Rarefaction	region where air pressure is lower than surrounding air pressure
Echo	The repetition of a sound due to the reflection of sound
Ultrasound	Sound with frequencies above the upper limit of the human range of audibility

15.1 What is Sound?

Propagation of sound wave

Sound

A form of energy that is transferred from one point to another as a longitudinal wave



Sound waves: **longitudinal waves**
→ travel parallel to direction of vibration of medium

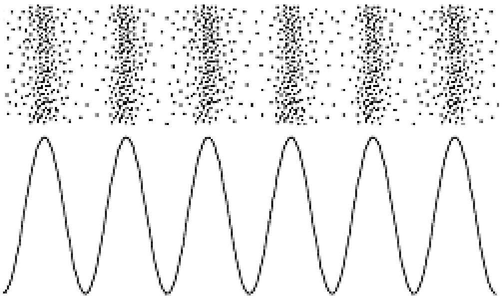
Sound is produced by vibrating sources placed in a **medium**
- Object vibrate in air → **displace the layers of air particles** around it
- Displacement of particles → sound waves **propagate**
- Direction of vibration of air molecules: **parallel** to direction in which wave travels

Sound waves propagate as a series of alternating:
1. **Compressions** (C)
2. **Rarefactions** (R)

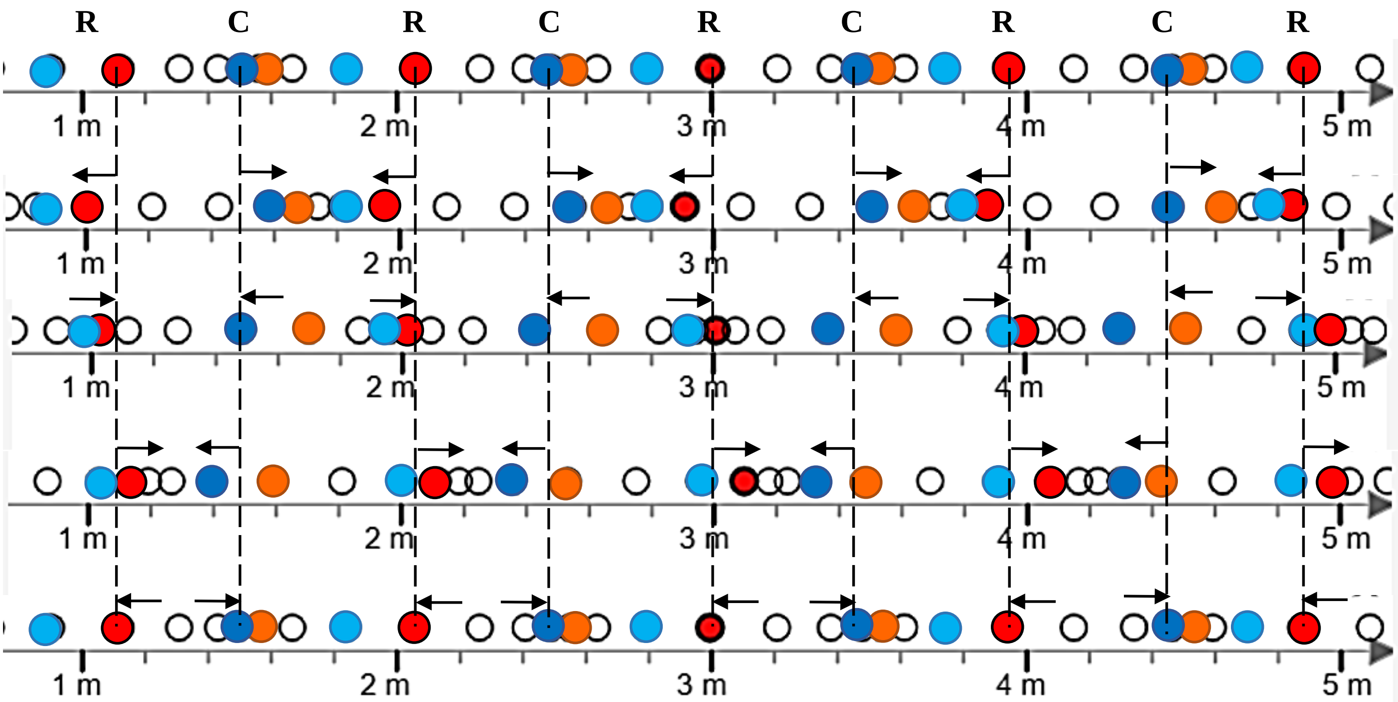
Tuning fork

Sound waves produced by a vibrating tuning fork

1. Layers of air are in undisturbed positions
2. Prongs push outward: a compression is produced (layer of air shifted outward)
   Prongs move inward: a rarefaction is produced (layer of air shifted inward)
3. A series of compressions and rarefactions are set up in the air



Movement of particles in the sound wave

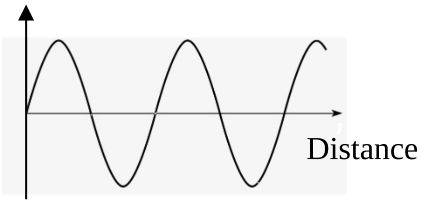
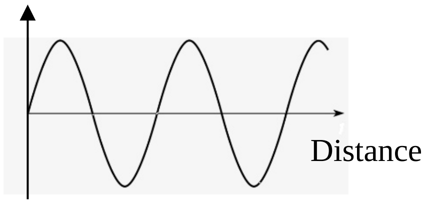
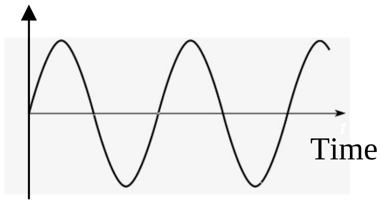


Direction of the wave: left → right

- Direction of C: move right and then left
- Direction of R: move left and then right

In half a period: C → R, R → C

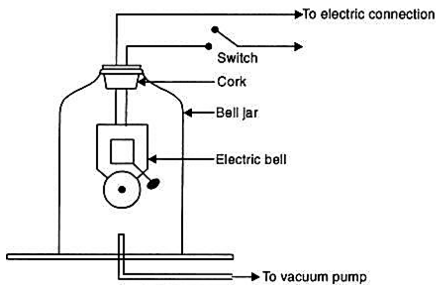
<u>Graphs of sound waves</u>
Graphs
1. **Pressure-distance graph**
2. **Displacement-distance graph**
3. **Displacement-time graph**

Pressure-distance graph	Displacement-distance graph	Displacement-time graph
		
Find pressure, wavelength	Find amplitude, wavelength	Find amplitude, period

15.2 Transmission of Sound
<u>Transmission of sound through vacuum</u> (experiment)
Sound waves: need a medium to propagate
→ cannot travel though vacuum

Bell jar experiment: electric bell is suspended in a sealed bell jar

Electric bell	Vacuum pump	Movement of air	Sound of bell
On	Off	No net movement	Can be heard
	On	Drawn out of bell jar	**Faint** and **disappear**
	Off	Flow back into bell jar	Can be heard again



<u>Medium of transmission</u>
Any medium containing particles that can vibrate will transmit sound
→ sound waves travel at **different speeds in different media**

Medium	Speed	Arrangement of particles
Gas	300 ~ 340 m/s	very loosely packed
Liquid	1500	less loosely packed, more closely packed
Solid	5000	very closely packed

15.3 Reflection of Sound

Formation of echo

Echo

The repetition of a sound due to the **reflection** of sound

Echo

- Formation: sound reflected off surfaces
  1. hard 3. smooth
  2. large 4. flat
- Laws of reflection apply to sound waves
  → loudest echo: angle of incidence = angle of reflection ($i = r$)

Reverberation	Echo
Reflected sound follows closely behind the direct sound, two **cannot be heard as separate sounds**	Reflected sound and direct sound **can be heard as separate sounds**

Uses of echo

Uses of echoes

1. Measure **large distances**
2. **Echolocation** (detect the location of objects)
3. **Sonar** (sound navigation and ranging): used by ships
   1) navigation at sea
   2) detect the position of other vessels

Formula:

$$\boldsymbol{v = \frac{2d}{t}}$$

v = speed of sound wave
d = distance of propagation of sound wave
t = time of propagation of sound wave

15.4 Ultrasound

Audible sounds

Range of audibility for humans: **20 ~ 20,000 Hz**

Limits of audibility: top & bottom values of the range of audibility

Sounds not in the human range of audibility

Sound	Frequency (Hz)	Human range of audibility	Example
1. **Infrasound**	< 20 (low)	Below lower limit	Vibrating ruler
2. **Ultrasound**	> 20000 (high)	Above upper limit	Dog whistle

Animal range of audibility

Higher than human	Lower than human
dog, **bat**, dolphin	elephant

Ultrasound

Ultrasound

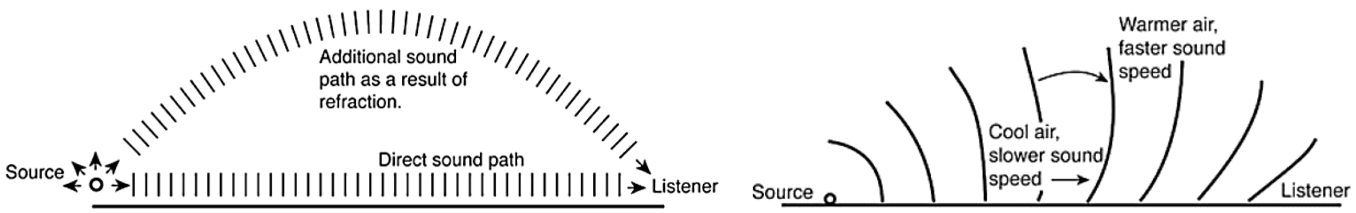
Sound with frequencies above the upper limit of the human range of audibility

Uses of ultrasound

Use	Explanation
1. **Quality control**	• Check for cracks in concrete slabs 1) Ultrasound emerges from a transmitter 2) Ultrasound **passes through concrete slab** & received by sensor 3) Compare ultrasound emitted & received → identify presence and location of defects • Inspect metal pipes + measure thickness of wooden boards
2. **Prenatal scanning**	• Obtain images of structures in the body • Examine development of foetuses ▪ Used instead of X-rays (less hazardous due to lower energy) ▪ Method 1) Send **ultrasound pulses into womb** via transmitter 2) Measure time taken for ultrasound pulses to be reflected → derive depth of reflecting surface within womb

Refraction of sound

If air above the earth is **warmer** than surface, sound will be **bent downward** towards the surface by refraction. Sound propagates in all directions from a point source. Normally, only that which is initially directed toward the listener can be heard, but refraction can bend sound downward. Normally, only the direct sound is received. But refraction can add some additional sound, effectively amplifying the sound.



15.5 Pitch and Loudness

Characteristic of sound to determine whether it is pleasant

1. **Pitch**
2. **Loudness**

Pitch

Pitch

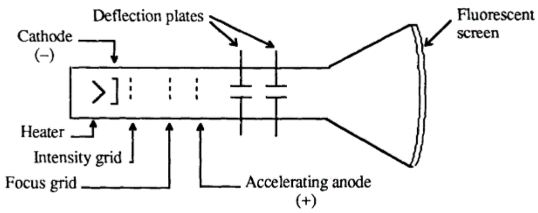
The higher the frequency, the higher the pitch

Tuning forks

Prongs set into vibration	λ	f	Pitch
Longer length	Long	Low	Low
Shorter length	Short	High	high

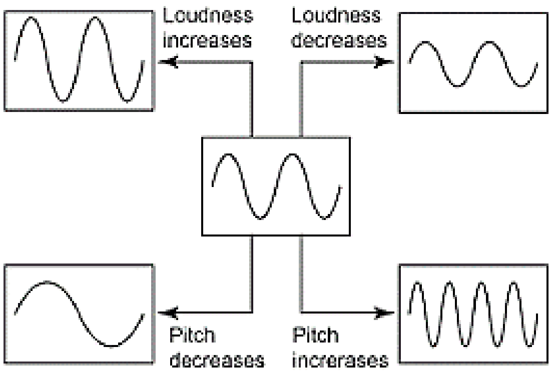
Cathode-ray oscilloscope (c.r.o.)

- Observe <u>waveforms</u> of sound waves
- Method
  1. Sound waves directed to microphone
  2. Microphone convert sound waves → electrical energy
  3. Waveform displayed on the screen: displacement-time graph



Effect on pitch of notes produced

Change applied	Pitch
1) Increase tension of vibrating string	higher
2) Shorten length of vibrating string	higher
3) Use thinner string	higher



<u>Loudness</u>

Loudness

The higher the amplitude, the louder the sound

<u>Timbre</u>

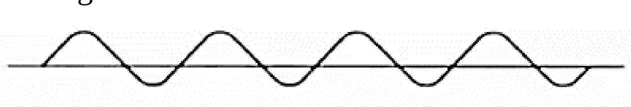
Timbre

Quality of a musical sound

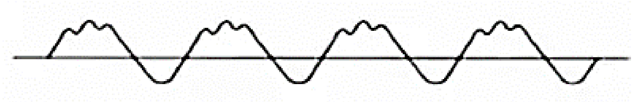
Different timbres

Sound	Explanation	Examples
1. **Pure tone**	Sound of a single frequency → represented by sinusoidal waveforms	(a) tuning forks (b) push-button telephones
2. **Complex sound**	Blending sound waves of different frequencies	(a) human voices (b) notes from musical instruments

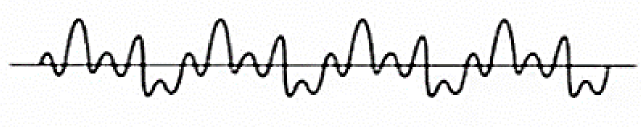
Tuning fork



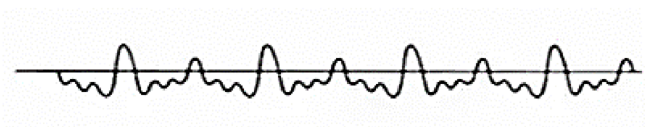
Flute



Violin



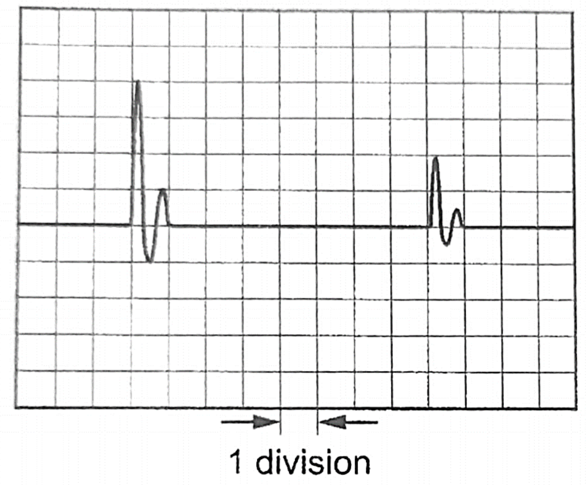
Human voice



Typical questions

Multiple choice questions

1. A man stands in front of a wall. There is a microphone next to him which is connected to a cathode-ray oscilloscope (c.r.o.). He claps his hands and hears the echo. (2018 P1 Q27)
   The diagram shows what is seen on the screen of the c.r.o.

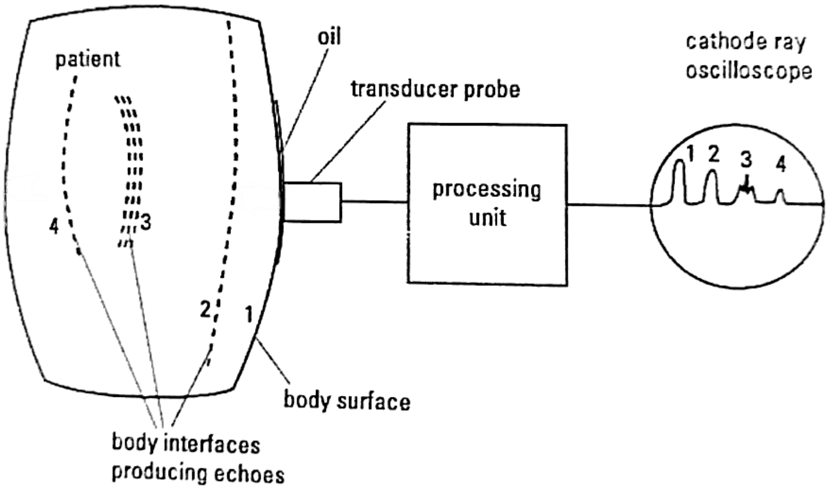
   

   Each division on the screen represents 10 ms and the speed of sound in air is 300 m/s.
   How far is the man from the wall?
   A 6.0 m
   B 12 m
   C 24 m
   D 1200 m

2. A metal plate is oscillating up and down continuously. In 4.0 ms, it moves from the bottom position to the top position.
   The oscillation of the plate causes sound waves to be generated in the surrounding air. Sound travels at a speed of 340 m/s. (2019 P1 Q24)
   What is the wavelength of these sound waves?
   A 0.37 m
   B 0.74 m
   C 1.4 m
   D 2.7 m

Structured questions

1. Ultrasound is a high-intensity sound wave that is commonly used as a non-invasive technique in hospitals. When an ultrasonic wave is incident on a boundary between the two media, some of the sound energy is reflected while some is refracted and transmitted through the boundary. In the diagram shown below, ultrasonic wave is used to measure the distances of various body interfaces. A probe sends out ultrasonic waves of frequency 1 MHz. The reflected sound energy is received by a processing unit and displayed on a cathode ray oscilloscope.



(a) Is ultrasonic wave a transverse wave or a longitudinal wave?
<u>longitudinal wave</u>

(b) An audible sound wave of frequency f_s = 500 Hz is being produced. Determine the ratio $\frac{f_u}{f_s}$ where f_u is the frequency of the ultrasonic waves.

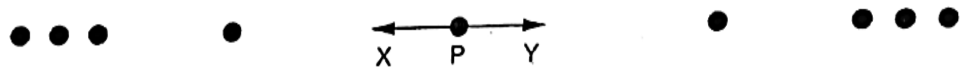
$$\frac{f_u}{f_s} = \frac{1 \times 10^6\ Hz}{5 \times 10^2\ Hz} = 2 \times 10^3$$

(c) Explain why there is a decrease in height of the wave pulse on the oscilloscope screen.
<u>When ultrasonic waves are incident at the interface between the two media, some are reflected while some are transmitted (refracted out). There is a loss in the energy received. Hence, the wave pulse on the c.r.o. decreases in height.</u>

(d) Explain why there are multiple reflections at interface 3.
<u>There are several layers of tissues at interface 3 which reflect waves at different times, resulting in multiple reflections.</u>

2. Give an example of an event which shows that light travels faster than sound.
<u>During a thunderstorm, lightning (light) and thunder (sound) are produced at the same time. However, lightning is seen instantly while thunder is heard a few seconds after the lightning. This shows that light travels faster than sound.</u>

3. A longitudinal wave passes through a medium. The particles in the medium vibrate from side to side. The figure below represents the particles at time $t = 0$.



Particle P vibrates from the position shown to X, then to Y and then back to the position shown.

(a) Describe what happens to the distance between adjacent particles, as the wave moves through the medium.

The distance between adjacent particles will alternate from being shorter to being longer.

(b) On the figure above, indicate two particles separated by a distance of one wavelength by labelling them both with a letter Q.

(c) The distance between X and Y is 6.0 mm.

Time $t = 2.0$ s is the first time that all the particles are back in the positions shown in the figure above.

The wavelength of the wave is 40 cm.

(i) Determine the amplitude of the wave.

$$A = \frac{6.0\text{ mm}}{2} = 3.0\text{ mm}$$

(ii) Calculate the frequency of the wave.

$T = 2.0$ s

$$f = \frac{1}{2.0} = 0.5\text{ Hz}$$

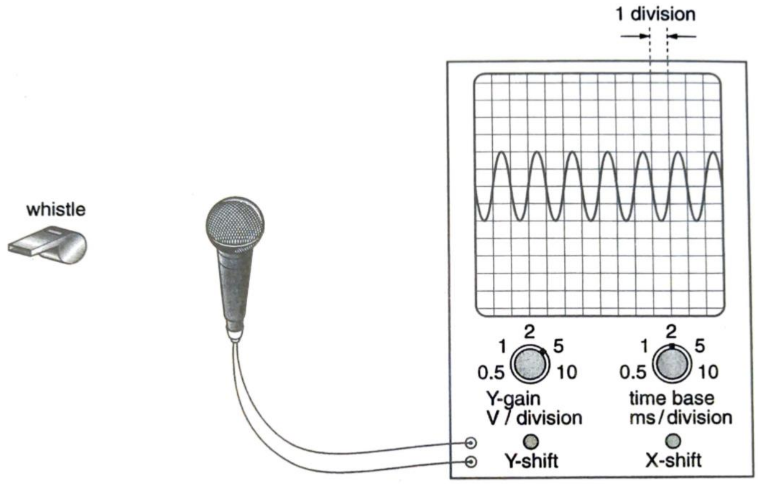
(iii) Calculate the speed of the wave.

$$\begin{aligned} v &= f\lambda \\ &= 0.5 \times 0.40 \\ &= 0.20\text{ m/s} \end{aligned}$$

(iv) In the space above the figure above, draw the positions of the particles for $t = 3.0$ s.

4. A teacher demonstrates the sound produced from a whistle by connecting a microphone to a cathode-ray oscilloscope (c.r.o.) as shown in the figure below. Four controls on the c.r.o. are shown.

(2013 P2A Q12a, b, c Either)



(a) Describe how the sound is transmitted from the whistle to the microphone. [3]

When the whistle is blown, the whistle vibrates. This causes the air molecules around the whistle to move back and forth about a fixed position, starting a sound wave (longitudinal wave). These layers of air moving back and forth pass on their energy from molecule to molecule in a longitudinal wave, spreading in all directions from the whistle and some of this energy reaches and is picked up by the microphone.

(b) The time base is set at 2ms / division.

Determine the frequency of the sound emitted by the whistle. [2]

T = 2 divisions = 4 ms

$$f = \frac{1}{T} = \frac{1}{0.004} = 250 \text{ Hz}$$

(c) The whistle is replaced with another of lower pitch. The controls on the c.r.o. are unaltered.

Describe and explain what happened to the trace on the c.r.o. screen. [2]

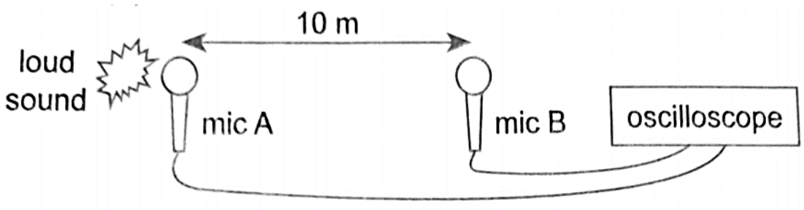
A lower pitch means that a lower frequency sound is produced. As the frequency is lowered, less sound waves are produced in the same period of time. As a result, less waves are seen on the c.r.o. screen.

5. (a) Light travels faster in air than in glass, but sound travels faster in glass than in air.

Using ideas about molecules, explain why sound travels faster in glass than air. [2]

Sound travels by transferring the energy of vibrations from particle to particle. As glass is a solid, where the particles are closely packed together, the energy can be transferred much faster than in air, where the molecules are far apart, with large spaces in between.

(b) Describe a direct method for the measurement of the speed of sound in air, making clear how the result is calculated. You may draw a diagram, if you wish. [3]



1 Place two microphones, mic A and mic B, a distance of 10 m apart.

2 Both microphones are connected to an oscilloscope, with time base switched on.

3 Use a clapper, or device to make a loud, sharp sound. This clapper should be placed directly behind mic A, away from mic B.

4 Note the time interval, t for the sound to be detected between mic A and B.

5 The speed of the sound can be calculated by using the formula $s = \frac{d}{t} = \frac{10}{t}$.

6 For increased accuracy, repeat experiment with clapper behind mic A. Take the average of the two time intervals obtained, and calculate the speed of sound using the same formula.