JSR IAS ACADEMY

GENERAL SCIENCE

PHYSICS

SOUND - 3

Speed of sound

- The speed of sound is the distance travelled by it in one second.
- It is denoted by **'v'**.
- It is represented by the expression, **v = nλ,**
- where 'n' is the frequency and 'λ' is the wavelength.

$$\text{Speed (v)} = \frac{\text{One wavelength } (\lambda)}{\text{One time period (T)}} \quad \text{(or)} \quad v = \frac{\lambda}{T}$$

As, $T = \frac{1}{n}$, the speed (v) of sound is also written as, $v = n\lambda$.

- In any medium the speed of sound increases if we increase the temperature of the medium.
- For example the speed of sound in air is 330 m s–1 at 0 °C and 340 m s–1 at 25 °C.

Sound travels almost five times faster through water and twenty times faster through iron than it travels in air. Speed of light ($3x10^8$m/s) is even faster than the speed of sound (340 m/s). This is why? Lightning flash is seen first and thunder sound (created by the lightning) is heard much later during thunderstorms.

State	Substance	Speed (ms-1)
Solids	Aluminum	6420
	Steel	5960
	Iron	5950
Liquid	Sea Water	1530
	Distilled Water	1498
Gases	Aluminum	6420
	Steel	965
	Iron	346
	Iron	316

Table 8.1 Speed of sound in different media at 25° C.

State	Medium	Speed in m s^{-1}
Solids	Aluminum	6420
	Nickel	6040
	Steel	5960
	Iron	5950
	Brass	4700
	Glass	3980
Liquids	Water (Sea)	1531
	Water (distilled)	1498
	Ethanol	1207
	Methanol	1103
Gases	Hydrogen	1284
	Helium	965
	Air	340
	Oxygen	316
	Sulphur dioxide	213

The amount of water vapour in the air is known as humidity. It is less during winter and more during summer. The speed of sound increases with increase in humidity. This is because the density of air decreases with increase in humidity.

DO YOU KNOW?

How do astronauts communicate with each other? The astronauts have devices in their helmets which transfer the sound waves from their voices into radio waves and transmit it to the ground (or other astronauts in space). This is exactly the same as how radio at your home works.

Problem 1

A sound wave has a frequency of 2 kHz and wavelength of 15 cm. How much time will it take to travel 1.5 km?

Solution:

Speed, $v = n\lambda$

Here, n = 2 kHz = 2000Hz

λ = 15 cm = 0.15 m

$v = 0.15 \times 2000 = 300 \text{ m s}^{-1}$

$$\text{Time (t)} = \frac{\text{Distance (d)}}{\text{Velocity (v)}}$$

$$t = \frac{1500}{300} = 5 \text{ s}$$

The sound will take 5 s to travel a distance of 1.5 km.

DO YOU KNOW?

Sound travels about 5 times faster in water than in air. Since the speed of sound in sea water is very large (being about 1530 $m s^{-1}$ which is more than 5500 km/h^{-1}), two whales in the sea which are even hundreds of kilometres away can talk to each other very easily through the sea water.

Sonic boom: When the speed of any object exceeds the speed of sound in air (330 $m s^{-1}$) 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.

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, $V_S > V_L > V_G$

- 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.

Sound Waves

- Sound is a form of energy. It is transferred through the air or any other medium, in the form of mechanical waves.
- It means that the energy is transferred from one particle to another as a wave motion.

Characteristics of a Sound Wave

A sound wave can be described completely by **five characteristics** namely **amplitude, frequency, time period, wavelength and velocity or speed.**

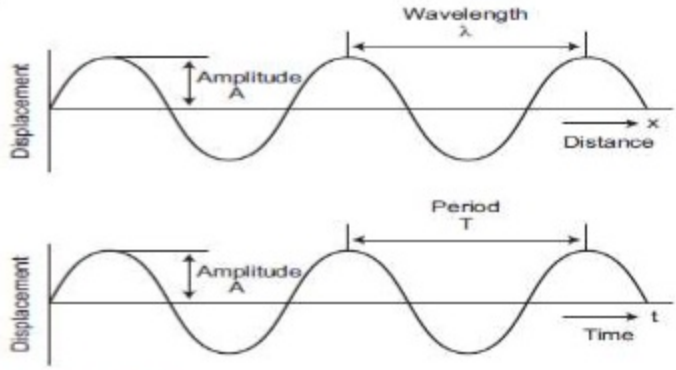


Figure 8.3 Characteristics of sound wave

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.
- If the vibration of a particle has large amplitude, the sound will be loud and if the vibration has small amplitude, the sound will be soft.
- 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).
- Frequency and time period are reciprocal to each other.

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 (Greek letter, lambda). The SI unit of wavelength is metre (m).

Echo

- This sound which we hear is called an echo. The sensation of sound persists in our brain for about 0.1s.
- The total distance covered by the sound from the point of generation to the reflecting surface and back should be at least 340 m $s–1 \times 0.1$ s = 34 m.

- Thus, for hearing distinct echoes, the minimum distance of the obstacle from the source of sound must be half of this distance i.e. 17 m.
- This distance will change with the temperature of air.

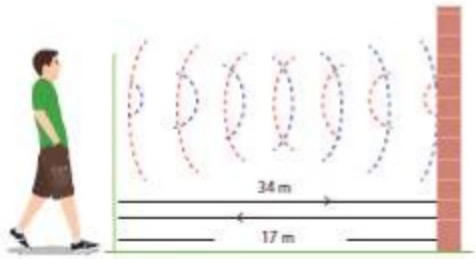


Figure 8.8 Echo

Reflection of Sound

Sound bounces off a surface of solid or a liquid medium like a rubber ball that bounces off from a wall.

Laws of 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 sound waves that travel towards the reflecting surface are called the incident waves.
- ✓ The sound waves bouncing back from the reflecting surface are called reflected waves.
- ✓ For all practical purposes, the point of incidence and the point of reflection is the same point on the reflecting surface.
- ✓ A perpendicular line drawn at the point of incidence is called the normal.
- ✓ 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'.

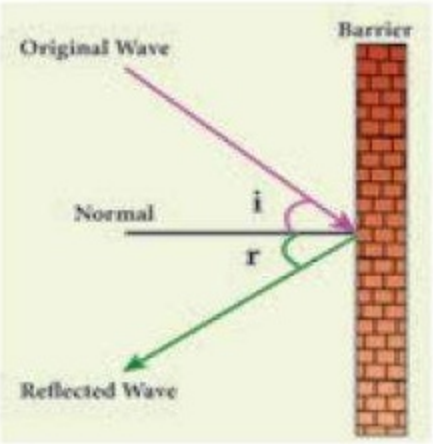


Figure 5.4 Laws of reflection

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.

Use of ear phones for long hours can cause infection in the inner parts of the ears, apart from damage to the ear drum. Your safety is in danger if you wear ear phones while crossing signals, walking on the roads and travelling. Using earphones while sleeping is all the more dangerous as current is passing in the wires. It may even lead to mental irritation. Hence, you are advised to deter from using earphones as far as possible.

Acoustical wonder of Golconda fort (Hyderabad, Telangana)

The Clapping portico in Golconda Fort is a series of arches on one side, each smaller than the preceding one. So, a sound wave generated under the dome would get compressed and then bounce back amplified sufficiently to reach a considerable distance.

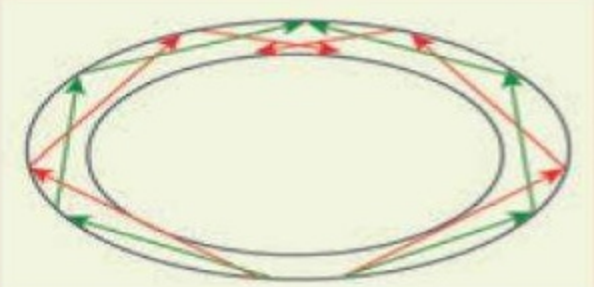
What is meant by rarer and denser medium?
The medium in which the velocity of sound increases compared to other medium is called rarer medium. (Water is rarer compared to air for sound).
The medium in which the velocity of sound decreases compared to other medium is called denser medium. (Air is denser compared to water for sound)

Reflection of sound in plane and curved surfaces

- The intensity of the reflected wave is neither decreased nor increased.
- But, when the sound waves are reflected from the curved surfaces, the intensity of the reflected waves is changed.
- When reflected from a convex surface, the reflected waves are diverged out and the intensity is decreased.
- When sound is reflected from a concave surface, the reflected waves are converged and focused at a point.
- So the intensity of reflected waves is concentrated at a point.
- Parabolic surfaces are used when it is required to focus the sound at a particular point. Hence, many halls are designed with parabolic reflecting surfaces.
- In elliptical surfaces, sound from one focus will always be reflected to the other focus, no matter where it strikes the wall.

Whispering Gallery

One of the famous whispering galleries is in St. Paul's cathedral church in London. It is built with elliptically shaped walls. When a person is talking at one focus, his voice can be heard distinctly at the other focus. It is due to the multiple reflections of sound waves from the curved walls.



DOPPLER EFFECT

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

Christian Johann Doppler (1803 – 53)

Christian Andreas Doppler was born on November 29, 1803, in Salzburg, Austria. After his death, he was referred to as Christian Johann Doppler for some reason.

In 1842, Doppler published the paper "Concerning the Coloured Light of Double Stars", which contained his first statement describing the Doppler Effect. He theorized that since the pitch of sound from a moving source varies for a stationary observer, the colour of light from a star should alter, according to the star's velocity relative to the Earth. Christian Doppler died on March 17.

This relative motion could be due to various possibilities as follows:

(i) The listener moves towards or away from a stationary source

(ii) The source moves towards or away from a stationary listener

(iii) Both source and listener move towards or away from one other

(iv) The medium moves when both source and listener are at rest

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.

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

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

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

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

Applications of Doppler effect

(a) 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.

(b) 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.

(c) 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.

(d) 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.

In the case of gases, the following factors affect the velocity of sound waves.

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.

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

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

Effect of relative humidity:

When humidity increases, the speed of sound increases.

Noise Pollution

- Any sound that is unpleasant to the ear is called noise.
- Noise gives you stress.
- The major source of noise pollution is from the industries.
- Noise pollution is the bi-product of industrialisation, urbanisation and modern civilisation.

Health hazards due to noise pollution

- Noise may cause irritation, stress, nervousness and headache.
- Long term exposure to noise may change the sleeping pattern of a person.
- Sustained exposure to noise may affect hearing ability. Sometimes, it leads to loss of hearing.
- Sudden exposure to louder noise may cause a heart attack and unconsciousness.
- It causes lack of concentration in one's work. Noise of horns, loud speakers, etc., cause disturbances leading to lack of concentration.
- Noise pollution affects a person's peace of mind. It adds to the existing tensions of modern living. These tensions results in disease like high blood pressure or short-tempered nature.

Controlling noise pollution

- Strict guidelines should be set for the use of loudspeakers on social, religious and political occasions.
- All automobiles should have effective silencers.
- People should be encouraged to refrain from excessive honking while driving.
- Industrial machines and home appliances should be properly maintained.
- All communication systems must be operated in low volumes.
- Residential areas should be free from heavy vehicles.
- Green corridor belt should be set up around the industries as per the regulations of the pollution control board.
- People working in noisy factories should wear ear plugs.
- People should be encouraged to plant trees and use absorbing materials like curtains and cushions in their home.