Sound

Concepts & Notes

Introduction

In daily life we hear sound everywhere, from various sources like vehicles, humans, televisions, mechanics and so on. Sound is a form of energy which produces a sensation of hearing in our ears. In this chapter we will study how sound is produced, and how is it propagated and how is it reflected etc.

Production of Sound

Sound is produced when an object vibrates. Sound is produced when we speak, when our fingers strike the membrane of a tabla, when signals are fed to the speakers of a radio, television or music system, when brakes are applied suddenly to stop a vehicle, when utensil bang against each other, and so on. In each case the source of sound vibrates.

The following activities demonstrate the production of sound.

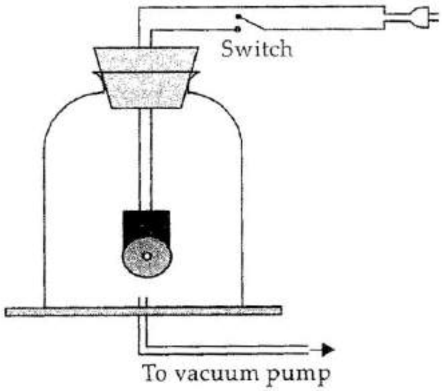
Activity Corner

1. Take a plastic scale or ruler from your geometry box.
Hold it flat on your desk or table with about half its length protruding (stick out from the surface) over the edge. Now bend it down and release it. It will move up and down rapidly (i.e., it will vibrate) and produce the sound at the same time. The sound will last as long as the vibration (i.e., rapid up and down motion) of the scale continues.

2. Take a trough and fill it with water up to the brim. Take a tuning fork and set it into vibrations by striking its prongs on a rubber pad. Gently touch the surface of the water with one of the prongs of the vibrating tuning fork. What do you observe? Waves are formed on the water surface.
The water particles vibrate to form these waves.

Sound needs a Medium to Travel

The substance or matter through which sound is transmitted is called a medium. The medium can be a 'solid, a liquid or a gas. When a school bell rings, the solid bell vibrates and produces sound (point of generation). The sound travels through air and finally reaches our ears (listener).
So, sound moves through a medium from the point of generation to the listener.
Let us perform an experiment to prove that sound requires a medium for its propagation.

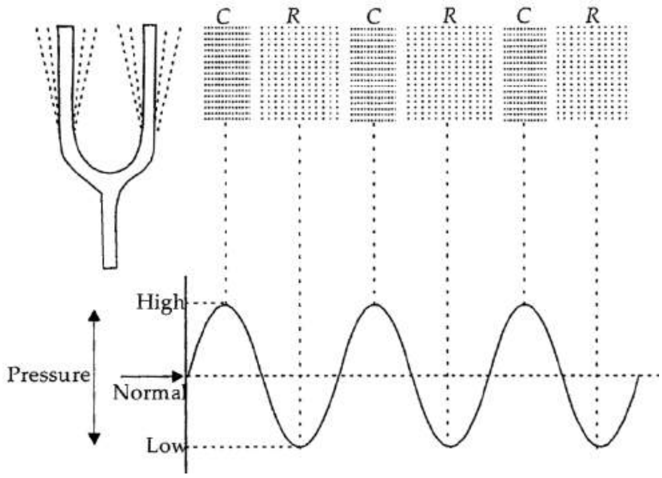


Take an electric bell, a big glass jar and vacuum pump. Hand an electric bell inside a jar connected to a vacuum pump. Switch on the bell and switch on the vacuum pump to take the air molecules out of the jar. The sound becomes feeble and finally you may not hear the sound.
When there was air in the jar sound travelled through it to the wall of the jar. This caused the wall to vibrate and send the sound to you and everyone around it. But when air was removed, sound from the bell could not travel to the wall of the jar.
This shows that sound needs a medium to travel.
The speed of sound depends on the medium through which it travels. It is fastest in solids and slowest in air. The reason behind it is that solids are most dense and therefore, carry sound fastest.

Propagation of Sound

Sound is produced by vibrating objects. The object that vibrates and produces sound is called point of generation.
Let us see how the sound travels from one place to another place.
When a body vibrates, then the particles of the medium (say air) around the vibrating body are set into vibrations. The particles of the medium which are very close to the vibrating body are pushed away from the body. These particles of the medium strike against the neighboring particles. Hence the number of particles of the medium in the region where the displaced particles strike against the neighboring particles is large. This region is known as compression (C).

Since pressure is directly proportional to the number of particles, so the compression is a region of high pressure or high density. When the vibrating body moves backward, a region of emptiness known as rarefaction (R) or a region of low pressure or low density is created. The displaced particles of the medium rebound into the region of low pressure or rarefaction. At the same time, compression is followed outwards. Therefore, when a body vibrates to produce sound, compressions and rarefactions follow one another as the sound waves travel through the medium away from the vibrating body. When a sound wave travels through a medium, the particles of the medium simply vibrate about their rest positions and they do not move from one place to another place in the medium.
Figure represents the region of compressions (or high pressures) and rarefactions (or low pressures) as the sound propagation in the medium.



ILLUSTRATION

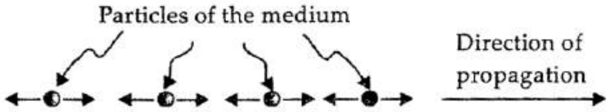
1. How sound is produced in Musical Instruments?

Sol.: When a drum is beaten, then the skin of drum vibrated and sound is produced. When the stings of a guitar are plucked and released, they vibrate and produce sound. When air is blown into the flute, pipe, clarinet etc., it vibrates in the tube of the instruments and hence sound is produced. Sound is also produced when the birds flap their wings during the flight.

Longitudinal Waves

A wave in which the particles of the medium oscillate (vibrate) to and fro about their mean position in the direction of propagation of the wave is called a longitudinal wave.

A longitudinal wave is described in figure.



Longitudinal waves can be produced in any medium, viz., in solids, liquids and in gases.

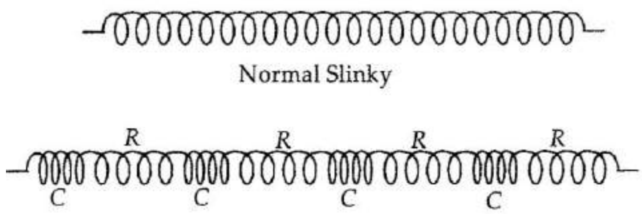
Examples:

(i) ***Sound waves are longitudinal waves.***

(ii) ***The waves produced in a spring (slinky) by compressing a small portion of it and releasing are longitudinal waves.***

Formation of Longitudinal Waves in a Slinky

The regions where the coils become closer are called compressions (C) and the regions where the coils are further apart are called rarefactions (R). As we already know, sound propagates in the medium as a series of compressions and rarefactions. Now, we can compare the propagation of disturbance in a slinky with the sound propagation in the medium. These waves are called longitudinal waves. In these waves the individual particles of the medium move in a direction parallel to the direction of propagation of the disturbance. The particles do not move from one place to another but they simply oscillate back and forth about their position of rest. This is exactly how a sound wave propagates, hence sound waves are longitudinal waves.

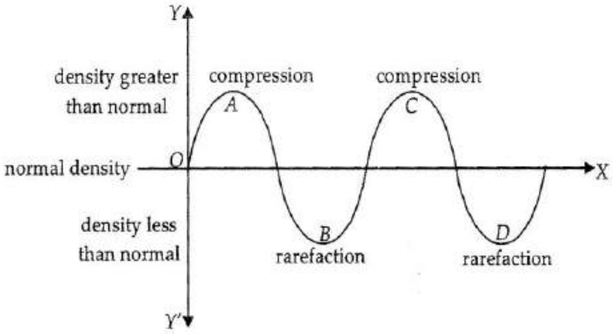


Back and forth Movement

Graphical Representation of Longitudinal Waves

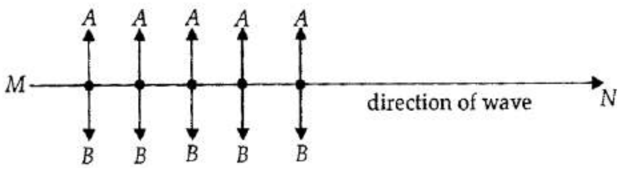
Longitudinal wave is represented by density-distance graph. In figure, the horizontal line OX represents the normal density of air. All the points above this line represent greater density. In a compression of a longitudinal wave, the density of the particles is high. So, here A and C represent compressions. All the points below the line OX represent less density (than normal).

In a rarefaction, the density of the particles is less than that in the normal. So, here B and D represent rarefactions.

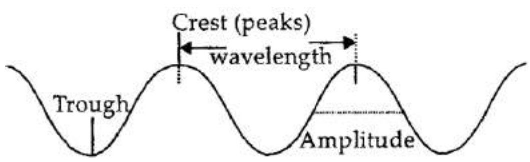


There is also another type of wave/ called a transverse waves. In a transverse wave the particles of the medium oscillate (vibrate) up and down/ i.e., perpendicular to the direction in which the wave is moving is called a transverse wave. A transverse wave is illustrated in figure. In this figure the direction of a wave is shown from M to N in the horizontal plane. The direction of vibrations of the particles of the medium is along AB or we can say/ perpendicular to the direction of the wave, i.e., the particles of the medium vibrate up and down perpendicular to the direction of propagation of the wave.

Particles of the medium vibrating up and down



Characteristics of a Sound Wave



- **Wavelength:** Distance between two consecutive peaks and trough is called wavelength. Wavelength is represented by X (lambda) and its unit is metre.
- **Frequency:** Number of oscillations of sound wave is called its frequency. Number of peak and troughs per unit of time will give frequency. It is represented by I) ^nu) and its unit is Hertz (Hz).
- **Time period:** Time taken by a vibrating particle or a body to complete one vibration or oscillation is known as time period. Its unit is second and is represented by T.
- **Relation between frequency and time period:** The number of waves produced per second is called its frequency. $\upsilon = \frac{1}{T}$
- **Amplitude:** The magnitude of the maximum disturbance in the medium on either side of the mean value is called the amplitude of the wave. It is usually represented by the letter A. For sound its unit will be that of density or pressure.
- **Softness or Loudness of Sound:** If the amplitude is smaller then the sound will be softer and if it is larger then sound will be louder. Higher amplitude helps the sound wave to travel fast.
- **Speed of sound:** It is the distance which a compression or a rarefaction travels per unit of time.

  Speed of sound $= \upsilon = \frac{\lambda}{T} = \frac{\text{Wavelength}}{\text{Time}}$

  or $\quad v = \lambda\upsilon(\text{because}\ \frac{1}{T} = \upsilon)$

  So, speed = Wavelength x Frequency

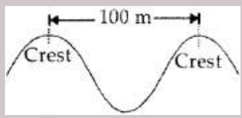
  The speed of the sound remains almost the same for all frequencies in a given medium under the same physical condition.

ILLUSTRATION

2. A boat at anchor is rocker by waves whose consecutive crests are 100 m apart. The wave velocity of the moving crests is $20\ m\ s^{-1}$. What is the frequency of rocking of the boat?

Sol.: Given $\lambda = 100\ m,\ \upsilon = 20\ m\ s^{-1}$

Now $\upsilon = u\lambda$



$$\therefore\ \upsilon = \frac{v}{\lambda} = \frac{20}{100} = 0.2 Hz$$

3. Audible ranges of frequencies is 20 Hz to 20, 000 Hz. Find the range of wavelengths corresponding to this frequency. Given, velocity of sound $= 340\ m\ s^{-1}$.

Sol.: We know,

$\upsilon = u\lambda$ or $\quad \lambda = \frac{\upsilon}{u}$

When $\quad \upsilon = 20\ Hz,$

$$\lambda = \frac{340\ m\ s^{-1}}{20\,Hz} = \frac{340\ m\ s^{-1}}{20\ s^{-1}} = 17\,m$$

When $\upsilon = 20{,}000$ Hz,

$$\lambda = \frac{340\ m\ s^{-1}}{20,000\ s^{-1}} = 0.017\ m$$

Thus, range of wavelength = 0.017 m to 17 m.

Speed of Sound in Different Medium

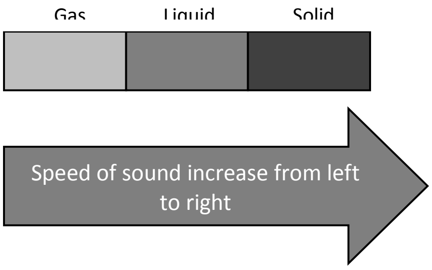
The speed of sound in different media is different. This is because the molecules are packed closer in solids and liquids than in air (or gas). Since molecules undergo vibrations, they do so more efficiently when they are closer together.

- The speed of sound depend upon:

(i) the properties (elasticity and density) of the medium through which it propagates and

(ii) temperature of the medium.

Sound (in general) has greatest speed in case of solids and least in case of gases. For liquids, the speed of sound is intermediate between these two extremes as shown in figure.



In general, speed of sound in solids > speed of sound in liquids > speed of sound in gases.

However, in certain solids, the speed (v) of sound is much less than that even in gases as v (for vulcanized rubber) = 54 m s^{-1} and v (for hydrogen) = 1284 m s^{-1}. The speed of sound in lead (a solid) = 1332 m s^{-1} and in sea water (a liquid) = 1531 m s^{-1}. The speed of sound in methyl alcohol (a liquid) = 1103 m s^{-1}.

The speed of sound increases with increase in temperature of the medium. In air, it increases roughly by 0.61 m s^{-1} with rise of 1°C in temperature. The speed of sound in air at 0°C is 331 m s^{-1} and at 22°C, it is 344 m s^{-1}.

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

- The speed of sound in some gases, liquids and solids are listed in table.

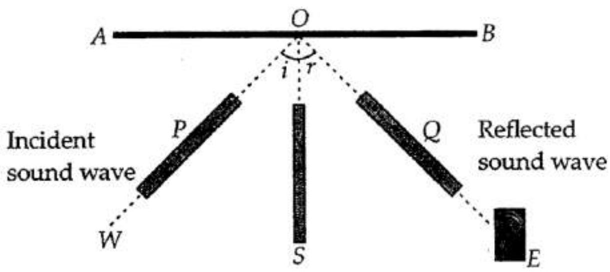
State	Substance	Speed in $m\ s^{-1}$
(a) Gases	1. Hydrogen	1284
	2. Helium	965
	3. Air	346
	4. Oxygen	316
	5. Sulphur dioxide	213
(b) Liquids	1. Water (sea)	1531
	2. Water (distilled)	1498
	3. Ethanol	1207
	4. Methanol	1103
(c) Solids	1. Aluminium	6420
	2. Nickel	6040
	3. Steel	5960
	4. Iron	5950
	5. Brass	4700
	6. Glass (Flint)	3980

Reflection of sound

Like light waves, sound waves also get reflected when fall on the surface of an obstacle. But unlike light waves, sound waves do not necessarily require a polished surface for reflection, i.e., for reflection of sound waves, the surface may be polished or rough. The following simple experiment establishes that reflection of sound follows the same laws as those for reflection of light.

(i) Place a large plane board, AB (of a metal, cardboard or wood) in the vertical position (i.e, perpendicular to the plane of the paper).

(ii) Take two hollow metallic tubes P and Q (each about 1 m long and about 8 to 10 cm in diameter) and place them in the plane of the paper and in positions inclined to the board as shown in figure.



(iii) Hold a watch W at the free end of the tube P and try to hear the ticking sound of the watch by positioning the ear at £.

(iv) Put a carboard screen S in between the two tubes so that sound produced by the watch does not reach the ear directly.

(v) Turn the tube Q till the ticking sound of the watch is the loudest. In this position, it is found that the tubes are inclined to S at the same angle, i.e., i (angle of incidence of sound wave) = r (angle of reflection of the sound wave).

(vi) If the tube Q is lifted slightly vertically upwards, no sound is heard. This implies that the reflected sound wave (OE) lies in the same plane (i.e., the plane of the paper) as the incident sound wave.

The normal OS to the surface lies in the same plane as that in which the incident and reflected sound waves lie.

From this experiment, we obtain the following two laws for the reflection of sound waves.

These laws are as follows.

- **First law.** The angle of reflection (r) is always equal to the angle of incidence (;'), i.e.,
  $\angle r = \angle i$ or $i = r$.
- **Second law.** The incident wave, the reflected wave and the normal (at the point of incidence), all lie in the same plane.

Examples:

(i) Speaking tube or Megaphone: You must have seen in fairs or tourist spots, people using megaphones addressing a group of people. Megaphone is simply a horn-shaped tube. The sound waves are prevented from spreading out by successive reflections and are confined to the air in the tube. For the same reason, loud speakers also have horn-shaped openings.

(ii) The circular runway round the base of a dome is a whispering gallery. If someone whispers at a point close to the wall of the gallery, the sound gets reflected round the wall of the gallery. The sound can be distinctly heard at all points near the wall all around.

(iii) Ear Trumpet or Hearing Aid: It is a device which is used by the persons who are hard of hearing. The sound waves received by the wide end of the trumpet are reflected into a much narrower area, leading it to the ear. This enhances the amplitude of vibrating layer of air inside the ear and helps in improving hearing.

(iv) Stethoscope: It is an instrument used by the doctors for listening sound produced with the body, especially in the heart and lungs. In the stethoscope, the sound produced within the body of a patient is picked up by a sensitive diaphragm and then reaches the doctors ears by multiple reflection.

Echo

The sound returning back towards the source after suffering reflection from a distant obstacle (a wall, a hill, a row of building etc.) is called an echo. When the sound is reflected repeatedly from a number of obstacles, more than one echoes, called multiple echoes are heard. Multiple echoes may be heard one after the other when sound gets repeatedly reflected from distant high rise buildings or hills. The rolling of thunder is an example of multiple echo formation.

Echo is a very familiar example of reflection of sound waves. The time gap between the two sounds - one direct and the other echo, depends upon the medium through which the sound wave travels.

The two sounds - one direct and the other echo, can be heard distinctly provided the distance between the observer and the reflecting surface is large enough to allow the reflected sound to reach him without interfering with the direct sound. Since the sensation of sound persists for $\frac{1}{10}$ second after it is produced, the echo can be heard distinctly only if it reaches at least $\frac{1}{10}$ second after the original sound is produced.

- **Minimum distance between the observer and the obstacle for echo to be heard**

  Let distance between the observer and the obstacle $= d$

  Speed of sound (in the medium) $= \upsilon$

  Time after which echo is heard $= t$

  Then, $t = \frac{2d}{\upsilon}$ or $d = \frac{\upsilon t}{2}$

  We know

  Speed of sound in air at 20° C = 343 m s^{-1}

  For an echo to be heard distinctly,

  $t \geq 0.1\ s$

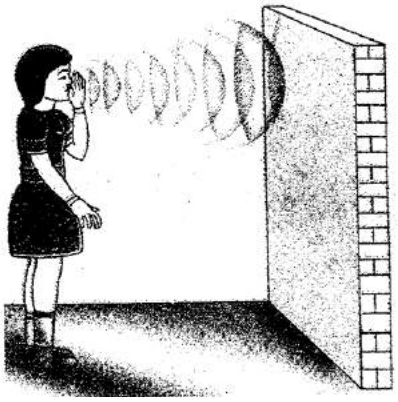
  Then $d \geq \frac{343\ m\ s^{-1} \times 0.1\ s}{2}$ or

  $d \geq 17.2\ m$

  Thus, the minimum distance (in air at 20°C) between the observer and the obstacle for the echo to be heard clearly should be 17.2 m.

Conditions for the Formation of Echoes

(i) The minimum distance between the source of sound and the reflector should be at least 17.2 metres (so that the echo is heard distinctly after the original sound is over or dies off).



(ii) The size of the reflector must be large (like tall mountains, hills, walls, etc.) compared to the wavelength of the incident sound (for reflection of sound to take place).

(iii) The intensity or loudness of the sound should be sufficient for the reflected sound reaching the ear to be audible.

Whispering gallery: We can experience extraordinary sound effects in the form of echoes at Gol Gumbaz, Bijapur (Karnataka). Even a whisper at the end is amplified and heard very clearly at different ends. A similar gallery is there at St. Paul's Cathedral in London (U.K.).

ILLUSTRATION

4. A child hears an echo from a cliff 4 seconds after the sound from a powerful cracker is produced. How far away is the cliff from the child? Velocity of sound in air at $20^{o}C$ is $344\ m\ s^{-1}$

Sol.: Let the distance the child and the cliff be d. Then,

Total distance travelled by the sound = 2d

Total time taken by the sound = 4 s

Then, velocity of sound $=\dfrac{2d}{4s}=\dfrac{d}{2s}$

$344\ ms^{-1}=\dfrac{d}{2s}$

This gives, $d=344\ m\ s^{-1}\times 2\ s=688\ m$

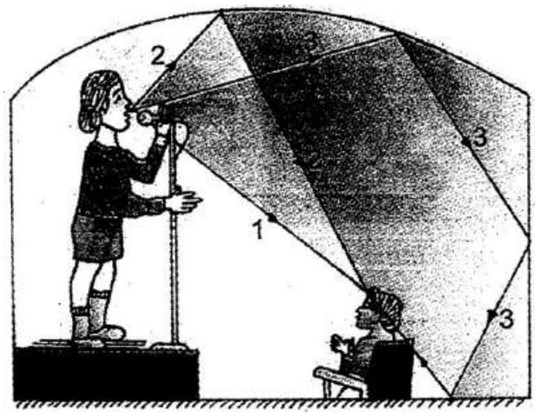
Thus, the cliff is at a distance of 688 m from the child.

Reverberation

Persistence of sound after its production is stopped, is called reverberation.

When a sound is produced in a big hall, its wave reflect from the walls and travel back and forth. Due to this energy does not reduce and the sound persist.

A short reverberation is desirable in a concert hall (where music is being played) because it gives life to sound. Too much reverberation confuses the programmers and must be reduced to reduce reverberation. The material having sound-absorbing properties is used for making the seats in a big hall or auditorium to reduce reverberations. Panels made of sound-absorbing materials (like compressed fibre board or felt) are put on the walls and ceiling of big halls and auditoriums to reduce reverberations.



Infrasonics or Infrasound

The waves of frequency less than 20 Hz are known as infrasonic waves.

The infrasonic waves are produced by large vibrating bodies. For example, infrasonic waves are produced by the vibration of the earth's surface during the earthquake. Some animals like elephants, rhinoceroses and whales etc. also produce infrasonic waves. These waves are not audible to a human ear.

It has been observed that animals behaviour becomes unusual just before the tremor is felt. This is because the animals has the ability to detect infrasonic waves produced at the time of tremor.

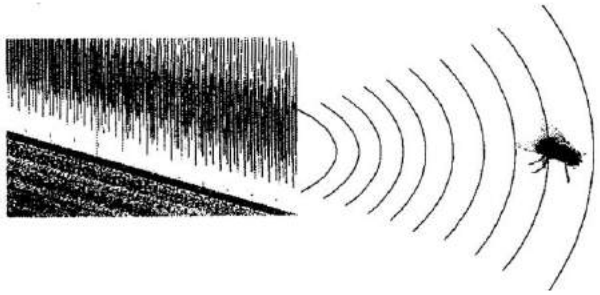
Ultrasonics or Ultrasound

The waves of frequency greater than 20,000 Hz are known as ultrasonic waves or ultrasound.

These waves are not audible to a human ear but they can be heard by animals and birds.

Bats can produce ultrasonic waves by flapping their wings. They can also detect these waves.

The ultrasonic waves produced by the bats after reflection from the obstacles like buildings guide them to remain away from the obstacles during their flights.



Properties of Ultrasound Waves

(i) **Ultrasonic waves** can travel easily in solid and liquid but not in gases. This is because the intensity of ultrasonic waves decreases fast with propagation in gases.
(ii) Good directionality: Due to high frequency of ultrasound, its wavelength is small. Therefore, these waves do not bend easily and therefore move along a straight line. It is because of this property that these waves are used for scanning objects and making their image. The imaging phenomenon also, depends on the fact that these waves can travel through opaque objects.
(iii) High power: Due to high frequency, the energy possessed by these waves is high. Therefore, if these waves are focused at a point, a high power is generated at that point which is used in breaking and cutting objects.

Applications of Ultrasound (Ultrasonic Waves)

Ultrasonic waves have number of uses:
(i) Ultrasonic waves are used to establish ship-to-ship communication.

(ii) Ultrasonic waves are used to determine the depth of a sea. It is done with the help of a SONAR.

(iii) Ultrasonic waves are used for cleaning the hidden parts of an instrument. The instrument or device whose hidden parts are to be cleaned is dipped in a liquid. The ultrasonic waves are passed through this liquid. These waves forces the dirt or any other impurity out from the parts of the instrument which cannot be approached directly.
(iv) Ultrasonic waves are used for welding plastic. Two plastic surfaces are pressed against each other. Then ultrasonic waves are allowed to fall at a point where plastic surfaces are in contact. These waves produces heat energy. This heat energy binds the two plastic surfaces together.

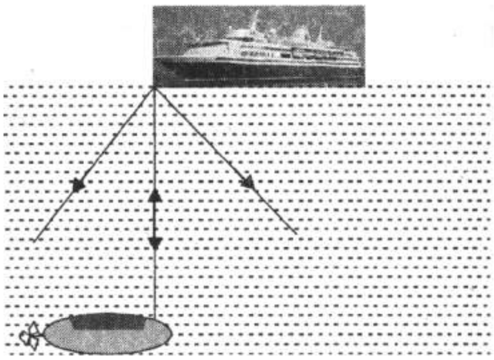
(v) Ultrasonic waves are used for diagonosing the diseases in human body. Different parts of the body like bone, fat muscles and liquid have different reflective properties. Ultrasonic waves are allowed to fall on the portion of the body of a patient to be diagonsed. These waves are reflected back by the different parts (like bones, tissues, liquids and muscles etc.) of that portion o64he body in different manners. The varying echoes are recorded for analyzing that part of the body.
The method used for diagonosing the different part of a human body with the help of the ultrasonic waves is known as ultra sonography.

(vi) Ultrasonic waves are used to kill bacteria in liquids. Thus, the liquids like milk can be preserved for a longer period of time.
(vii) Ultrasonic waves are used to find faults and cracks in metals. Ultrasonic waves are thrown on a metal under investigation. The beam of ultrasonic waves reflected by the metal is investigated. The intensity of the ultrasonic waves reflected from the fault or a crack is different from the intensity of the waves reflected from the other part of metal. Thus, the position of the fault or a crack in the metal can be easily located. In fact, the picture of the metal produced by the reflection of ultrasonic waves is taken on the screen or the monitor.
By analyzing this picture, the position of the crack or fault in the metal is detected.

(viii) Ultrasonic waves are also used to analyze the development of an unborn child. Any abnormality in the growth of an unborn child can be detected by observing the picture taken by ultrasound.

SONAR [Sound Navigation and Ranging]

It is a device which is used in the ships to locate rocks, icebergs, submarines, old ships sank
Ultrasonic waves of high frequency are sent from a ship on the surface. These waves travel in a straight line till they hit a body like a shipwreck or submarine from where these waves are reflected back as shown in the figure. The transmitter sending the waves notes the time interval t between sending the signal and receiving it back. If d is the distance of the submarine from the ship, then the total distance travelled by the wave in time interval t is 2d.



Using speed $= \dfrac{\text{Distance}}{\text{Time}} \Rightarrow \upsilon = \dfrac{2d}{t}$

$\therefore \quad d = \dfrac{1}{2}\left(\dfrac{\upsilon}{t}\right)$

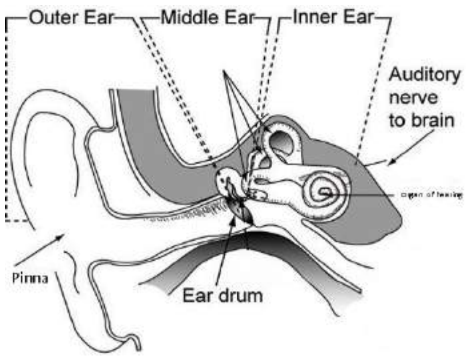
The velocity v of the ultrasonic wave in water is same as that of audible range in water.

Structure of human Ear

The human ear is a very sensitive device and faintest sound detected by it has a pressure variation of about 2×10^{-5} N/m^2 (corresponding to an amplitude of about 10^{-1} m).

The ear has the following parts:

- **Outer ear:** The part seen outside is known as the pinna. This part collects the sound and sends it to the auditory canal. A tightly stretched membrane called eardrum separates the outer ear from the middle ear.



- **Middle ear:** It consists of three small bones, the hammer, the anvil and the stirrup. The amplified vibrations of sound are transmitted through these bones to the cochlea.
- **Inner ear:** The inner ear contains the organs of hearing which perceive sound and send a message to the brain via the **auditory nerve**.

Essential Points

- Sound is a form of energy which produces the sensation of hearing in our ears.
- Wave or wave motion carries energy from one place to another place of the medium.
- Mechanical wave is a periodic disturbance which requires material medium (i.e., solid, liquid or gas) for its propagation.
- Sound needs material medium for its propagation.
- Sound cannot travel through vacuum.
- Compression is a region (of a medium) of high pressure or high density.
- Rarefaction is region (of a medium) of low pressure or low density.
- Pitch or shrillness is a characteristic of a sound that depends on the frequency received by a human ear.
- Loudness of a sound is the characteristic of a sound that depends upon the amplitude of the vibrating body producing sound.
- Timber or quality is a characteristic of sound that enables us to distinguish between two sounds of same pitch and same loudness.
- Intensity of a sound is defined as the sound energy transferred per unit time per unit area placed perpendicular to the direction of sound.
- Intensity of sound is an objective physical quantity and can be measured.
- The S.I. unit of intensity of sound is $J\,s^{-1}\,m^{-2}$ or $W\,m^{-2}$.
- The relationship between speed of wave, wavelength and frequency is $\upsilon = u\lambda$
- A wave of high frequency in a given medium has small wavelength.
- The speed of an object moving faster than the speed of sound is known as supersonic speed.
- Supersonic jet air craft's and a bullet fired from a gas produced a shock wave.
- Shock wave carries a huge amount of energy and it produces a loud sound called sonic boom.
- When echoes due to multiple reflection of sound follow so closely behind the original sound that the original sound appears to be prolonged even when the source of sound stops to produce sound, then the effect is known as reverberation.
- Reverberation time is the time interval for which the audible sound persists after the production of original sound.
- The audible range of frequency is 20 Hz to 20,000 Hz (or 20 kHz).

- Ultrasonic waves (or ultrasound) are the waves of frequencies greater than 20,000 Hz (or 20 kHz).
- Human ears cannot hear infrasonic and ultrasonic waves but animals and birds can hear these waves.
- Human ear is hearing device. It consists of three parts - the external ear, the middle ear and the inner ear.

CONCEPT MAP