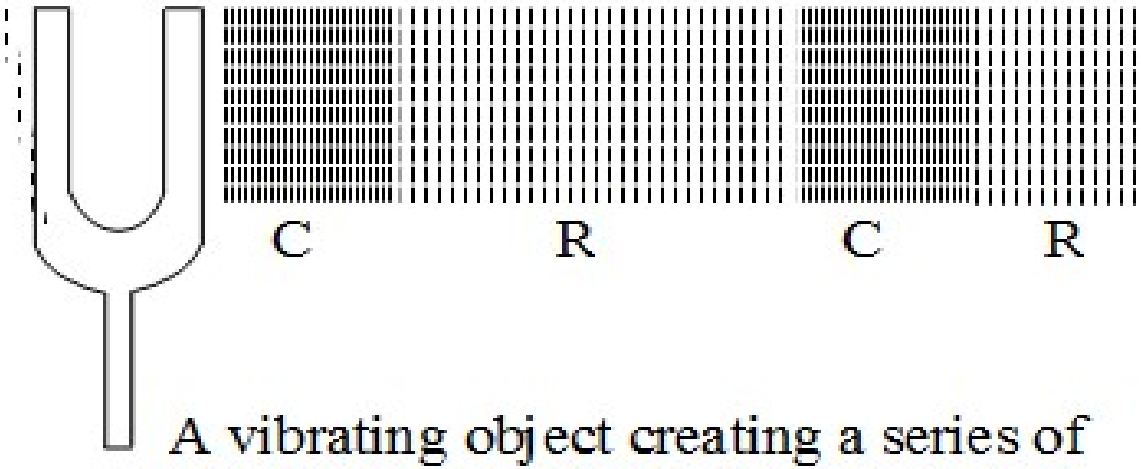
SOUND

- Sound is a mechanical wave that travels through a medium, such as air, water, or solids, as vibrations. These vibrations create changes in air pressure that our ears can detect, and our brain interprets these changes as sound.
- Vibration means a kind of rapid to and fro motion of an object. For example - the sound of the human voice is produced due to vibrations in the vocal cords.

Propagation of Sound

- When an object vibrates, it sets the particles of the medium around it vibrating. The particles do not travel all the way from the vibrating object to the ear. A particle of the medium in contact with the vibrating object is first displaced from its equilibrium position. It then exerts a force on the adjacent particle. As a result of which the adjacent particle gets displaced from its position of rest. After displacing the adjacent particle the first particle comes back to its original position. This process continues in the medium till the sound reaches your ear.

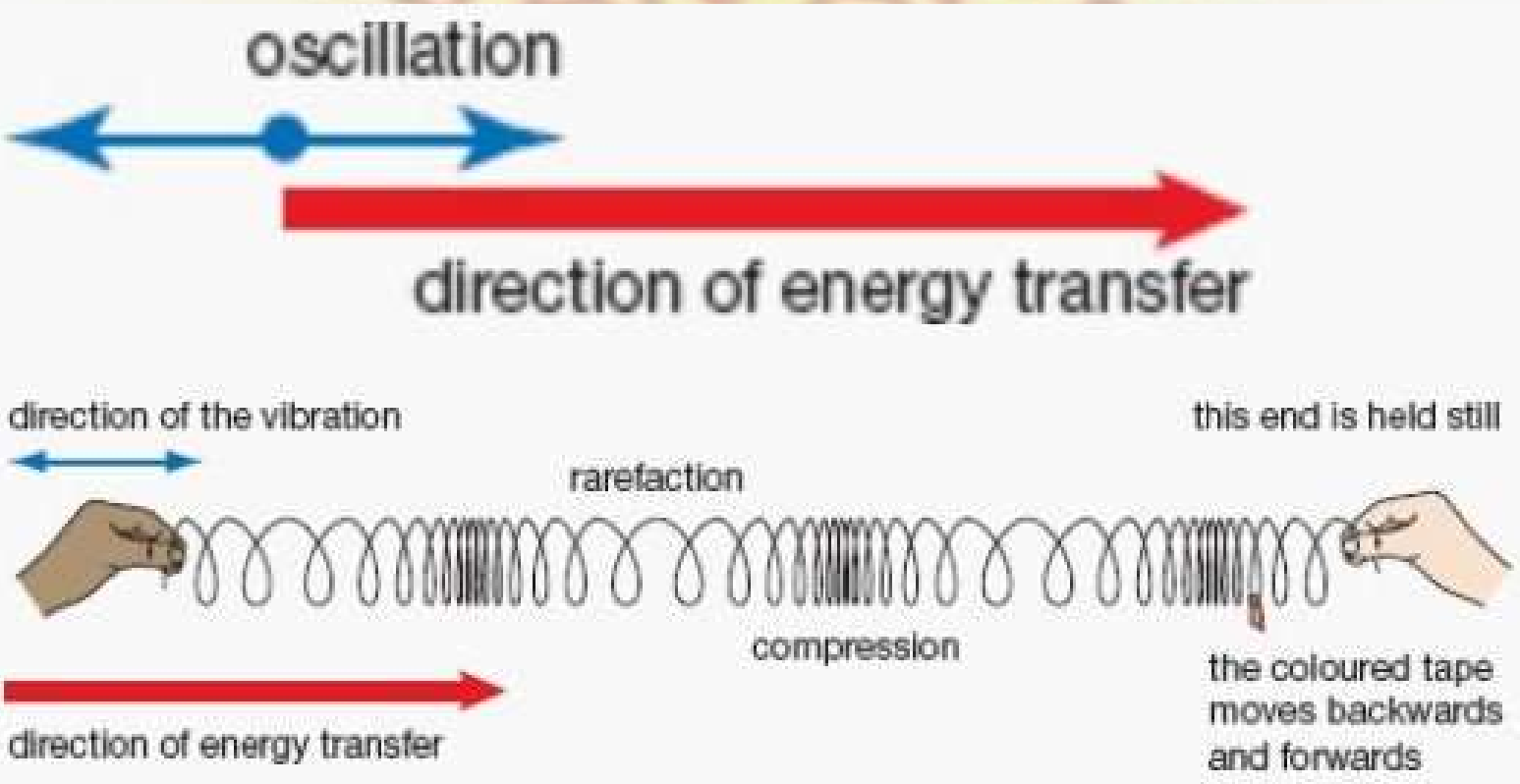
- A wave is a disturbance that moves through a medium when the particles of the medium set neighboring particles into motion. They in turn produce similar motion in others. The particles of the medium do not move forward themselves, but the disturbance is carried forward. This is what happens during propagation of sound in a medium, hence sound can be visualized as a wave.
- When a vibrating object moves forward, it pushes and compresses the air in front of it creating a region of high pressure. This region is called a compression (C).
- This compression starts to move away from the vibrating object. When the vibrating object moves backwards, it creates a region of low pressure called rarefaction (R).



A vibrating object creating a series of compression (C) and rarefactions (R) in the medium

Sound Waves are Longitudinal Waves

- As the topic says itself, sound waves are longitudinal in nature.
- 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.
- There is also another type of wave, called a transverse wave where the wave particles do not oscillate along the direction of wave propagation but oscillate up and down about their mean position in a direction perpendicular to the direction of wave propagation..

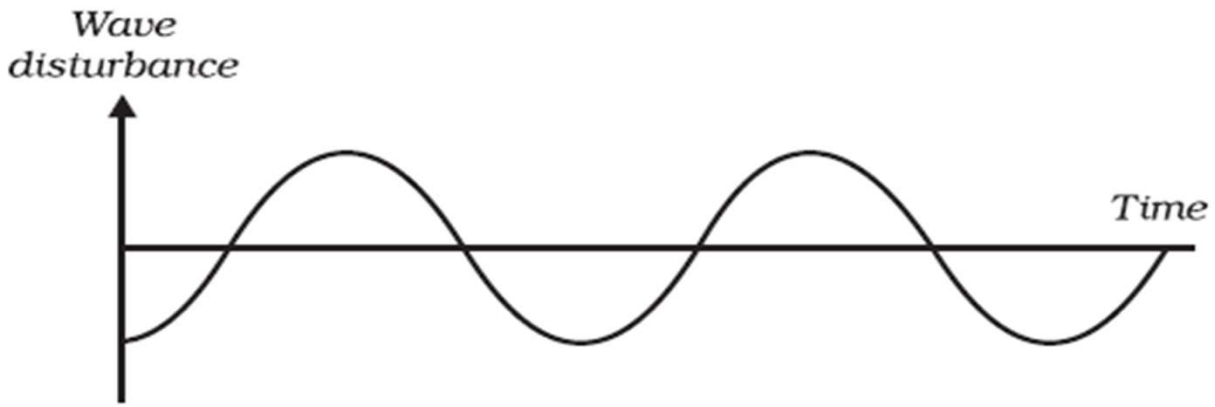


Characteristics of Sound Wave

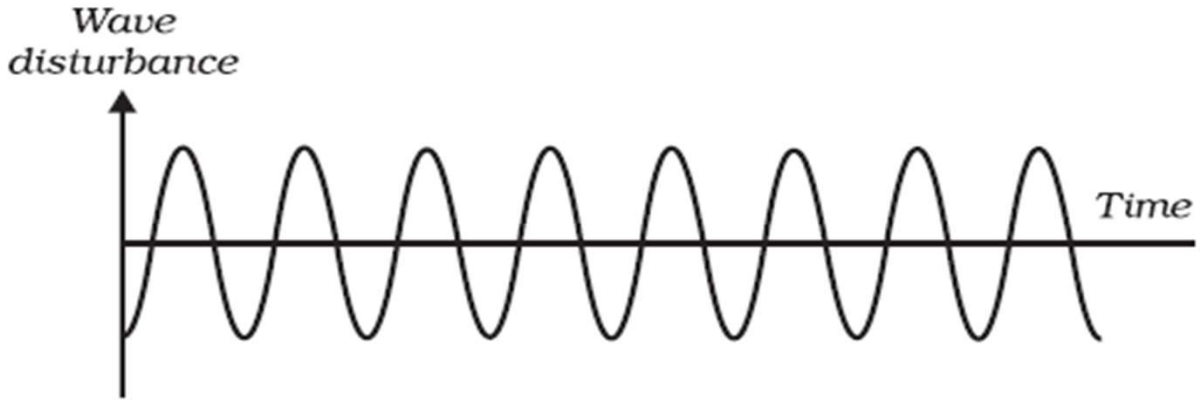
- Three characteristics –
  - Frequency - It is a measure of the number of oscillations or cycles of a periodic wave that occur in a unit of time. The unit of frequency is the hertz (Hz), which represents cycles per second.

    mathematically, $v = 1/T$

    Pitch is one of the characteristics of frequency. The faster the vibration of the source, the higher is the frequency and the higher is the pitch. Thus, a high pitch sound corresponds to more number of compressions and rarefactions passing a fixed point per unit time

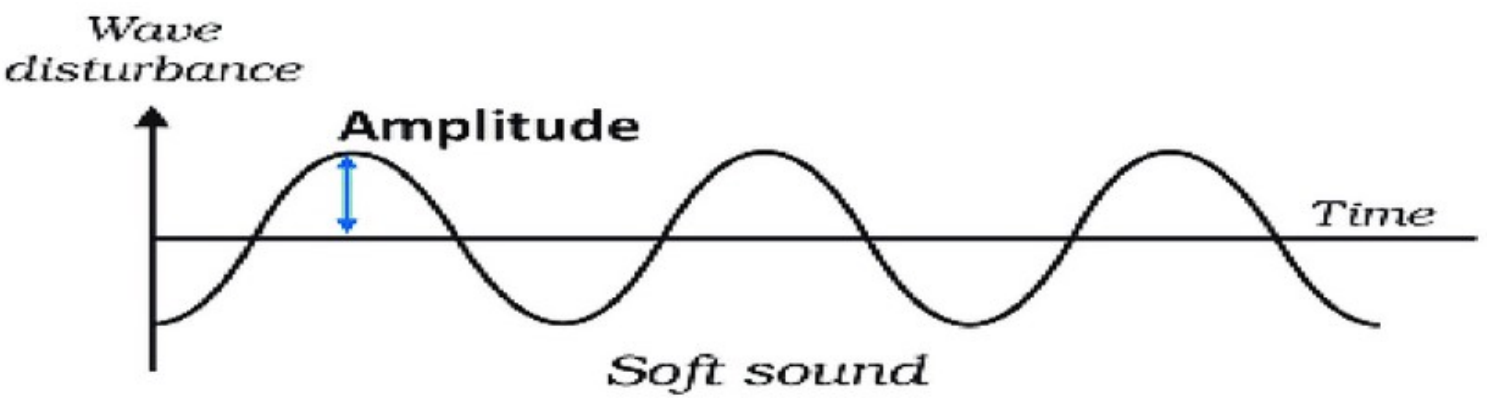


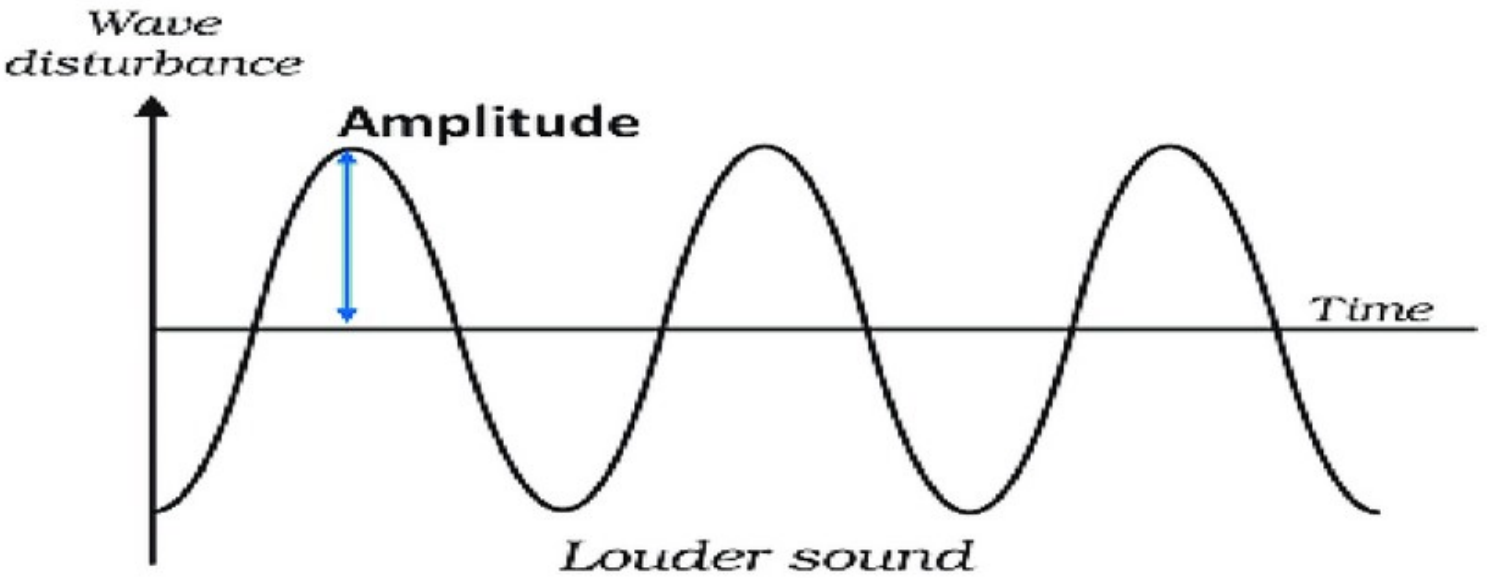
Wave shape for a low pitched sound



Wave shape for a high pitched sound

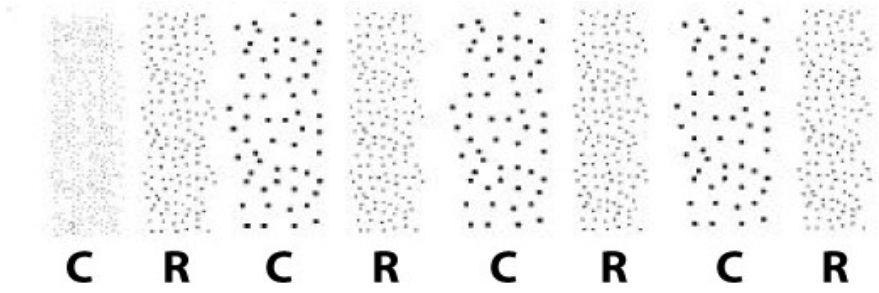
- Amplitude - The magnitude of the maximum disturbance in the medium on either side of the mean value is called the amplitude of the wave. It is usually represented by the letter A. For sound its unit will be that of density or pressure. The loudness or softness of a sound is determined basically by its amplitude. The amplitude of the sound wave depends upon the force with which an object is made to vibrate.





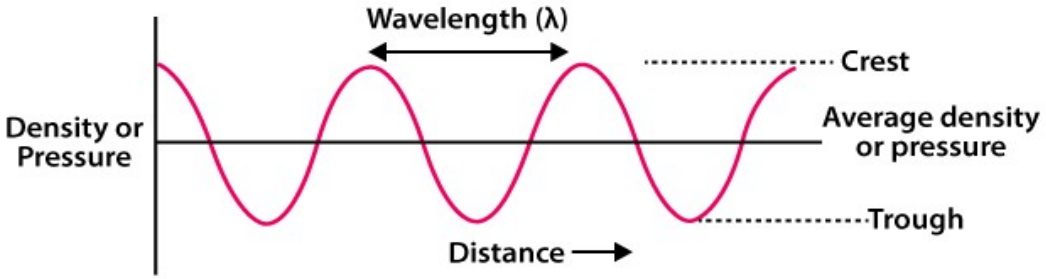
- Wavelength - The distance between two consecutive compressions (C) or two consecutive rarefactions (R) is called the wavelength. The wavelength is usually represented by λ (Greek letter lambda). Its SI unit is meter (m).

Compressions (C) are the regions where particles are crowded together and represented by the upper portion of the curve. The peak represents the region of maximum compression. Thus, compressions are regions where density as well as pressure is high. Rarefactions (R) are the regions of low pressure where particles are spread apart and are represented by the valley, that is, the lower portion of the curve. A peak is called the crest and a valley is called the trough of a wave.



Density variations

Pressure variations



- Speed of the sound is defined as the distance which a point on a wave, such as a compression or a rarefaction, travels per unit time.

$$\text{speed, } u = \text{distance / time}$$

$$u = \lambda / T$$

- The frequency can be deduced from the speed equation –

$$u = \lambda \nu, \quad (1/T = \nu)$$

A sound wave has a frequency of 2 kHz and wave length 35 cm. How long will it take to travel 1.5 km?

Calculate the wavelength of a sound wave whose frequency is 220 Hz and speed is 440 m/s in a given medium.

Reflection of Sound

- Like light, sound gets reflected at the surface of a solid or liquid and follows the same laws of reflection.
- The directions in which the sound is incident and is reflected make equal angles with the normal to the reflecting surface at the point of incidence, and the three are in the same plane.
- An obstacle of large size which may be polished or rough is needed for the reflection of sound waves.

- Echo – It is basically the reflection or bouncing off of sound from a surface. To hear a distinct echo the time interval between the original sound and the reflected one must be at least 0.1s. For hearing distinct echoes, the minimum distance of the obstacle from the source of sound must be 17.2 m, i.e., half of 34.4 m.

A person clapped his hands near a cliff and heard the echo after 2 s. What is the distance of the cliff from the person if the speed of the sound, v is taken as 346 ms^{-1} ?

An echo is heard in 3 s. What is the distance of the reflecting surface from the source, given that the speed of sound is 342 m s–1?

- Reverberation - A sound created in a big hall will persist by repeated reflection from the walls until it is reduced to a value where it is no longer audible. The repeated reflection that results in this persistence of sound is called reverberation.

To reduce reverberation, the roof and walls of the auditorium are generally covered with sound-absorbent materials like compressed fiberboard, rough plaster or draperies.

USES OF MULTIPLE REFLECTION OF SOUND

- Megaphones or loudhailers, horns, musical instruments such as trumpets and shehanais, 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 is a medical instrument used for listening to sounds produced within the body, mainly in the heart or lungs. In stethoscopes the sound of the patient's heartbeat reaches the doctor's ears by multiple reflection of sound

- Generally the ceilings of concert halls, conference halls and cinema halls are curved so that sound after reflection reaches all corners of the hall. Sometimes a curved soundboard may be placed behind the stage so that the sound, after reflecting from the sound board, spreads evenly across the width of the hall

Why are the ceilings of concert halls curved?

Range of Hearing

- The audible range of sound for human beings extends from about 20 Hz to 20000 Hz (one Hz = one cycle/s).
- Children under the age of five and some animals, such as dogs can hear up to 25 kHz (1 kHz = 1000 Hz).
- Sounds of frequencies below 20 Hz are called infrasonic sound or infrasound.
  For ex - if we could hear infrasound we would hear the vibrations of a pendulum just as we hear the vibrations of the wings of a bee.
- Frequencies higher than 20 kHz are called ultrasonic sound or ultrasound.
  Ultrasound is produced by animals such as dolphins, bats and porpoises.

- Hearing Aid: People with hearing loss may need a hearing aid. A hearing aid is an electronic, battery operated device. The hearing aid receives sound through a microphone. The microphone converts the sound waves to electrical signals. These electrical signals are amplified by an amplifier. The amplified electrical signals are given to a speaker of the hearing aid. The speaker converts the amplified electrical signal to sound and sends to the ear for clear hearing.

Applications of Ultrasound

- Ultrasound is generally used to clean parts located in hard-to-reach places, for example, spiral tube, odd shaped parts, electronic components, etc. Objects to be cleaned are placed in a cleaning solution and ultrasonic waves are sent into the solution. Due to the high frequency, the particles of dust, grease and dirt get detached and drop out.
- Ultrasounds can be used to detect cracks and flaws in metal blocks in construction of big structures like buildings, bridges, machines and also scientific equipment. Ultrasonic waves are allowed to pass through the metal block and detectors are used to detect the transmitted waves. If there is even a small defect, the ultrasound gets reflected back indicating the presence of the flaw or defect.

- Ultrasonic waves are made to reflect from various parts of the heart and form the image of the heart. This technique is called 'echocardiography'.
- Ultrasound scanner is an instrument which uses ultrasonic waves for getting images of internal organs of the human body. It helps the doctor to detect abnormalities, such as stones in the gall bladder and kidney or tumours in different organs. This technique is called 'ultrasonography'.
- Ultrasound may be employed to break small 'stones' formed in the kidneys into fine grains. These grains later get flushed out with urine.

Questions

- A person has a hearing range from 20 Hz to 20 kHz. What are the typical wavelengths of sound waves in air corresponding to these two frequencies? Take the speed of sound in air as 344 ms^{-1}
- The frequency of a source of sound is 100 Hz. How many times does it vibrate in a minute?
- A stone is dropped from the top of a tower 500 m high into a pond of water at the base of the tower. When is the splash heard at the top? Given, $g = 10\ ms^{-2}$ and speed of sound $= 340\ ms^{-1}$.
- A sound wave travels at a speed of 339 m s–1. If its wavelength is 1.5 cm, what is the frequency of the wave? Will it be audible?