Sound Waves: Characteristics and Applications

PERIODIC MOTION

- When a body repeats its motion continuously on a definite path in a definite interval of time then its motion is called **periodic motion.**
- The constant interval of time after which the motion is repeated is called the **'Time period of motion.' (T)**
  Example : Time period of hour hand is 12 hours.

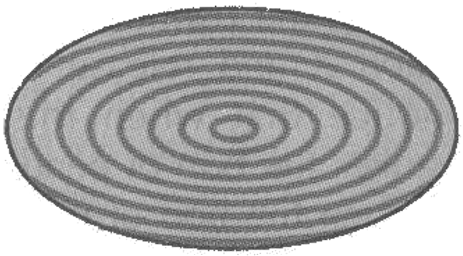
OSCILLATORY MOTION

- If a body in periodic motion moves along the same path to and fro about a definite point (equilibrium position), then the motion of the body is a vibratory motion or oscillatory motion
  Note: Resultant force acting on the particle is zero in equilibrium condition.
- It is to be noted here that every oscillatory motion is periodic but every periodic motion is not oscillatory

WAVE MOTION

Introduction :

When a pebble is thrown in a pond of still water, circular ripples called waves or pulses move outward on the surface of water as shown in the figure. These waves are in the form of disturbance that travels outward, and no portion of the medium (water in this case) is transported from one part to another part of the medium. The particles of the medium simply vibrate about their mean positions.



Ripples on the surface of water

Thus, wave is a form of disturbance which travels through a material medium due to the repeated periodic motion of the particles of the medium about their mean positions. The disturbance is handed over from one particle to another particle of the medium without the actual movement of the particles of the medium.

Definition :

A wave motion is a means of transferring energy from one point to another without any actual transportation of matter between these points.

In a wave motion, disturbance travels through some medium, but the medium does not travel along with the disturbance.

CLASSIFICATION OF WAVES

Depending on medium requirement, waves can be classified as :

(i) Mechanical waves

(ii) Non Mechanical or Electromagnetic waves

(i) Mechanical wave :

Those waves which need a material medium (like solid, liquid or gas) for their propagation, are called mechanical waves or elastic waves.

A mechanical wave cannot travel through vacuum.

Examples of mechanical waves :

(i) Sound wave

(ii) Water waves.

(iii) Waves produced in a stretched string.

(iv) Waves produced in spring.

(ii) Electromagnetic waves

Those waves which do not need a material medium for their propagation and can travel even through a vacuum, are called electromagnetic waves because they do not require a material medium (like solid, liquid or gas) for their propagation. Examples of electromagnetic waves are (i) Radio waves (ii) Infra-red waves (iii) Visible (light) waves.

Difference between Mechanical waves & Electromagnetic waves

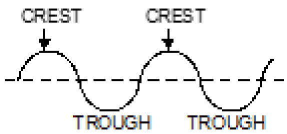
	Mechanical waves	Electromagnetic waves
1.	Mechanical waves need a material medium for their propagation. These waves cannot travel through vacuum.	Electromagnetic waves do not need any material medium for their propagation. These waves can travel through vacuum.
2.	Speed of mechanical waves are low and depends upon the source and the medium through which they travel.	(EMW) a electromagnetic waves travel with the speed of light (3×10^8 m/s) in vacuum. The speed of an electromagnetic wave in any material medium is less than that in vacuum.
3.	Mechanical waves are due to the vibrations of the particles of the medium.	electromagnetic waves are not due to vibration of medium particles
4.	Mechanical waves may be longitudinal or transverse waves.	Electromagnetic are transverse waves.
5.	Example : Sound waves, water waves, string waves are mechanical waves.	Examples : Light waves, radio and TV waves, and X-rays are electromagnetic

Depending upon the direction of vibration of medium, particles waves are classified as :

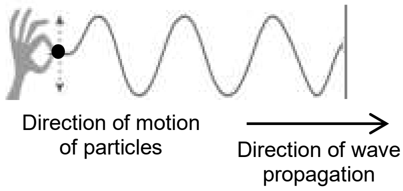
(i) Transverse waves (ii) Longitudinal waves

(i) Transverse wave

A wave motion in which an individual particle of the medium vibrates in a direction at right angles to the direction of propagation of wave is called transverse wave motion.



(a) Water waves show crests and troughs



(b) Transverse waves on a stretched string

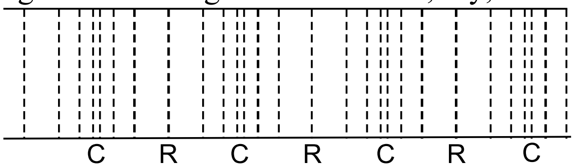
In the case of waves formed over the surface of water, the individual particles of water oscillate in a direction at right angles to the direction of propagation of wave figure (a). Similarly, if a heavy rope with one of its ends tied to a hook H in the wall is stretched along the length of the room and is given an upward and downward jerk at the free end A, a wave is seen to travel along the length of the room as shown in figure(b). Every part of rope vibrates up and down while wave train travels along the rope.

(ii) Longitudinal Wave :

A wave motion in which the particles of the medium vibrate about their mean position along the direction of propagation of the wave is called longitudinal wave motion.
For example, sound wave in air (340 m/s).

When a longitudinal wave travels in a medium then the particles of the medium vibrate back and forth in the same direction in which the wave travels.

At any instant there are points in space where pressure or density is maximum, called as compression and there are points where pressure or density is minimum called as rarefaction. These compressions and rarefactions occur one after the other. From a compression to a rarefaction the pressure or density continually varies from a maximum to a minimum. Figure below shows the propagation of a longitudinal wave in, say, air.

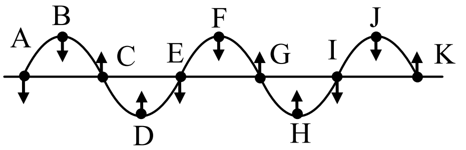


Differences between transverse and Longitudinal wave :

S.No.	Transverse waves	Longitudinal waves
1.	Particles of medium vibrate perpendicular to the direction of wave propagation	Particles of medium vibrate in the direction of wave propagation
2.	Transverse mechanical waves can propagate through solids and over liquid surfaces	They can propagate through solids, liquids and gases
3.	Examples are electromagnetic waves, water, waves, etc.	Examples are sound waves, waves on slinky etc.

SOME DEFINITION

Phase : All the points on a wave which are in the same state of vibration are said to be in the same phase. Thus, in the wave shown in fig.



(a) Points B, F and J are in the same phase – all lie on the crests and direction of velocity is downward.
(b) Points D and H are in the same phase – both lie on the troughs and direction of velocity is upward.
(c) Points A, E and I are in the same phase. All these points are just about to start their vibration in the downward direction from their mean positions.
(d) Points C, G and K are in the same phase. All these points are just about to start their vibration in the upward direction from their mean positions.

Amplitude :

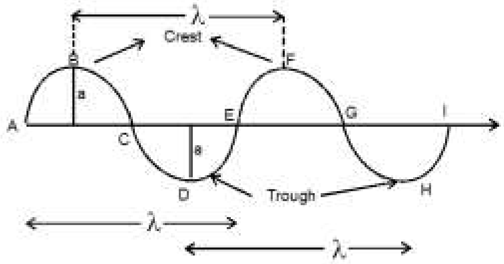
The maximum displacement of vibrating particles from its mean position is known as amplitude. It is denoted by **a** or **A**.

Wavelength :

Wavelength is defined in following different ways:

- It is the distance travelled by a wave during one complete vibration of the vibrating particle.
- It is the distance between two nearest particles in the same phase.
- It is the distance between two consecutive crests or troughs of a transverse wave.
- It is the distance between two consecutive rarefactions or compressions of a longitudinal wave.
- It is the length of one complete wave.

Wavelength is denoted by λ (**lambda**). Its unit is **metre** (**m**).



Time-period :

Time taken by a vibrating particle to make one complete vibration is called its time-period. Also, time taken by a wave to move a distance equal to its wavelength λ is called the time-period of the wave.

It is denoted by **T**. Its unit is **second** (**s**).

Frequency :

The number of vibrations completed by a particle in one second is called its frequency.

Frequency is also defined as the number of waves (or crests) passing a given point in one second.

It is denoted by **n** or **N** or **f**. Its unit is **hertz** (**Hz**).

Wave Velocity : The distance travelled by the wave in one second is called the wave velocity. It is represented by 'v' and its unit is ms^{-1}.

RELATION BETWEEN FREQUENCY AND TIME PERIOD

Let Frequency = **n**

Time taken to complete n vibrations = 1 second or Time taken to complete 1 vibration = $\frac{1}{n}$ second

But the time taken to complete one vibration is called time-period T, hence

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

or $n \cdot T = 1$

Frequency × Time period = 1

RELATION BETWEEN WAVE VELOCITY FREQUENCY AND WAVELENGTH

Wave-velocity is defined as the distance travelled by the wave in one second.

$$\text{Wave-velocity} = \frac{\text{Distance travelled by one wave}}{\text{Time taken by one wave}} = \frac{\text{Wavelength}}{\text{Time period}}$$

or $v = \frac{\lambda}{T}$

But $n = \frac{1}{T}$

$\mathbf{v = n\lambda}$

or Wave-velocity = Frequency × wavelength

CHARACTERISTICS OF WAVE MOTION

- Wave is a disturbance travelling through the medium.
- Only energy (and no particle) is transferred in a wave motion.
- Energy transfer takes place with a constant speed, if medium properties are homogenous.
- Wave velocity ($v = f\lambda$) is constant throughout the medium while the velocity of particle is different at different positions (maximum at mean, zero at extreme position).
- There is a continuous phase difference amongst the successive particles of the medium.
- Wave motion is possible in a medium which possesses the property of elasticity and inertia.

ILLUSTRATION

1. A source produce 50 crests and 50 troughs in 0.5 second. Find the frequency.

Sol. 1 crest and 1 trough = 1 wave

$\therefore$ 50 crests and 50 troughs = 50 waves

Now, Frequency, $\nu = \dfrac{\text{Number of wave}}{\text{Time}} = \dfrac{50}{0.5} = 100$ Hz

2. The wave length of sound emitted by a source is 1.7×10^{-2} m. Calculate frequency of the sound, if its velocity is 343.4 ms^{-1}

Sol. The relation ship between velocity, frequency and wave length of a wave is given by the formula $v = \nu \times \lambda$

Here, velocity, $v = 343.4\ ms^{-1}$

frequency ν = ?

and wavelength, $\lambda = 1.7 \times 10^{-2}$ m

So, putting these values in the above formula, we get :

$343.4 = \nu \times 1.7 \times 10^{-2}$

$\nu = \dfrac{343.4}{1.7 \times 10^{-2}} = \dfrac{343.4 \times 10^2}{1.7} = 2.02 \times 10^4$ Hz

Thus, the frequency of sound is 2.02×10^4 hertz.

3. A wave pulse on a string moves a distance of 8m in 0.05 s.

(i) Calculate the velocity of the pulse.

(ii) What would be the wavelength of the wave on the same string, if its frequency is 200 Hz ?

Sol. (i) Velocity of the wave,

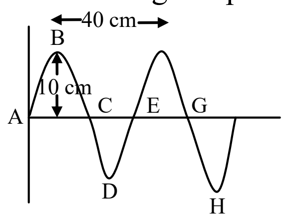
$v = \dfrac{\text{Distance covered}}{\text{Time taken}} = \dfrac{8m}{0.05s} = 160$ m/s

(ii) Periodic wave has the same velocity as that of the wave pulse on the same string.

$\therefore$ Wavelength, $\lambda = \dfrac{v}{\nu} = \dfrac{160\ m/s}{200\ Hz} = 0.8$ m

Thus, the wavelength of the wave is 0.8 m.

4. Wave of frequency 200 Hz produced in a string is represented in figure. Find out the following :



(i) amplitude (ii) wavelength (iii) wave velocity

Sol. (i) Amplitude=Maximum displacement = 10 cm

(ii) Wavelength λ = Distance between two successive crests = 40 cm

(iii) Now, frequency, ν = 200 Hz

Wavelength, λ = 40cm = 0.4 m

$\therefore$ Wave velocity, $v = \nu\lambda = 200 \times 0.4$ m/s = 80m/s

5. In a ripple tank, 10 full ripples are produced in one second. The distance between a trough and a crest is 15 cm. Calculate :

(i) the frequency, (ii) the wavelength and (iii) the velocity of the ripples

Sol. (i) We know, frequency is the number of ripples produced in one second.

Frequency (n) = 10 Hz.

(ii) We know that the distance between consecutive trough and crest is equal to $\lambda/2$.

$\lambda/2 = 15$ cm or $\lambda = 30$ cm

(iii) Velocity $v = n\lambda = 10 \times 30 = 300\ cm\ s^{-1}$ $v = 3\ ms^{-1}$

SOUND WAVE

Sound is a form of energy which effects our sensation of hearing through the ear. The sensation is produced by longitudinal waves in an elastic medium, where the vibrations (oscillations) of the particles are in the same direction in which the wave propagates.

Sound need Material to Travel : You have learnt in previous section that vibrations produce sound. To produce vibrations, we need a material body. Therefore, we can say that a medium is needed for sound to travel. Sound can travel through air (or gases), liquids and solids, but not through vacuum.

Speed of Sound : The speed of sound is the rate at which sound travels from the sound producing body of our ears. The speed of sound depends on the

- **Nature of Material** (or medium) through which it travels. Speed of sound in air is 344 m/s.
- **Temperature :** As the temperature increases the speed of sound in air increases.
- **Humidity of Air :** Sound travel fast in humid air.

The Time Gap between 'Seeing' and 'Hearing' is due to the difference between the time taken by the light and the sound to travel from the source to the observer.

The speed of light high 3×10^8 meters per second (30 crore metres per second) and the speed of sound in the air under normal conditions is 344 metres per second. So, the light travels almost instantaneously, whereas sound takes some time.

Sound Wave are Longitudinal Waves : Sound travels through air in the form of longitudinal waves.

PRODUCTION OF SOUND WAVES

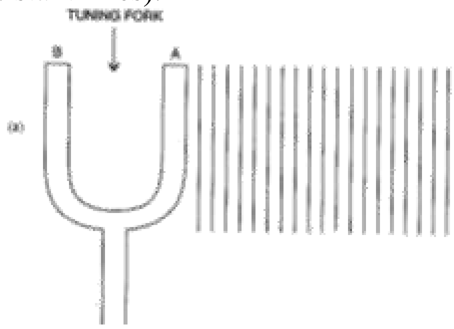
In laboratory sound is produced by a tuning fork by striking its one prong on a soft rubber pad. Sound can also be produced by plucking a stretched string (violin), by blowing flute, by striking table and many other ways.

Can you think why ?
- Why the church bell has larger surface area?
- Sound wave cannot be polarized?

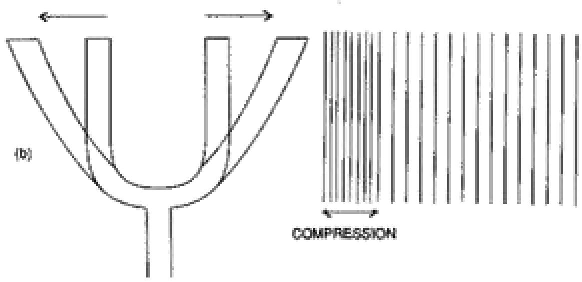
PROPAGATION OF SOUND

Take a tuning fork (a source of standard frequency). It is set into vibrations and its prongs A and B are kept vertical. The prongs move in and out from their mean position and have a transverse vibratory motion.

When the prongs are in mean position, the air in their surroundings has normal density. (It is shown in figure (a) with equidistant lines).

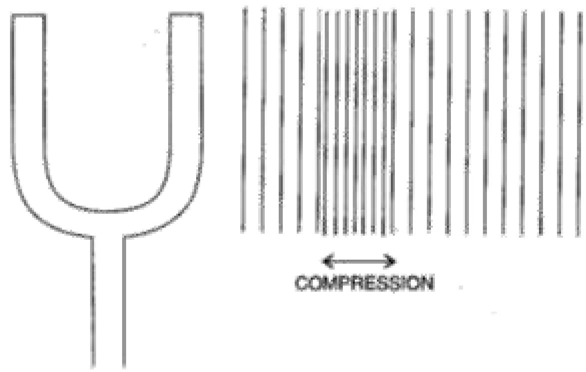


As the right prong moves out towards right, it pushes the air layers to the right. This produces a compression (It is shown in figure (b) with closer lines).



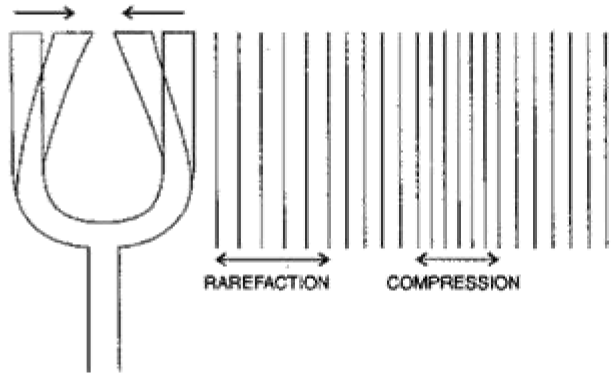
The prong returns inwardly to mean position. The compression moves to the right. The air near the prong again has normal density as shown in figure (c).

(c)



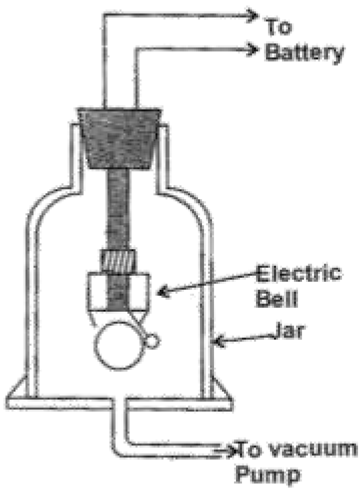
As the prong continues moving towards extreme left, vacating the space, density of air falls in the region and a rarefaction is produced (It is shown in figure(d) with spread lines).

(d)



As the prong moves back to right extreme, it completes one vibration. Also the motion of the prong produces a new compression. This completes one wave.
Since one vibration of the prong has generated one wave in the medium (air), in one second as many waves will be generated as the number of vibrations that the tuning fork will make in one second. This number is called frequency of the tuning fork (This number is engraved on the tuning fork near the bend). Hence we conclude that the wave frequency (the number of waves being generated per second) is equal to the frequency of the tuning fork.

SOUND NEEDS A MATERIAL MEDIUM FOR ITS PROPAGATION



An electric bell is enclosed inside an inverted bell jar by hanging from the rubber cork. The jar is closed at the bottom by an airtight plate with a hole in the centre. A pipe through the hole leads out to a vacuum pump (pump which draws the air out of a vessel).
The bell is connected to a battery through a key.
The bell is started by closing the key. Initially when jar has normal air inside it, sound waves produced by the ringing bell heard outside the jar.
The vacuum pump is started and the air from inside the jar is gradually drawn out. With decrease air inside the jar, sound heard becomes weaker and weaker. After sometime no sound is heard, though the bell hammer is seen in vibration.

Conclusion :
In the absence of medium (air) around the source, sound is not being propagated.

A natural fact : Moon has no atmosphere. The space above the atmosphere is also vacuum. If some explosion takes place on moon, sound of the explosion will not be propagated to the earth. So the sound waves never reach the earth.

WAVE TERMINOLOGY

Pitch :

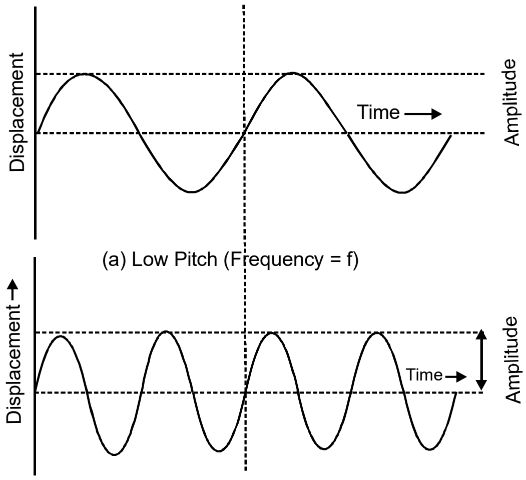
Pitch is the sensation (brain interpretation) of the frequency of an emitted sound.

Faster the vibration of the source, higher is the frequency and higher is the pitch. Similarly low pitch sound corresponds to low frequency.

A high pitch sound is called a shrill sound

(**Eg :** humming of a bee, sound of guitar etc).

A low pitch sound is called a hoarse sound

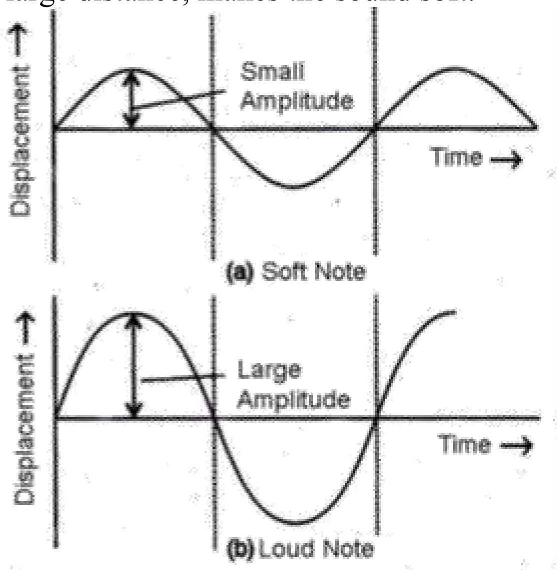


(b) High Pitch (Frequency 2f)

(**Eg :** roar of a lion, car horn etc.)

Loudness or softness :

Loudness or softness of a sound wave is the sensation that depends upon its amplitude. When we strike a table top with more force, it vibrates and produces loud sound waves which have more amplitude. When struck with smaller force, vibrating table top produces soft sound waves which have less amplitude. A loud sound wave carries more energy and can be heard at large distance. Reduction in amplitude at large distance, makes the sound soft.

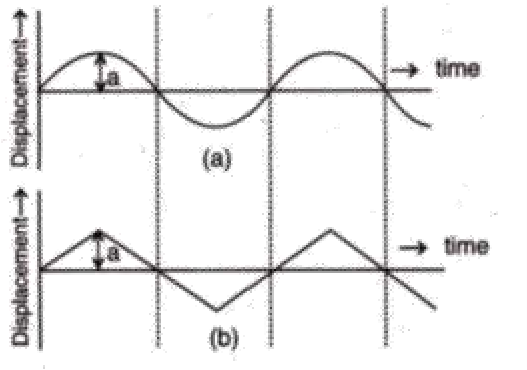


Timbre or quality :

Quality or timbre is a characteristic of a sound which enables us to distinguish between the sounds of same loudness and pitch. This characteristic of sound helps us to recognise our friend from his voice without seeing him. The quality of two sounds of same loudness and pitch produced by two different sources are distinguishable because of different wave forms produced by them.

Eg : The violin and flute (Bansuri).

Following figure shows the wave forms of two sounds of same loudness and same frequency, but emitted by two different types of sources. They produce different sensations on the ears because they differ in wave form.



Intensity :

Intensity of a sound is defined as the sound energy transferred per unit time per unit area placed perpendicular to the direction of the propagation of sound.

That is, intensity of sound $= \dfrac{\text{Sound energy}}{\text{Time} \times \text{Area}}$

Intensity of a sound is an objective physical quantity. It does not depend on the response of our ears.

The S.I. unit of intensity of sound is joule s^{-1} m^{-2} or watt m^{-2} $(\therefore 1\ Js^{-1} = 1W)$

Difference between loudness and intensity of sound :

S.No.	Loudness	Intensity of a sound
1	Loudness is a subjective quantity. It depends upon the sensitivity of the human ear. A sound may be loud for a person but the same sound may be feeble for another who is hard of hearing.	Intensity of a sound is an objective physical quantity.It does not depend on the sensitivity of a human ear.
2	Loudness cannot be measured as a physical quantity because it is just sensation which can be felt only.	Intensity of a sound can be measured as a physical quantity.

RANGE OF HEARING

The human ear is able to hear sound in a frequency range of about 20Hz to 20kHz. We can not hear sounds of frequencies less than 20Hz or more than 20kHz, these limits vary from person to person and with age. Children can hear sounds of somewhat higher frequencies, say upto 30 kHz. With age, our ability to hear high frequency sound diminishes. For the elders, the upper limit often falls to 10-12 kHz. We take 20Hz-20 kHz as the audible range for an average person.

Even in the audible range the human ear is not equally sensitive for all frequency. It is most sensitive to frequencies around 2000-3000 Hz.

Sound of frequencies less than 20 Hz is known as infrasonic sound or infrasound. Sound of frequency greater than 20kHz is known as ultrasonic or ultrasound.

Different animals have different ranges of audible frequencies. A dog can hear sounds of frequencies upto about 50 kHz and a bat upto about 100kHz Dolphins can hear sounds of even higher frequencies. Animals such as elephants and whales can hear sounds of frequencies less than 20 Hz. Some fishes can hear sounds of frequencies as low as 1-25 Hz.

SONIC BOOM

When a body moves with a speed which is greater than the speed of sound in air, then it is said to be travelling at supersonic speed Jet fighters, bullets, etc, often travel at supersonic speed. And when they do so, they produce a sharp, loud sound called a sonic boom.

The source moves at a speed greater than that of sound, sound waves travelling at the speed of sound, are left behind. The high-pressure layers due to sound waves originating at different points bunch together as shown in figure-III. Actually, these layers fall on the surface of an imaginary cone of which OA, OB is a part. The total pressure on the surface of this cone is very high.

The source is at the apex of this cone. As the source moves ahead, it drags the cone together with it. When the surface of the cone reaches a person, the ears experience a sudden increase in pressure. After the surface crosses him, the pressure is suddenly reduced. This causes the person to hear a sharp, loud sound which is known as the sonic boom.

Can you think why ?
- Sound moves from rare to denser medium then it move away from normal?
- What do you mean by natural eco of room?

A region consisting of a very-high-pressure layer followed by a lower-pressure layer travels through the space together with the cone. This is called a shock wave. This shock wave gives rise to the sonic boom when it reaches a person.

The shock waves produced by supersonic aircraft have enough energy to shatter glass and even damage weak buildings.

To explain the sonic boom we take following cases :

- **Case- I :** When plan speed is less than speed of sound.

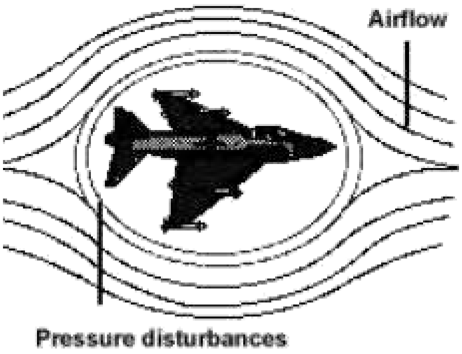


Figure -I

Then slow–flying planes create air pressure disturbances that move at the speed of sound, travelling well in front of the plane. The airflow adjusts and disturbances disperse.

- **Case- II :** When plan speed is equal to the speed of sound.

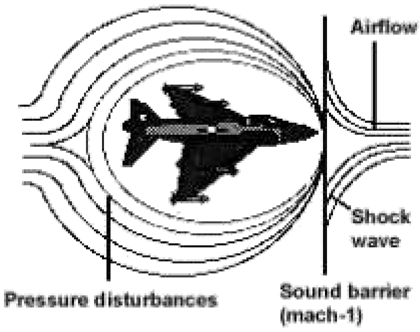


Figure -II

Then planes flying at the speed of sound experience a dramatic increase in their drag because disturbances accumulate instead of disperse. The airplane has almost caught up with the pressure waves it is creating with its forward thrust.

- **Case- III :** When plan speed is greater than the speed of sound.

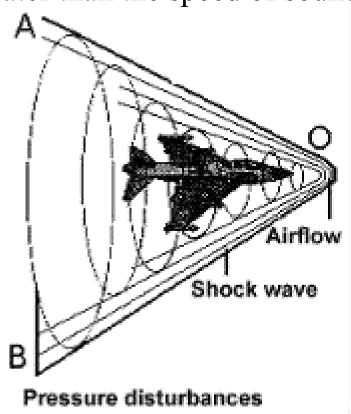


Figure -III

Then planes flying faster than the speed of sound cause powerful shock waves because airflow has no time to adjust for them. The sonic boom is the sound associated with the shock wave.

REFLECTION OF SOUND

When sound waves strike a surface, they return back into the same medium. This phenomenon is called reflection of sound.

The reflection of sound waves is similar to that of light rays. The only difference is that sound waves being larger in length, require bigger surfaces for reflection.

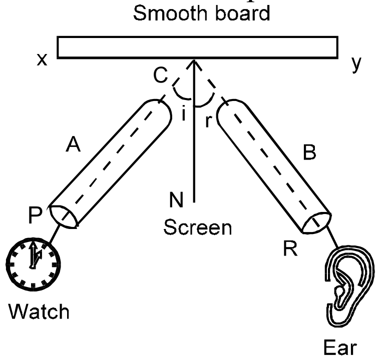
Laws of Reflection :

• Angle of incidence is equal to the angle of reflection.

• The incident wave, the reflected wave and the normal, all lie in the same plane.

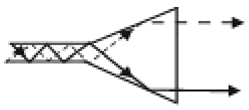
Verification of Laws of Reflection :

Take a smooth polished large wooden board and mount it vertically on the table. At right angle to the board, fix a wooden screen. On each side of the screen, place a long, narrow and highly polished tube (inside). Place a clock at the end of the tube A. Move the tube B slightly from left to right, till a distinct tick of clock is heard. Measure the $\angle PCN$ and $\angle RCN$ between tubes and wooden screen. It is found $\angle PCN = \angle RCN$. This experiment illustrates the laws of reflection.



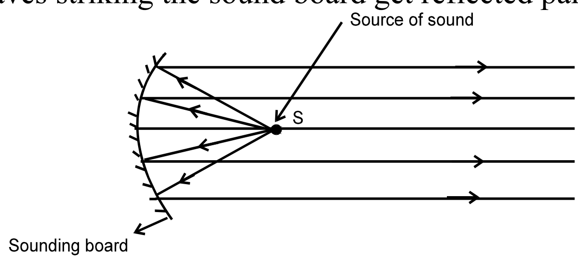
Applications of Reflection of Sound :

- **Mega phone or speaking tube :**
  When we have to call someone at a far off distance (say 100m), we cup our hands and call the person with maximum sound we can produce. The hands prevent the sound energy from spreading in all directions. In the same way, the people use horn shaped metal tubes, commonly called megaphones.
  The loud speakers have horn shaped openings. In all these devices, the sound energy is prevented from spreading out by successive reflections from the horn shaped tubes.



- **Stethoscope :**
  It is an instrument used by the doctors for listening sounds produced within the body, specially in the heart and lungs. In the stethoscope, the sound produced within the body of a patient to picked up by a sensitive diaphragm and then reaches the doctors ears by multiple reflection.

- **Sound board :**
  The sound waves obey the laws of reflection on the plane as well as curved reflecting surfaces. In order to spread sound evenly in big halls or auditoriums, the speaker (S) is fixed at the principal focus of the concave reflector. This concave reflector is commonly called sounding board . The sound waves striking the sound board get reflected parallel to the principal axis.



SPEED OF SOUND IN DIFFERENT MEDIUM

Sound travels with different speed in different media like solid, liquid and gas. This is because, sound travels in a medium due to the transfer of energy from one particle to another particle of the medium.

Solid : Since the particles of solid are close to each other, so transfer of energy from one particle to another takes place in less time (i.e. faster). Hence speed of sound in solids is large.

Liquid : Speed of sound in liquids is less than in solids since the particles are away from each other as compared to solids.

Gas : Speed of sound in gases is less than the speed in liquids and solids as the particles are far away as compare to solids and liquids.

Gas < Liquid < Solid

Speed of sound increases from left to right.

> **Boost your knowledge**
>
> ☛ Acoustics is the interdisciplinary science that deals with the study of all mechanical waves.

EFFECT OF TEMPERATURE ON THE SPEED OF SOUND

Sound travels faster as the temperature of the medium increases and vice-versa. This happens because as temperature increases, the particles of the medium collide more frequently and hence the disturbance spreads faster.

Speed of sound in air increases by 0.61 m/s with every 1°C increase in temperature. For example if speed of sound in air at 0°C is 330 m/s, then its speed at 25°C will be 345 m/s.

Speed of sound does not depend on the pressure of the medium if temperature of the medium remains constant.

ECHO

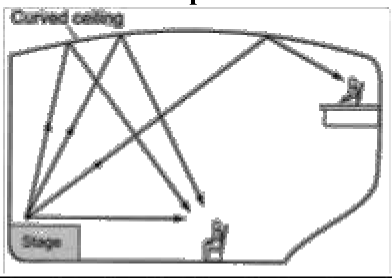
Echo is based on the reflection of sound. An echo is defined as repetition of sound due to reflection. There are a number of tourist places where echo points are marked. If you speak something from there loudly you will hear back your sound after sometime. This is called an echo. At some places, you might listen a number of echos one after the other. This is called as multiple echo. It is not that you will hear an echo at any place. There are certain conditions required for an echo to be heard. Before discussing these conditions we will firstly talk about the term persistence of sound. The impact of any sound heard by us does not vanish immediately. It is due to this that a person can't hear two sounds if the time delay between them is less than the minimum required. It is found by scientists that if the time delay between the sounds is less than 1/10 sec, they are heard as single sound. Thus to hear two sounds as different sounds the time delay must be at least 1/10 sec. This forms the basis of an important condition needed to hear an echo.

Conditions for formation of an echo :

- The minimum distance between the source of sound and the reflecting body should be 17 metres.
- The wavelength of the sound should be less than the height of the reflecting body.
- The intensity of sound should be sufficient so that it can be heard after reflection.

REVERBERATION

When a sound is produced in a big hall, its waves reflects from the walls and travel back and forth. Due to this the sound does not vanish at once but it fades away gradually, that is the sound persists even after its production has been stopped. A small amount of reverberation is desirable in large halls or cinemas as it makes the sound pleasant and more effective. However too much reverberation is undesirable as it makes the sound confusing. To reduce reverberation the roof and walls of the hall are covered with sound absorbing materials like rough plaster and thick curtains. One may define reverberation as **the persistence of sound due to repeated reflection and its gradual fading away.**



If **t** is the time at which an echo is heard, **d** is the distance between the source of sound and the reflecting body and v is the speed of sound. The total distance travelled by the sound is **2d**.

Speed of sound, $v = \frac{2d}{t}$ or $d = \frac{vt}{2}$

Calculation of Minimum Distance of Hearing Echo :

d is minimum distance required for hearing an echo when persistence of hearing is $\frac{1}{10}$ second.

Since the velocity of sound (at room temperature) is 340 m/sec.

So, $d = \frac{vt}{2} = \frac{340}{2} \times \frac{1}{10} = \frac{340}{2 \times 10}$

$d = 17$ metre.

17 metre is the minimum distance of hearing echo.

AUDIBLE, ULTRASONIC AND INFRA SONIC WAVES

Audible Wave :

The human ear is sensitive to sound waves of frequency between **20Hz** to **20kHz**. This range is known as audible range and these waves are known as audible waves.

Eg. : Waves produced by vibrating sitar, guitar, organ pipes, flutes, shehnai etc.

Ultrasonic Wave :

A longitudinal wave whose frequency is above the upper limit of audible range i.e. **20 kHz,** is called ultrasonic wave. It is generated by very small sources.

Eg. : Quartz crystal.

Infrasonic Wave :

A longitudinal elastic wave whose frequency is below the audible range i.e. **20Hz**, is called an infrasonic wave.

It is generally generated by a large source.

Eg. : Earthquake.

ULTRASOUND

Sound of very high frequency (greater than 20 kHz) is called ultrasound.

Production :

These are produced by electronic oscillator using high frequency vibrations of quartz crystal.

Properties :

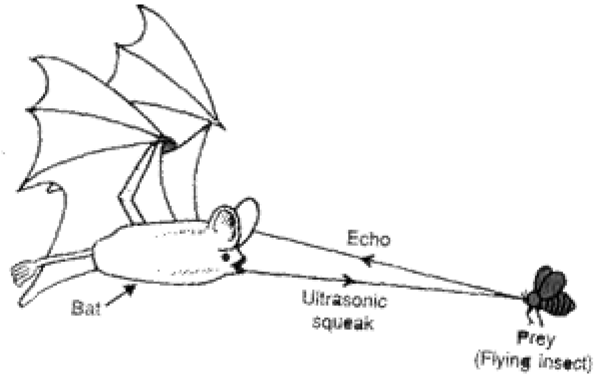
Sound wave of all frequencies carry energy with them, with increase in frequency, vibration becomes faster and also energy contents and force increase. When ultrasound travels in solid, liquid and gas it subjects the particles of matter to face large force and energy.

Applications of ultrasound :

- **Welding metal :**
  They are used for welding metals like tungsten which cannot be welded by conventional methods. One of the two pieces of the tungsten is held firmly against the other piece and then vibrated with an ultrasonic vibrator. The heat produced due to friction, at the point of contact, melts the metal. On stopping the vibrator, the melted ends of metal fuse to form a tight weld.
- **Medical purposes :**
  The ultrasonic vibrations can be reflected from the boundaries between the materials of nearly same density. The technique is used in scanning the internal organs of human body. It is superior to the X-ray scanning, as it does not cause any harm to human cells, unlike X-rays.
  The instrument which uses ultrasonic waves for getting the images of internal organs of human body is called ultrasound scanner . In this technique, the ultrasound waves travel through the tissues of the body and get reflected from the region where there is change in density. These reflected waves are then converted into electrical signals. These signals are then displayed on T.V. monitor or can be printed on a film.
  This technique is called ultrasonography and helps doctors to detect abnormalities, such as stones in gall bladder and kidney or tumors in different organs.
  Ultrasound waves of high intensity are employed to break small stones in the kidney into fine grains. The fine grains then get flushed out with urine.

Can you think why ?
- What is the wave number?

- **Drilling holes or making cuts of desired shape** :
  We can use a hammer and a steel punch to make holes in metal plates, plastic sheets or other solid materials. Such holes can also be made using ultrasonic vibrations produced in a metallic rod, called a horn. The horn acts like a hammer, hammering the plate about hundred thousand times per second. The shape of the hole is the same as that of the tip of the horn. The shape of the tip can be designed as per the requirement of the application. Ultrasonic cutting and drilling are very effective for fragile materials like glass, for which ordinary methods do not give good results.
- **Ultrasonic cleaning :**
  We normally clean dirty clothes, plates or other large objects by applying detergent or organic solutions, rubbing and washing. But for small parts such as those used in watches, electronic components, odd-shaped parts such as a spiral tube and parts located in hard to reach places, this method is inconvenient and sometimes impossible. Such objects are placed in a cleaning solution and ultrasonic waves are sent into the solution. Because of vibrations at high frequencies, all dirt and grease particles get detached from the surface and object gets thoroughly cleaned.
- **Ultrasonic detection of defects in metals :**
  Metallic components are used in buildings, bridges, machines, scientific equipments and so on. If there are cracks or holes inside the metal used, the strength of the structure or component is reduced and it can fail. Such defects are not visible from the outside. Ultrasonic waves can be used to detect such defects.
  Ultrasonic waves are sent through the metallic object under study. If there is no crack or cavity in its path, it goes through the object. A detector placed on the other side detects the transmitted wave. A defect present in the path of the wave reflects the wave. Thus, the intensity of the emerging waves falls in the region that is in line with the defect. When this happens, we know that the object has defect inside.
  Ordinary sound is not used for this application because ordinary sound will bend considerably round the corners of cracks or cavities and will emerge on the other side at almost full intensity.
- **Emulsions of immiscible liquids**
  When a strong beam of ultrasound is passed through a liquid, it is heated to a very high temperature. This fact is utilized in preparing homogeneous stable emulsion of immiscible liquids. Ultrasound treated honey does not crystallize.
- Bats fly in the darkness of night without colliding with other objects by the method of echolocation. Bats emit high frequency ultrasonic squeaks while flying and listen to the echoes produced by the reflection of their squeaks from the objects in their path. From the time taken by the echo to be heard, bats can judge the distance of the object in their path and hence avoid it by changing the direction. Bats search their prey at night by the method of echolocation.



ILLUSTRATION

6. An echo is returned in 3s. What is the distance of the reflecting surface from the source, given that the speed of sound is 342 ms^{-1} ?

Sol. Given, Speed of sound, V = 342 ms^{-1}

Time interval of echo return, t = 3 s

Let the distance of the reflecting surface be, S.

Sound travels a distance 2S in return journey.

$$2S = Vt$$

$$S = \frac{vt}{2} = \frac{342 \times 3}{2} = 513 \text{ m}$$

$$S = 513 \text{ m}$$

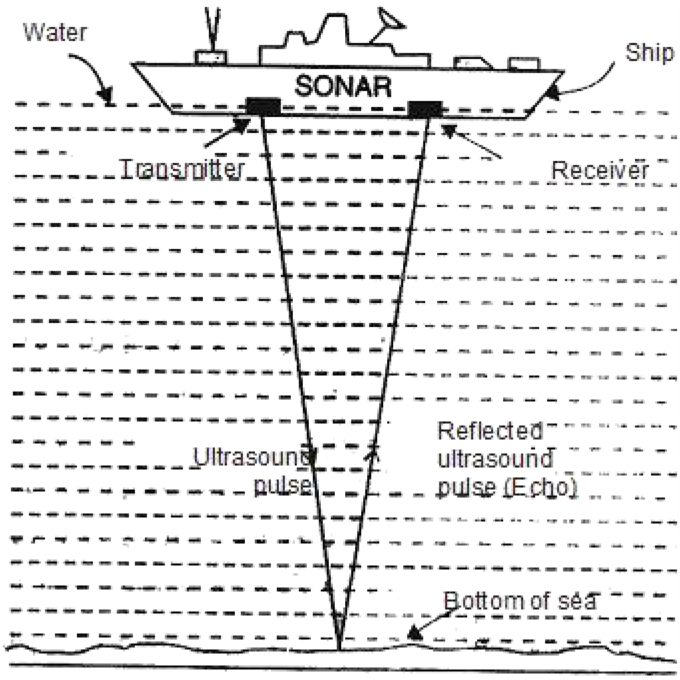
SONAR

The word 'SONAR' stands for 'Sound Navigation and Ranging'.

Principle of Sonar :

Sonar is an apparatus which is used to find the depth of a sea or to locate the under water things like shoals of fish, enemy submarines etc. Sonar works by sending short bursts of ultrasonic sound from a ship down into sea-water and then picking up the echo produced by the reflection of ultrasonic sound from under-water objects like bottom of sea, shoal of fish, a submarine.

Working of Sonar :



A sonar apparatus consists of two parts :

(i) A transmitter (for emitting ultrasonic waves) and (ii) a receiver (for detecting ultrasonic waves). Now, suppose a sonar device is attached to the under-side of a ship and we want to measure the depth of sea (below the ship). To do this, the transmitter of sonar is made to emit a pulse of ultrasonic sound with a very high frequency of about 50,000 hertz. This pulse of ultrasonic sound travels down in the sea-water towards the bottom of the sea. When the ultrasonic sound pulsestrikes the bottom of the sea, it is reflected back to the ship in the form of an echo. This echo produces an electrical signal in the receiver part of the sonar device. The sonar device measures the time taken by the ultrasonic sound pulse to travel from the ship to the bottom of the sea and back to the ship. Half of this time gives the time taken by the ultrasonic sound to travel from the ship to the bottom of the sea.

$$\text{Depth of sea} = \frac{\text{Velocity of sound in sea water} \times \text{time recorded by the recorder}}{2}$$

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

ILLUSTRATION

7. The ultrasonic waves take 4 seconds to travel from the ship to the bottom of the sea and back to the ship. What is the depth of the sea? (Speed of sound in water = 1500 m/s.)

Sol. The time taken by the ultrasonic sound waves to travel from the ship to the sea-bed and back to the ship is 4 seconds. So, the time taken by the ultrasonic sound to travel from the ship to sea-bed will be half of this time, which is $\frac{4}{2} = 2$ seconds. This means that the sound takes 2 seconds to travel from the ship to the bottom of the sea.

Now, $\text{Speed} = \frac{\text{Distance}}{\text{Time}}$

So, $1500 = \frac{\text{Distance}}{2}$

And, Distance = 1500 × 2 m = 3000 m

8. A submarine emits a sonar pulse which returns from the underwater cliff in 1.02s. If the speed of sound in salt water is 1531 ms^{-1}, how far away is the cliff ?

Sol. Given : Speed of sonar pulse, V = 1531 ms^{-1}, Time interval of return journey of the pulse, t = 1.02 s

Let the distance of the underwater cliff be S.

For distance S of the cliff, the pulse travels a total distance of 2S in return journey.

From relation, distance = speed × time

$$2S = Vt$$

We have, $S = \frac{Vt}{2}$

$$S = \frac{1531\ ms^{-1} \times 1.02s}{2}$$

$$S = 780.8\ m$$

REASON FOR USING ULTRASONIC WAVES IN SONAR

- Ultrasonic waves have a very high frequency due to which they can penetrate deep in sea water without being absorbed.
- Ultrasonic waves cannot be confused with the noises, such as the voice of engines of ship. It is because the ultrasonic waves are not perceived by human ear.

THE HUMAN EAR

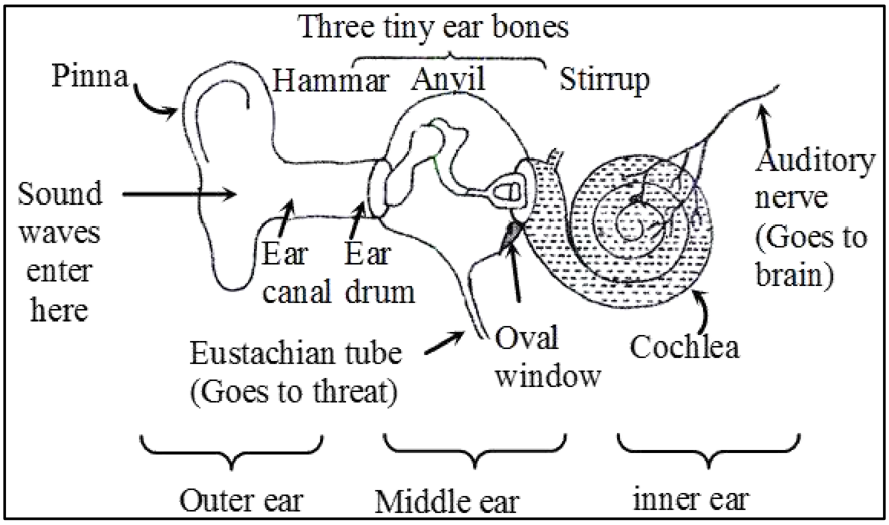
The ears are the sense organs which help us in hearing sound.

- **Structure of Human Ear :**

The ear consists of three compartments : outer ear, middle ear and inner ear.

The part of ear which we see outside the head is called outer ear. The outer ear consists of broad part called pinna and about 2 to 3 centimeters long passage called ear canal. At the end of ear canal there is a thin, elastic and circular membrane called ear-drum. The ear-drum is also called tympanum. The outer ear contains air. The middle ear contains three small and delicate bones called hammer, anvil and stirrup. These ear-bones are linked to one another.

One end of the bone called hammer is touching the ear-drum and its other end is connected to the second bone called anvil. The other end of anvil is connected to the third bone called stirrup and the free end of stirrup is held against the membrane over the oval window of inner ear. The middle ear also contains air. The lower part of middle ear has a narrow tube called 'eustachian tube' going to the throat. Eustachian tube connects the middle ear to throat and ensures that the air pressure inside the middle ear is the same as that on the outside.



The inner ear has a coiled tube called cochlea. One side of cochlea is connected to the middle ear through the elastic membrane over the oval window. The cochlea is filled with a liquid. The liquid present in cochlea contains nerve cells which are sensitive to sound. The other side of cochlea is connected to auditory nerve which goes into the brain.

- **Working of Human Ear :**

  The sound waves (coming from a sound producing body) are collected by the pinna of outer ear. These sound waves pass through the ear canal and fall on the ear-drum. Sound waves consist of compressions (high pressure regions) and rarefactions (low pressure regions). When the compression of sound wave strikes the ear-drum, the pressure on the outside of ear-drum increases and pushes the ear-drum inwards and when the rarefaction of sound wave falls on the ear-drum, the pressure on the outside of ear-drum decreases and it moves outward. Thus, when the sound waves fall on the ear-drum, the ear-drum starts vibrating back and forth rapidly.

  The vibrating ear-drum causes a small bone hammer to vibrate. From hammer, vibrations are passed on to the second bone anvil and finally to the third bone stirrup. The vibrating stirrup strikes on the membrane of the oval window and passes its vibrations to the liquid in the cochlea. Due to this, the liquid in the cochlea begins to vibrate. The vibrating liquid of cochlea sets up electrical impulses in the nerve cells present in it. These electrical impulses are carried by auditory nerve to the brain. The brain interprets these electrical impulses as sound and we get the sensation of hearing.