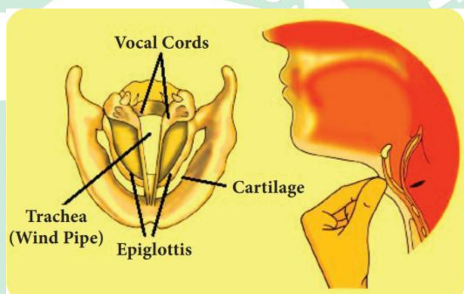
SOUND

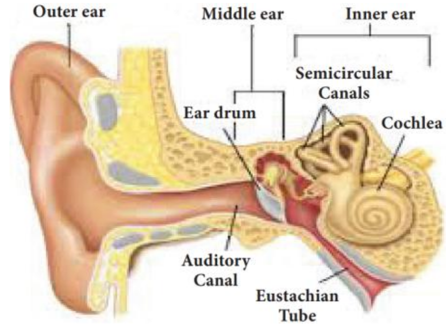
The System of Sound Production in Man:

In human being, the sound is produced in the voice box, called the larynx, which is present in the throat. It is located at the upper end of the windpipe. The larynx has two ligaments called 'vocal cords', stretched across it. The vocal cords have a narrow slit through which air is blown in and out. When a person speaks, the air from the lungs is pushed up through the trachea to the larynx. When this air passes through the slit, the vocal cords begin to vibrate and produce a sound. By varying the thickness of the vocal cords, the length of the air column in the slit can be changed. This produces sounds of different pitches. Males generally have thicker and longer vocal cords that produce a deeper, low pitch sound in comparison with females.



Human Ears Work:

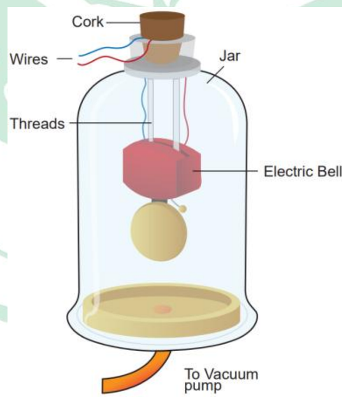
Ear is the important organ for all animals to hear a sound. We are able to hear sound through our ears. Human ear picks up and interprets high frequency vibrations of air. Ears of aquatic animals are designed to pick up high frequency vibrations in water. The outer and visible part of the human ear is called pinna (curved in shape). It is specially designed to gather sound from the environment, which then reaches the ear drum (tympanic membrane) through the ear canal. When the sound wave strikes the drum, the ossicles move inward and outward to create the vibrations. These vibrations are then picked up by special types of cells in the inner ear. From the inner ear the vibrations are sent to the brain in the form of signals. The brain perceives these signals as sounds.



Sound Waves:

Sound needs a material medium like air, water, steel etc., for its propagation. It cannot travel through vacuum. This can be demonstrated by the Bell – Jar experiment.

An electric bell and an airtight glass jar are taken. The electric bell is suspended inside the airtight jar. The jar is connected to a vacuum pump, as shown in Figure 8.1. If the bell is made to ring, we will be able to hear the sound of the bell. Now, when the jar is evacuated with the vacuum pump, the air in the jar is pumped out gradually and the sound becomes feebler and feebler. We will not hear any sound, if the air is fully removed (if the jar has vacuum).



Resonances:

An echo is the sound reproduced due to the reflection of the original sound from various rigid surfaces such as walls, ceilings, surfaces of mountains, etc.

If you shout or clap near a mountain or near a reflecting surface, like a building you can hear the same sound again. The sound, which you hear is called an echo. It is due to the reflection of sound. One does not experience any echo sound in a small room. This does not mean that sound is not reflected in a small room. This is because smaller rooms do not satisfy the basic conditions for hearing an echo.

Conditions necessary for hearing echo:

The persistence of hearing for human ears is 0.1 second. This means that you can hear two sound waves clearly, if the time interval between the two sounds is at least 0.1 s. Thus, the minimum time gap between the original sound and an echo must be 0.1 s.

The above criterion can be satisfied only when the distance between the source of sound and the reflecting surface would satisfy the following equation:

Velocity = distance travelled by sound / time taken

$v = 2d / t$

$d = vt / 2$

Since, $t = 0.1$ second, then $d = v \times 0.1 / 2 = v / 20$

Thus the minimum distance required to hear an echo is $1/20^{th}$ part of the magnitude of the velocity of sound in air. If you consider the velocity of sound as 344 ms^{-1}, the minimum distance required to hear an echo is 17.2 m.

Applications of echo:

Some animals communicate with each other over long distances and also locate objects by sending the sound signals and receiving the echo as reflected from the targets.

The principle of echo is used in obstetric ultrasonography, which is used to create real-time visual images of the developing embryo or fetus in the mother's uterus. This is a safe testing tool, as it does not use any harmful radiations.

Echo is used to determine the velocity of sound waves in any medium.

Applications Reflection of Sound:

Sound board:

These are basically curved surfaces (concave), which are used in auditoria and halls to improve the quality of sound. This board is placed such that the speaker is at the focus of the concave surface. The sound of the speaker is reflected towards the audience thus improving the quality of sound heard by the audience.

Ear trumpet:

Ear trumpet is a hearing aid, which is useful by people who have difficulty in hearing. In this device, one end is wide and the other end is narrow. The sound from the sources fall into the wide end and are reflected by its walls into the narrow part of the device. This helps in concentrating the sound and the sound enters the ear drum with more intensity. This enables a person to hear the sound better.

Mega phone:

A megaphone is a horn-shaped device used to address a small gathering of people. Its one end is wide and the other end is narrow. When a person speaks at the narrow end, the sound of his speech is concentrated by the multiple reflections from the walls of the tube. Thus, his voice can be heard loudly over a long distance.

Reflection of Sound:

Sound bounces off a surface of solid or a liquid medium like a rubber ball that bounces off from a wall. An obstacle of large size which may be polished or rough is needed for the reflection of sound waves. The laws of reflection are:

The angle in which the sound is incident is equal to the angle in which it is reflected.

Direction of incident sound, the reflected sound and the normal are in the same plane.

Uses of multiple reflections of sound:

Musical instruments:

Megaphones, loud speakers, horns, musical instruments such as nathaswaram, shehnai and trumpets are all designed to send sound in a particular direction without spreading it in all directions. In these instruments, a tube followed by a conical opening reflects sound successively to guide most of the sound waves from the source in the forward direction towards the audience.

Stethoscope:

Stethoscope is a medical instrument used for listening to sounds produced in the body. In stethoscopes, these sounds reach doctor's ears by multiple reflections that happen in the connecting tube.

Applications of reflection of sound waves:

Stethoscope: It works on the principle of multiple reflections.

It consists of three main parts:

Chest piece: It consists of a small disc-shaped resonator (diaphragm) which is very sensitive to sound and amplifies the sound it detects.

Ear piece: It is made up of metal tubes which are used to hear sounds detected by the chest piece.

Rubber tube: This tube connects both chest piece and ear piece. It is used to transmit the sound signal detected by the diaphragm, to the ear piece. The sound of heart beats (or lungs) or any sound produced by internal organs can be detected, and it reaches the ear piece through this tube by multiple reflections.

Echo: An echo is a repetition of sound produced by the reflection of sound waves from a wall, mountain or other obstructing surfaces. The speed of sound in air at 20°C is 344 ms^{-1}. If we shout at a wall which is at 344 m away, then the sound will take 1 second to reach the wall. After reflection, the sound will take one more second to reach us. Therefore, we hear the echo aft er two seconds.

SONAR: Sound Navigation and Ranging. Sonar systems make use of reflections of sound waves in water to locate the position or motion of an object. Similarly, dolphins and bats use the sonar principle to find their way in the darkness.

Reverberation: In a closed room the sound is repeatedly reflected from the walls and it is even heard long after the sound source ceases to function. The residual sound remaining in an enclosure and the phenomenon of multiple reflections of sound is called reverberation. The duration for which the sound persists is called reverberation time. It should be noted that the reverberation time greatly affects the quality of sound heard in a hall. Therefore, halls are constructed with some optimum reverberation time.

Sonic Boom:

When the speed of any object exceeds the speed of sound in air (330 ms–1) it is said to be travelling at supersonic speed. Bullets, jet, aircrafts etc., can travel at supersonic speeds. When an object travels at a speed higher than that of sound in air, it produces shock waves. These shock waves carry a large amount of energy. The air pressure variations associated with this type of shock waves produce a very sharp and loud sound called the 'sonic boom'. The shock waves produced by an aircraft have energy to shatter glass and even damage buildings.

Doppler Effect:

The whistle of a fast moving train appears to increase in pitch as it approaches a stationary listener and it appears to decrease as the train moves away from the listener. This apparent change in frequency was first observed and explained by Christian Doppler (1803-1853), an Austrian Mathematician and Physicist. He observed that the frequency of the sound as received by a listener is different from the original frequency produced by the source whenever there is a relative motion between the source and the listener. This is known as Doppler Effect this relative motion could be due to various possibilities as follows:

- The listener moves towards or away from a stationary source
- The source moves towards or away from a stationary listener

- Both source and listener move towards or away from one other
- The medium moves when both source and listener are at rest

For simplicity of calculation, it is assumed that the medium is at rest. That is the velocity of the medium is zero.

Let S and L be the source and the listener moving with velocities v_S and v_L respectively. Consider the case of source and listener moving towards each other. As the distance between them decreases, the apparent frequency will be more than the actual source frequency.

Let n and n' be the frequency of the sound produced by the source and the sound observed by the listener respectively. Then, the expression for the apparent frequency n' is

$$n' = \left(\frac{v + v_L}{v - v_s}\right) \mathbf{n}$$

Here, v is the velocity of sound waves in the given medium. Let us consider different possibilities of motions of the source and the listener. In all such cases, the expression for the apparent frequency.

Case No.	Position of source and listener	Note	Expression for apparent frequency
1	Both source and listener move They move towards each other	Distance between source and listener decreases. Apparent frequency is more than actual frequency.	$n' = \left(\frac{v + v_L}{v - v_s}\right) n$
2	Both source and listener move They move away from each other	Distance between source and listener increases. Apparent frequency is	$n' = \left(\frac{v - v_L}{v + v_s}\right) n$

		less than actual frequency. v_S and v_L become opposite to that in case-1.	
3	Both source and listener move They move one behind the other Source follows the listener	Apparent frequency depends on the velocities of the source and the listener. v_S becomes opposite to that in case-2.	$n' = \left(\frac{v - v_L}{v - v_s}\right) n$
4	Both source and listener move They move one behind the other Listener follows the source	Apparent frequency depends on the velocities of the source and the listener. v_S and v_L become opposite to that in case-3.	$n' = \left(\frac{v + v_L}{v + v_s}\right) n$
5	Source at rest Listener moves towards the source	Distance between source and listener decreases. Apparent frequency is more than actual frequency. $v_S = 0$ in case-1.	$n' = \left(\frac{v + v_L}{v}\right) n$
6	Source at rest Listener moves away	Distance between source and listener	$n' = \left(\frac{v - v_L}{v}\right) n$

	from the source	increases. Apparent frequency is less than actual frequency. $v_S = 0$ in case-2.	
7	Listener at rest Source moves towards the listener	Distance between source and listener decreases. Apparent frequency is more than actual frequency. $v_L = 0$ in case-1.	$n' = \left(\frac{v}{v - v_s}\right) n$
8	Listener at rest Source moves away from the listener	Distance between source and listener increases. Apparent frequency is less than actual frequency. $v_L = 0$ in case-2.	$n' = \left(\frac{v}{v + v_s}\right) n$

Suppose the medium (say wind) is moving with a velocity W in the direction of the propagation of sound. For this case, the velocity of sound, 'v' should be replaced with (v + W). If the medium moves in a direction opposite to the propagation of sound, then 'v' should be replaced with (v – W).

Conditions for no Doppler effect:

Under the following circumstances, there will be no Doppler effect and the apparent frequency as heard by the listener will be the same as the source frequency.

When source (S) and listener (L) both are at rest.

When S and L move in such a way that distance between them remains constant.

When source S and L are moving in mutually perpendicular directions.

If the source is situated at the center of the circle along which the listener is moving.

Applications of Doppler Effect:

To measure the speed of an automobile:

An electromagnetic wave is emitted by a source attached to a police car. The wave is reflected by a moving vehicle, which acts as a moving source. There is a shift in the frequency of the reflected wave. From the frequency shift, the speed of the car can be determined. This helps to track the over speeding vehicles.

Tracking a satellite:

The frequency of radio waves emitted by a satellite decreases as the satellite passes away from the Earth. By measuring the change in the frequency of the radio waves, the location of the satellites is studied.

RADAR (RAdio Detection And Ranging):

In RADAR, radio waves are sent, and the reflected waves are detected by the receiver of the RADAR station. From the frequency change, the speed and location of the aeroplanes and aircrafts are tracked.

SONAR:

In SONAR, by measuring the change in the frequency between the sent signal and received signal, the speed of marine animals and submarines can be determined.

Resonance:

It is a special case of forced vibrations where the frequency of external periodic force (or driving force) matches with the natural frequency of the vibrating body (driven). As a result the oscillating body begins to vibrate such that its amplitude increases at each step and ultimately it has a large amplitude. Such a phenomenon is known as resonance and the corresponding vibrations are known as resonance vibrations.

Example: The breaking of glass due to sound.

Soldiers are not allowed to march on a bridge. This is to avoid resonant vibration of the bridge. While crossing a bridge, if the period of stepping on the ground by marching soldiers equals the natural frequency of the bridge, it may result in resonance vibrations. This may be so large that the bridge may collapse.