WAVES

A wave is a disturbance through a medium which transfers energy from one point to another without causing any permanent displacement of medium itself.

Waves can be seen when;
- A stone is thrown into water.
- Oscillating a spring.
- A rope is fixed at one end and then jerked at another end.

CLASSIFICATION OF WAVES:
There are two classes of waves namely;
- Mechanical waves.
- Electromagnetic waves.

MECHANICAL WAVES:
These are waves that require a material medium to transfer energy from one point to another.
These waves are produced by vibrating bodies.
These waves can't travel through a vacuum.
They normally have a low velocity.
Examples of mechanical waves include;
- Sound waves.
- Water waves.
- Waves in stretched strings.

ELECTROMAGNETIC WAVES:
These are waves that do not require a material medium to transfer energy from one point to another.
They are produced by varying electric and magnetic fields.
They can travel through a vacuum.
All electromagnetic waves travel at a speed of light $(\mathbf{3\times10^{8}}\boldsymbol{ms^{-1}})$
Examples of electromagnetic waves include;
- Gamma rays
- X-rays
- Radio waves
- Infrared
- Visible light
- Ultra-violet light (UV), etc

Differences between mechanical and electromagnetic waves.

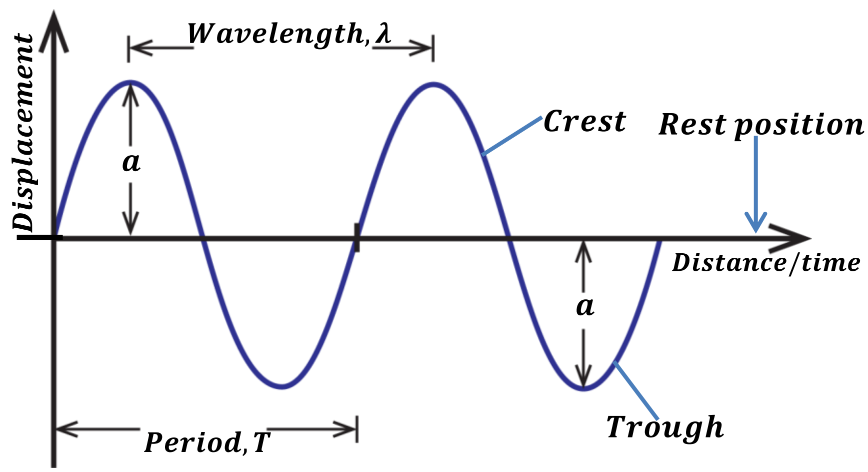
Mechanical waves	Electromagnetic waves
▪ They require a material medium for their transmission. ▪ They can't travel through a vacuum. ▪ They are produced by vibrating bodies ▪ They are slower.	▪ Don't require a material medium for their transmission. ▪ They can travel through a vacuum. ▪ They are produced by varying electric and magnetic fields. ▪ They are faster since they travel at a speed of light.

REPRESENTATION OF A WAVE:

Waves are normally represented in form of oscillations or cycles.

Definition:

An **oscillation** is a complete to and fro movement of a wave.



Rest position:

This is the undisturbed position of a wave.

Amplitude, a:

This is the maximum displacement of a wave particle from the rest position.

Crest:

This is the maximum displacement of a wave above the rest position.

Trough:

This is the maximum displacement of a wave below the rest position.

Wavelength, λ:

This is the distance between two successive crests or troughs of a wave.

OR

This is distance covered in one complete oscillation/cycle.

Wavelength is measured in metres.

Period, T:
This the time taken to complete one oscillation.

$$T = \frac{1}{f}$$

It is measure in seconds.

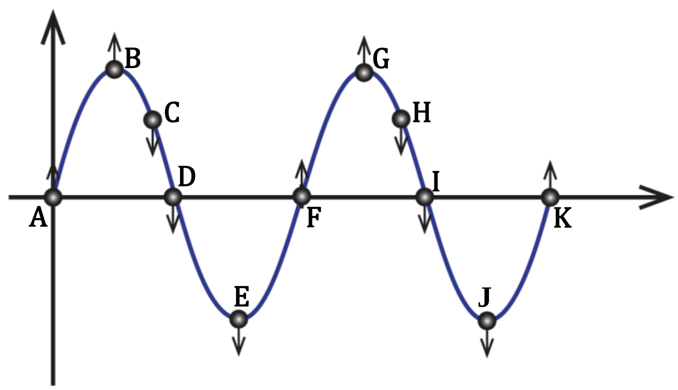
Frequency, f:
This is the number of oscillations per second.

$$f = \frac{1}{T}$$

It is measured in Hertz (**Hz**)

Wave form:
This is the shape of the wave.

Wave phase:
This is the timing of one oscillation of a wave in comparison with another oscillation of another wave.
Wave particles are in phase if they are exactly at the same point at the same time at same distance from rest position and are moving in the same direction.



Particles A and F and K are in phase.
Particles B and G are in phase.
Particles C and F are not in phase.
Particles A and D are not in phase.

VELOCITY OF A WAVE

This is the distance travelled by a wave per unit time.

$$velocity = \frac{distance}{time}$$

Since in one complete cycle/oscillation, a wave travels a distance equal to wavelength, λ in time equal to period, **T**.

$$velocity = \frac{wavelength}{period}$$

$$V = \frac{\lambda}{T} \quad But\ T = \frac{1}{f}$$

$$Therefore,\ \boxed{V = \lambda f}$$

NOTE:

If the number of oscillations is not known then,

$$Period,\ \boldsymbol{T} = \frac{\boldsymbol{t}}{\boldsymbol{n}}$$

Where **t** – time taken for $\boldsymbol{n}$ oscillations.

Examples:

1. Calculate the frequency of the wave if its velocity and wave are 5ms^{-1} and 0.5m respectively.

$$\boldsymbol{V = f\lambda}$$
$$\boldsymbol{5 = f \times 0.5}$$
$$\boldsymbol{f = \frac{5}{0.5}}$$
$$\boldsymbol{f = 10m}$$

2. A vibrator of frequency 50Hz produces circular waves. If the distance between the two successive crests is 5cm. find the speed of the waves.

$$\boldsymbol{\lambda = \frac{5}{100} = 0.05m}$$
$$\boldsymbol{V = f\lambda}$$
$$\boldsymbol{V = 50 \times 0.05}$$
$$\boldsymbol{V = 2.5ms^{-1}}$$

3. A vibrator with a frequency of 20Hz vibrates for a distance of 25cm in 5 seconds. Find
   (i) The speed of the wave produced
   (ii) Wave length of the wave produced

(i)

$$\boldsymbol{d = \frac{25}{100} = 0.25m, \qquad t = 5s}$$
$$\boldsymbol{V = \frac{d}{t}}$$
$$\boldsymbol{V = \frac{0.25}{5}}$$
$$\boldsymbol{V = 0.05ms^{-1}}$$

(ii)

$$\boldsymbol{V = f\lambda}$$
$$\boldsymbol{0.05 = 20\lambda}$$
$$\boldsymbol{\lambda = \frac{0.05}{20}}$$
$$\boldsymbol{\lambda = 0.0025m}$$

4. A vibrator produces waves which travel a distance of 35cm in 2 seconds. If the distance between two successive crests is 5cm. find
   (i) The velocity of the waves
   (ii) The frequency of the waves

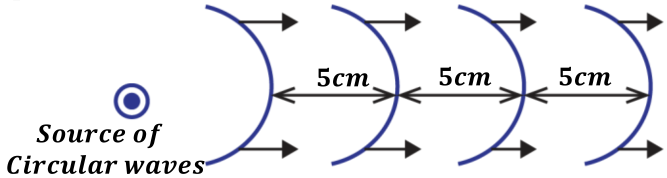
(i)

$$\boldsymbol{d = \frac{35}{100} = 0.35m \ \ t = 2s \ \ \lambda = \frac{5}{100} = 0.05m}$$
$$\boldsymbol{V = \frac{d}{t}}$$
$$\boldsymbol{V = \frac{0.35}{2}}$$
$$\boldsymbol{V = 0.175ms^{-1}}$$

(ii)

$$\boldsymbol{V = f\lambda}$$
$$\boldsymbol{0.175 = f \times 0.05}$$
$$\boldsymbol{f = \frac{0.175}{0.05}}$$
$$\boldsymbol{f = 3.5Hz}$$

5. The figure below shows circular waves produced by a vibrator of frequency 32Hz. Calculate their speed.



$$\textbf{wavelength} = \textbf{distance in one cycle} \quad \textbf{so } \lambda = 5cm = \frac{5}{100} = 0.05m$$

$$V = f\lambda$$

$$V = 32 \times 0.05 = 1.6ms^{-1}$$

6. A radio station produces radio waves of wavelength 10m.
   (i) Calculate the frequency of the wave.
   (ii) Period of the wave
   (iii) Number of oscillations in 10s.
   (iv) State any assumption taken.

(i)

$$V = f\lambda$$
$$3 \times 10^8 = f \times 10$$
$$f = \frac{3 \times 10^8}{10}$$
$$f = 3 \times 10^7 Hz$$

(ii)

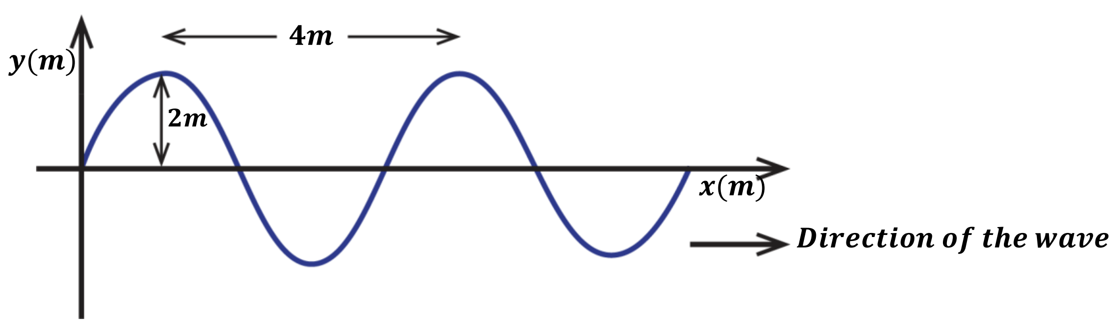
$$T = \frac{1}{f}$$
$$T = \frac{1}{3 \times 10^7}$$
$$T = 3.3 \times 10^{-8} s$$

(iii)

$$T = \frac{t}{n}$$
$$3.3 \times 10^{-8} = \frac{10}{n}$$
$$n = \frac{10}{3.3 \times 10^{-8}}$$
$$n = 3.03 \times 10^8 \textit{oscillations}.$$

(iv) Radio waves are electromagnetic waves so they travel at a speed of light $(3 \times 10^8 ms^{-1})$

7. The diagram below represents a wave travelling from left to right with a velocity of $300ms^{-1}$



Find
   (i) Amplitude in metres.
   (ii) Frequency of the wave.

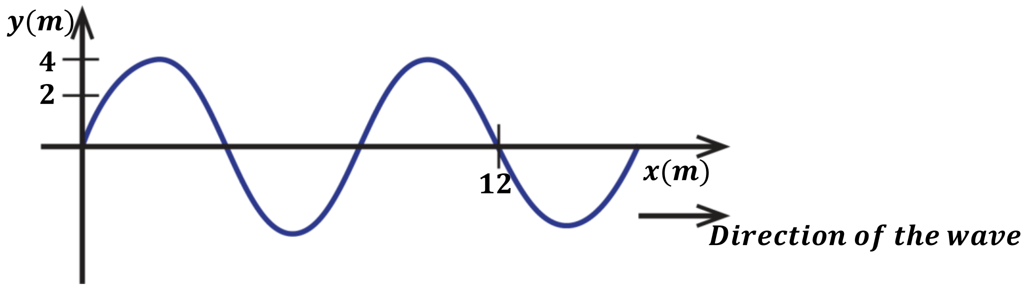
(i)

$$a = 2cm = \frac{2}{100} = 0.02m$$

(ii)

$$V = 300ms^{-1},\ \lambda = 4m$$
$$V = f\lambda$$
$$300 = f \times 4$$
$$f = \frac{300}{4}$$
$$f = 75Hz$$

8. The wave below has a velocity of $320ms^{-1}$.



Find;

(i) The amplitude.

(ii) Wavelength.

(iii) Frequency of the wave

(i) **Amplitude,** $a = 4m$

(ii)

$$\lambda = distance\ by\ one\ oscillation.$$
$$\frac{3}{2}\ oscillations = 12m$$
$$1\ oscillation = \frac{12}{3/2} = 8m$$
$$therefore, \quad \lambda = 8m$$

(iii)

$$V = 320ms^{-1},\ \lambda = 8m$$
$$V = f\lambda$$
$$320 = f \times 8$$
$$f = \frac{320}{8}$$
$$f = 40Hz$$

<u>NOTE</u>:

If the distance, d between n successive crests or troughs then;

Wavelength, $\lambda = \frac{distance, d}{n-1}$

$$\lambda = \frac{d}{n-1}$$

9. If the distance between 9 successive crests is 48cm.find the wavelength of the wave.

$$d = 48cm = \frac{48}{100} = 0.48m, \qquad n = 9$$
$$\lambda = \frac{d}{n-1}$$
$$\lambda = \frac{0.48}{9-1}$$
$$\lambda = 0.06$$

10. Water waves are produced at a frequency of 50Hz and the distance between 10 successive troughs is 18cm. Calculate the velocity of the waves.

$$d = 18cm = \frac{18}{100} = 0.18m,$$
$$n = 10$$
$$\lambda = \frac{d}{n-1}$$
$$\lambda = \frac{0.18}{10-1}$$
$$\lambda = 0.02m$$

$$V = f\lambda$$
$$V = 50 \times 0.02 = 1ms^{-1}$$

WAVE MOTION

When a wave is setup in a medium, the particles of the medium vibrate from their rest position while carrying energy. The energy is passed from one particle to another until when the final destination is reached.

Types of waves according to their motion:

There are two types of waves which include:

- Progressive waves.
- Stationary/standing waves.

PROGRESSIVE WAVES

These are waves which carry energy away from the source and spread out continuously.
There are two forms of progressive waves namely;

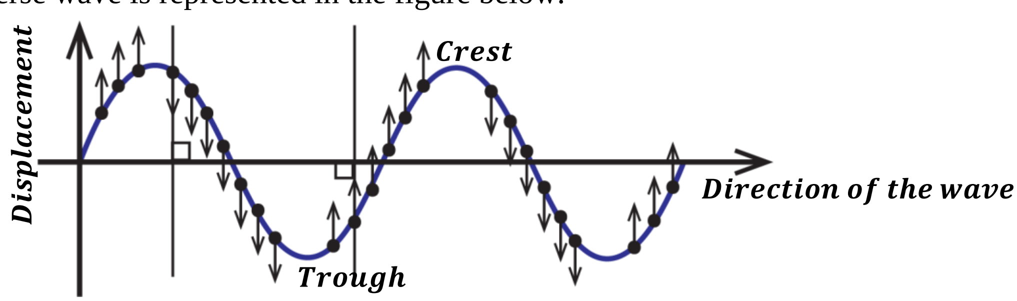
- Transverse waves.
- Longitudinal waves.

TRANSVERSE WAVES

These are waves in which particles of a medium vibrate perpendicular to the direction of propagation of a wave.
They form crest and troughs.
Examples include;

- ✓ Water waves.
- ✓ Waves from vibrating strings.
- ✓ Electromagnetic waves.

A transverse wave is represented in the figure below.



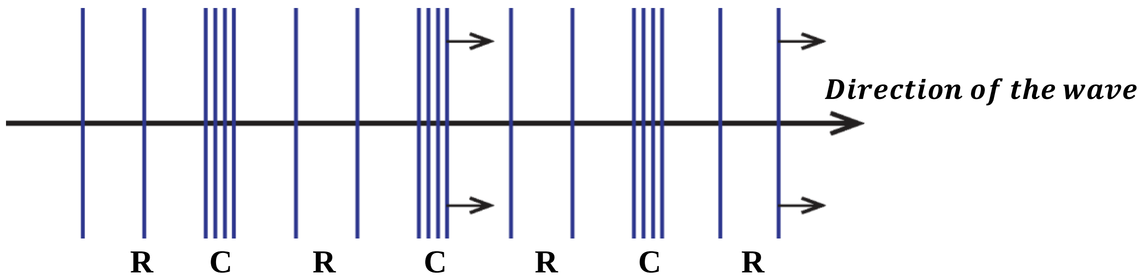
LONGITUDINAL WAVES:
These are waves in which particles of a medium vibrate parallel to the direction of propagation of a wave.

OR

These are waves in which particles of a medium vibrate in the same direction as the direction of propagation of a wave.

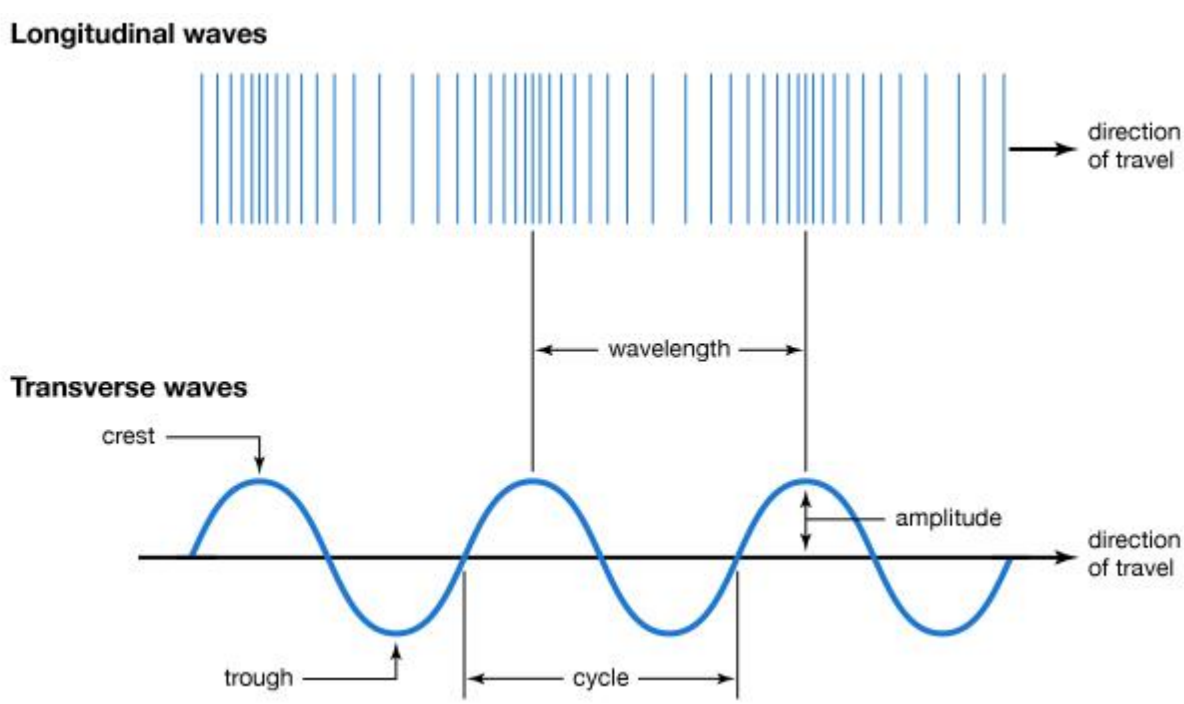
Longitudinal waves form compressions and rare factions.
Examples include;

- ✓ Sound waves
- ✓ Waves from compressed or stretched strings.



Where $\boldsymbol{C} - Compressions$
$\boldsymbol{R} - Rare\ factions$

Compression: This is a region where particles of a wave are close together.
Rare faction: This is a region where particles of a wave are far apart from each other.



NOTE:

Wavelength of a longitudinal wave is the distance between two successive compressions or rarefactions of a wave.

Example: The distance between two successive compressions is 20m. Find the speed of a wave if its frequency is 16Hz.

$$\lambda = 20m, \qquad f = 16Hz$$
$$V = f\lambda$$
$$V = 16 \times 20$$
$$V = 320ms^{-1}$$

DIFFERENCES BETWEEN LONGITUDINAL AND TRANSVERSE WAVES.

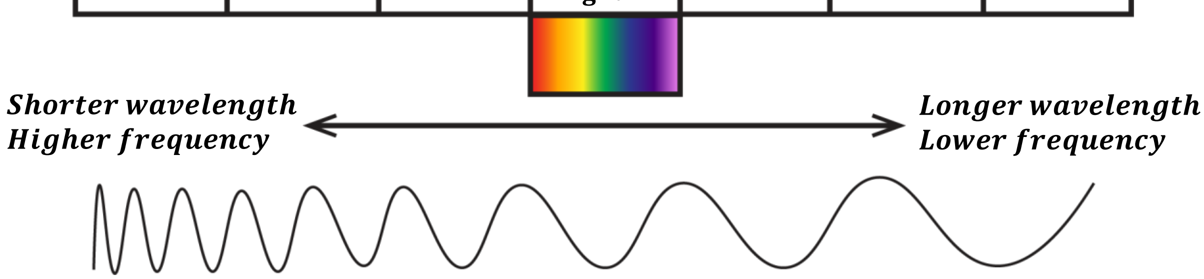
Transverse waves	Longitudinal waves
▪ Particles vibrate perpendicular to direction of propagation of a wave. ▪ Forms crests and troughs. ▪ Distance between successive crests or troughs is the wavelength.	▪ Particles vibrate parallel to direction of propagation of a wave. ▪ Forms compressions and rare factions. ▪ Distance between successive compressions or rare factions is wavelength.

Question; State differences between light waves (transverse) and sound waves (longitudinal)

ELECTROMAGNETIC SPECTRUM/BAND

Electromagnetic waves are categorized in terms of their wavelength.

Gamma ray	X – ray	Ultraviolet	Visible light	Infrared	Microwave	Radiowave



Gamma rays:

- They have the shortest wavelength.
- They have the highest frequency.
- They have the greatest penetrating power.
- They destroy body tissues if exposed for a long time.
- They harden rubber solutions.
- They are emitted from radioactive substances.

X-rays:
- They have a longer wavelength than the gamma rays.
- They are produced by fast moving electrons (cathode rays) on hitting the metal target in the X-ray tube.
- They destroy body tissues if exposed for a long time.
- They are used in industries to detect leakages in pipes and in hospitals to detect fractures of bones.

Ultra violet light (UV):
- These are radiations got from very hot bodies (e.g. sun) and also through gases (e.g. mercury vapour)
- It causes sun burn.
- Causes blindness if there is too much exposure.
- It causes electrons to give off electrons by the process called photo-electric emission.
- Used to detect forged bank notes.

Visible light:
- This is the light that enables us to see.
- It's got from lamps, flames etc.
- It determines the colour and appearance of an object.
- It makes objects appear bent due to refraction.
- Used in photosynthesis.

Infrared:
- All objects emit infrared radiations.
- They cause the body temperature to rise because most of the heat in light is carried by infrared. Infrared enables us to get vitamin D.
- Used in production of night vision cameras.
- Used in T.V remotes.

Micro-waves:
- They are used to cook food in micro-ovens.
- They transmit information in radar systems.

Radio waves:
- They are produced when electrons are accelerated in an aerial.
- They have the longest wavelength and shortest frequency.
- Used in broadcasting radio and T.V signals.

Properties of electromagnetic waves:
- They are transverse waves.
- They can travel through a vacuum.
- They travel at a speed of light $(3 \times 10^8)ms^{-1}$
- They carry energy.
- They do not need a material medium for their propagation.
- They can be reflected, refracted and diffracted.

Similarities between mechanical waves and electromagnetic waves:

- Both carry energy from one place to another.
- Both are subject to interference.
- Both can be reflected, refracted and diffracted

WAVE FRONT

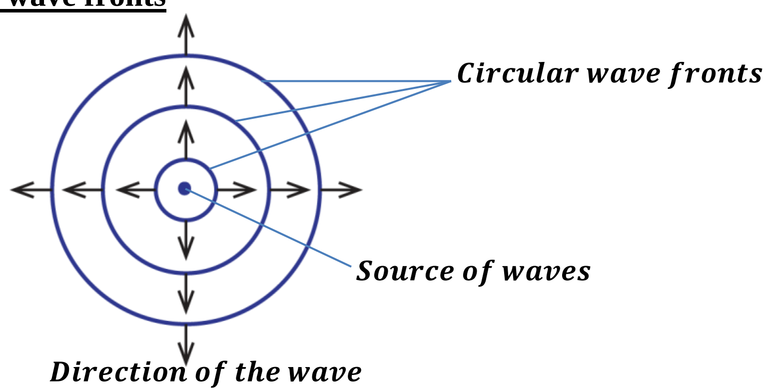
This is the surface of a wave in which every particle is at the same distance from the source of the wave.

OR

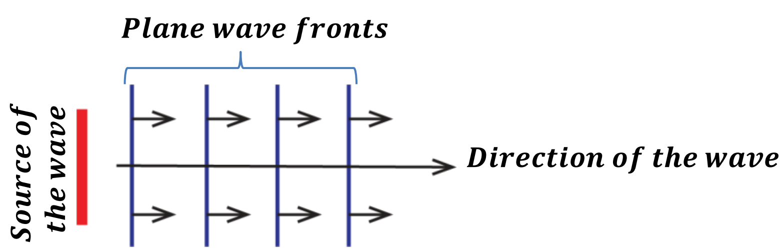
This is a line that joins particles of a wave that are in phase.

There are two types of wave fronts namely;

Circular wave fronts

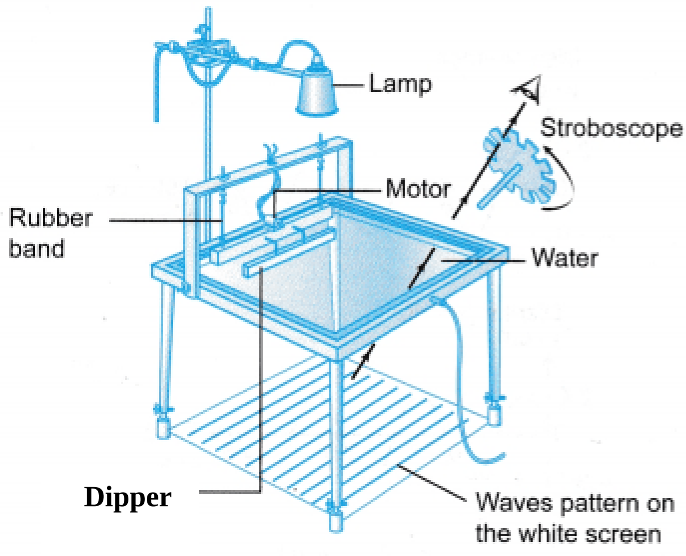


Plane/straight wave fronts



NB: The distance between successive wave fronts is equal to wavelength.

RIPPLE TANK



A ripple tank is an instrument used to study the properties of water waves.
It has a transparent glass trough containing water.
The images of the waves are formed on the white screen placed below it.
The ripple tank is illuminated with a source of light (lamp) in order to observe the wave patterns clearly.
The waves are produced by means of a dipper when it hits the surface of the water.
The dipper is vibrated by an electric motor which is connected to it.
The stroboscope helps to make the waves stationary so they can be studied very well.

How to produce wave fronts:

- Circular wave fronts are produced when a spherical dipper is vibrated on the surface of water by an electric motor.
- Plane wave fronts are produced when a straight rod dipper is vibrated on the surface of water by an electric motor.

PROPERTIES OF WAVES

Waves undergo the following properties;

- Reflection.
- Refraction.
- Diffraction.
- Interference.

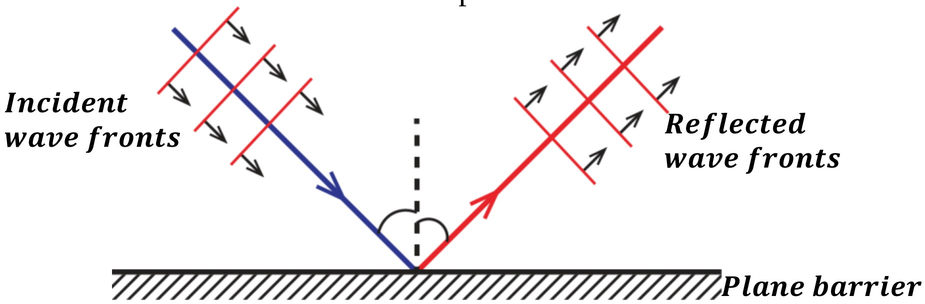
REFLECTION OF WAVES.

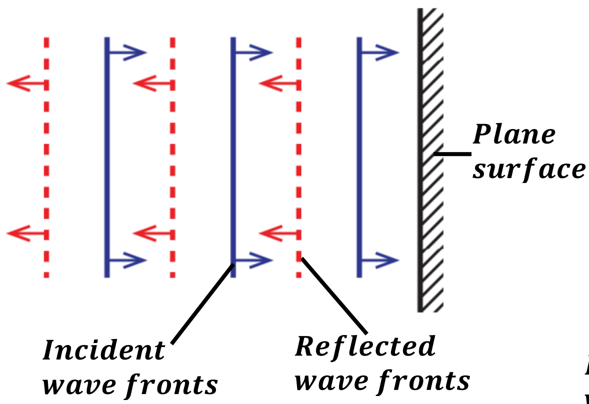
This is the bouncing off of waves as they meet a barrier.
The shape of the reflected waves depends on the shape of the barrier.

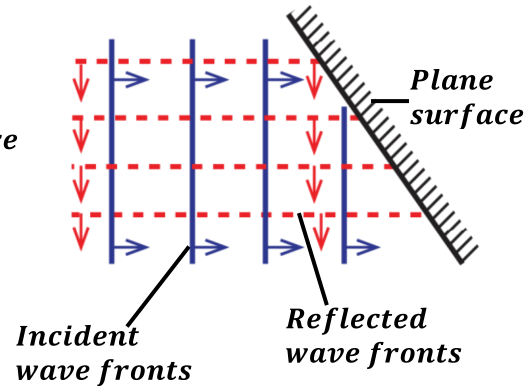
Reflection of plane waves:

(a) On a plane surface.

Plane wave fronts are reflected as plane wave fronts.

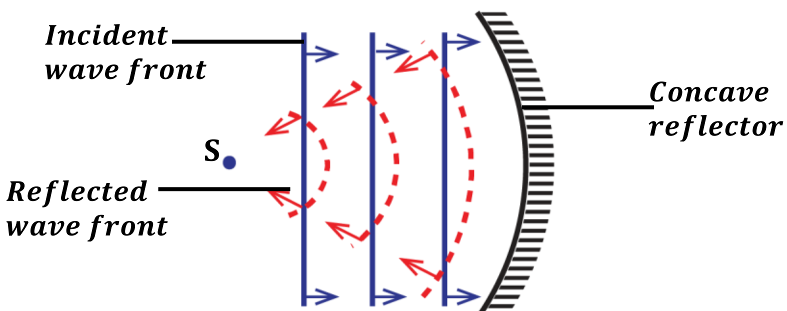




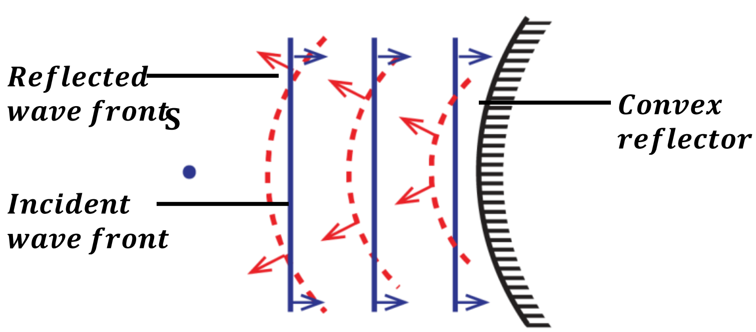


(b) On curved surfaces.

Plane wave fronts incident on a concave reflector are reflected as concave wave fronts.



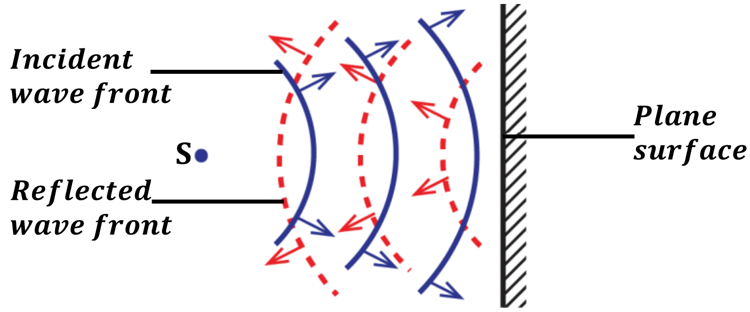
Plane wave fronts incident on a convex reflector are reflected as convex wave fronts.



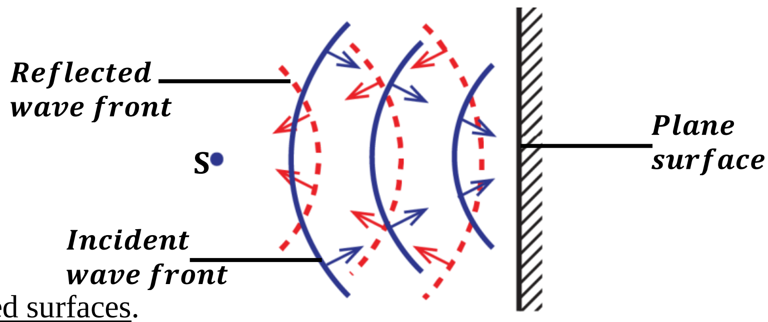
Reflection of circular waves;

(a) On plane surfaces.

Concave wave fronts incident on a plane surface are reflected as convex wave fronts.

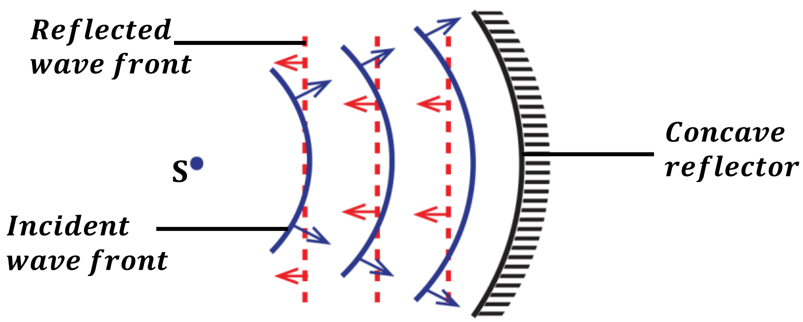


Convex wave fronts incident on a plane surface are reflected as concave wave fronts.

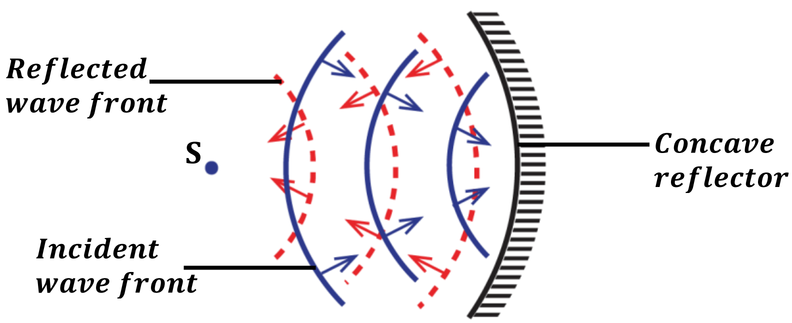


(b) On curved surfaces.

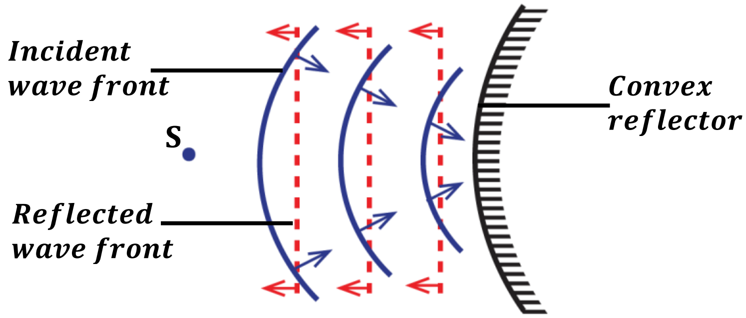
(i) ***Concave reflector***: Concave circular wave fronts incident on a concave reflector are reflected as plane wave fronts



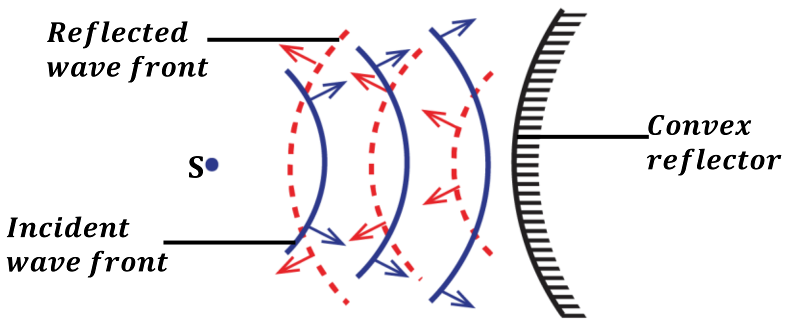
Convex circular wave fronts incident on a concave reflector are reflected as concave wave fronts.



(ii) **Convex reflector:** Convex circular wave fronts incident on a convex reflector are reflected as plane wave fronts.



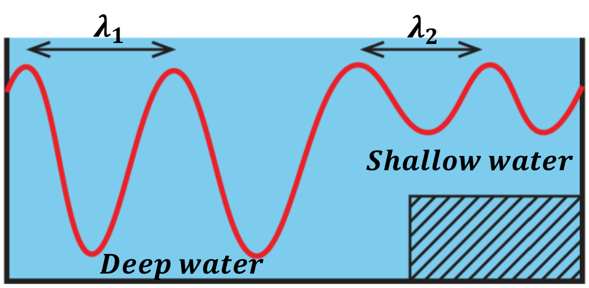
Concave circular wave fronts incident on a convex reflector are reflected as convex circular wave fronts.



<u>REFRACTION OF WAVES</u>:

This is the change in direction of a wave as it moves from one medium to another of different depth.

Water waves can be refracted in a ripple tank by placing a sheet of glass in water to make it shallow.



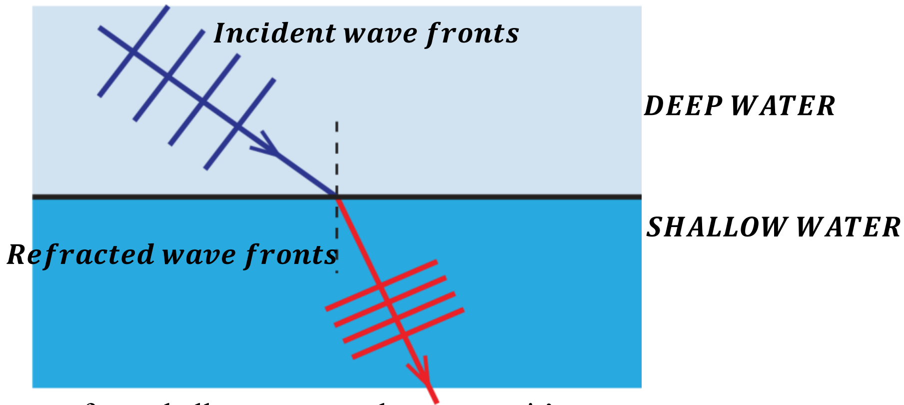
When a wave is refracted, there is change in wavelength and speed but frequency remains constant.

<u>NOTE</u>:

When waves move from deep water to shallow water, it's;

- Wavelength decreases
- Speed decreases in the shallow water.
- Frequency remains constant
- Waves bend towards the normal.

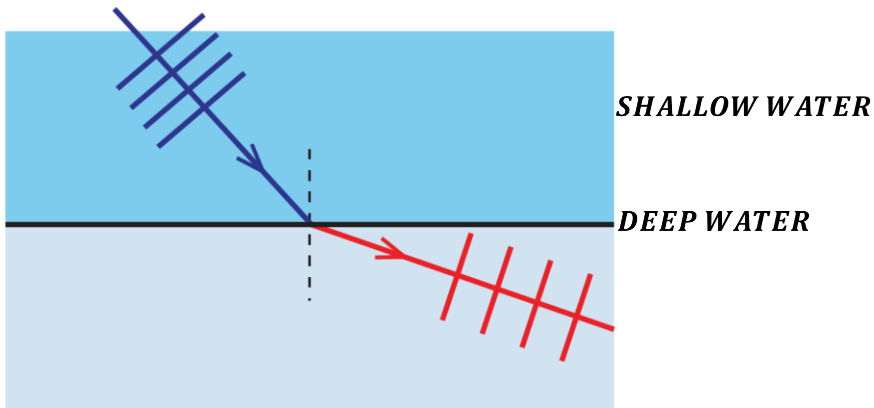
Wave fronts become close to one another in shallow water than in deep water as shown in the diagram below.



When waves move from shallow water to deep water, it's;

- Wavelength increases.
- Speed increases in the deep water.
- Frequency remains constant
- Waves bend away from the normal.

Wave fronts become further apart from one another in deep water than in shallow water as shown in the diagram below.

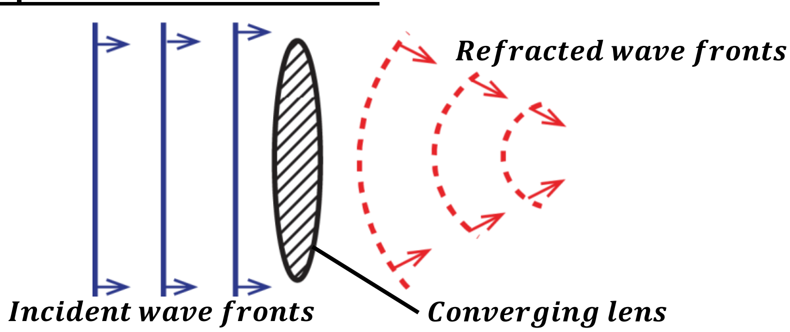


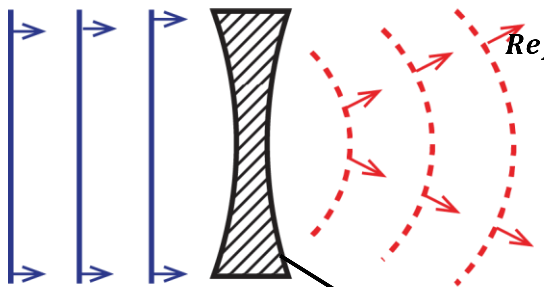
$$\textit{Refractive index of water} = \frac{\textit{velocity in deep water } (V_1)}{\textit{velocity in shallow water } (V_2)}$$

$$\cap = \frac{\lambda_1 f}{\lambda_2 f}$$

$$\cap = \frac{\lambda_1}{\lambda_2}$$

Refraction of plane wave fronts at lenses:



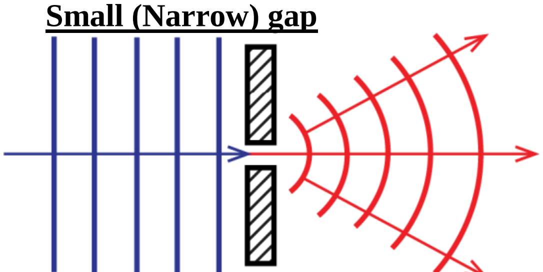


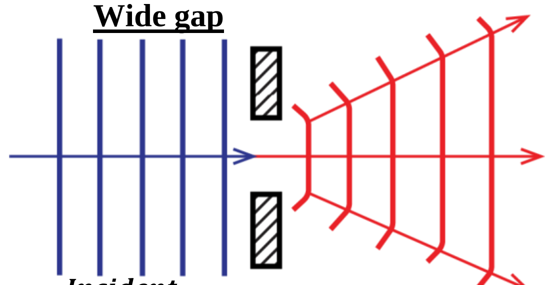
DIFFRACTION OF WAVES:

This is the spreading of waves as they as they pass through holes, around corners or edges of an obstacle.

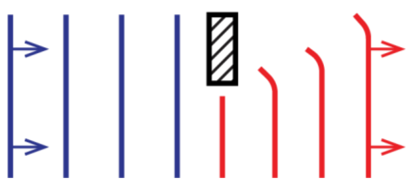
In a ripple tank, diffraction can be made by placing two barriers with a gap between them.

- If the gap between two barriers is small (narrow), then plane wave fronts with a circular shape and then spread out.
- If the gap between the two barriers is wide, then plane wave fronts emerge when slightly bent at the edges.





At a corner or edge of an obstacle:



EFFECT OF LONG AND SHORT WAVELENGTH:

- Waves are greatly diffracted (spread out more) when the wavelength is longer and they are less diffracted (spread out less) when the wavelength is small.

QUESTION 1: Explain why sound can be heard in corners yet light can't be seen in corners (corners are always dark)

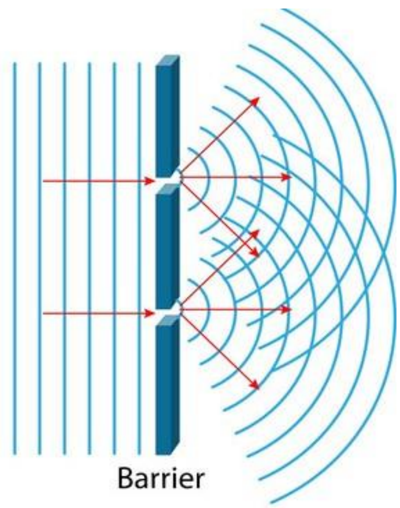
This is because sound waves are more diffracted than light waves since they have a longer wavelength than the light waves. Therefore, light can't spread out to all the corners of the room since it has a shorter wavelength hence the darkness.

- Waves of short wavelength are easily scattered than waves of long wavelength i.e. blue light are more scattered when it strikes different molecules than red light.

QUESTION 2: Explain why the sky appears red during sun-rise or sun-set.
When rising/setting of the sun, light rays travel a longer distance in the earth's atmosphere to reach our eyes. So blue light scatters away easily and is removed before reaching our eyes. Therefore, only light of longer wavelength reach straight to our eyes and that light is red.

QUESTION 3: Explain why the sky appears blue during day-time.
During day, the sun is overhead the atmosphere so light travels a shorter distance to reach our eyes. The blue light which has a short wavelength is easily scattered throughout all directions in the atmosphere hence the blue appearance of the sky.

When two or more gaps are in a barrier, the waves will be diffracted and interference occurs.



INTERFERENCE OF WAVES:
This is the superposition of two identical waves travelling in the same direction to form a single wave with lower or greater amplitude.
OR
This is the overlapping of two identical waves travelling in the same direction to form a single wave with lower or greater amplitude.

Conditions for interference to occur:
- The two waves should have the same frequency.
- The two waves should have the same speed.
- The two waves should have the same wave length.
- The two waves should have the same amplitude.
- The two waves should be moving in the same direction

Types of interference:

There are two types of interference namely;

- Constructive interference.
- Destructive interference.

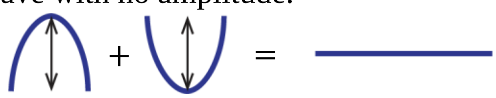
CONSTRUCTIVE INTERFERENCE

This is the type of interference which occurs when a crest of one wave meets a crest of another wave or a trough of one wave meets a trough of another wave forming a single wave with greater amplitude.

For light: Constructive interference would give increased brightness.
For sound: Constructive interference would give increased loudness.

DESTRUCTIVE INTERFERENCE

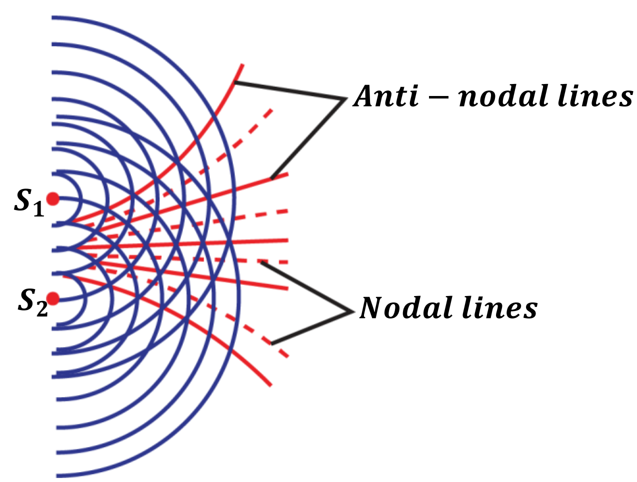
This is the type of interference which occurs when a crest of one wave meets a trough of another wave forming a single wave with no amplitude.



For light: Destructive interference gives darkness or reduced brightness.
For sound: Destructive interference gives reduced loudness or no sound at all.

NOTE:

When two sources of waves are placed close to each other, both destructive and constructive interference occur.



Anti-nodal lines: These are lines joining points of constructive interference.

Nodal lines: These are lines joining points of destructive interference.

EXERCISE:

1. The wave length of a radio wave is 10m. Given that the speed of the radio wave is $3 \times 10^8 ms^{-1}$. Find the frequency and period of the wave
   Ans: $(3.0 \times 10^7 Hz, 3.33 \times 10^{-8} s)$
2. The frequency of a radio wave is 6.0 x 107Hz. Given that the speed of the radio wave is $3 \times 10^8 ms^{-1}$. Find the wave length of the wave.
   Ans: $(5m)$
3. Water waves travel a distance of 36cm in 6 seconds and the separation between two successive troughs is 3.0cm. Calculate the velocity and the frequency of the waves
   Ans: $(6 \times 10^{-2} ms^{-1}, 2Hz)$
4. A source produces waves which travel a distance of 140cm in 0.08 seconds and the separation between two successive crests is 20cm. Calculate the velocity and the frequency of the waves.
   Ans: $(17.5 ms^{-1}, 87.5 Hz)$
5. Water waves of frequency of 6Hz travel a distance of 24m in 10 seconds. Calculate the velocity and wave length of the waves
   Ans: $(2.4 ms^{-1}, 0.4m)$
6. A vibrator in a ripple tank vibrates at 500Hz. If the distance between 10 successive crests is 37.8cm. Calculate the wave length and the velocity of the waves
   Ans: $(4.2cm, 21.0 ms^{-1})$
7. A vibrator produces waves which travel a distance of 315cm in 20 seconds and the separation between two successive crests is 20cm. Calculate the velocity and the frequency of the waves
   Ans: $(0.1575 ms^{-1}, 0.7875 Hz)$
8. The frequency of a sound wave is 6.8 x 105Hz. Given that the speed of the sound wave is 340ms-1. Find the wave length of the wave.
   Ans: $(5 \times 10^{-4} m)$

SOUND WAVES

This is the form of energy produced by vibrating objects.
Sound waves are produced when particles of a medium are set into vibrations e.g. plucking a guitar string, drumming etc.
Sound waves are longitudinal waves and mechanical waves so they require a medium for their transmission e.g. solids, liquids and gases.

PROPERTIES OF SOUND WAVES:

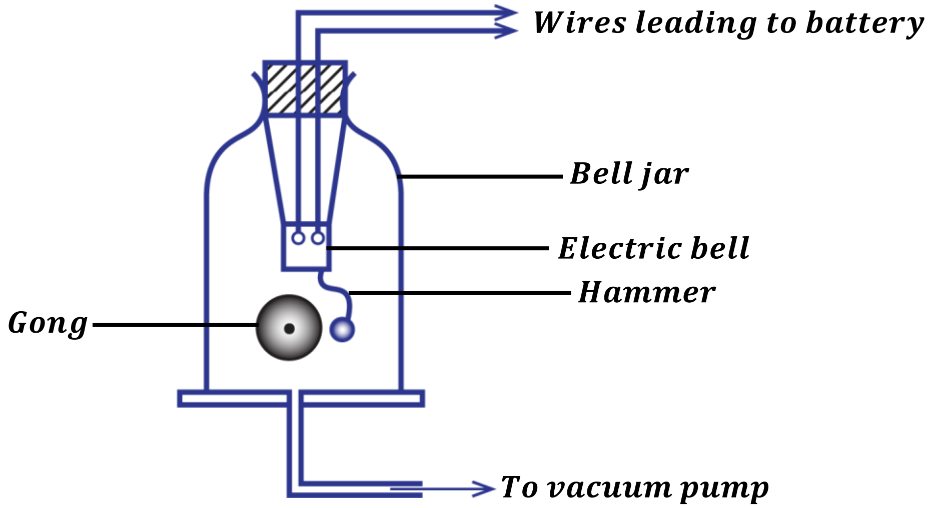
- They are longitudinal waves.
- They require a material medium to travel so they can't travel through a vacuum.
- They can be reflected, refracted and diffracted.
- They undergo interference.
- They travel at a lower speed.

TRANSMISSION OF SOUND

Sound is a mechanical wave; therefore, it requires a material medium for its transmission so it cannot travel through a vacuum.

Experiment to show that sound waves need a material medium for its transmission:

(Describe an experiment to show that sound is a mechanical wave)



- When an electric bell inside a bell jar is switched on, a loud sound is heard.
- When the air inside the bell jar is gradually removed by means of a vacuum pump, the loudness starts to fade out/ die away.
- When all the air is completely removed from the bell jar, no sound is heard even though the hammer is seen hitting the gong.
- When air is again allowed in the bell jar, sound is heard again.
- This shows that sound requires a material medium for its transmission.

Factors that affect the speed of sound in a medium:

The speed of sound in a medium depends on; -

Temperature:

Increase in temperature increases the speed of sound. This is because temperature increases the speed of molecules of the medium.

Sound travels faster in hot air than in cold air.

Density of medium:

Speed of sound is more in denser medium than in a less dense medium.

Sound travels faster in solids than in liquids and gases. This is because molecules of a solid are closely packed together; therefore, movement of sound energy from one molecule to another is very easy.

Wind:

Speed of sound is increased if sound travels in the same direction of wind.

Altitude:
Sound travels faster at lower altitude and slower at higher altitudes because temperature is higher at low altitudes than at high altitudes.

Humidity:
Humidity is the amount of water vapour in the air.
The higher the humidity, the higher the speed of sound.

QUESTION: Explain why a person hears sound of a moving train at a distance further away from where he is when he places his ears on the rails.
The rails are solids, sound from the train travels faster in solids because the molecules of solids are closely packed together so it is easy for sound to move from one molecule to another.

REFLECTION OF SOUND WAVES:
This is the bouncing off of sound waves as they meet a barrier.

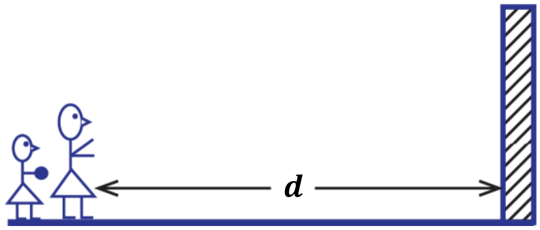
Laws of reflection of sound:
1st law: The incident wave, reflected wave and the normal at the point of incidence all lie in the same plane.
2nd law: The angle of incidence of the wave is equal to angle of reflection of the wave.

ECHOES

An echo is a reflected sound.
Echoes are produced when sound waves are move to and fro from the reflecting surface e.g. on walls, mountains, etc.
The time taken before an echo returns back depends on; -
- Distance from the reflecting surface.
- Speed of sound in the medium.

QUESTION: Explain why echoes are not heard in small rooms.
In small rooms, echoes are not heard because reflected sound from the walls of the room returns very quickly and mix up with the original sound so the ear cannot differentiate between the two sounds.

EXPERIMENT TO MEASURE THE SPEED OF SOUND IN AIR BY ECHO METHOD

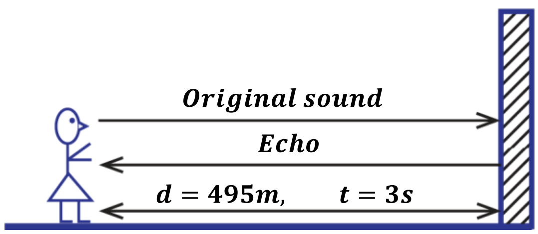


- Two people stand at a distance, d from a tall vertical wall.
- One person claps and the other immediately starts a stop clock.
- On hearing the echo, a stop clock is stopped and time, t is noted.
- The speed of sound is then calculated from;

$$speed, V = \frac{2d}{t}$$

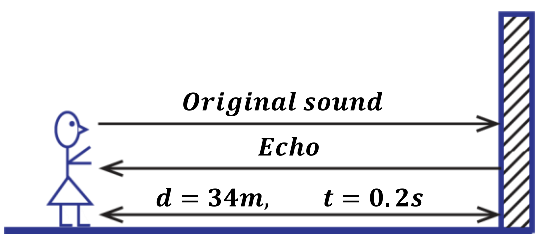
EXAMPLES:

1. A man stands at 495m away from a cliff and makes a loud sound, he hears the echo after 3 seconds. Calculate the speed of sound.



$$speed = \frac{2d}{t}$$
$$V = \frac{2 \times 495}{3}$$
$$V = \frac{990}{3}$$
$$V = 330ms^{-1}$$

2. A girl stands 34m away from a wall. She makes sound and hears an echo 0.2seconds after. Find the velocity of sound.



$$speed = \frac{2d}{t}$$
$$V = \frac{2 \times 34}{0.2}$$
$$V = \frac{68}{0.2}$$
$$V = 340ms^{-1}$$

3. A gun was fired and an echo from a cliff was heard 8 seconds later. If the velocity of sound is $340ms^{-1}$, how far was the gun from the cliff.

$$V = \frac{2d}{t}$$
$$340 = \frac{2d}{8}$$
$$d = \frac{340 \times 8}{2}$$
$$d = 1360m$$

4. A man stands between two cliffs and makes a loud sound. He hears the first echo after one second and the second echo after 2 seconds. Find the distance between the two cliffs if the speed of sound in air is $330ms^{-1}$.

For first echo;

$$V = \frac{2d_1}{t_1}$$
$$330 = \frac{2d_1}{1}$$
$$d_1 = 165m$$

For second echo;

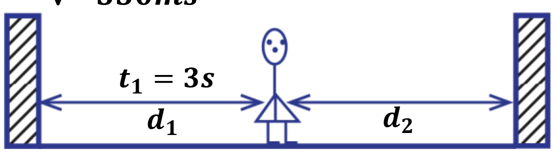
$$V = \frac{2d_2}{t_2}$$
$$330 = \frac{2d_2}{2}$$
$$d_1 = 330m$$

Total distance

$$d = d_1 + d_2$$
$$d = 165 + 330$$
$$d = 495m$$

5. A man is standing midway between two cliffs. He claps his hands and hears an echo after 3 seconds. Find the distance between the two cliffs. (speed of sound in air is $330ms^{-1}$)

V= $330ms^{-1}$



$$V = \frac{2d_1}{t_1}$$
$$330 = \frac{2d_1}{33}$$
$$d_1 = 495m$$

Total distance

$$d = d_1 + d_2$$
$$d = 495 + 495$$
$$d = 990m$$

6. A sound wave of frequency 200Hz is produced 300m away from a high wall. If the echo is received after 2s. Find the wavelength of the sound wave.

$$f = 200Hz, d = 300m, t = 2s$$
$$V = \frac{2d}{t}$$
$$V = \frac{2 \times 300}{2}$$
$$V = 300ms^{-1}$$

$$V = f\lambda$$
$$300 = 200 \times \lambda$$
$$\lambda = 1.5m$$

EXERCISE:

1. A person standing $\mathbf{99m}$ from a tall cliff claps his hands and hears an echo $\mathbf{0.6s}$ later. Calculate the velocity of sound in air.
   Ans: ($330ms^{-1}$)
2. A gun was fired and an echo from the cliff was heard $\mathbf{8s}$ later. If the velocity of sound is $\mathbf{330m/s}$, how far was the gun from the cliff?
   Ans: ($1320m$)
3. A girl standing between two cliffs hears the first echo after $\mathbf{2s}$ and hears another after a further $\mathbf{3s}$. If the velocity of sound is $\mathbf{330m/s}$, calculate the distance between the two cliffs.
   Ans: ($1155m$)
4. A child stands between 2 cliffs and makes a loud sound, if the child hears the first echo after 1.5s and the second after $\mathbf{2s}$. Find the distance between the two cliffs if the speed of sound in air is $\mathbf{330m/s}$.
   Ans: ($560m$)

5. A boy standing between two cliffs $\boldsymbol{A}$ and $\boldsymbol{B}$ claps his hands and hears the first echo from $\boldsymbol{A}$ after $\boldsymbol{4s}$ and the second echo from $\boldsymbol{B}$ after $\boldsymbol{5s}$. If the velocity of sound in air is $\boldsymbol{330m/s}$, find the distance between $\boldsymbol{A}$ and $\boldsymbol{B}$.
6. A sound wave is produced 600m away from a high wall. If an echo is received after 4 seconds. Find the frequency of sound wave with the wavelength of 2m.
7. A man standing midway between two cliffs makes sound. He hears the first echo after 3s. Calculate the distance between the two cliffs. (velocity of sound is 330m/s)
8. A man stands between two cliffs and fires a gun. He hears the first echo after 2 seconds and second echo after $3\frac{1}{2}$ seconds. Calculate the distance between the two cliffs. (speed of sound in air is 330m/s)

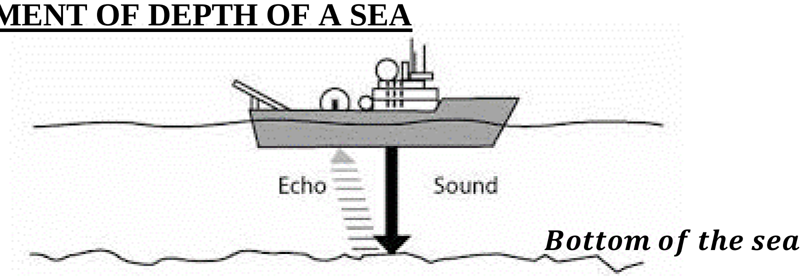
<u>USES/APPLICATION OF ECHOES</u>:

- Used in measurement of speed of sound.
- Used in echo sounding.
- Used in ultrasound scanning e.g. scanning womb in pregnant women.
- Used in radar equipment e.g. determining speed of vehicles by traffic officers.

<u>ECHO SOUNDING</u>:

Echo sounding is used in measurement of depth of a sea.
The device used is called an <u>echo sounder</u>.
An echo sounder consists of a transmitter and a hydrophone (microphone)

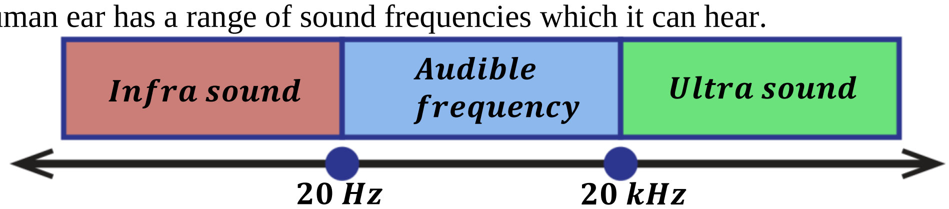
<u>MEASUREMENT OF DEPTH OF A SEA</u>



- The transmitter of an echo sounder sends out sound of very high frequency to the bottom of the sea at regular time intervals.
- The echo from the bottom of sea is received by the hydrophone which is connected to an electric timing circuit.
- The circuit automatically calculates the depth of sea from the graph plotted.

<u>ULTRASONIC SOUNDS</u>:

This is the sound of very high frequency which the human can't hear.
The human ear has a range of sound frequencies which it can hear.

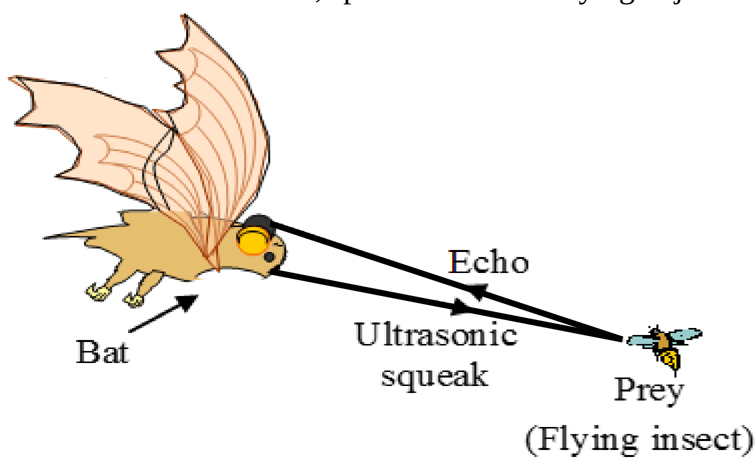


The lowest limit of audibility of human ear is 20Hz and the highest limit of audibility is 20 kHz. Therefore, sounds above 20 kHz cannot be heard by the ear.

Applications of ultrasonic sounds:

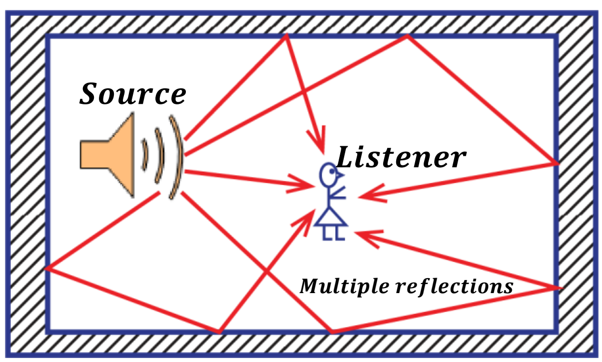
- They are used in measuring the depth of the sea.
- They are used in ultrasonic scanning e.g. scanning the womb of a pregnant woman.
- They enable bats and dogs to communicate and navigate.

  The bats send out repeated ultrasonic sounds, hear and process the echo. This enables them to;
  - ✓ Distinguish between an obstacle and flying insects.
  - ✓ Determine direction, speed and size of flying objects



REVERBERATION

This occurs in large halls with many reflecting surfaces or walls where many echoes are produced due to multiple reflections. Therefore, sound lasts longer and it appears as if it is prolonged.
If the time taken to hear the echo is less than 0.1s, the human ear cannot distinguish between the original sound and the echo. If the time is just 0.1s, the original sound appears to be prolonged. This prolonged sound is called reverberation.



Definition:

Reverberation is the prolonged sound due to multiple reflections.

Advantage of reverberation:

- Reasonable reverberation makes speeches audible.

Disadvantage of reverberation:

- Unreasonable reverberation produces disorganized sound so sound becomes unclear.

Reverberation in large halls is minimized by using sound absorbing materials e.g. soft boards, curtains, carpets and cushioning seats.

QUESTION: Explain why reverberation time in a church filled with people is less than when the church is empty.

In an empty church, only the roof, walls, floor and furniture can absorb the sound but when the church is filled with people, human bodies and clothes are included to absorb sound.

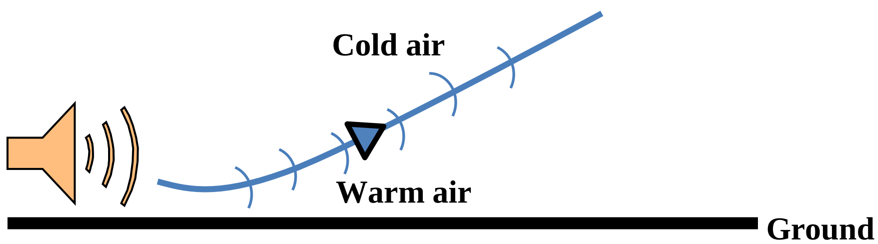
REFRACTION OF SOUND WAVES:

Refraction occurs when the speed of sound waves changes as it crosses the boundary between two media. The speed of sound is affected by temperature.

Refraction of sound waves during day:

During day, air around the ground is warm (less dense) and air above the ground is cold (more dense). The sound waves move from a less dense medium to a more dense medium hence they are refracted away from the ground thus moving upwards.
This explains why;

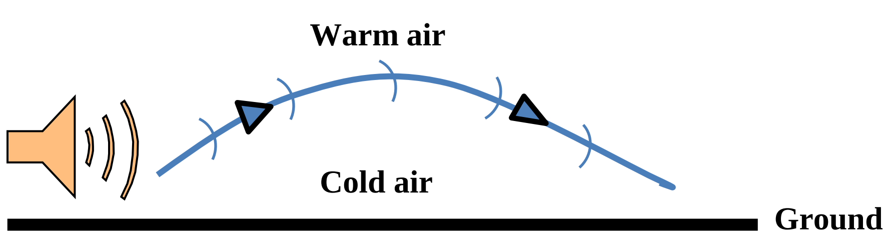
- Sound is not easily heard during day.
- Radio signals are not clear during day.



Refraction of sound waves during day:

During night, air around the ground is cold (more dense) and air above the ground is warm (less dense). The sound waves move from a more dense medium to a less dense medium hence they are refracted towards the ground after undergoing through total internal reflection.
This explains why;

- Sound is easily heard during night.
- Radio signals are clear during clear.

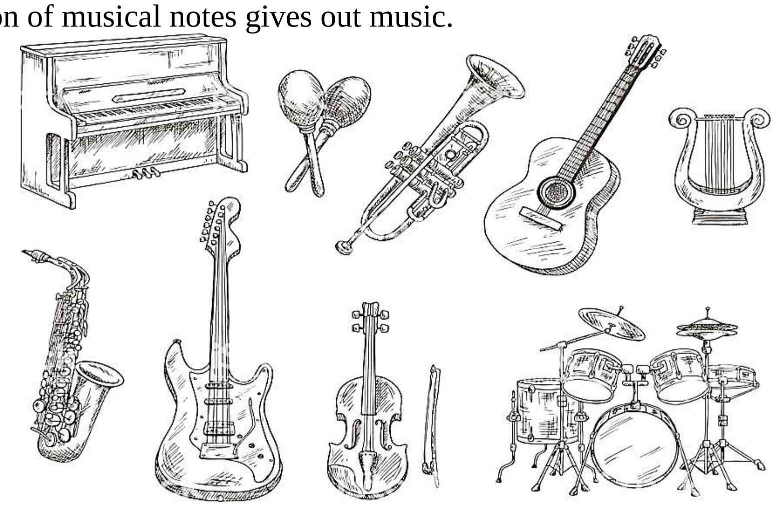


Differences between sound waves and light waves:

Sound waves	Light waves
▪ They are longitudinal waves. ▪ They are mechanical waves so they require a material medium for their travel. ▪ They can't ravel through a vacuum. ▪ They have a longer wavelength. ▪ They travel at a low speed i.e. $330ms^{-1}$	▪ They are transverse waves. ▪ They are mechanical waves so they require a material medium for their travel. ▪ They can travel through a vacuum. ▪ They have a short wavelength. ▪ They travel at a high speed i.e. $3 \times 10^8 ms^{-1}$

MUSICAL SOUNDS

These are sounds of regular and uniform vibrations.
Musical sounds are also called musical notes or tones.
Definition:
A musical note is a sound of regular frequency produced by a musical instrument.
A combination of musical notes gives out music.



MUSIC AND NOISE:
Music: This is an organized sound produced by regular vibrations.
Noise: This is a disorganized sound produced by irregular vibrations.

Characteristics of musical sounds:

There are properties of music namely; -

- Pitch
- Loudness
- Quality/timbre

Pitch:
This is the loudness or softness of sound.
It depends on the frequency of sound produced. The higher the frequency, the higher the pitch.

Loudness of sound:
This is the amount of sound energy that enters the ear per second.
It depends on the:
- Amplitude i.e. a loud note has higher amplitude and a soft note has a low amplitude.
- Sensitivity of the ear i.e. a more sensitive ear will hear a soft note as being loud.
- Intensity of sound i.e. rate of flow of sound per unit area.

Quality/Timbre:
This is the characteristic which helps the ear to differentiate between sounds of same pitch and loudness.
It depends on the frequency and amplitude of a note therefore, the number of overtones produced by a musical instrument determines the quality of music.

VIBRATING STRINGS

Many musical instruments produce sound by plucking their strings e.g. guitar, violins

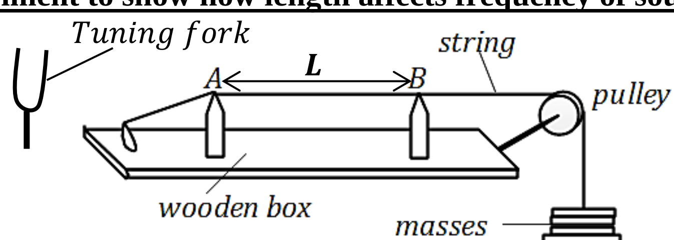
Violin

Guitars

FACTORS AFFECTING FREQUENCY OF STRETCHED VIBRATING STRINGS

(a) Length, L:
Frequency is inversely proportional to length of the string. Increasing the length of a string produces a note of low frequency and decreasing the length gives a note of high frequency.

Experiment to show how length affects frequency of sound waves using a sonometer:



- Known masses are hung at the end of the string passing over the bridges A and B.
- A tuning fork of known frequency, f is sounded.
- Keeping A fixed, B is moved until a note heard by plucking in the middle of the string is same as that from the fork.
- The length between A and B is measured and recorded.

- The experiment is repeated with tuning forks of different frequencies.
- A graph of f against L is plotted and it is a non-straight graph showing that frequency is inversely proportional to length.

$$f \propto \frac{1}{L}, \qquad f = K\frac{1}{L}$$
$$fL = K \;\; hence \; f_1 L_1 = f_2 L_2$$

EXAMPLES:

1. A string has length of 0.75m and the first frequency of 200Hz. Find the new frequency if the length is increased to 1m.

$$f_1 = 200Hz \;\; L_1 = 0.75m \;\; f_2 = ? \;\; L_2 = 1m$$
$$f_1 L_1 = f_2 L_2$$
$$200 \times 0.75 = f_2 \times 1$$
$$f_2 = 150Hz$$

2. A musical note has frequency of 420Hz and length, L. If the length of the string reduced by a half. Find the new frequency.

$$f_1 = 420Hz \;\; L_1 = L \;\; f_2 = ? \;\; L_2 = \frac{L}{2}$$
$$f_1 L_1 = f_2 L_2$$
$$420 \times L = f_2 \times \frac{L}{2}$$
$$f_2 = 420 \times 2$$
$$f_2 = 840Hz$$

(b) Tension, T:

The higher the tension in the string, the higher the frequency of the note produced. Therefore, increasing tension increases the frequency.

In the above experiment, adding more masses will increase the frequency of note.

Note: This explains why drummers first warm their drums before using them.

(c) Mass per unit length (thickness of string):

Thin strings/wires normally produce notes of high frequency while thick strings/wires normally produce notes of low frequency.

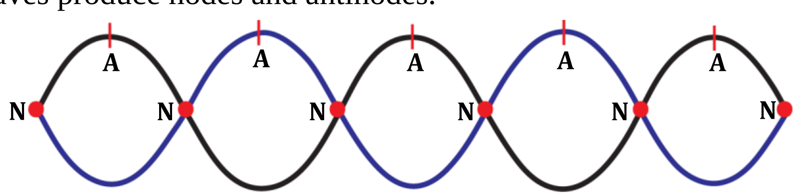
WAVES PRODUCED BY A VIBRATING STRING

When the ends of a string are fixed and it is plucked in the middle, two transverse waves are formed and travel in opposite directions along the string forming a stationary wave.

STATIONARY (STANDING) WAVE:

This is the wave formed when two progressive waves of the same frequency and wavelength travelling in opposite direction meet.

Stationary waves produce nodes and antinodes.



NODE (N): This is a point on a stationary wave where wave particles are at rest.
The amplitude of a wave is zero at this point.

ANTINODE: This is a point on a stationary wave where wave particles have maximum displacement.
The amplitude of a wave at this point is maximum.

NOTE:

The distance between two successive nodes or antinodes is equal to half of wavelength $(\frac{1}{2}\lambda)$

EXAMPLES:

1. The distance between two successive nodes is 12cm. Find the wavelength of the wave.

$$\frac{1}{2}\lambda = 12$$
$$\lambda = 24cm$$

Conditions necessary for stationary waves to be formed:

- The waves should have the same frequency.
- The waves should have the same speed.
- The waves should have the same wavelength.
- The waves should have the same amplitude.
- The waves should be moving in opposite directions.

IMPORTANT TERMS:

Fundamental note:

This is the lowest audible note produced by a musical instrument.

Fundamental frequency (f_1)**:**

This is the frequency of the fundamental note.

Overtone:

This is the note whose frequency is higher than the fundamental frequency.

- Overtones are used to determine the quality of sound.

Harmonic:

This is a note whose frequency is an integral multiple of the fundamental frequency.
i.e. $f_1,\ 2f_1,\ 3f_1,\ 4f_1$ ...

Octave:

This is the interval between one note and another note which is half or double its frequency. i.e.

$\boxed{f_2 = 2^n f_1}$ *where* f_1 *is the lower frequency*
f_2 *is the higher frequency*
n *is the number of octaves.*

Examples:

1. Find the frequency of a note four octaves above a note of frequency 20Hz.

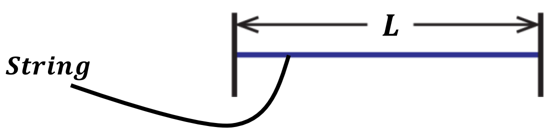
$$f_1 = 20Hz, f_2 = ?, n = 4$$
$$f_2 = 2^n f_1$$
$$f_2 = 2^4 \times 20$$
$$f_2 = 320Hz$$

2. Find the frequency of a note 2 octaves below a note of frequency 512Hz.

$$f_2 = 512Hz, f_1 = ?, n = 2$$
$$f_2 = 2^n f_1$$
$$512 = 2^2 \times f_1$$
$$f_1 = \frac{512}{4}$$
$$f_1 = 128Hz$$

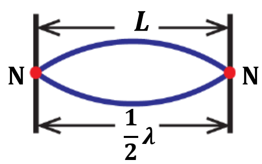
NOTE:

Consider a string of length, L fixed at both ends.



1st harmonic (fundamental note):

This is produced when the string is plucked half-way from one end (middle). The frequency of the note is the fundamental frequency, f_1.

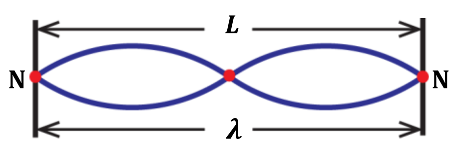


$$L = \frac{1}{2}\lambda, \quad \Rightarrow \lambda = 2L$$
$$\text{from velocity } V = f_1\lambda$$
$$f_1 = \frac{V}{\lambda}$$
$$f_1 = \frac{V}{2L} \dots\dots\dots\dots\dots\dots (i)$$

2nd harmonic (first overtone):

This is produced when the string is plucked quarter-way from one end.

The frequency of the note is f_2.



$$L = \lambda, \quad \Rightarrow \lambda = L$$
$$\text{from velocity } V = f_2\lambda$$
$$f_2 = \frac{V}{\lambda}$$
$$f_2 = \frac{V}{L} \dots\dots\dots\dots\dots\dots (ii)$$

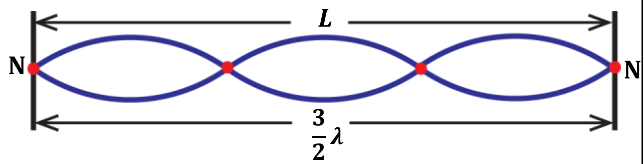
Combining equations (i) and (ii)

Making V the subject in equation (i) $V = 2Lf_1 \dots\dots\dots\dots..$ **

Substitute equation ** into (ii)

$$f_2 = \frac{2Lf_1}{L}$$
$$\boxed{f_2 = 2f_1}$$

3rd harmonic (second overtone):
This is produced if the string is plucked a sixth-way from one end.
The frequency of the note is f_3.



$$L = \frac{3}{2}\lambda, \quad \Rightarrow \lambda = \frac{2L}{3}$$
$$from\ velocity\ \ V = f_3\lambda$$
$$f_3 = \frac{V}{\lambda}$$
$$f_3 = \frac{V}{\frac{2L}{3}}$$
$$f_3 = \frac{3V}{2L} \ldots\ldots\ldots\ldots\ldots\ldots (iii)$$

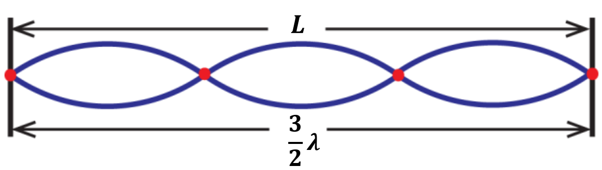
Substitute equation ** into (iii): $f_3 = \frac{3\times 2Lf_1}{2L}$
$$\boxed{f_3 = 3f_1}$$

NOTE:

From the above, the harmonics are $f_1, 2f_1, 3f_1, 4f_1, 5f_1, 6f_1, 7f_1 \ldots\ldots\ldots.$
Therefore, a vibrating string produces both odd and even harmonics and overtones.

EXAMPLES:

1. The frequency of the third harmonic produced by a vibrating string is 660Hz. Find the length of the string if the speed of sound is 330m/s



$$f_3 = 660Hz \quad L = \frac{3}{2}\lambda, \quad \Rightarrow \lambda = \frac{2L}{3}$$
$$from\ velocity\ \ V = f_3\lambda$$
$$f_3 = \frac{V}{\lambda} \quad \Rightarrow f_3 = \frac{V}{\frac{2L}{3}}$$
$$f_3 = \frac{3V}{2L}$$
$$660 = \frac{3\times 330}{2L}$$
$$\frac{1320L}{1320} = \frac{990}{1320}$$
$$L = 0.75m$$

Alternatively:
$$f_3 = 3f_1$$
$$660 = 3f_1$$
$$f_1 = \frac{660}{3}$$
$$f_1 = 220Hz$$
$$But \quad f_1 = \frac{V}{2L}$$
$$220 = \frac{330}{2L}$$
$$L = 0.75m$$

2. Find the frequency of the second harmonic produced by a vibrating string whose fundamental frequency is 300Hz.

$$f_1 = 300Hz$$
$$f_2 = 2f_1$$
$$f_2 = 2 \times 300$$
$$f_2 = 600Hz$$

3. The frequency of the second overtone is 300Hz. Find the fundamental frequency.

$$second\ overtone = third\ harmonic, \quad f_3 = 300Hz$$
$$f_3 = 3f_1$$
$$300 = 3f_1$$
$$f_1 = \frac{300}{3}$$
$$f_1 = 100Hz$$

WAVES PRODUCED IN PIPES

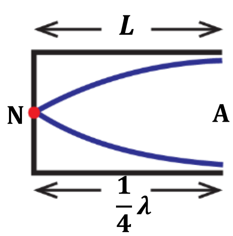
Pipes used are either closed and open.

<u>Closed pipes</u>:

These are pipes which are closed at one end and open at the other end.
The wave formed has a node at closed end and the antinode at open end
The length of the tube is L.

<u>1st harmonic</u> (fundamental note):

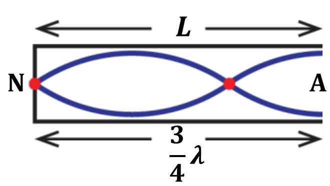
This is the first position of resonance.
The frequency is the fundamental frequency, f_1.



$$L = \frac{1}{4}\lambda, \quad \Rightarrow \lambda = 4L$$
$$from\ velocity\ \ V = f_1\lambda$$
$$f_1 = \frac{V}{\lambda}$$
$$f_1 = \frac{V}{4L} \ldots\ldots\ldots\ldots\ldots\ldots (i)$$

<u>3rd harmonic</u> (first overtone):

This is the second position of resonance.
The frequency of the note is f_3.



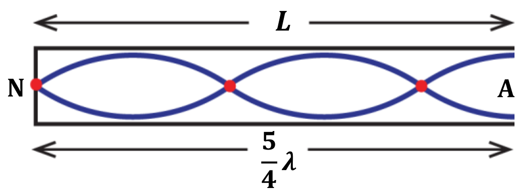
$$L = \frac{3}{4}\lambda, \quad \Rightarrow \lambda = \frac{4L}{3}$$
$$from\ velocity\ \ V = f_3\lambda$$
$$f_3 = \frac{V}{\lambda}$$
$$f_3 = \frac{V}{\frac{4L}{3}}$$
$$f_3 = \frac{3V}{4L} \ldots\ldots\ldots\ldots\ldots\ldots (ii)$$

Combining equations (i) and (ii)
Making V the subject in equation (i) $V = 4Lf_1 \dots \dots \dots \dots ..$ **
Substitute equation ** into (ii)

$$f_3 = \frac{3(4Lf_1)}{4L}$$

$$\boxed{f_3 = 3f_1}$$

5th harmonic (second overtone):
This is the third position of resonance.
The frequency of the note is f_5.



$$L = \frac{5}{4}\lambda, \quad \Rightarrow \lambda = \frac{4L}{5}$$

$$from\ velocity\ V = f_5\lambda$$

$$f_5 = \frac{V}{\lambda}$$

$$f_5 = \frac{V}{\frac{4L}{5}}$$

$$f_5 = \frac{5V}{4L} \dots \dots \dots \dots \dots \dots (iii)$$

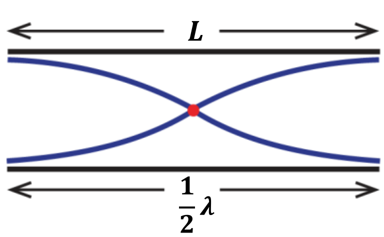
Substitute equation ** into (iii):

$$f_5 = \frac{5 \times (4Lf_1)}{4L}$$

$$\boxed{f_5 = 5f_1}$$

NOTE:
Closed pipes only produce odd harmonics i.e. $f_1, 3f_1, 5f_1, 7f_1, 9f_1, 11f_1, \dots \dots$
Open pipes:
Open pipes are open at both ends.
Antinodes are formed at both ends.

1st harmonic (fundamental note):
This is the first position of resonance.
The frequency of the note is the fundamental frequency, f_1.



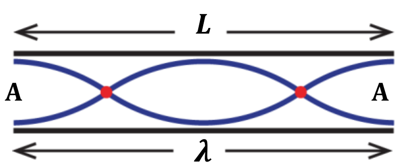
$$L = \frac{1}{2}\lambda, \quad \Rightarrow \lambda = 2L$$

$$from\ velocity\ V = f_1\lambda$$

$$f_1 = \frac{V}{\lambda}$$

$$f_1 = \frac{V}{2L} \dots \dots \dots \dots \dots \dots (i)$$

2nd harmonic (first overtone):
This is the second position of resonance.
The frequency of the note produced is f_2.

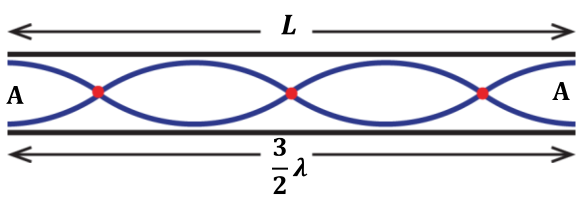


$$L = \lambda, \quad \Rightarrow \lambda = L$$
$$from\ velocity\ \ V = f_2\lambda$$
$$f_2 = \frac{V}{\lambda}$$
$$f_2 = \frac{V}{L} \ldots\ldots\ldots\ldots\ldots\ldots (ii)$$

Combining equations (i) and (ii)
Making V the subject in equation (i) $V = 2Lf_1 \ldots\ldots\ldots\ldots..$ **
Substitute equation ** into (ii)

$$f_2 = \frac{2Lf_1}{L}$$
$$\boxed{f_2 = 2f_1}$$

3rd harmonic (second overtone):
This is the third position of resonance.
The frequency of the note produced is f_2.



$$L = \frac{3}{2}\lambda, \quad \Rightarrow \lambda = \frac{2L}{3}$$
$$from\ velocity\ \ V = f_3\lambda$$
$$f_3 = \frac{V}{\lambda}$$
$$f_3 = \frac{V}{\frac{2L}{3}}$$
$$f_3 = \frac{3V}{2L} \ldots\ldots\ldots\ldots\ldots\ldots (iii)$$

Substitute equation ** into (iii):

$$f_3 = \frac{3 \times 2Lf_1}{2L}$$
$$\boxed{f_3 = 3f_1}$$

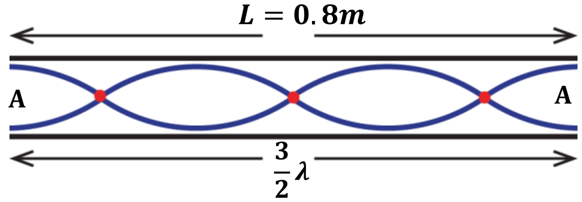
NOTE:
Open pipes produce both odd and even harmonics i.e.

$$f_1, 2f_1, 3f_1, 4f_1, 5f_1, 6f_1, 7f_1 \ldots\ldots....$$

QUESTION: Explain why open pipes are preferred more than closed pipes in making music.
Open pipes are preferred more than closed pipes because they produce high quality sound since they produce both odd and even harmonics.

EXAMPLES:

1. The frequency of the third harmonic in an open pipe is 750Hz. Find the speed of sound if the length of pipe is 0.8m.



$$L = \frac{3}{2}\lambda, \quad \Rightarrow \lambda = \frac{2L}{3} = \frac{2 \times 0.8}{3} = \frac{8}{15}m$$

$$from\ velocity\ \ V = f_3\lambda$$

$$V = 750 \times \frac{8}{15}$$

$$V = 400ms^{-1}$$

Alternatively:

$$f_3 = 750Hz, \qquad L = 0.8m$$

$$f_3 = 3f_1$$

$$750 = 3f_1$$

$$f_1 = \frac{750}{3}$$

$$f_1 = 250Hz$$

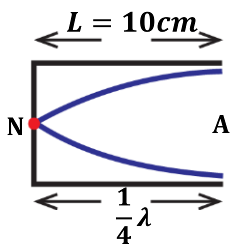
$$But\ f_1 = \frac{V}{2L}$$

$$V = 2Lf_1$$

$$V = 2 \times 0.8 \times 250$$

$$V = 400ms^{-1}$$

2. A pipe closed at one end has length 10cm. if the velocity of sound is 340m/s. find
   (i) Fundamental frequency
   (ii) Frequency of third harmonic.



(i)

$$L = \frac{1}{4}\lambda, \quad \Rightarrow \lambda = 4L = 4 \times \frac{10}{100} = 0.4m$$

$$from\ velocity\ \ V = f_1\lambda$$

$$f_1 = \frac{V}{\lambda}$$

$$f_1 = \frac{340}{0.4}$$

$$f_1 = 850Hz$$

Alternatively:

$$f_1 = \frac{V}{4L}$$

$$f_1 = \frac{340}{4 \times 0.1}$$

$$f_1 = 850Hz$$

(ii)

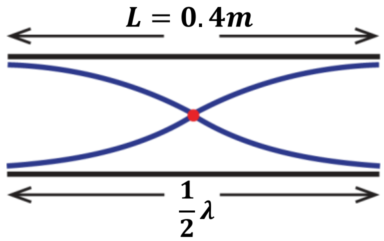
$$f_3 = 3f_1$$

$$f_3 = 3 \times 850$$

$$f_3 = 2550Hz$$

3. A pipe open at both ends has length 40cm. If the velocity of sound is 340m/s. Find the frequency of the;
   (i) Fundamental note.
   (ii) First overtone.

$$L = 40cm = \frac{40}{100} = 0.4m, \quad V = 340m/s$$



(i)

$$L = \frac{1}{2}\lambda, \quad \Rightarrow \lambda = 2L = 2 \times 0.4$$
$$= 0.8m$$
$$from\ velocity\ \ V = f_1\lambda$$
$$f_1 = \frac{V}{\lambda}$$
$$f_1 = \frac{340}{0.8}$$
$$f_1 = 425Hz$$

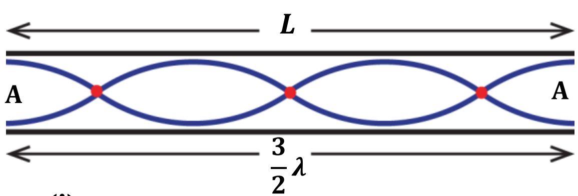
Alternatively:

$$f_1 = \frac{V}{2L}$$
$$f_1 = \frac{340}{2 \times 0.4}$$
$$f_1 = 425Hz$$

(i) **First overtone (2nd harmonic)**

$$f_2 = 2f_1$$
$$f_2 = 2 \times 425$$
$$f_2 = 850Hz$$

4. The frequency of third harmonic in an open pipe is 660Hz, if the speed of sound in air is 330m/s. Find;
   (i) the length of the air column
   (ii) the fundamental frequency



(i)

$$f_3 = 660Hz \quad V = 330m/s$$
$$from\ velocity\ \ V = f_3\lambda$$
$$\lambda = \frac{V}{f_3}$$
$$\lambda = \frac{330}{660}$$
$$\lambda = 0.5m$$

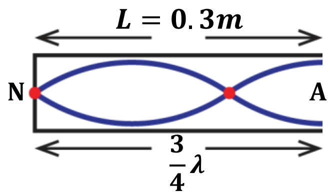
$$But \quad L = \frac{3}{2}\lambda$$
$$L = \frac{3}{2} \times 0.5$$
$$L = 0.75m$$

(ii)

$$f_3 = 3f_1$$
$$f_1 = \frac{f_3}{3}$$
$$f_1 = \frac{660}{3}$$
$$f_1 = 220Hz$$

5. A third harmonic (first overtone) of a closed pipe occurs when the length of the air column is 30cm, if the speed of sound in air is 330m/s. Find the;
   (i) frequency of the sound wave
   (ii) fundamental frequency

$$L = 30cm = \frac{30}{100} = 0.3m, \qquad V = 330m/s$$



(i)

$$L = \frac{3}{4}\lambda, \qquad \Rightarrow \lambda = \frac{4L}{3} = \frac{4 \times 0.3}{3}$$

$$\lambda = 0.4m$$

$$from\ velocity\ \ V = f_3\lambda$$

$$f_3 = \frac{V}{\lambda}$$

$$f_3 = \frac{330}{0.4}$$

$$f_3 = 825Hz$$

(ii) **Fundamental frequency**

$$f_3 = 3f_1$$

$$f_1 = \frac{f_3}{3}$$

$$f_1 = \frac{825}{3}$$

$$f_1 = 275Hz$$

6. The frequency of the 4th overtone in an open pipe is 900Hz when the length of the air column is 0.4m. Find the
   (i) Frequency of the fundamental note
   (ii) Speed of sound in air.

$$4^{th}\ overtone = fifth\ harmonic$$

(i) $f_5 = 900Hz \qquad L = 0.4m$

$$f_5 = 5f_1$$

$$f_1 = \frac{f_5}{5}$$

$$f_1 = \frac{900}{5}$$

$$f_1 = 180Hz$$

(ii)

$$f_1 = \frac{V}{2L}$$

$$V = 2Lf_1$$

$$V = 2 \times 0.4 \times 180$$

$$V = 144ms^{-1}$$

RESONANCE

This occurs when a body is set into vibrations at its own natural frequency by another nearby body vibrating at the same frequency.
The resonating body will then vibrate strongly with a greater amplitude.

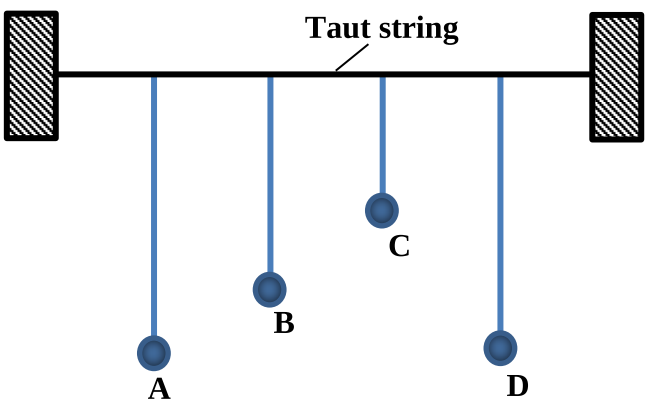
Examples of resonance in daily life.

- Shaking of window glasses as a heavy vehicle passes by.
- Swinging of legs in a swing so as to swing higher.
- Breaking of wine glass by an opera singer's sound.
- A working generator makes dust to move up and down
- Tuning a radio changes the frequency of the radio waves until it is exactly same as frequency of the waves at transmitting station.

NOTE:

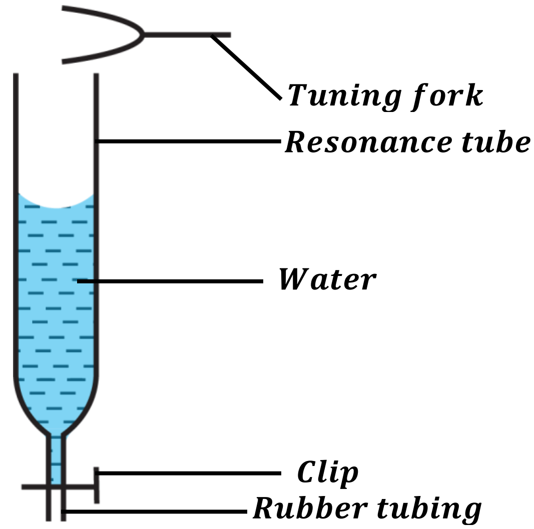
Resonance may lead to collapse of tall buildings, bridges when they resonate with strong winds or earthquakes.

Experiment to demonstrate resonance using coupled pendulum and tubes:



- Hang four pendulum bobs on the same taut string such that pendulum, A has a variable length and other pendulums B, C and D have different fixed lengths.
- Set pendulum, A to the same length as D and make it to swing. It is observed that pendulum, D swings with a larger amplitude but pendulums B and C swing with smaller amplitudes.
- Set pendulum, A to the same length as B and make it swing. It is observed that pendulum, B swings with noticeable amplitude but pendulums C and D just jiggle without a noticeable amplitude.

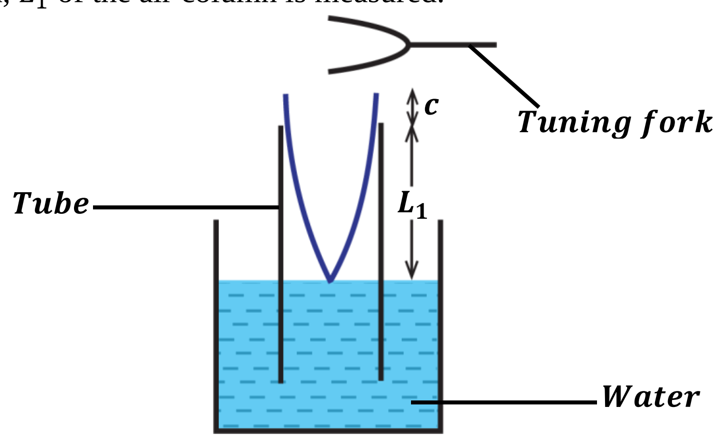
Experiment to demonstrate resonance using a closed air tube:



- A resonance tube is almost filled with water.
- A tuning fork is sounded near and above the mouth of the tube.
- Water level is allowed to fall gradually by means of a clip.
- It is observed that at some level of water, the sound suddenly becomes louder. Resonance is said to have occurred.

EXPERIMENT TO DETERMINE SPEED OF SOUND IN AIR BY RESONANCE TUBE

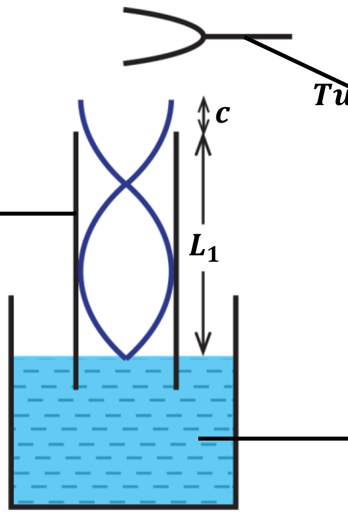
- A tuning fork of known frequency, f is held over the mouth of a resonance tube and then sounded.
- The tube is slowly raised until a first loud sound is heard. This is the first position of resonance.
- The length, L_1 of the air column is measured.



$$L_1 + c = \frac{1}{4}\lambda \ldots\ldots\ldots\ldots\ldots (i)$$

where $\boldsymbol{c}$ *is the end correction of the tube.*

- The tube is again raised until a second loud sound is heard. This is the second position of resonance.
- The length, L_2 of the air column is measured.



$$L_2 + c = \frac{3}{4}\lambda \ldots\ldots\ldots\ldots\ldots (ii)$$

subtracting equation (i) from (ii)

$$\left[L_2 + c = \frac{3}{4}\lambda\right] - \left[L_1 + c = \frac{1}{4}\lambda\right]$$

$$L_2 - L_1 = \frac{3}{4}\lambda - \frac{1}{4}\lambda$$

$$L_2 - L_1 = \frac{1}{2}\lambda$$

therefore, $\lambda = 2(L_2 - L_1)$

But $V = f\lambda$

$$V = 2f(L_2 - L_1)$$

- Hence velocity can be calculated from $V = 2f(L_2 - L_1)$.

EXAMPLES:

1. A tube is partially immersed in water and a tuning fork of frequency 425Hz is sounded above it. If the tube is gradually raised, find the length of the tube when first resonance occurs. (velocity of sound is 340m/s and neglect end correction)

$$\textit{for first resonance},\ L_1 + c = \frac{1}{4}\lambda$$

$$\textit{But}\ V = f\lambda$$

$$340 = 425 \times \lambda$$

$$\lambda = \frac{340}{425} = 0.8m$$

$$\lambda = 0.8m$$

$$L_1 + c = \frac{1}{4}\lambda$$

$$L_1 = \frac{1}{4}\lambda$$

$$L_1 = \frac{1}{4} \times 0.8$$

$$L_1 = 0.2m$$

2. A tube closed at one end resonates first at length 28.5cm and again at 88.5cm when a tuning fork of frequency 285Hz is held near the open end. Find the velocity of sound.

$$f = 285Hz \;\; L_1 = 28.5cm = \frac{28.5}{100} = 0.285m \;\; L_2 = 88.5cm = \frac{88.5}{100} = 0.885m$$
$$V = 2f(L_2 - L_1)$$
$$V = 2 \times 275 \times (0.885 - 0.285)$$
$$V = 330ms^{-1}$$

3. A tuning fork produces resonance in a tube at a length of 15.0cm and also at length 40.0cm. Find the frequency of the tuning fork if the speed of sound is 330m/s.

$$L_1 = 15cm = \frac{15}{100} = 0.15m \;\; L_2 = 40cm = \frac{40}{100} = 0.4m \;\; V = 330m/s$$
$$V = 2f(L_2 - L_1)$$
$$330 = 2 \times f \times (0.4 - 0.15)$$
$$330 = 0.5f$$
$$f = 600Hz$$

4. A tuning fork of frequency 256Hz was used to produce resonance at a length 32.5cm and also at length 95.0cm. Calculate the speed of sound in air.

$$f = 256Hz \;\; L_1 = 32.5cm = \frac{32.5}{100} = 0.325m \;\; L_2 = 95cm = \frac{95}{100} = 0.95m$$
$$V = 2f(L_2 - L_1)$$
$$V = 2 \times 256 \times (0.95 - 0.325)$$
$$V = 320ms^{-1}$$

5. In an experiment the velocity of sound in air using a resonance tube, the following results were obtained:
Length of 1st resonance = 16.1cm
Length of 2nd resonance = 51.1cm
Frequency of tuning fork = 480 Hz
Calculate:

(i) Wavelength of sound

$$L_1 = \frac{16.1}{100} = 0.161m$$
$$L_2 = \frac{51.1}{100} = 0.511m$$
$$\lambda = 2(L_2 - L_1)$$
$$\lambda = 2(0.511 - 0.161)$$
$$\lambda = 0.7m$$

(ii) Speed of sound

$$V = 2f(L_2 - L_1)$$
$$V = 2 \times 480 \times (0.511 - 0.161)$$
$$V = 2 \times 480 \times 0.35$$
$$V = 336ms^{-1}$$

(iii) End correction of tube

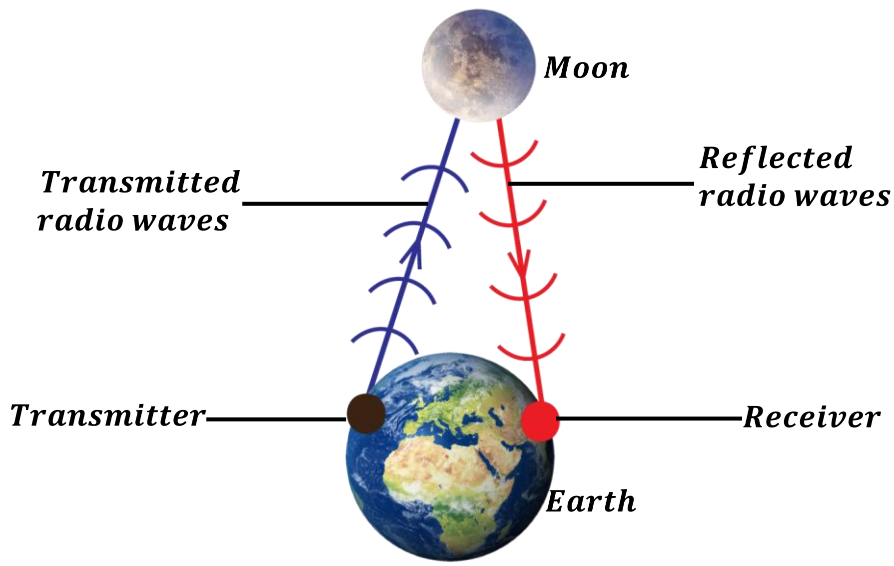
$$L_1 + c = \frac{1}{4}\lambda$$
$$0.161 + c = \frac{1}{4} \times 0.7$$
$$c = 0.175 - 0.161$$
$$c = 0.014m$$

COMMUNICATION BETWEEN EARTH AND MOON

Moon does not have an atmosphere so there is a vacuum (space without air) around it.
So, communication is possible between earth and moon by use of electromagnetic waves called radio waves.

QUESTION: Describe how communication is possible between moon and earth yet the moon has no atmosphere.

- **Radio waves from a transmitter on earth are directed towards the moon. They are able to travel through vacuum around the moon since they are electromagnetic waves.**
- **On reaching the surface of the moon, they are reflected back to the earth's receiver.**
- **Through this process communication is possible.**



QUESTION: Describe how communication in radios and televisions**.**

- **Radio stations have transmitters which convert electrical signals into radio waves and send them over a wide area.**
- **On reaching the radios, the antennas (aerials) on radios convert the radio waves back to electrical signals which can be heard by a person**

EXERCISE:

1. A stretched wire adjusted to a length of 48cm produces the same note as a tuning fork whose frequency is 256Hz. If the wire is adjusted to 32cm, what frequency of the tuning fork would be in tune with the wire?
   Ans: ($384Hz$)
2. The frequency of a vibrating wire is 280Hz, when its length is 75cm. Find its frequency when the length is reduced to 50cm
   Ans: ($420Hz$)
3. The frequency of the third harmonic in an open pipe is 590Hz. Find the length of the air column if the speed of sound in air is $330ms^{-1}$
   Ans: ($0.84m$)
4. The length of air column in an open pipe is 1.6m. Find the frequency of the third harmonic if the speed of sound in air is $320ms^{-1}$
   Ans: ($300Hz$)
5. A pipe closed at one end has a length of 10cm. If the velocity of sound in air of the pipe is $340ms^{-1}$, calculate the fundamental frequency and the frequency of the first overtone
   Ans: ($850Hz, 2550Hz$)
6. The frequency of the second harmonic produced in a vibrating string is 600Hz. Find the length of the string given that the speed of sound is $320ms^{-1}$.
   Ans: ($0.55m$)
7. The frequency of the fourth overtone produced by a vibrating string of length 25cm given that speed of sound in air is $320ms^{-1}$.
   Ans: ($3200Hz$)
8. The length of air column in a closed pipe is 150cm. Find the frequency of the third harmonic if the speed of sound in air is $330ms^{-1}$
   Ans: ($165Hz$)
9. The frequency of the third overtone in an open pipe is 750Hz. Find the length of the air column if the speed of sound in air is $300ms^{-1}$
   Ans: ($0.8m$)

EXAMINATION QUESTIONS:

1. a) Define the following terms;
   i) Wavelength
   ii) Reverberation
   iii) Stationary waves

   b) i) What is meant by resonance
   ii) State three examples and one hazard caused by resonance

   c) Describe an experiment to determine the velocity of sound in air by resonance tube method

   d) Calculate the frequency of vibration of the fundamental note and the second overtone in an open tube of 25cm long if the velocity of sound is $330ms^{-1}$

Ans: $660Hz$, $1980Hz$.

   e) Given the factors which affect the frequency of vibrations of a stretched string

2. a) What do you understand by the following terms;
   i) Anti-node
   ii) Resonance

   b) State the factors which affect the frequency of wave produced by a vibrating string

   c) A sound wave of frequency 300Hz is produced 160m away from a high wall. Calculate
   i) The wavelength of the sound wave.
   ii) The time taken for the sound wave to travel to the wall and back to the source.

   Ans: i) $1.1m$ ii) $0.97s$

   d) A boy standing some distance from a cliff claps his hands and hears an echo after 5 seconds
   i) What is distance between the boy and the cliff?
   ii) How long would it take the boy to hear the echo if there was a wind blowing towards the cliff at a speed of $20ms^{-1}$

   Ans: i) $825m$ ii) $4.71s$

3. a) What is a wave

   b) As regards to a wave, what is meant by the following
   i) Frequency
   ii) Wavelength

   c) State four properties of waves

   d) Describe how a resonance tube may be used to determine the velocity of sound in air

   e) A boy stands between two parallel cliffs but nearer to one of them. When he claps hard once he hears the first echo after 1 second and a second echo 1 second after the first. If the distance between the cliffs is 510m, find the speed of sound.

   Ans: $340ms^{-1}$

4. a) Define the following terms as applied to waves
   i) Amplitude
   ii) Frequency

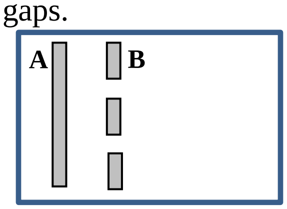
   b) i) What is meant by interference of waves
   ii) Using a labeled diagram show how circular waves are reflected from a straight barrier

   c) Use a labeled diagram to show the bands of electromagnetic waves.

5. a) i) Define an echo.
ii) State the conditions required for a stationary wave to be formed
b) List the factors on which the frequency of a wave in a vibrating string depends
c) Describe an experiment to demonstrate resonance in a closed pipe
d) A child stands between two cliffs and makes a loud sound. If he hears the first echo after 1.5 seconds and the second echo after 2.0 seconds, find the distance between the two cliffs, if the speed of sound in air is 330ms^{-1}.

Ans: $577.5m$

6. The diagram below is of a cross section of a ripple tank in which A is a straight dipper and B a barrier with two gaps.



a) Sketch a diagram showing waves produced when A vibrates perpendicular to the water surface
b) What will happen when?
i) The gaps are made narrower
ii) The separation of the gaps is increased
iii) The frequency of the vibrator A is decreased
c) If A vibrates with a frequency of 20Hz and is 25cm from B, find
i) The speed of the wave if the wave front takes 5s from A to B
ii) The wavelength of the waves

Ans: i) $0.05ms^{-1}$ ii) $2.5 \times 10^{-3}m$

d) State differences between water waves and light waves

7. a) Give three similarities and three differences between sound waves and radio waves
b) i) Describe how the speed of sound in air can be determined by an echo method
ii) A student standing between two vertical cliffs produces sound by clapping his hands together. He hears the first echo after 3seconds and a second echo after 5seconds. Calculate the distance between the two cliffs

Ans: ii) $1320m$

c) A radio station broadcasts at 100m band
i) What is meant by this statement?
ii) Calculate the frequency of the broadcast.

Ans: ii) $3.0 \times 106Hz.$

8. a) State two differences between sound and light waves
b) i) Describe a simple experiment to determine the velocity of sound in air
ii) Explain why the speed of sound is higher in solids than in air
c) Two people X and Y stand in a line at a distance of 330m and 660m respectively from a high wall. Find the time interval taken for X to hear the first and sounds when Y makes a loud sound if the speed of sound in air is 330 ms^{-1}

Ans: $2.0s$

d) i) What is meant by a stationary wave
ii) Give any two conditions
iii) Name one musical instrument which produces stationary waves

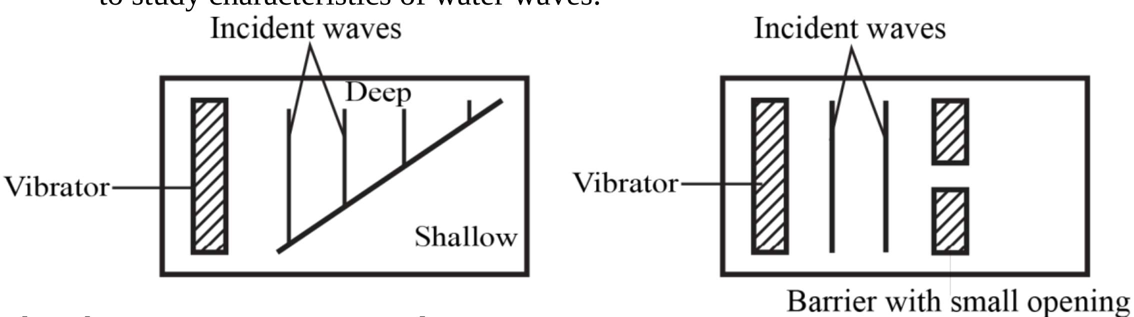
9. a) With aid of a diagram explain the terms amplitude and wavelength as applied to wave motion
b) i) Derive an equation relating velocity, V frequency, f and wavelength, λ of a wave
ii) A radio wave is transmitted at a frequency of 150Hz. Calculate its wavelength

Ans: $\mathbf{2.0 \times 10^6 Hz}$.

c) i) List four properties of electromagnetic waves
ii) A long open tube is partially immersed in water and a tuning fork of frequency 425Hz is sounded and held above it. If the tube is gradually raised, find the length of air column when resonance first occurs. Neglect end correction and take speed of sound in air = $340ms^{-1}$

Ans: ii) $\mathbf{0.2m}$

10. a) Explain the difference between transverse and longitudinal waves. Give one example of each
b) The diagram in the figure below represents a plane view of horizontal ripple tanks set up to study characteristics of water waves.



The vibrators were set up to produce waves
(i) Draw diagrams to show wave patterns in A and B.
(ii) Explain what happens to plane waves in each case.

11. a) i) Describe how the speed of waves in a ripple tank can be decreased
ii) Explain the effect of decreasing the speed of the wave in (a) (i) on frequency
b) With the aid of sketch diagrams, explain the effect of size of a gap on diffraction of waves
c) i) Give two reasons why sound is louder at night than during the day
ii) An echo-sounding equipment on a ship receives sound pulses reflected from the sea bed 0.02 seconds after they were sent out from it. If the speed of sound in water is $1500ms^{-1}$, calculate the depth of water under the ship.

Ans: ii) $\mathbf{15m}$

d) Identify two differences between water and sound waves

12. a) Define the following terms as applied to waves;
i) Amplitude
ii) Frequency
b) i) What is meant by interference of waves
ii) Using a labeled diagram show how circular water waves are reflected from a straight barrier

c) i) Use a labeled diagram to show the bands of an electromagnetic spectrum
ii) Calculate the frequency of a radio wave of wavelength 2m

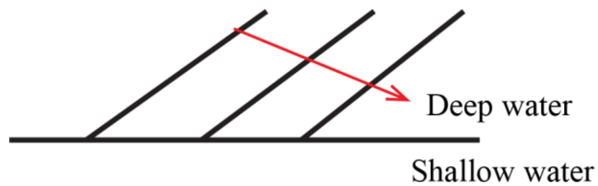
Ans: ii) $1.5 \times 10^3 Hz$

d) i) State any three effects of electromagnetic radiation on matter
ii) State two properties that electromagnetic waves have in common

13. a) i) Explain each of the following observations;
ii) Sound from a distant source is louder at night than during day time
b) Describe an experiment to show interference of sound waves
c) A man stands between two cliffs and makes a loud sound. He hears the first echo after 1 second and the second echo after a further 1 second. Find the distance between the cliffs

Ans: $495m$

d) Straight water waves travel from deep to shallow water as shown below

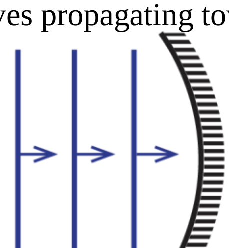


Copy and complete the wave front pattern in shallow water

14. a) State differences between sound and light waves
b) i) Explain how stationary waves are formed
ii) State three main characteristics of stationary waves
c) i) Define the terms frequency and wavelength as applied to sound
ii) Describe an experiment to demonstrate resonance in sound
d) The velocity and frequency of sound in air at a certain time were $320ms^{-1}$ and 200Hz respectively. At a later time, the air temperature changed and the velocity of sound in air was found to be $340ms^{-1}$. Determine the change in wavelength of sound.

Ans: $0.1m$

15. a) List three differences between sound waves and radio waves
b) Figure below shows waves propagating towards a concave reflector



i) Draw a diagram to show how the waves are reflected
ii) If the velocity of the waves is $320ms^{-1}$ and the distance between two successive crests is 10cm, find the period of the waves

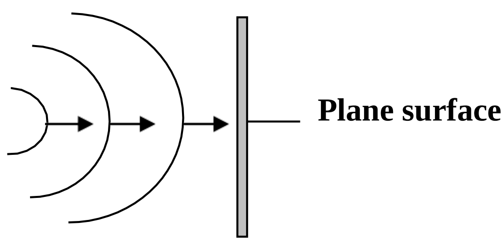
Ans: $3.125 \times 10^{-4} s$

c) Describe a simple echo method of determining the speed of sound in air.

16. a) What is meant by sound
b) Describe an experiment to show that sound waves require a material medium for transmission
c) Explain briefly the following;
i) A dog is more able than a human being to detect the presence of a thief tiptoeing at

night
ii) An approaching train can easily be detected by human ears placed close to the rails
d) A sound frequency 250Hz is produced 120m away from a high wall. If the speed of sound in air is $330ms^{-1}$, calculate the
i) Wavelength ii) Time it takes the sound wave to travel to and from the wall.
Ans: i) $1.32m$ ii) $0.73s$
17. a) i) State two factors which affect the frequency of the note produced by the string
ii) Why does the quality (timbre) of the sound produced by a violin differ from that produced by a piano?
b) Describe an experiment to show that sound waves do not travel through a vacuum
c) A pipe is closed at one end has a length of 10cm. if the velocity of sound in the air of the pipe is $340ms^{-1}$. Calculate
i) The fundamental frequency
ii) The first overtone
Ans: i) $850Hz$ ii) $2550Hz$
d) State four differences between sound waves and light waves
18. a) i) Describe a simple experiment to determine the velocity of sound in air
ii) What factors would affect the value of velocity of sound obtained from the experiment in (i) above
b) Explain why a musical note played on a piano sounds different from that played on a guitar
c) i) Calculate the wavelength of sound waves of frequency 3.3kHz and speed $330ms^{-1}$
ii) State four differences between sound and radio waves
Ans: i) $0.1m$

19. a) List three differences and three similarities between sound waves and light waves
b) The diagram below shows circular waves propagating towards a plane reflector



i) Draw a diagram to show how the waves will be reflected
ii) Calculate the frequency of the waves if their velocity and wavelength are $5.0ms^{-1}$ and 0.5m respectively
Ans: ii) $10Hz$
c) A man stands midway between two cliffs and makes a loud sound. He hears the first echo after 3 seconds. Find the distance between the cliffs, if the velocity of sound in air is $330ms^{-1}$.
Ans: $990m$
20. a) Define each of the following terms as applied to wave motion
i) Wave front
ii) Wavelength

b) The wavelength of radio wave is 10m. Calculate
   i) The frequency
   ii) The period of the wave

Ans: i) $\mathbf{3.0 \times 10^7 Hz}$ **ii)** $\mathbf{3.33 \times 10^{-8} s}$

c) Why does sound travel faster in solids than in gases

d) i) What is meant by the term resonance
   ii) The frequency of the third harmonic in a closed pipe is 280Hz. Find the length of the air column in the pipe.

Ans: ii) $\mathbf{0.75m}$