Sound

Sound is a form of energy which produces sensation of hearing in our ears. But have you ever thought how sound is produced?

Vibrations are produced when some mechanical work is done. Vibration is nothing but to and for movement of a particle. Thus, mechanical energy vibrates an object and when these vibrations reach our ear, we hear the sound.

Propagation of Sound Waves

Sound needs a material medium like air, water, steel etc., for its propagation. It cannot travel through vacuum.

Sound travels in water and solids also. The speed of sound is more in solids than in liquids and it is very less in gases.

When a body vibrates, the particle of the medium in contact with the vibrating body is first displaced from its equilibrium position. It then exerts a force on the adjacent particle. This process continues in the medium till the sound reaches the ear of the person.

In order to understand this, let us consider a vibrating tuning fork. When a vibrating tuning fork moves forward, it pushes and compresses the air in front of it, creating a region of high pressure. This region is called a compression. When it moves backward, it creates a region of low pressure called rarefaction (R). These compressions and rarefactions produce the sound wave, which propagates through the medium.

The disturbance which is caused by the vibrations of the particles is passed over to the next particle. It means that the energy is transferred from one particle to another as a wave motion.

There are two types of mechanical wave.

Transverse wave

In a transverse wave the particles of the medium vibrate in a direction, which is perpendicular to the direction of propagation of the wave. E.g. Waves in strings, light waves, etc. Transverse waves are produced only in solids and liquids.

Longitudinal wave

In a longitudinal wave the particles of the medium vibrate in a direction, which is parallel to the direction of propagation of the wave. E.g. Waves in springs, sound waves in a medium. Longitudinal waves are produced in solids, liquids and also in gases.

Categories of sound waves based on their frequencies

Audible waves – These are sound waves with a frequency ranging between 20 Hz and 20,000 Hz. These are generated by vibrating bodies such as vocal cords, stretched strings etc.

Infrasonic waves – These are sound waves with a frequency below 20 Hz that cannot be heard by the human ear. e.g., waves produced during earth quake, ocean waves, sound produced by whales, etc.

Ultrasonic waves – These are sound waves with a frequency greater than 20 kHz, Human ear cannot detect these waves, but certain creatures like mosquito, dogs, bats, dolphins can detect these waves. e.g., waves produced by bats

Amplitude (A)

The maximum displacement of the particles of the medium from their original undisturbed positions, when a wave passes through the medium is called amplitude of the wave. Amplitude is denoted as A. Its SI unit is meter (m)

Frequency (n)

The number of vibrations (complete waves or cycles) produced in one second is called frequency of the wave. It is denoted as n. The SI unit of frequency is s^{-1} (or) hertz (Hz).

Time period (T)

The time required to produce one complete vibration (wave or cycle) is called time period of the wave. It is denoted as T. The SI unit of time period is second (s).

Wavelength (λ)

The minimum distance in which a sound wave repeats itself is called its wavelength. In a sound wave, the distance between the centers of two consecutive compressions or two consecutive rarefactions is also called wavelength. The wavelength is usually denoted as λ . The SI unit of wavelength is metre (m).

Speed or Velocity:

The speed of sound is the distance travelled by sound in one second. It is denoted by 'v'. It is represented by the expression, $v = n\lambda$, where 'n' is the frequency and 'λ' is the wavelength.

A sound has a frequency of 50 Hz and a wavelength of 10 m. What is the speed of the sound?

A sound has a frequency of 5 Hz and a speed of 25 ms-1. What is the wavelength of the sound?

The speed of sound depends on the properties of the medium through which it travels, like temperature, pressure and humidity. In any medium, as the temperature increases the speed of sound also increases. For example, the speed of sound in air is 331 ms-1 at 0°C and 344 ms-1 at 22°C.

Velocity of sound waves

When you talk about the velocity associated with any wave, there are two velocities, namely particle velocity and wave velocity.

SI unit of velocity is ms-1

Particle velocity:

The velocity with which the particles of the medium vibrate in order to transfer the energy in the form of a wave is called particle velocity.

Wave velocity:

The velocity with which the wave travels through the medium is called wave velocity. In other words, the distance travelled by a sound wave in unit time is called the velocity of a sound wave.

$$\therefore \text{Velocity} = \text{Distance}/\ \text{Time taken}$$

If the distance travelled by one wave is taken as one wavelength (λ) and, the time taken for this propagation is one time period (T), then, the expression for velocity can be written as

$$\therefore V = \lambda / T$$

Therefore, velocity can be defined as the distance travelled per second by a sound wave. Since, Frequency (n) =1/T, it can be written as $V = n\lambda$.
Velocity of a sound wave is maximum in solids because they are more elastic in nature than liquids and gases. Since, gases are least elastic in nature, the velocity of sound is the least in a gaseous medium. So, vS > vL > vg.

PROBLEMS:

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Factors affecting velocity of sound:

In the case of solids, the elastic properties and the density of the solids affect the velocity of sound waves. Elastic property of solids is characterized by their elastic moduli. The speed of sound is directly proportional to the square root of the elastic modulus and inversely proportional to the square root of the density. Thus the velocity of sound in solids decreases as the density increases whereas the velocity of sound increases when the elasticity of the material increases. In the case of gases, the following factors affect the velocity of sound waves.

Effect of density
Effect of temperature
Effect of relative humidity

Effect of density:

The velocity of sound in a gas is inversely proportional to the square root of the density of the gas. Hence, the velocity decreases as the density of the gas increases.

$$v \propto \sqrt{1/d}$$

Effect of temperature:

The velocity of sound in a gas is directly proportional to the square root of its temperature. The velocity of sound in a gas increases with the increase in temperature.

$$v \propto \sqrt{T}$$

Velocity at temperature T is given by the following equation:
$v_T = (v_o + 0.61\ T)\ ms^{-1}$
Here, v_o is the velocity of sound in the gas at 0° C.
For air, $v_o = 331\ ms^{-1}$.
Hence, the velocity of sound changes by $0.61\ ms^{-1}$ when the temperature changes by one degree celsius.

Effect of relative humidity:

When humidity increases, the speed of sound increases. That is why you can hear sound from long distances clearly during rainy seasons.
Problems:

At what temperature will the velocity of sound in air be double the velocity of sound in air at 0o C?

Reflection of Sound

When sound waves travel in a given medium and strike the surface of another medium, they can be bounced back into the first medium. This phenomenon is known as reflection.

The incident wave, the normal to the reflecting surface and the reflected wave at the point of incidence lie in the same plane.

The angle of incidence ∠i is equal to the angle of reflection ∠r.

The angle which the incident sound wave makes with the normal is called the angle of incidence, 'i'. The angle which the reflected wave makes with the normal is called the angle of reflection, 'r.

Reflection at the boundary of a denser medium.

Reflection at the boundary of a rarer medium.

Reflection of sound in plane and curved surfaces.

Echoes:

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.

Conditions necessary for hearing echo:

The persistence of hearing for human ears is 0.1 second.

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

$$V = 2d/t$$

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 foetus 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.

Sound board, Ear trumpet, Mega phone.

Doppler Effect:

Whenever there is a relative motion between a source and a listener, the frequency of the sound heard by the listener is different from the original frequency of sound emitted by the source. This is known as "Doppler effect".

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.
Tracking a satellite
RADAR (Radio Detection and Ranging)
SONAR

SONAR:

SONAR stands for Sound Navigation and Ranging

Sonar is a device that uses ultrasonic waves to measure the distance, direction and speed of underwater objects. Sonar consists of a transmitter and a detector and is installed at the bottom of boats and ships. The transmitter produces and transmits ultrasonic waves. These waves travel through water and after striking the object on the seabed, get reflected back and are sensed by the detector. The detector converts the ultrasonic waves into electrical signals which are appropriately interpreted. The distance of the object that reflected the sound wave can be calculated by knowing the speed of sound in water and the time interval between transmission and reception of the ultrasound. Let the time interval between transmission and reception of ultrasound signal be ‘t’. Then, the speed of sound through sea water is 2d /t = v.

This method is called echo-ranging. Sonar technique is used to determine the depth of the sea and to locate underwater hills, valleys, submarine, icebergs etc.

Electrocardiogram (ECG):

The electrocardiogram (ECG) is one of the simplest and oldest cardiac investigations available. It can provide a wealth of useful information and remains an essential part of the assessment of cardiac patients. In ECG, the sound variation produced by heart is converted into electric signals. Thus, an ECG is simply a representation of the electrical activity of the heart muscle as it changes with time. Usually, it is printed on paper for easy analysis. The sum of this electrical activity, when amplified and recorded for just a few seconds is known as an ECG.