TOPIC: WAVES
General Objective
The Learner should be able to establish different sources of waves, the common properties of waves and their behaviour.

WAVES

WAVES AS A SOURCE OF ENERGY.
When a stone is dropped in a pool of still water, ripples spread out in a circular form. This constitutes what is called water waves. There are many different types of waves. These include radio and T.V. waves which are very useful in communication, microwaves used for cooking, water waves for production of electricity and sound waves used in ultra sounding in hospitals.

Since waves can do work as seen from the above examples, then waves are indeed a form of energy which when properly harnessed can provide a useful source of energy that is safe and environmentally friendly.

Earthquakes produce shock waves that are very destructive because they possess enormous and uncontrolled amounts of energy that shake and destroy buildings. A good example of shock waves is the wave known by the Japanese as Tsunami. These waves cause enormous damage to infrastructure and the environment.

In this chapter we shall study the production of waves and some common terms used in describing wave motion.

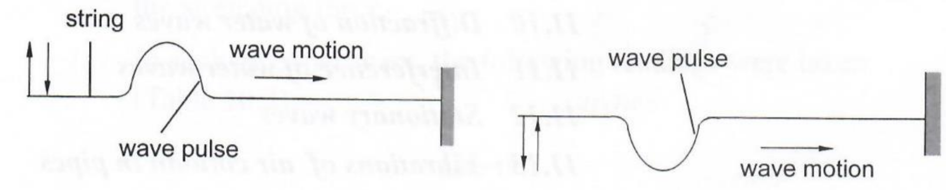
SUB-TOPIC: Wave motion (Progressive waves)
SPECIFIC OBJECTIVES.
The Learner should be able to;
- Explain how a wave is produced.
- Define technical terms used.
- Derive the relation $T = \frac{1}{f}$
- State transverse and longitudinal waves.
- Define progressive wave.
- State examples of progressive waves.
- Derive the wave equation.
- Use the wave equation to solve numerical problems.

DEFINITION OF A WAVE
A wave is a travelling disturbance which carries energy from one point to another without the net movement of the particles e.g. water waves, sound waves, waves formed when a string is plucked.

WAVE MOTION (PROGRESSIVE WAVES)
When a wave is set up on the medium, the particles of the medium vibrate about a mean position as the wave passes. The vibrations are passed from one particle to the next until the final destination is reached.

Formation of pulses and waves.

A pulse is a sudden short-lived disturbance that moves along a string or a spring.



Note: Pulses travel along the spring but the spring does not move.

In the rope and slinky spring experiments, pulses are produced regularly giving rise to a continuous wave motion.

Waves or a wave train is a continuous disturbance of the medium which arises due to regular pulses being produced.

WAVE MOTIOM (PROGRESSIVE WAVES)

This is a wave where energy travels with the same amplitude with respect to time and distance.

A progressive wave is categorized into two types of waves;

(i) Transverse waves

(ii) Longitudinal waves

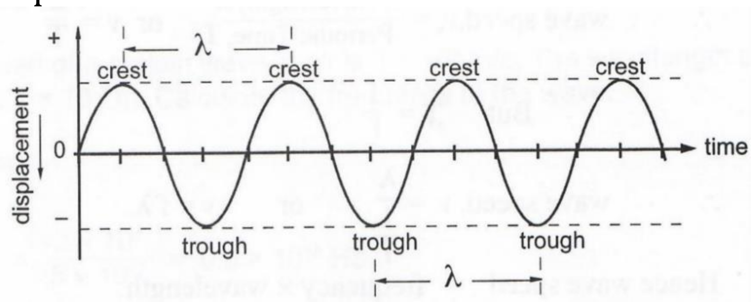
TRANSVERSE WAVES

A transverse wave is a wave in which the wave travels at right angles to the motion of the particles.

Its wave profile: It has crests and troughs.

A crest is the highest point of a transverse wave.

A trough is the lowest point of the transverse wave.



Examples of transverse waves are water waves, waves formed when a rope is moved up and down, light waves and all electromagnetic waves.

LONGITUDINAL WAVES

A longitudinal wave is a wave which travels parallel to the direction of the vibration of the particles of the medium.

Examples of longitudinal waves are sound waves.

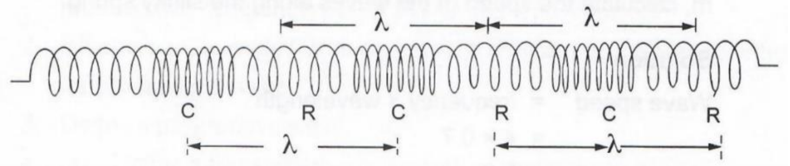
Longitudinal waves travel by formation of compressions and rare factions.

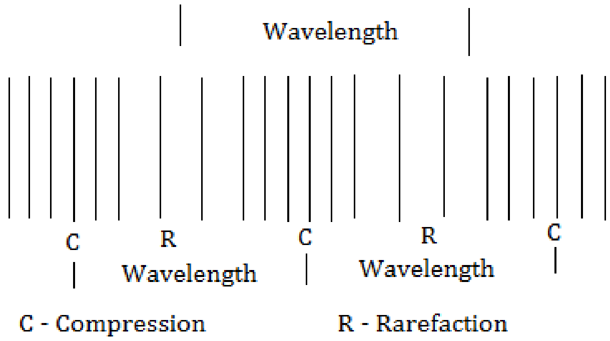
Compressions

These are regions where particles are close together and are hence under high pressure.

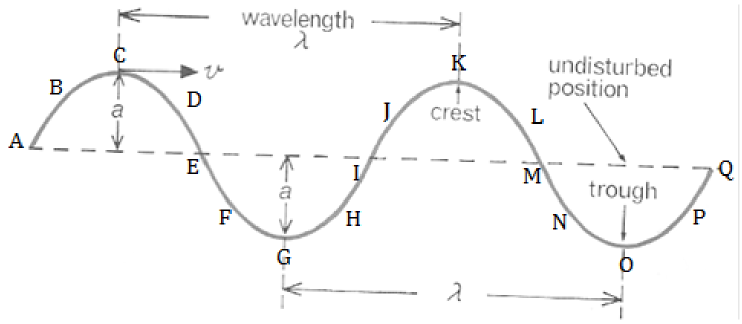
Rare factions

These are regions where particles are further apart and are hence under low pressure.





General representation of a wave and terms used.



TERMS USED IN DESCRIBING WAVES

1. **Rest position (Mean position), AQ**
   This is a line where particles are stationary
   or
   This is a line where the displacement of a particle is zero

2. **Cycle/Oscillation/Vibration – ABCDEFHI**
   This is one complete to and fro motion about the mean position.

3. **Displacement**
   This is the distance from the mean position.

4. **Amplitude, a**
   This is the maximum displacement of a wave particle from the rest position.
   Note: Amplitude is a measure of the energy of the wave. The bigger the amplitude, the more the energy of the wave.

5. **Phase**
   This is a state of motion of a particle in terms of Position (displacement) and direction of vibration.
   For example, in the diagram above the following pairs of particles are in phase; A,I and Q; B and J; C and K; D and L; E and M; F and N; G and O

Thus, particles are said to be in phase if they are at equal displacements in their paths and are moving in the same direction.

Particles are in **antiphase** when they are at the same displacement but moving in opposite directions.

6. **Wave length, λ** – lambda
This is the distance between two successive particles which are in phase e.g. A and I or I and Q or C and K or G and O.
Or
This is the distance between two successive crests or troughs. (Transverse wave)
Or
This is the distance covered by one complete cycle of a wave. E.g. A and I or I and Q or C
Or
This is the distance between two successive compressions or rare factions. (longitudinal wave)

7. **Periodic time or period**
This is the time taken by a wave to make one complete cycle (oscillation)
i.e. $T=\frac{t}{n}$ where n is number of cycles (oscillations).
T = periodic time or period.
t = time for n oscillations.

8. **Frequency**
This is the number of cycles (oscillations) a wave completes in one second
i.e. $f = \frac{n}{t}$
S.I. unit = Hertz (Hz)

9. A **hertz** is defined as one oscillation per second.

Larger frequency units in common use are
The kilohertz (kHz) = 1000Hz
The megahertz (MHz) = 1000000Hz
The gigahertz (GHz) = 1000000000Hz

Relationship between f and T
If f complete oscillations are made 1s
Then I oscillation is made in $\frac{1}{f}$
But this is the periodic time, T

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

Or

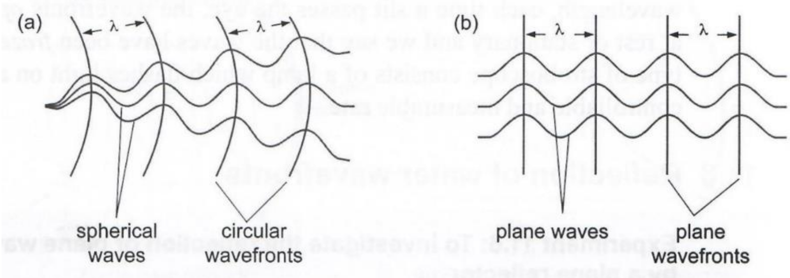
$$\text{Frequency} = \frac{\text{number of oscillations}}{\text{time taken}}$$

If the number of oscillations = 1 oscillation
then the time taken for one oscillation = periodic time, T

$$\therefore \text{Frequency} = \frac{\text{one oscillation}}{\text{periodic time}}$$

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

8. **Wave front**
Is any line or section taken through an advancing wave in which all the particles are in the same phase.
Or
A wavefront is an imaginary line which joins a set of particles which are in phase in a wave motion.



9. **Crest**
It is the maximum displaced point above the line of zero disturbance.

10. **Trough**
It is the maximum displaced point below line of zero disturbance.

11. **Wave velocity**
It is the distance which the wave travels in one second in a given direction.
SI unit is ms^{-1}.

THE WAVE EQUATION

$$\textbf{velocity/speed of the wave, V} = \frac{\textbf{Distance travelled by the wave in a particular direction}}{\textbf{Time}}$$

The distance travelled by a wave in one periodic time is the wavelength of the wave

$$\textbf{velocity/speed of the wave, V} = \frac{\textbf{Wavelength}, \lambda}{\textbf{Periodic Time, T}}$$

$$\textbf{velocity/speed of the wave, V} = \frac{\lambda}{\mathbf{T}}$$

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

$$\textbf{velocity/speed of the wave, V} = \frac{\lambda}{\frac{\mathbf{1}}{\mathbf{f}}}$$

$$\therefore \quad V = f\lambda$$

i.e. $Velocity = frequency\ x\ wavelength$

Examples

1. A slinky spring is made to vibrate in a transverse mode with a frequency of 4Hz. If the distance between two successive crests of the wave train is 0.7m, calculate the speed of the waves along the slinky spring. ($2.8ms^{-1}$)

2. Calculate the frequency of the wave if its speed is $30cms^{-1}$ and the wave length is 6cm. (5Hz)

3. A source of frequency 256Hz is set into vibration. Calculate the wave length of the waves produced, the speed of sound in air is $332ms^{-1}$ in air. (1.30m)

4. The speed of a certain wave in air is $3 \times 10^8 ms^{-1}$. The wave length of the wave is 5×10^{-7}m. calculate the frequency of the wave. (6×10^{14}Hz)

5. A radio station produces waves of wave length 10m. If the wave speed is $3 \times 10^8 ms^{-1}$ calculate
   (i) Frequency of radio wave.
   (ii) Period, T
   (iii) Number of cycles completed in 10^8

   (i) $\lambda = 10m$, $v = 3\times10^8$ m/s t= 10s

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

   $= \frac{3\times 10^8}{10}$

   $= 3\times10^{-1}$ Hz

   (ii) period $T = \frac{1}{f} = \frac{1}{3\times10^{-1}}$

   $= 3.3 \times10^{-8}$s

   (iii) Number of cycles $\rightarrow f = \frac{n}{t} \rightarrow n = f\,t$

   $= 3\times10^{-1} \times 10^8$

   $= 3\times10^7$ cycles

6. The distance between 10 consecutive crests is 36cm. Calculate the velocity of the wave. If the frequency of the wave is $12H_z$.

   $V = f\lambda$ but $d = (n - 1)\lambda$

   $= 12\times0.04$ $= (10- 1)\lambda$

   $= 0.48\ ms^{-1}$ $0.36 = 9\lambda$

   $\lambda = \frac{0.36}{9}$

   $= 0.04$m

7. A vibrator produces waves which travel 35 m in 2 seconds. If the waves produced are 5cm from each other, calculate;
   (a) the wave velocity

$$V = \frac{displacement}{time}$$

$$V = \frac{35}{2}$$

$$V = 17.5ms^{-1}$$

   (b) wave frequency

$$V = f\lambda$$
$$17.5 = 0.05f$$
$$f = 350\text{Hz}$$

Exercise.

1. A progressive wave travels a distance of 31.5m in 20 seconds. If the distance travelled is equivalent to the distance between 10 consecutive crests, calculate;
   (i) the wave length of the wave.
   (ii) the period of the wave.

2. Calculate the wavelength of a radio wave of frequency 2.5×10^5 Hz, given that the velocity of electromagnetic waves in free space is 2.5×10^5Hz, given that the velocity of electromagnetic waves in free space is $3.0 \times 10^8 \text{ms}^{-1}$.

3. A radio station broadcasts on frequency of 300kHz and the wavelength of its signal is 1000m. Calculate the speed of the radio wave in ms^{-1}.

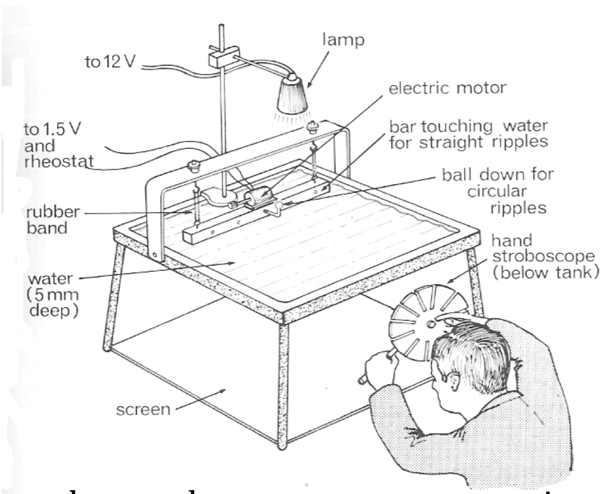
4. **Exercise 11.1 page 207-208 in Longhorn book 2**

SUB-TOPIC: Reflection and refraction of waves.
SPECIFIC OBJECTIVES.
The Learner should be able to;

- Define a ray and wave front.
- Demonstrate the relationship between rays and wave fronts.
- Carry out experiments on reflection and refraction of waves.
- Draw the reflection and refracted wave fronts.
- Use the relationship between rays and wave fronts, and the laws of reflection and refraction to predict the shape of the reflected and refracted wave fronts.

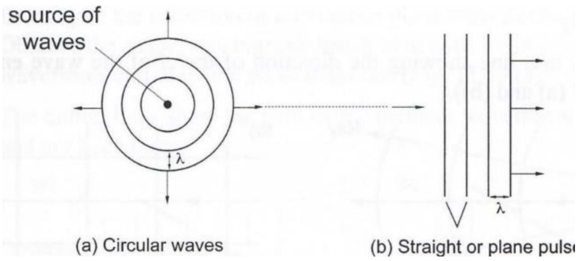
WATER WAVES

THE RIPPLE TANK

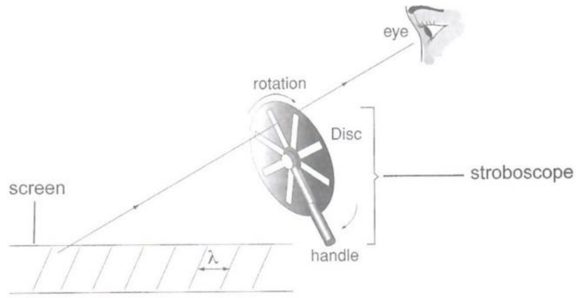


A ripple tank is an instrument used to study water wave properties. It is a shallow glass trough which is transparent. The images of the wave are projected on the screen which is placed below it.
Note: Water waves are also called ripples and are transverse in nature.
The waves are produced by means of a dipper which is either a strip of a metal or a sphere.

When the dipper is moved up and down by vibration of a small electric motor attached to it, the sphere produces circular wave fronts and the metal strip is used to produce planes waves.



A **stroboscope** helps to make the waves appear stationery and therefore allows the wave to be studied in detail.



It is a disc with equally spaced slits which can be rotated by hand or a motor.

When the frequency of the ripples is equal to the frequency of revolution of the disc then the waves seem to be stationary standstill) and not moving at all.
Now the wave fronts are said to be **frozen**

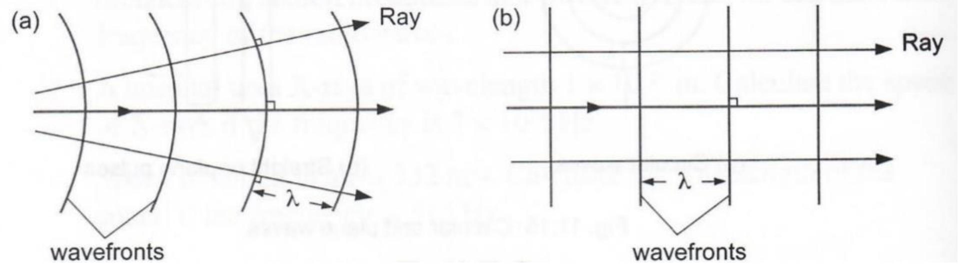
N.B: Therefore, the speed of the wave in a ripple tank can be reduced by reducing the depth of water in the tank.

The effect of reducing speed of waves is that wave length of water reduces but frequency does not. The frequency can only be changed by the source of wave.

WAVE PROPERTIES
TERMS USED

WAVEFRONTS AND RAYS
Wavefront
A wave front is an imaginary line which joins a set of particles in phase in a wave motion.

A ray
This is a line drawn perpendicular to the wave front showing the direction of travel of the wave energy.

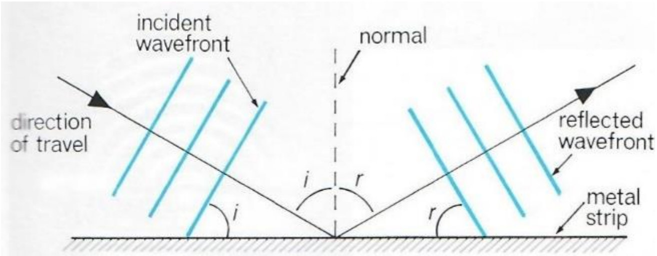


Wavefronts can be seen on the white paper underneath the ripple tank.

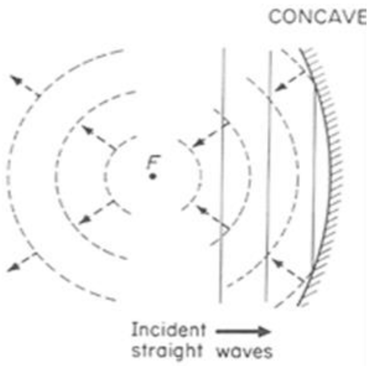
The wave produced in a ripple tank can undergo.
(a) Reflection
(b) Refraction
(c) Diffraction
(d) Interference

REFLECTION OF WAVES
A wave is reflected when a barrier is placed in its path.
The **shape of the reflected wave depends on the shape of the barrier.**
Water waves like light waves obey the laws of reflection.

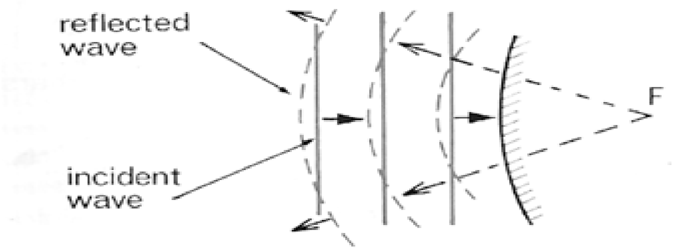
Reflection of plane wave
(a) On a plane surface.



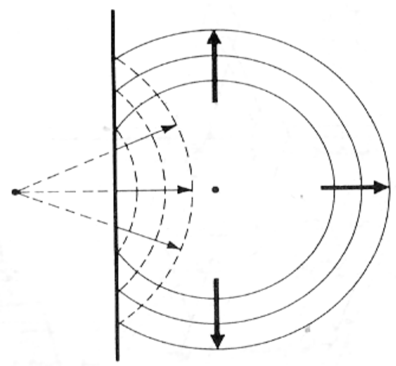
(b) On a concave reflector



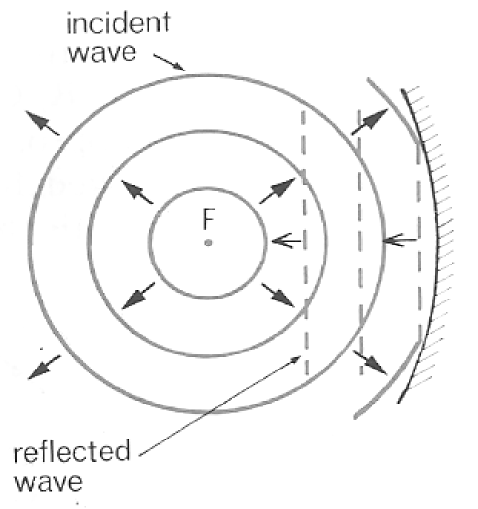
(c) On a convex reflector



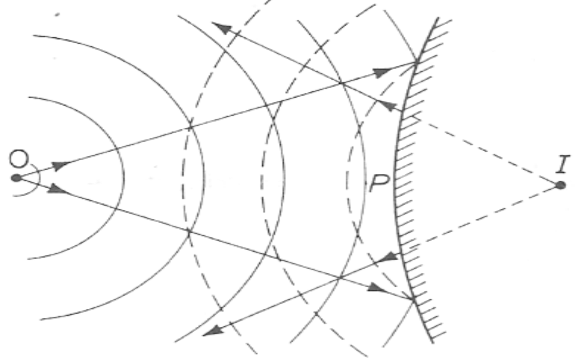
Reflection circular waves
(a) On a plane surface



(b) Reflection of circular wave concave reflector

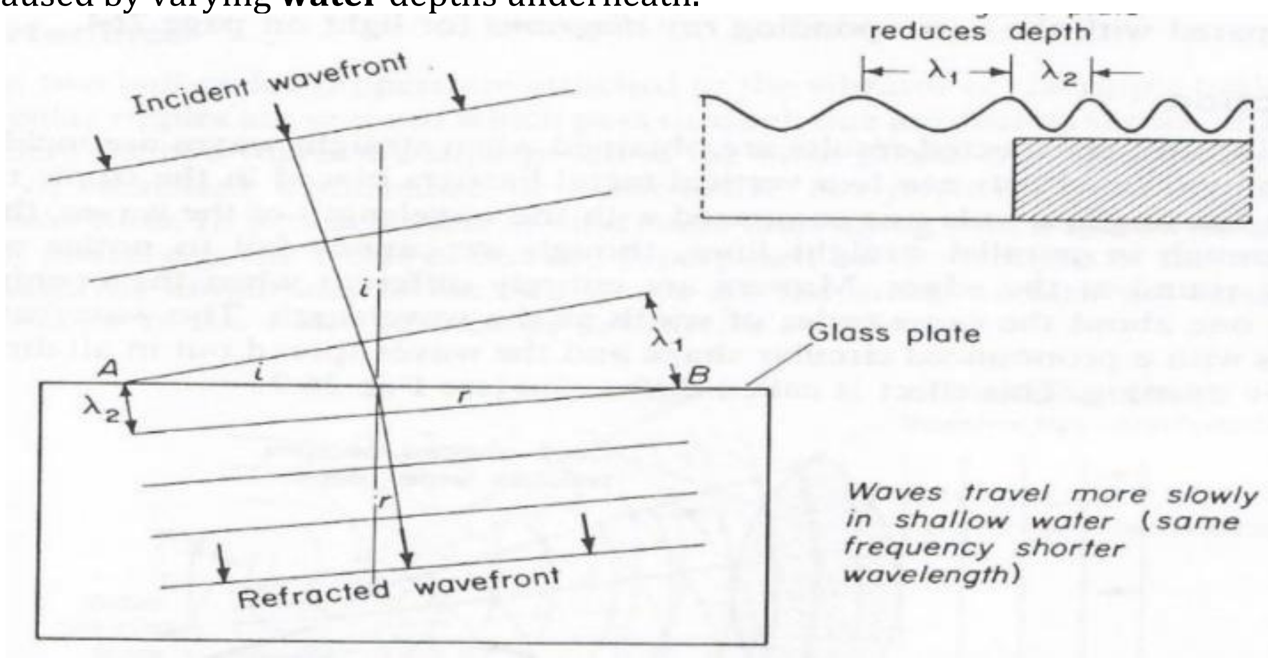


(c) Reflection of a circular wave on convex reflector

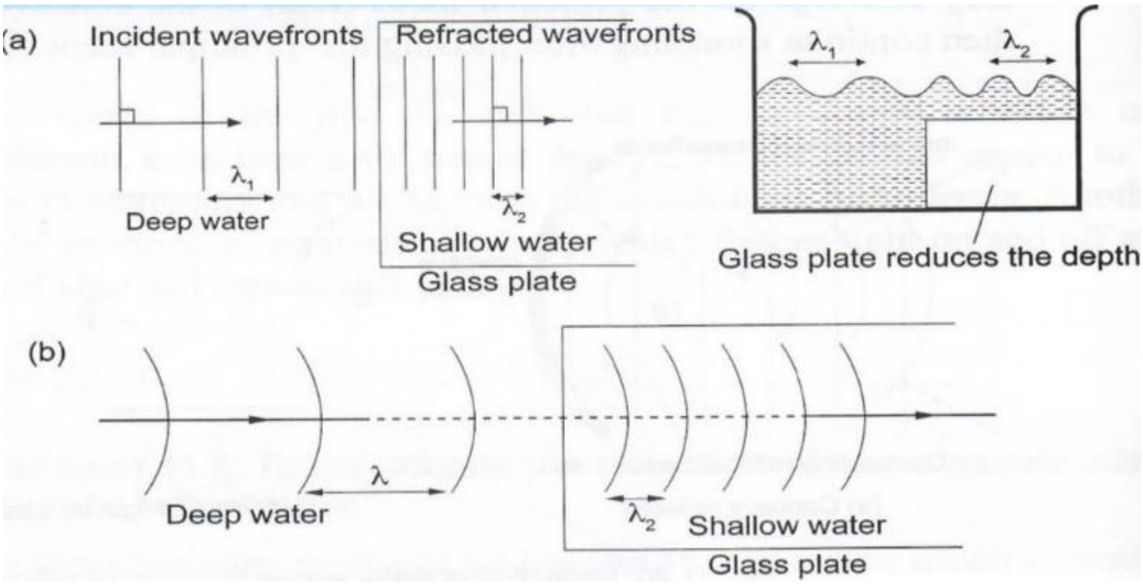


Note:
During reflection of water waves, the frequency and velocity of the wave **do not change**.

REFRACTION
This is the change in direction of wave motion as it moves in a medium of varying depths.
or
Refraction of water waves is the bending of **waves** due to changes in **wave** velocity caused by varying **water** depths underneath.



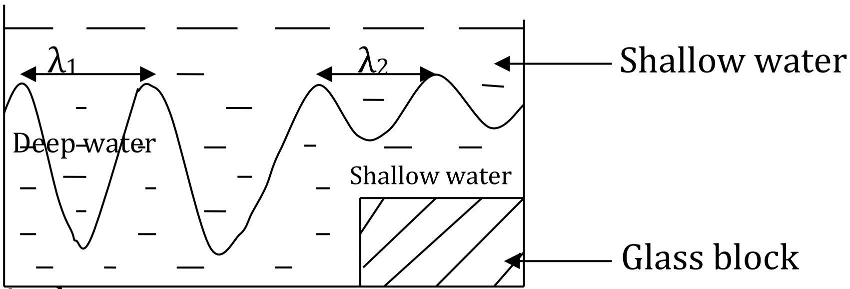
More illustrations of refraction of waves



Refraction is caused by change in wave length and velocity of the wave.

However, the frequency and the period are not affected because frequency depends on the vibrator or source of the wave.

In a ripple tank, the change in direction is brought about by the change in water depth.



λ_1 = wave length in deep water
λ_2 = wave length in shallow water

Note (i) $\lambda_1 > \lambda_2$

(ii) $v_1 = f\lambda$ and $v_2 = f\lambda_2$

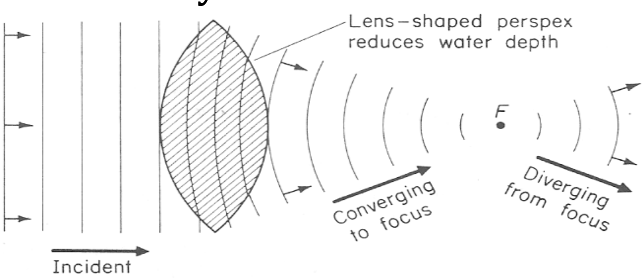
$\therefore v_1 > v_2$ When f – is constant.

Refractive index $n = \frac{\text{velocity in deep water}}{\text{velocity in shallow water}}$

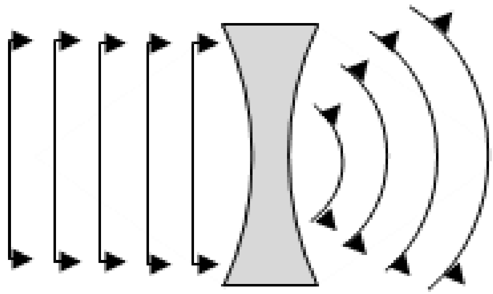
$= \frac{v_1}{v_2} = \frac{f\lambda_1}{f\lambda_2}$

$n = \frac{\lambda_1}{\lambda_2} = \frac{\text{wave length in deep water}}{\text{wave length in shallow water}}$

Refraction of plane waves by a convex lens



Refraction of plane waves by a concave lens



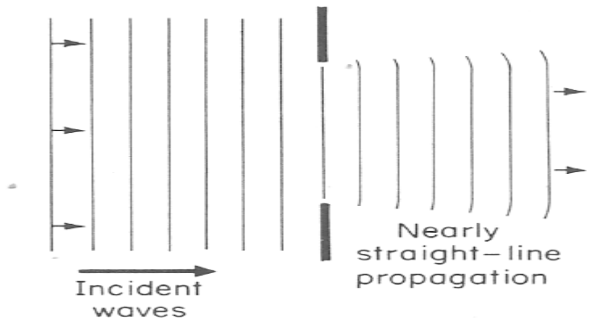
SUB-TOPIC: Diffraction
SPECIFIC OBJECTIVES.
The Learner should be able to;

- Define diffraction.
- Carry out practical investigation of diffraction by narrow and wide slits.
- State the relationship between wave length and amount of diffraction.
- Describe examples where diffraction is applied.

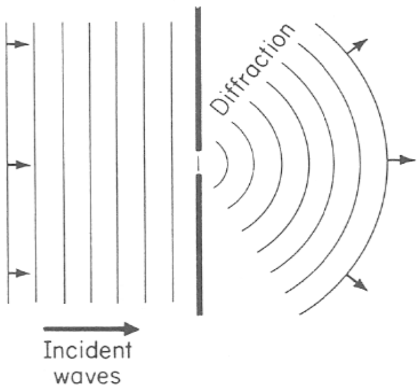
DIFFRACTION
This is the spreading of waves as they pass through holes, round corners or edges of obstacle.

It takes place when the diameter of the hole is in the order of wave length of the wave i.e. the smaller the gap the greater the degree of diffraction as shown below.

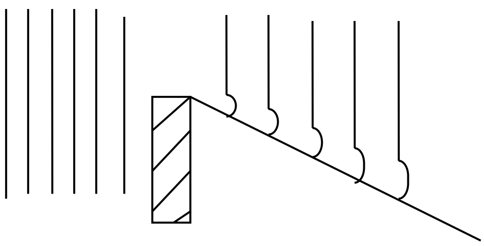
Wide gap



Narrow gap



Edge of obstacle



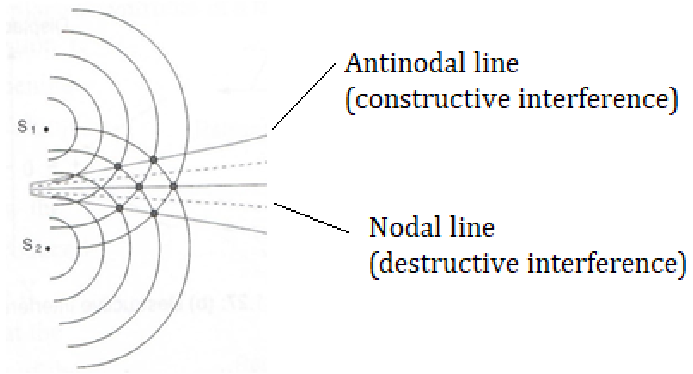
Note: Sound waves are more diffracted than **light waves** because their wave length is greater than that of light. Therefore, sound can be heard in hidden corners.
N.B: When waves undergo diffraction, wave length and velocity remain constant.

SUB-TOPIC: Interference of waves.
SPECIFIC OBJECTIVES.
The Learner should be able to;
- Define interference.
- Demonstrate interference patterns in a ripple tank.
- Mention applications of interference.

INTERFERENCE
This is the super imposition of two identical waves travelling in the same direction to form a single wave with a larger amplitude or smaller amplitude.

The two waves should be in phase (matching).

Note: the term interference is used to describe the effect of overlapping of the waves travelling through the same medium in the same direction.



Circular waves from sources s_1 and s_2 of the same frequency overlap in space.

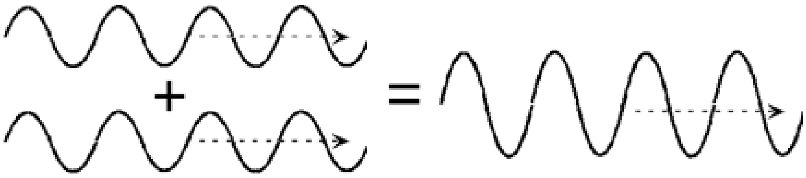
At points where the two waves are exactly in phase the amplitude of the wave is increased (increased disturbance) and **constructive interference** is said to occur.

A line joining such points in the direction of the wave is known as an **antinodal line**.
Note: Sources which produce waves in phase and of the same frequency are called **coherent sources.**

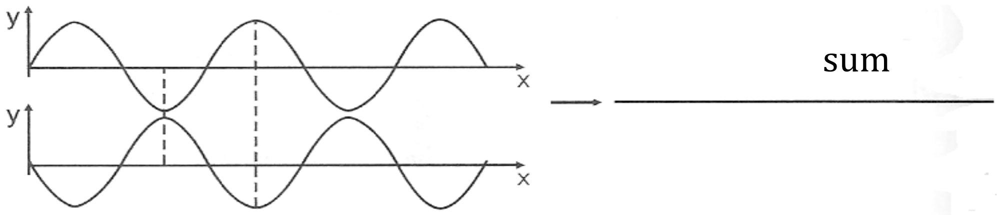
At points where the waves are exactly out of phase, the amplitude of the resultant wave is zero (or minimum) and **destructive interference** is said to occur.
A **nodal line** joins points of destructive interference.

The distance between the nodal (or antinodal) lines increases:-
(i) As the distance from the sources S_1 and S_2 increases
(ii) When the separation of S_1 and S_2 is made smaller
(iii) If the wavelength increases (i.e as frequency decreases)

CONSTRUCTIVE INTERFERENCE
This occurs when a crest from one wave source meets a crest from another source or a trough from one source meets a trough from another causing reinforcement of the wave i.e. increased disturbance is obtained.
The resulting amplitude is the sum of the individual amplitudes.



DESTRUCTIVE INTERFERENCE
This occurs when the crest of one wave meets a trough of another wave resulting in wave cancelling i.e.



Note: If the two water wave sources s_1 and s_2 are replaced two point light sources then, a similar constructive and destructive interference occurs. Increased brightness occurs along the antinodal lines and darkness along the nodal lines.

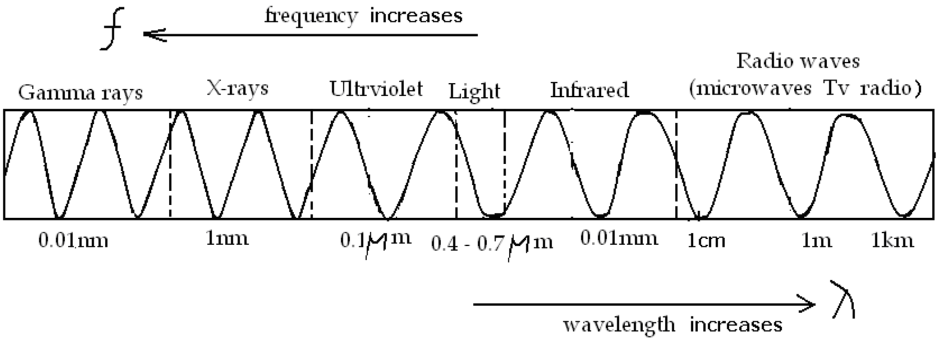
Attempt Exercise 11.2 in Longhorn book two pages 216-217

Waves are further categorized into two, namely;

(a) **Mechanical waves**
These are waves which require a medium for their transmission e.g sound waves, water waves etc.

(b) **Electromagnetic waves**
This is a family of waves which are made up of electric and magnetic vibrations of very high frequency.
An electromagnetic wave such as light from the sun travels most places of its journey through a vacuum before it reaches the earth.
This implies that, an electromagnetic wave **does not need a material medium for its transmission.**

ELECTROMANGETIC SPECTRUM
The table below shows the whole range of an electromagnetic wave.
Any electromagnetic range of wave length is referred to as a band.



Typical wavelength:

$1\text{nm} = 10^{-9}\text{m}$

$1\mu\text{m} = 10^{-6}\text{m}$

PROPERTIES OF ELECTROMAGNETIC WAVES

- Can travel through a vacuum
- Possess energy
- Travel with a speed of $3.0 \times 10^{8}\text{ms}^{-1}$ in a vacuum
- Are transverse
- Undergo interference.
- Do not need a material medium for its transmission.
- Carry no charge
- Can be emitted or absorbed by matter.

EFFECTS OF EACH BAND OF THE SPECTRUM ON MATTER

Gamma rays:

- Gamma rays destroy the body tissue especially when the body is exposed to it for a long time or many times.
- Gamma rays cause rubber solution to harden and lubricating oil to thicken when the rubber solution and lubricating oil are exposed to it.

X-rays:

- It destroys body tissue especially when they are exposed to it for a long time.
- X-rays may cause certain metals to emit electrons.

Ultra Violet

It causes;

- Certain metals to emit electrons
- Sun burn
- Blindness when too much of it falls into the eye
- Photosynthesis in green plants to take place.
- It can penetrate and kill certain bacteria and it is used in bacteriology.

Visible Spectrum

The visible spectrum;

- May change the apparent colour of an object
- Enable one to see
- May make an object appear bent

Infrared

- It is produced by all hot bodies such as the sun, red-hot or white-hot metals, furnace, electric fires and so on…..
- The eye does not respond to this radiation but sense organs in the skin detect it as heat.
- It can cause the body temperature to rise.

Radio Waves

They are used in radar and in new methods of cooking food right through quickly VHF (very high frequency).

Radio waves are transmitted due to electric and magnetic fields oscillating perpendicular to direction of the wave propagation. It is sent into space, and the wave is refracted away from the normal, until the critical angel is reached, when the wave undergoes total internal refraction, only to be received on the other side of the earth.

ORIGIN AND SOURCE OF ELECTROMAGNETIC WAVES

WAVE – BAND	ORIGIN	SOURCES
GAMMA RADIATION	Energy changes in nuclei of atoms	Radioactive substances
X – RADIATION	a. High energy changes in electron structure of atoms b. Decelereted electrons	X-ray tubes
ULTRAVIOLET RADIATION	Fairly high energy changes in electron structure of atoms	a. Very hot bodies, e.g., electric arc b. Electric discharge through gases, e.g., mercury vapur
VISIBLE RADIATION	Energy changes in electron structure of atoms	Various lamps, flames and anything at or above the temperature at which it begins to emit red light
INFRARED RADIATION	Low energy changes in electron structure of atoms	All matter over a wide range of temperature from absolute zero upwards
RADIO WAVES	a. High-frequency oscillatory electric currents b. Very low energy changes in electron structure of atoms	Radio transmitting circuits and associated aerial equipment

APPLICATIONS OF ELECTROMAGNETIC RADIATIONS.

TYPES OF RADIATION	APPLICATIONS
Gamma rays	• In medicine, gamma rays are used in gamma ray therapy i.e. they are used to destroy cancerous cells in human beings. However, care is usually taken not to kill healthy human cells.

	• The rays are also used in sterilisation of equipment in industries. • The rays are used in detecting flaws in metal castings. Note high voltage is required.
X-rays	• In medicine, X-rays are used in X-ray photography. • they are used treatment of cancerous cell and tumours. • In agriculture, X-rays are used to control pests. • In industries, they are used in detection of flaws and cracks. In metal castings. High voltage is required to operate X-ray machine.
Ultra-violet	• Ultra-violet radiations are used in burglar alarms, automatic door openers, counters, detecting forged bank notes, photo finishing in races. • Ultra-violet from the sun is used by human skin to produce vitamin D. • Since they cause fluorescence, they are used in advertising signs. • Excessive ultra-violet is harmful to the eye and skin.
Visible light	• Visible light is used by the human eye to enable us to see. • Plants use visible light to manufacture their food in the process called photosynthesis. • Ordinary photography uses visible light.
Infra-red	• Infra-red is used in infra-red photography. • It used in drying of objects and as a source of warmth.
Radiowaves	• Used in radio and television communication and also in radar detection.
Microwaves	• They are used in cooking and in radar communication.

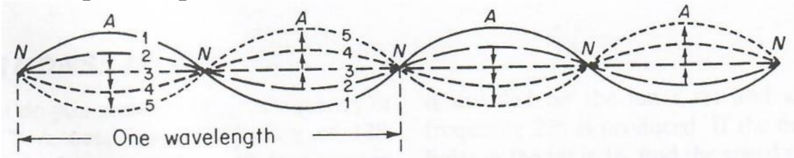
SUB-TOPIC: Stationary waves (Standing waves)
SPECIFIC OBJECTIVES.

The Learner should be able to;

- Define a stationary wave.
- Demonstrate formation of stationary waves.
- List characteristics of stationary waves.
- State examples of stationary waves.

STATIONARY WAVES OR STANDING WAVES

This is a wave formed when two identical progressive waves travelling in the opposite directions overlap or superimpose.



A **node** is a point of zero amplitude.
Or

Nodes- these are points that are permanently at rest.
No disturbance occurs at these points.

The particles at the node are not vibrating. They have zero energy and therefore they are at rest.
An **antinode** is a region of maximum amplitude.
i.e moving from a node, the amplitude of vibration progressively becomes greater up to the antinode.

$\therefore$ Wavelength = 2NN = 4NA
i.e two loops make one wavelength.

Conditions for stationary wave
(i) Waves must be of the same speed
(ii) Same frequency
(iii) Nearly of the same amplitude.

CHARACTERISTICS OF STATIONARY WAVES
(i) The wave profile is seen not moving along the profile.
(ii) The wave forms points of stationary or destructive interference called the nodes(N) and constructive interference called antinodes(A) as shown in the diagram above.
(iii) Particles of the medium at antinodes vibrate with maximum amplitude while at the nodes particles have zero amplitude.
(iv) The distance between the A and N is $\frac{1}{4}\lambda$ where λ, is the wavelength.
(v) The distance between A and the adjacent A is $\frac{1}{2}\lambda$.

Differences between progressive and stationary waves.

Progressive wave	Stationary wave
• There is continuous energy transfer through the medium.	• There is no energy transfer.
• All the particles vibrate with maximum amplitude at some time or the other.	• Only some particles vibrate with maximum amplitude and some do not vibrate at all.
• Crests and troughs (transverse) or compressions and rare factions (longitudinal) are formed.	• Nodes and antinodes are formed.
• Wavelength is the *distance* between two consecutive crests/troughs or compressions/rare factions.	• Wavelength is the distance between two alternate nodes or antinodes.
• A single wave moves in one direction.	• Two identical waves travelling in the opposite directions superimpose.

Stationary waves are produced in string musical instruments like guitar, sitar, etc and in air (wind) blown musical instruments like violin, bungles clarinet, trumpet, mouth-horn (harmonica) etc.

VIBRATION IN STRINGS

Many musical instruments use stretched strings to produce sound.

A string can be made to vibrate by plucking it like in a guitar or in a harp, pushing it in pianos. Different instruments produce sounds of different qualities even if they are of the same note.

The **ways** in which a string vibrates are called **harmonics**.

Sound is produced when nodes are formed at both ends of a stationary wave. Vibrating strings often display a **stationary wave**. The incident wave travels and is reflected back with the same speed and frequency.

TERMS USED

Fundamental frequency, f_o

This is the lowest frequency that can be obtained when a musical instrument is played. It is also known as the **natural frequency** of the string.

A stationary wave in its simplest form is a fundamental note.

Overtone

This is a note smaller in amplitude but of a higher frequency than the fundamental note that accompanies the fundamental note.

NB: Overtones determine the **quality** of sound.

Notes of the same pitch produce different sounds on different instruments because of **difference in quality or timbre**

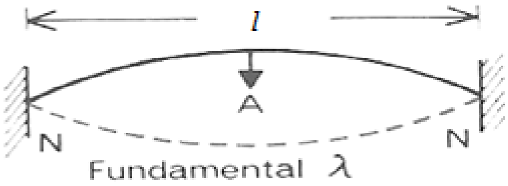
Sound of a tuning fork is pure and has no overtones.
1st, 2nd and 3rd above fundamental note are called 1st, 2nd and 3rd overtones respectively.

Harmonics

This is a whole number multiple of the fundamental frequency e.g. f_o, $2f_o$, $3f_o$,………. as 1st, 2nd and 3rd harmonics.

1st harmonic vibration

Fundamental note (1st harmonics) is obtained when a string is plucked **midway.**
Diagram



Let v = velocity of sound in air and l - the vibrating length of the string.

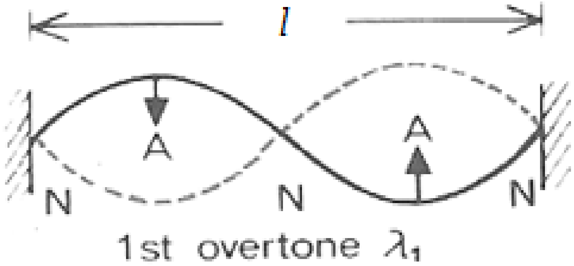
$l = \frac{1}{2}\lambda \rightarrow \lambda = 2l$

$v = \lambda f$

but $f_0 = \frac{v}{\lambda} = \frac{v}{2l}$

Fundamental frequency, $f_o = \frac{v}{2l}$

2nd harmonic (1st overtone): string plucked $\frac{1}{4}$ way)



$$l = \lambda$$

$$v = \lambda f$$

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

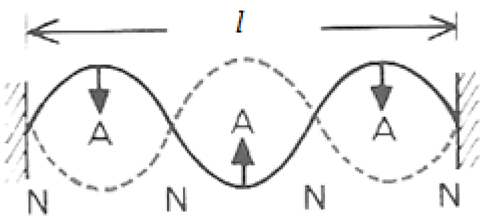
$$f_1 = 2\left(\frac{v}{2l}\right)$$

$$\mathbf{f_1 = 2f_o} \textbf{ – first overtone.}$$

3rd harmonics

3rd harmonics (2nd overtone): string plucked $\frac{1}{6}$ way from one end.

Diagram



$$l = \frac{3}{2}\lambda$$

$$\lambda = \frac{2}{3}l$$

$$V = \lambda f$$

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

$$f_3 = \frac{v}{\frac{2}{3}}$$

$$f_3 = 3\left(\frac{v}{2l}\right)$$

$$\mathbf{f_2 = 3f_o} \textbf{ – second overtone.}$$

Thus harmonics obtained from vibrating strings are f_o, $2f_o$, $3f_o$ etc. hence both even and odd harmonics are obtained.

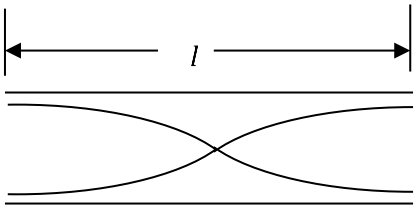
Vibrations of air in pipes. (stationary waves in pipes)
There are two types of pipes, namely **closed** and **open-ended**.
In a closed pipe one end is closed while in an open one both ends are open.
When a wave of a particular wave length and frequency is sent into a closed pipe, **reflection** of the wave occurs at the bottom of the pipe.
The reflected wave will interfere with the incident wave when the length of the wave is adjacent so that a node is reflected at the reflected surface, a standing wave is produced. The air column is now forced to vibrate at the same frequency as that of the source of the wave which is a natural frequency of the air column.
In closed pipes, only odd harmonics (f_o, $3f_o$, $5f_o$,$7f_o$etc) are obtained. **Because of the presence of odd harmonics, closed pipes are not as rich as open pipes.**

In closed pipes, **nodes are formed at closed ends** and **antinodes at open end.**

Open pipes
In open pipes, standing waves resulting into resonance are created when the incident waves are reflected by the air molecules at the other end.
Possible ways in which waves travel are shown below.

In open pipes, the sound notes are produced **when antinodes are formed at both ends.**

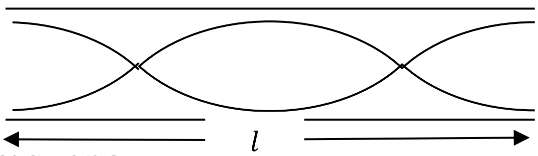
Open ended pipe
1st harmonic



The simplest harmonic, the fundamental, is one for which the length of the pipe is half of the wavelength.
Let λ_o be the wavelength of the fundamental note and V the velocity of sound.
Then $l = \frac{1}{2}\lambda o$,
$\therefore \lambda o = 2l$ and the fundamental frequency,

$$f_0 = \frac{V}{\lambda_0} = \frac{V}{2l}$$

2nd harmonic
The next harmonic to be obtained is such that the length l of the pipe is equal to the wavelength, say λ_1, as shown.



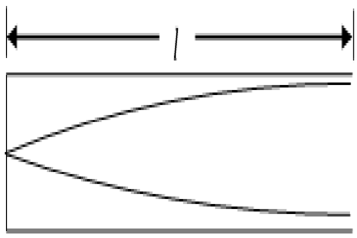
Thus, $l = \lambda_1$ and the frequency,

$$f_1 = \frac{V}{\lambda_1} = \frac{V}{l} = 2f_0$$

i.e, the frequency is twice the fundamental frequency. So, this is the second harmonic. In fact you may prove that in open-ended pipes all harmonics are possible.

NOTE:
Open ended pipes produce a more brilliant tone because they produce **more overtones** than the closed-ended pipes.
Open pipes are preferred to closed pipes because they give both odd and even harmonics hence better quality sound.

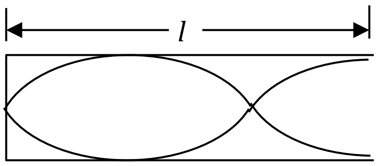
Closed-end pipe
1st harmonic



The simplest harmonic, the fundamental, is one for which the length of the pipe is one quarter of the wavelength.

Let λ_o be the wavelength of the fundamental note and V the velocity of sound.
Then $l = \frac{1}{4}\lambda o$
$\therefore \lambda_o = 4l$ and the fundamental frequency,
$f_o = \frac{V}{4l}$

2nd harmonic



The next harmonic to be obtained is such that the length *l* of the pipe is equal to $\frac{3}{4}$ of the wavelength, say λ_1, as shown.
Thus, $l = \frac{3}{4}\lambda_1$
$\therefore \lambda_1 = \frac{4}{3}l$, and the frequency, $f_1 = \frac{V}{\lambda_1} = \frac{3V}{4l} = 3f_o$
i.e, the frequency is three times the fundamental frequency. So, this is the third harmonic. But you realise that it is the first overtone.

You may prove that the next harmonic will have a frequency equal to $5f_o$, hence it will be the 5th harmonic.
Can you guess the next one?
It can be realised that only odd-numbered harmonics are possible in a closed pipe.

Attempt;
Exercise 11.3 on page 223
Revision exercise 11 on pages 225-231

SUB-TOPIC: Sound waves
SPECIFIC OBJECTIVES.
The Learner should be able to;
- Describe how sound is produced.
- Describe experiment to show the sound does not travel in vacuum.
- List other properties of sound.
- Explain factors that affect the velocity of sound in air.
- Compare the velocity of sound in different states of matter.
- Compare velocities of sound waves and light waves in air.

SOUNDS WAVES
Sound is a form of energy produced by vibrating objects.
E.g. when a tuning fork is struck on a desk and dipped in water, the water is splashed showing that the prongs are vibrating or when a guitar string is struck.

SPECTRUM OF SOUND WAVES

Frequency	0Hz	20Hz	20,000Hz
Type of sound	Subsonic sound	Audible sound waves	Ultra sonic sound wave.

SUBSONIC SOUND WAVES
These are not audible to human ear because of very low frequency of less than 20Hz.
AUDIBLE SOUND WAVES
These are audible to human ear.
This frequency ranges from 20Hz - 20 KHz. This range is known as the audible range.
ULTRA SONIC SOUND WAVES
These are sound waves whose frequencies are above 20kHz. They are not audible to human ears.
They are audible to whales, Dolphins, bats etc.

APPLICATION OF ULTRA SONIC SOUND WAVES
- They are used by bats to detect obstacles e.g. buildings a head.
- Used in spectacles of blind to detect obstacles.
- Used in radio therapy to detect cracks and faults on welded joints.
- Used in industries to detect rocks in seas using sonar.
- Used to measure the depth of seas and other bodies.

PROPERTIES OF SOUND WAVES
- Cannot travel in a vacuum because there is no material needed.
- Can cause interference.
- Can be reflected, refracted, diffracted, planes polarized and undergo interference.

- Travels with a speed $V = 330ms^{-1}$ in air.

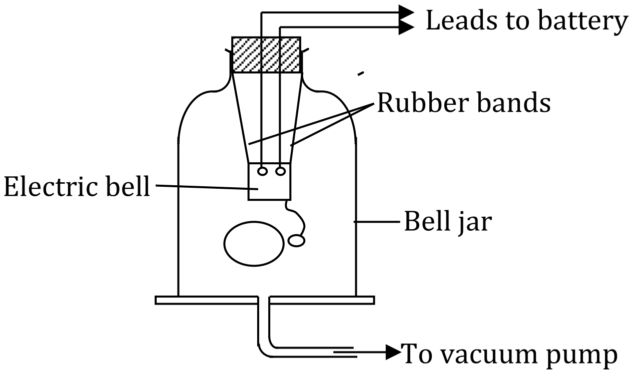
TRANSMISSION OF SOUND.

Sound requires a material medium for its transmission.
It travels through liquid, solids and gases, travels better in solids and does not travel through vacuum.

Speed of sound in air and in solids.

Imagine a long straight stretch of a railway track. On a particular day, you are not able to 'see' the approaching train (which is expected to come around that time) or 'hear' the sound produced by the expected train. If you place your ear quickly in the steel rails, you clearly hear the sound of the approaching train. This proves that sound waves reached your ear much faster through steel. Sound travels much faster in solids than in air.

EXPERIMENT TO SHOW THAT SOUND WAVES CAN NOT PASS THROUGH A VACCUM ORAN EXPERIMENT TO SHOW THAT SOUND IS A MECHANICAL WAVE.



Procedure

A small electric bell is hung from rubber bands inside a bell jar and switched on.
A vacuum pump connected to the bell jar is operated to evacuate it.

Observation:

As the air is sucked out, the sound of the bell becomes fainter and fainter until it dies out completely, although the hammer can still be seen striking the gong.

When now air is gradually allowed in, the bell is heard again and its loudness keeps on increasing with more let in.
This shows that actually sound requires a material medium for its propagation.

Factors affecting speed of sound in air

Temperature: A change in the temperature of the gas changes its density and hence affects the speed of sound through it. If temperature increases, the density of air decreases and hence the speed of sound increases. If the temperature decreases the reverse is the effect.

Humidity: Moist air containing water vapour is less dense than dry air. The density of water vapour is about 0.6 times that of dry air under the same temperature conditions.

If the humidity of air increases, density of air decreases and hence the speed of sound in air increases.

Early in the morning the percentage of humidity of air is more and sound travels faster in the morning air.

Density: If the density of a gas is more, the speed of sound is less. For example, the density of oxygen is 16 times the density of hydrogen and hence sound travels faster in hydrogen than in oxygen (speed of sound in hydrogen = 4× speed of sound in oxygen).

Wind: The wind drifts air through which the sound waves travel. If air blows in the direction of sound, then the speed of sound increases. The wind speed must be added to the speed of sound in air, to get the resultant speed. If the wind blows in the opposite direction to that of sound, then the sound travels more slowly.

NB: Pressure does not affect speed of sound in air.
Change in pressure of air does not affect speed of sound because density is not affected by change in pressure.

Lightning and thunder

Charged thunder clouds in the atmosphere produce thunder storms. These thunder storms produce a lot of sound which we hear as thunder on the earth.
Due to the spark discharge between two charged clouds or between a cloud and the earth, electric spark discharge, called lightning occurs.
Though the sound through thunder is produced first, we see the flash of lightning first and after a few seconds we hear the sound of thunder. This due to the fact that light travels much faster than sound in air.
Experiments have proved that speed of light in air (vacuum) is $3.0 \times 10^{8}\text{ms}^{-1}$

Example

The time interval between "seeing" the flash of lightning and the "hearing" the sound of thunderclouds is 5s.

(a) Calculate the distance between the thunder clouds and the observer on the earth.

$$\text{Speed of sound} = \frac{\text{distance}}{\text{time}}$$

$$V = \frac{\text{distance}}{\text{time}}$$

$$\text{Distance} = \text{velocity} \times \text{time}$$

$$\text{Distance} = 330 \times 5$$

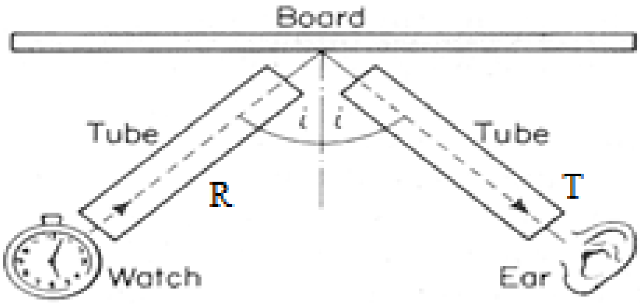
$$\text{Distance} = 1650\text{m}$$

(b) Explain why calculated distance is only approximate (speed of sound in air = 330ms^{-1})
The clouds maybe moving.

SUB-TOPIC: Reflection of sound waves.
SPECIFIC OBJECTIVES.
The Learner should be able to;

- Demonstrate reflection of sound and compare it to reflection of light at plane surfaces.
- Define echo, reverberation and the echelon echo.
- Describe the echo method to determine the velocity of sound in air.
- Describe applications of reflected waves.

EXPERIMENT TO VERIFY THE LAWS OF REFLECTION OF SOUND



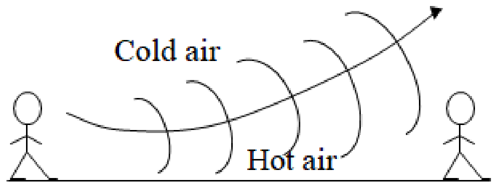
R – Closed tube
T – Open tube

A ticking clock is put in a tube R on a table and is made to face a hard plane surface e.g. a wall.
Tube T is put near the ear and is moved on either sides until the ticking sound of the clock is heard loudly.
Angles i and r are measured and these are the angles of incidence and reflection.
From the experiment, sound is heard distinctly due to reflection.
Angle of incidence, i and angle of reflection, r are equal and lie along XY in the same plane.
This verifies the laws of reflection.

Note: When sound waves meet a boundary between one medium and another, a part of it is reflected, a part of it is refracted and the remaining part is absorbed.
The relative amounts of these parts are determined by the size and nature of the boundary under consideration. The proportion of energy reflected is greater in the case of hard surfaces such as stone and metal.
An echo, a reflection of sound, is frequently heard from mountainous regions.
There is very little reflection from cloth, wool and foam rubber. Sound which is incident on such soft materials is, mainly transmitted through them or absorbed.

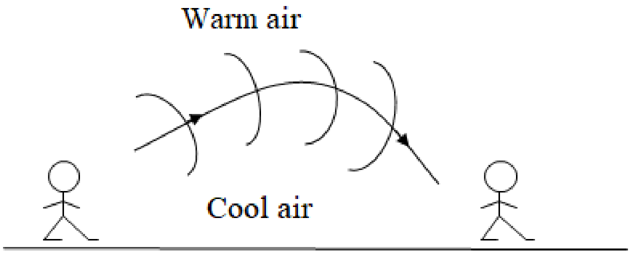
REFRACTION OF SOUND WAVES
Refraction occurs when speed of sound waves changes. The speed of sound in air is affected by temperature. Sound waves are refracted when they are passed through areas of different temperature. This explains why it is easy to hear sound waves from distant sources at night than during day.

REFRACTION OF SOUND DURING DAY.



During day, the ground is hot and this makes the layers of air near the ground to be hot while that above the ground is generally cool. The wave fronts from the source are refracted away from the ground.

REFRACTION OF SOUND DURING NIGHT



During night, the ground is cool and this makes layers of air near the ground to be cool while above to be warm. The wave fronts from the source are refracted towards the ground making it easier to hear sound waves over long distances.

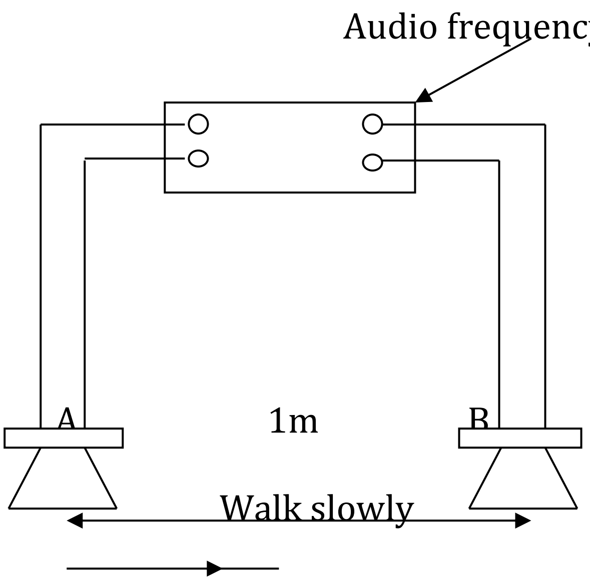
DIFFRACTION OF SOUND

This refers to the spreading of sound waves around corners or in gaps, when sound waves have wave length similar to the size of the gap, they are diffracted most. It is due to diffraction that a person behind the house can hear sound from inside

INTERFERENCE OF SOUND

When two sound waves from two different sources overlap, they produce regions of loud sound and regions of quiet sound. The regions of loud sound are said to undergo constructive interference while regions of quiet sound are said to undergo destructive interference.

EXPERIMENT TO SHOW INTERFERENCE OF SOUND



PROCEDURE

As one walks from A towards B reaches a point where sound is loudest and at this point interference is said to occur.

ECHOES

An echo is a reflected sound.

Echoes are produced when sound moves to and fro from a reflecting surface e.g. a cliff wall. The time taken before an echo arrives depends on the distance away from the reflecting surface. In order for a girl to hear the echo; sound travels a distance of 2d.

Velocity = $\frac{\text{distance}}{\text{time}}$

For an echo; velocity of sound = $\frac{2d}{t}$

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

Examples

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

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

$= \frac{2 \times 34}{0.2}$

$= 340 ms^{-1}$

2 A person standing 99m from a tall building claps his hands and hears an echo after 0.6 seconds. Calculate the velocity of sound in air.

$V = \frac{2d}{t} = \frac{2 \times 99}{0.6} = \frac{198}{0.6} = \underline{330} ms^{-1}$

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?

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

$8 \times 340 = \frac{2d}{8} \times 8$

$\frac{8 \times 340}{2} = \frac{2d}{2}$

1360 m= d

d = 1360m

4 A student is standing between two walls. He hears the first echo after 2 seconds and then another after a further 3 seconds. If the velocity of sound is $330ms^{-1}$, find the distance between the walls.

$V = \frac{2d_1}{t}$

$330 = \frac{2 \times d_1}{2}$

$\underline{d_1 = 330m}$

$V = \frac{2d_2}{t}$

$5 \times 330 = \frac{2 \times d_2}{5} \times 5$

$\frac{5 \times 330}{2} = \frac{2d_2}{2}$

= 825 m

= 330 + 825

= <u>1155m</u>

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. (Velocity of sound = $330ms^{-1}$)

$V= \frac{2d_1}{t}$

$3 \times 330 = \frac{2d_1}{3} \times 3$

$\frac{3 \times 330}{2} = \frac{2d_1}{2}$

$3 \times 165 = d_1$

$495 = d_1$

$d_1 = 495m$

$d_1 = d_2$

$d_1 + d_2 = 495 + 495$

$= \underline{990m}$

EXERCISE

1. A man stands in front of a cliff and makes a loud sound. He hears the echo after 1.2s. if the speed of sound in air is $330ms^{-1}$. Calculate the distance between the man and the cliff.

2. A man standing between two parallel cliffs fires a gun. He hears the first echo after 1.5s and second echo after 2.5s
   (a) What is the distance between the cliffs?
   (b) When does he hear the third echo? (Take speed of sound in air to be $336ms^{-1}$)

MEASUREMENT OF VELOCITY OF SOUND USING AN ECHO METHOD

Two experimenters standing at least 100m from a wall are required.
One claps together two pieces of wood and listens to echoes.
He keeps clapping and gradually changing the frequency of the clapping until apparently no echo is heard.
Then his colleague starts the stop clock and finds the time for a good number of claps e.g 30 or more.
The time taken between claps is calculated. i.e. $\frac{t}{N}$
t = total time for N claps.

$$\text{Then, speed of sound} = \frac{\text{2 x distance from the wall}}{\text{Time between claps}}$$

Example
A student made 50 claps in one minute. If the velocity of sound is $330ms^{-1}$, find the distance between the student and the wall.

$$V= \frac{2dN}{t}$$

$$60 \times 330 = \frac{2 \times d \times 50}{60} \times 60$$

$$\frac{60 \times 330}{100} = \frac{100d}{100}$$

$$198 = d$$

$$\underline{d = 198m}$$

NB: The value of velocity obtained may be an error due to the following factors:

- Human reaction time in timing the sound when it is made and heard.
- Interference due to sound and echo when the distance between is small.
- Wind .

REVERBERATION AND ECHELON ECHO

REVERBERATION

In a large hall where there are many reflecting walls, multiple (repeated) reflections occur and cause or create an impression that sound lasts for a longer time such that when somebody makes a sound; it appears as if it is prolonged. This is called reverberation.

Definition of Reverberation

Reverberation is the effect of the original sound being prolonged due to multiple reflections.
In large halls multiple sound reflections can occur from roofs and floor.

In some cases, this is undesirable e.g. in a concert hall. It may take about 5s for the organ to die away after the organist has stopped playing, whereas when the cathedral is full of people, this may take about 1s.
This is because in an empty cathedral, the only surfaces to absorb sound are the roof, walls, floor and may be some additional furniture implying longer time for sound to die out but when it is full of people, people's soft bodies and clothes occupy much of the space and on the whole reflection of sound is reduced.

ADVANTAGES OF REVERBERATION

In grammar, reverberation is used in producing sound. Complete absence of reverberation makes speeches inaudible.

DISADVANTAGES OF REVERBERATION

During speeches, there is a nuisance because the sound becomes unclear.

PREVENTION OF REVERBERATION

The internal surfaces of a hall should be covering the sound absorbing material called acoustic materials.

WHY ECHOES ARE NOT HEARD IN SMALL ROOMS?

This is because the distance between the source and reflected sound is so **small** such that the incident sound mixes up with the reflected sound making it harder for the ear to differentiate between the two

Echelon echo

If two reflecting walls are not far apart, any sudden sound produced between them will be reflected back and forth and may continue to reach the listener between the walls at regular intervals. A note of definite frequency is produced.
Similarly, if a sharp sound is made in front of a flight of stairs of equal width, a musical note may be heard. This is due to reflections taking place from various steps and following each other with the frequency of the audible sound produced. The effect is known as **echelon effect**.
The effect can be avoided by breaking at intervals the regularity of equal spacing between the steps.

Acoustic in buildings

The characteristics of a building in relation to sound (i.e the absorption or reflecting behavior for sound), is termed the **acoustics of a building.**
A building is said to be **acoustically dead** if no multiple reflections of sound occur in it. Such rooms are used in investigation of the properties of sound equipment.

It is sometimes observed that a speech made in a certain hall or building is not audible at certain places in the hall or there is so much of interference that it is difficult to understand what is spoken. It is. In fact, necessary to keep some important points in mind like echo, echelon effect, reverberation etc. while designing and constructing a hall for public speaking or a hall for entertainment so that the reception of sound is clear and perfect from every point in the hall and there are no acoustical defects.
Experiments have revealed that a sound produced can be heard directly up to a distance of about 30m in the front, about 23m on each side and about 9m at the back.

Applications of Echoes

- In fathometers for measuring the depth of the sea. (sonar or sound navigation and ranging)
- In ultrasound equipment used in hospitals for producing pictures of internal parts of the body.
- In industries for checking the quality of certain products.
- In radar equipment for finding distances of various objects from the transmitter using high frequency radio waves.
- In public halls and churches, a parabolic sound board is often placed behind the speaker. It reflects the sound waves back to the audience and thus increasing the loudness of the sound.
- Sound waves undergo total internal reflection just like light. Speaking metal tubes are used to pass message on ships.

Comparison of Sound Waves and Light Waves

SOUND WAVES	LIGHT WAVES
• Mechanical in nature • Longitudinal in propagation • Need a material medium • Travel at much lower speeds • Have longer wavelength	• Electromagnetic in nature • Transverse in nature • Can travel in vacuum • Travel at much higher speed • Have shorter wavelength

<u>Question</u>

Distinguish between (i) sound waves and light waves.
sound waves and water waves
(ii) A man standing midway between two cliffs makes a sound. He hears the first echo after 3s. Calculate the distance between the two cliffs (Velocity of sound in air = $330ms^{-1}$)

SUB-TOPIC: Resonance and musical instruments.
SPECIFIC OBJECTIVES.
The Learner should be able to;
- Define forcing and forced (natural) frequency.
- Define resonance.
- Practically demonstrate resonance.
- Define beats and explain how they are formed.
- Define loudness, pitch and intensity, and state factors affecting them.
- Compare intensities at different distances mathematically from the source.
- Define fundamental frequency, overtones, harmonics and octaves, and relate them to quality of sound.
- Determine factors affecting the pitch of a note from a vibration string.
- Describe applications of resonance in stretched string instruments.

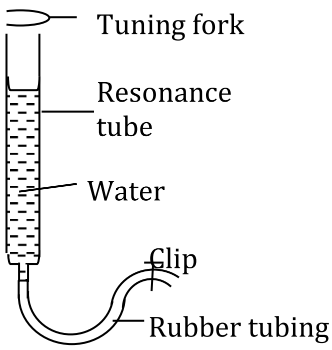
RESONANCE AND MUSICAL INSTRUMENTS.
RESONANCE
This is when a body or system is set into vibration at its own natural frequency as a result of impulses received from some other system which is vibrating with the same frequency.

Everyone knows that the best way to set a child's swing in motion is to give it small pushes in time with the natural period of swing. This is an example of a general principle in physics which called **resonance.**

Applications of Resonance.
- In determining the speed of sound in air using a tuning fork and the resonance tube.
- In tuning strings of a musical instrument e.g a guitar and tuning electrical circuits which include indicators.

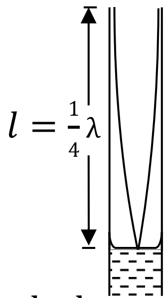
Dangers of Resonance
- Causes bridges to collapse as soldier's match across them. This can be prevented by stopping the matching.
- Causes buildings to collapse due to earthquake.
- Chimneys can also collapse due to strong resonance.

Experiment: To Demonstrate Resonance in a closed Tube.

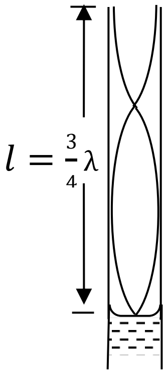


A resonance tube is almost filled with water
A tuning fork of known frequency is sounded near and above the mouth of the tube while the water level is allowed to fall gradually using the clip.

Observation:
At some level the sound suddenly becomes louder. Resonance is said to have occurred.
Explanation

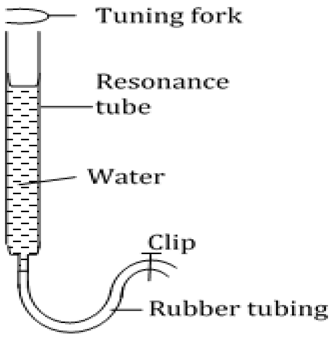


Sound from the tuning fork travels down and is reflected by the water surface and a stationary wave is formed of a node corresponds to the water level.
The air column in the tube = $\frac{1}{4}\lambda$



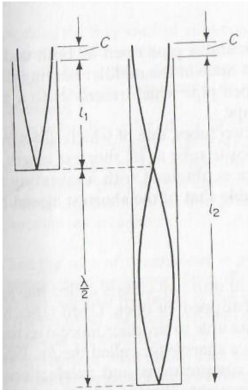
If the water level is lowered further, another point is reached lower down for which resonance again occurs. The air column = $\frac{3}{4}\lambda$

Experiment to measure speed of sound in air by the resonance tube



The resonance tube is first filled with water
A tuning fork of **known frequency** is sounded near and above the mouth of the tube, and the water level is lowered slowly until the sound increases in intensity. Then the length of the air column is measured and noted. It is equal to a quarter of the wavelength (λ).
Let l = length of the air column
f = frequency of the fork
Then $\lambda = 4l$
$\therefore$ Velocity, $V = 4fl$

NOTE: End correction, c
There is a difficulty in the above method. The antinode at the top does not coincide exactly with the top of the tube, but projects slightly above it by an amount which is called the **end correction, c.**
Fortunately, the difficulty may be overcome by measuring the length of the tube for the second position of resonance as well as the first.



By subtracting one from the other, the end correction is eliminated and we obtain a correct value for half a wavelength.
Thus, if length of tube for 1st position of resonance $= l_1$
And length of the tube for 2nd position of resonance $= l_2$

then $\frac{\lambda}{4} = l_1 + c$…………….(1)

$\frac{3\lambda}{4} = l_2 + c$……………………………..(2)

$$\frac{\lambda}{2} = l_2 - l_1$$

$$\lambda = 2(l_2 - l_1)$$

substituting in $v = f\lambda$

We have $v = 2f(l_2 - l_1)$

Free, forced and resonant vibrations.
Free vibrations.
When a pendulum bob is displaced slightly from its normal position and then left to go, it begins to vibrate to and fro with its natural time period depending on its length and acceleration due to gravity at that place.
Similarly, a child's swing, a violin swing etc vibrates with their natural periods.

Definition
Free vibrations which a body executes undisturbed by the influence of any other body or system. The corresponding frequency of vibration is known as the natural frequency (f_0)

Natural frequency, f_0 is the frequency at which the system will oscillate after and external force is applied and then removed.

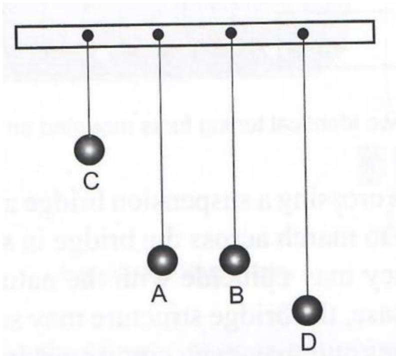
Forced vibrations.
This is when a body is made to vibrate with a frequency other than its own national frequency.

For example, when a tuning fork is set into vibrations and then its stem is pressed against the top surface of the table. The table begins to vibrate with a frequency equal to that of tuning fork. Such vibrations are called forced vibrations.

Similarly, all of us talk with our natural frequency. If we talk with an "affected" tone by putting on an accent, we are forcing ourselves to talk with a forced or an artificial frequency. Thus, when a body is compelled to vibrate with a frequency other than its own natural frequency, it is said to be executing forced vibrations.

The sounding boards or boxes of all the stringed musical such as a guitar, violin etc are forced to vibrate with frequencies equal to the natural frequencies of the vibrating strings.

Resonant vibrations.



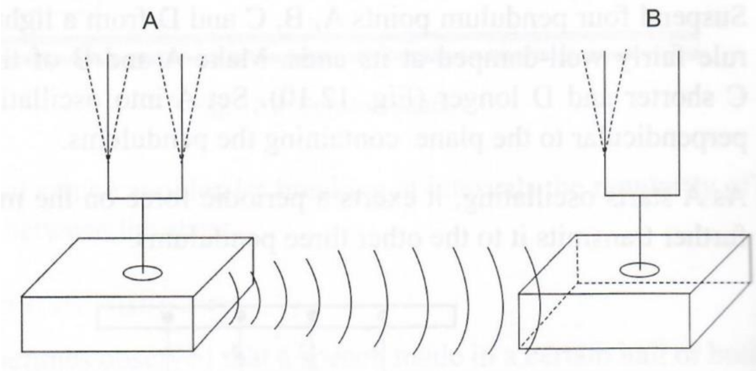
Four pendulum points A, B, C and D are suspended from a light wooden metre rule fairly well-damped at its ends. A and B are made of the same length, C shorter and D longer. A is set into oscillations, in a plane perpendicular to the plane containing the pendulums.

As A starts oscillating, it exerts a periodic force on the metre rule which further transmits it to the other three pendulums.
On watching the pendulums, it is seen that B soon begins to vibrate with a large amplitude. The reason is that the impulses imparted to B through the metre rule arrive at intervals equal its own natural time period.
The frequency of B is equal to the frequency of A and the its amplitude is large.
The vibrations of B are thus resonant vibrations or B is said to be in **unison** with A. We say resonance has taken place.

Resonance is a phenomenon where one system in a vibrating state induces vibrations to another system by which both vibrate with the same natural frequency.

The time periods of the pendulums C and D are different from that of A. The impulses do not reach them fitting with their natural time periods. They first make rather irregular motions but eventually settle down to vibrate with the frequency of A.
The pendulums and D are said to undergo forced vibrations. These vibrations never attain large amplitude.
Illustrations of resonance.

1.



A and B are two identical tuning forks of the same frequency, mounted on resonating boxes with their open ends facing each other as shown in the diagrams above, A is set into vibrations and the vibrations are stopped after a few seconds, by bonding its prong with the hand, the other for B will be found to vibrate. Notice that there is no direct contact between the two. The waves produced by A act on the fork B regularly and force it into vibrations. Since their frequencies are equal resonance takes place.

2. Soldiers crossing a suspension bridge are warned to “break” their steps and not to march across the bridge in step. If they march in step, their frequency may coincide with natural frequency of the bridge. In such a case, the bridge structure may set into large amplitude resonant vibrations and even crash down.

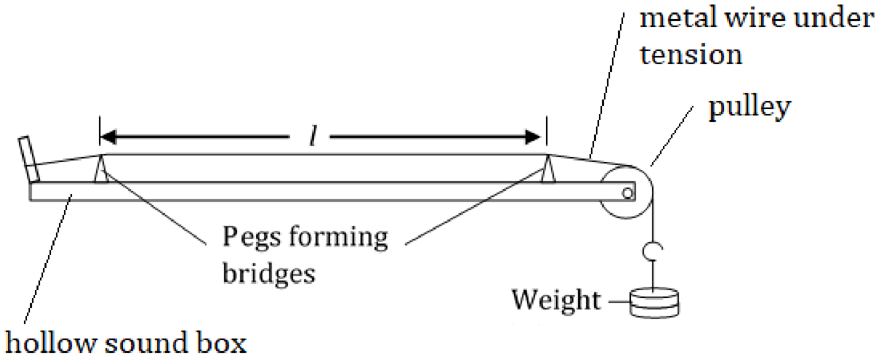
3. If we play a particular note on a piano, a glass bottle placed on the top of a piano or a nearby shelf is set into resonant vibrations and may even break if the amplitude of vibration is large.

4. When a car is running at a particular speed, brisk rattling sound is heard. But the sound disappears if the speed changes. The sound is due to resonance taking place between the car engine and the rattling object.

5. Modern toys have been constructed in a way that they are able to respond to a particular word of command. This is due to resonant vibrations of a “disc” placed inside the toy when some sound of a particular frequency falls on it.

6. In a radio or transistor receiver set, a large current flows in a particular circuit called the “tuning” circuit, if the frequency of the electrical vibrations of the circuit coincides with the frequency of one of the radio waves in the atmosphere. Different radio stations in the world broadcast news at different frequencies.

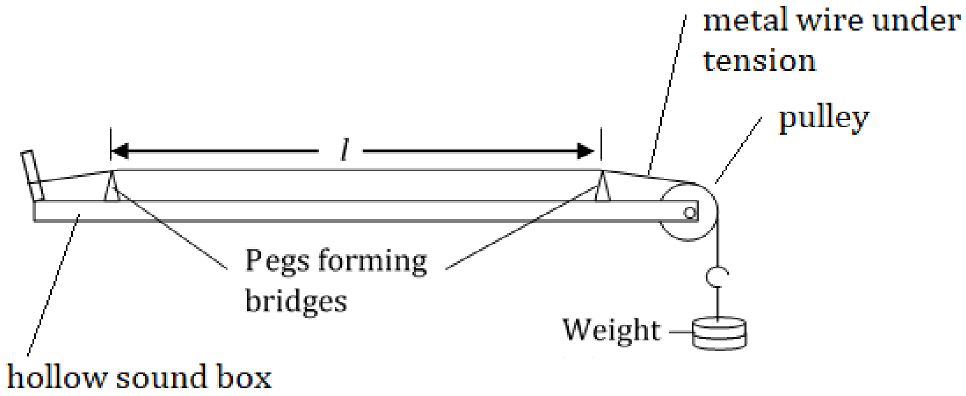
The Sonometer



This is an instrument used for studying behavior of vibrating strings.
It consists of a string or wire kept in tension by either a weight or other means and a long sounding board or box with a peg at one end and a pulley at the other. One end of a string or wire is attached to the peg at one and the end passes over the pulley. Iron weights are hung from the wire to vary the tension.
Two bridges are provided for the purpose of altering the effective vibrating length of the wire.

If the string is gently plucked or bowed in the centre, waves travel out to the bridges and are then reflected back, thus setting up a stationary wave of the string (not of air).

An experiment to demonstrate resonance with a sonometer.

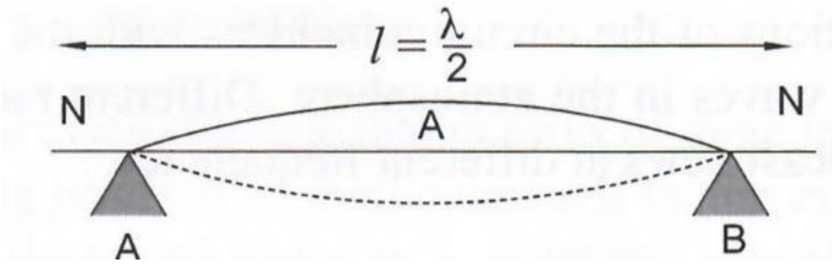


A tuning fork of known frequency is set into vibrations and the stem of the vibrating tuning fork is gently pressed on the sonometer box. The tuning fork in the vibrating state "forces" the box to vibrate, the vibrations are transmitted through the box to the wire.
The position of the movable bridge is gradually altered, so that the shortest vibrating length l, is such that the frequency of the wire is equal to the frequency of the tuning fork.
Therefore, resonance has taken place. The wire vibrates with maximum amplitude.

To check resonance in this position, a small piece of paper in the form of an inverted V can be placed in the middle of the wire. The paper rider will vibrate considerably and is thrown off the wire.

When resonance takes place for the first time, the length l, of the wire $= \frac{\lambda}{2}$.

The simplest wave produced will be that due to vibrations of the string as a single segment. At the same time, it gives out a note of definite pitch which is termed as the **fundamental**.



If l is the distance between the pegs, then the fundamental has a wavelength equal to $2l$.

Factors affecting the frequency of vibrating string

(i) **Tension**: The higher the tension the higher the frequency.
(ii) **Length**: The longer the string the lower the frequency.
(iii) **Mass per unit length**: The thicker the lower the frequency.

MUSICAL SOUNDS.

Music.

This is an organized sound produced by regular and periodic vibrations.
Eg. Sound from a guitar, sound from a tuning fork set into vibrations.

Noise.

This is a disorganized sound produced by irregular vibrations. e.g thunder sound, rattling sound of some parts of a car, sound from slamming of a door.

Musical note/ tone

This is a single sound of a certain pitch made by a musical instrument or voice.

Or

It is sound of regular frequency.

Characteristics of musical notes

There are three important characteristics of musical sounds namely;

(a) Pitch
(b) Intensity and loudness
(c) Quality

Pitch

This is the degree of highness or lowness of a tone.
It depends on the frequency of sound produced, the higher the frequency the higher the pitch.
It is the characteristic of a musical sound which enables us to distinguish a **shrill** (high-pitched and piercing) note from a **hoarse** (rough and harsh) one.
The voice of a woman or of children, usually is of high pitch than of men. Similarly, the note produced by buzzing of a bee or the humming of a mosquito is of much higher pitch than the roaring of a lion, though the latter is much louder.
Pitch is purely qualitative and cannot be measured quantitatively.
Note: Pitch is not frequency. Frequency is a physical quantity and can be measured. Pitch cannot be measured.

Factors that affect pitch.

(i) Frequency of the sound produced.
Pitch is directly proportional to frequency.

(ii) Relative motion between the source and the observer.
When a source of sound is approaching a listener or is being approached by a listener, the pitch (frequency) of sound of sound appears to be higher than the original frequency. On the other hand, if the source is away from the listener or the listener is moving away from the source, the pitch appears to fall below the original frequency. (This effect is known as the Doppler's effect)

Intensity and loudness

Intensity of a sound wave is defined as the rate of flow of energy per unit area perpendicular to the direction of the wave.

Loudness

This is the degree of sensation of sound produced in the ear.
This depends upon the intensity of sound waves producing the sound and the response of the ear. In general, the sound waves of higher intensity are louder.

Intensity of sound depends on the following factors;

(i) Amplitude of vibrating body
The intensity or loudness I, of sound is directly proportional to the square of the amplitude of the vibrating body.
If the amplitude of the vibrating body is doubled, the loudness of sound produced becomes four times greater.

(ii) Distance from the vibrating body.
The intensity or loudness of sound I, is inversely proportional to the square of the distance from the vibrating body.

$$\therefore \text{Intensity } \alpha \ \frac{1}{(\text{distance})^2}$$

(iii) Area of the vibrating surface.
Intensity α surface area of the vibrating body. The reason is that the greater the area of the vibrating surface, the larger is the energy transmitted to the medium and greater is the loudness of the sound.

(iv) Density of the medium.
Intensity α density of the medium in which it vibrates.

(v) Motion of the medium.
If the wind blows in the direction in which the sounds travels, the intensity of sound at a point in the direction of the wind increases and vice versa.

Quality or Timbre (pronunciation - tamba)
This is the quality of sound produced, it depends on the number of overtones produced, the more the number of overtones, the richer and the sweeter the music and therefore the better the quality.
Quality is that characteristic of musical note which enables us to distinguish a note produced by one instrument from another of the same pitch and intensity produced by a different instrument.
If, for example, a note of a given pitch is successfully produced by a violin, a guitar or a piano, the ear can distinguish between three notes.

Factors affecting the pitch (frequency) of a note from a vibrating string.
We have seen that in a sonometer, if the frequency of the wire under tension is equal to the frequency of the tuning fork, resonance takes place and the vibrating wire has the maximum amplitude.

Experiments have proved that the frequency of the wire depends upon the following factors.

(a) Length of the vibrating segment between the bridges A and B
$frequency\ \alpha \frac{1}{length}$, if all the other factors are kept constant.
For example: if the length of the vibrating wire is doubled, the frequency will be halved.

(b) The stretching force, called the tension on the vibrating wire.
$frequency\ \alpha\sqrt{Tension}$, if all the other factors are kept constant.
For example, if a mass of 200g is attached to the wire, tension T is 2.0N ($\text{mg} = 0.200 \times 10 = 2.0N$) and say the frequency is 500Hz. If the tension of the wire is 4 times, then the frequency of the wire will be increased by 2 times, i.e the frequency will be 1000Hz.

(c) The density of the material of the wire.
$frequency\ \alpha \frac{1}{\sqrt{density\ of\ the\ wire}}$, if all the other factors are kept constant.
For example, if the density of the material of the wire used is 4 times more, the frequency of vibration will be decreased by 2 times.

(d) The diameter (thickness of the wire used)
$frequency\ \alpha \frac{1}{\sqrt{diameter\ of\ the\ wire}}$, if all the other factors are kept constant.
For example, if a wire whose thickness or diameter is two times more, then the frequency of the vibration will be decreased by two times.

Beats
This refers to the periodic rise and fall in the intensity of sound caused by two notes of nearly equal pitch.

Sensitivity of the ear.
If the ear is sensitive, then soft sound will be loud enough to be detected and yet it will not be detected by the ear which is insensitive.

PURE AND IMPURE MUSICAL NOTES.
Pure musical note refers to a note without overtones. It is very boring and only produced by a tuning fork.

Impure musical note refers to a note with overtones. It is sweet to the ear and produced by all musical instruments.

Musical scale
A musical interval is the ratio of frequencies between two notes.
The interval is called a consonant interval if the interval is such that a pleasant effect is produced.
A musical scale is a series of notes with consonant intervals.
It consists of 8 notes of definite frequencies, the interval between the 8^{th} and the 1^{st} is $\frac{2}{1}$. This interval is called an actave.

Beginning with the first note of frequency 24 Hz, called the key-note the frequencies of other notes in the musical scale shall be as follows.

24	27	30	32	36	40	45	48	Hz
Do	re	mi	fa	sol	la	ti	do	

Revision exercise 12 pages 257 – 261 Longhorn book two

END.