Chapter – 1

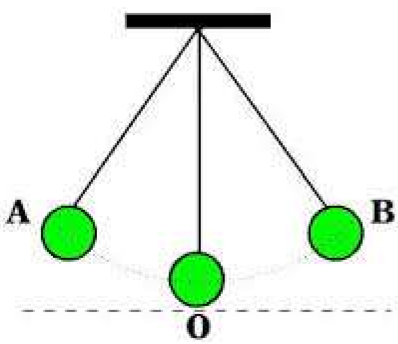
SOUND WAVES

OSCILLATION

Oscillation is a periodic motion in which an object moves to and fro at regular intervals of time about its equilibrium position.

When does the swing complete one oscillation?

when the pendulum starts from O, reaches A, then to B and back to O



Characteristics of oscillation

- Amplitude (A)
- Period (T)
- Frequency (f)

Quantity	Common Symbol(s)	Standard SI Unit	Unit Symbol
Amplitude	A	Meter	m
Period	T	Second	s
Frequency	f	Hertz	Hz

Amplitude (A)

The magnitude of maximum displacement to one side from its equilibrium position is amplitude. The symbol of amplitude is a. The SI unit of amplitude is metre (m).

Period (T)

The time taken for one oscillation is called period. Its symbol is T. SI unit of period is second.

Time Period (T) = $\frac{\boldsymbol{Total\ Time\ Taken\ (t)}}{\boldsymbol{Number of Oscillations (n)}}$ **OR** $\frac{\mathbf{1}}{\boldsymbol{Frequency\ (f)}}$

If a pendulum takes 1 minute to complete 30 oscillations, how long does it take to complete one oscillation?

Time for 30 oscillations = 1 minute = 60 s

$$\text{Time for 1 oscillation} = \frac{60s}{30} = 2\ s$$

Frequency(f)

The number of oscillations in one second is called frequency. The SI unit of frequency is hertz (Hz). Frequency is denoted by the letter f.

When the length of the pendulum increases, frequency decreases.

$$\text{Frequency (f)} = \frac{Number\ of\ Oscillations\ (n)}{Total\ Time\ Taken\ (t)}$$

$$\text{Frequency (f)} = \frac{1}{period\ (T)}$$

As the period increases, frequency decreases.

natural frequency

When an object vibrates freely, it vibrates in its innate frequency. This is the natural frequency of that object.

Factors that influence the natural frequency of an object

- Length of the object
- Size of the object
- Elasticity
- Nature of the material

Forced Vibration

Forced vibration is the vibration of an object induced by an external vibrating object

Resonance

If the natural frequency of the forcing object and that of the forced object are equal, the objects are said to be in resonance. The objects undergoing resonance will vibrate with maximum amplitude.

Applications of forced vibration and resonance

- MRI scanning
- Radio tuning
- In musical instruments like guitar, violin, veena, harmonium, mridangam etc

Example Problems

The frequency of a simple pendulum is 1 Hz. What is its period?

Frequency f = 1 Hz

$$\text{Period (T)} = \frac{1}{Frequency(f)}$$

$$T = \frac{1}{1\,Hz} = 1 \text{ second}$$

If a pendulum takes 0.5 s to complete one oscillation, what is its frequency?

Given: Period T = 0.5 seconds

$$\text{Frequency (f)} = \frac{1}{Period(T)}$$

$$f = \frac{1}{0.5} = 2 \text{ Hz}$$

Wave Motion

- Wave motion is one of the modes of transfer of energy from one part of the medium to other parts.
- The continuous propagation of energy from one part to the other parts through oscillations is called wave motion
- Radio waves
- Seismic waves
- Light waves
- Sound waves
- Ripples on the surface of water

Classification

Waves can be classified as either mechanical or electromagnetic based on whether they require a medium to travel

Electromagnetic Waves

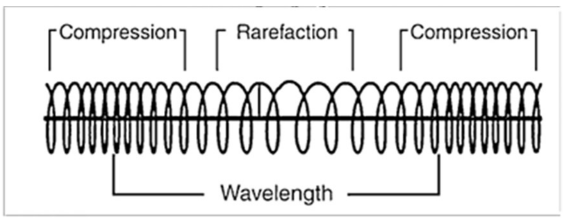
Radio waves, microwaves, infrared rays, visible light, ultraviolet rays, X-rays and gamma rays are electromagnetic waves. They do not require a medium for transmission.

Mechanical Waves

Mechanical waves are those that require a medium for transmission. Mechanical waves are mainly of two types. They are longitudinal waves and transverse waves.

Longitudinal Waves

Longitudinal waves are those in which the particles in the medium vibrate parallel to the direction of propagation of the wave



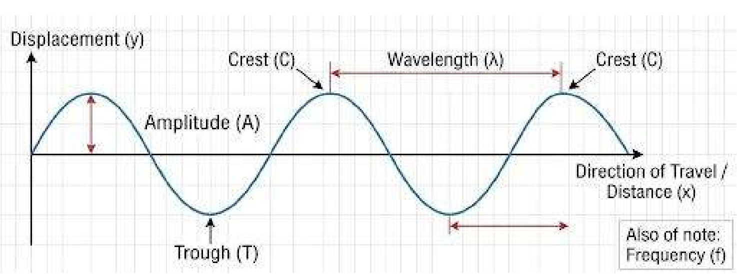
SOUND

- Sound is a longitudinal wave, meaning the vibration of particles is parallel to the direction the wave travels
- As the sound source vibrates (like a tuning fork or a speaker), it pushes and pulls on nearby air particles.
- When particles are pushed together, it creates a compression - a region of high pressure.
- When particles are pulled apart, it forms a rarefaction a region of low pressure
- These compressions and rarefactions move outward from the source in all directions (if in open air), carrying energy with them.
- This alternating pattern of compressions and rarefactions is what we detect as sound when it reaches our ears.

Transverse Waves

When the particles of a medium vibrate perpendicular to the direction of propagation of the wave they are called transverse waves

In transverse waves, the elevated portions from the equilibrium position are called crests and the lowest portions from the equilibrium position are called troughs



Difference between Longitudinal and Transverse waves

Longitudinal waves	Transverse waves	Examples
Particles in the medium vibrate parallel to the direction of propagation	Particles in the medium vibrate perpendicular to the direction of propagation	**Longitudinal:** Sound waves traveling through air **Transverse:** Ripples on the surface of a pond
Compressions and rarefactions are formed	Crests and troughs are formed	**Longitudinal:** A slinky spring pushed and pulled horizontally **Transverse:** A plucked guitar string
Pressure variations occur in the medium	No pressure variations occur in the medium	**Longitudinal:** Seismic P-waves (primary earthquake waves) **Transverse:** Electromagnetic waves (visible light, radio waves)

Characteristics of Waves

- Amplitude (A)
- Frequency (f)
- Period (T)
- Wavelength (λ)
- Speed of wave (v)

Amplitude

The magnitude of maximum displacement to one side from its equilibrium position is amplitude

Period

time taken by the particle in the medium to complete one vibration

Frequency

The frequency of a wave is the number of cycles that pass through a point in one second.

Wavelength (λ)

Wavelength is the distance between two consecutive particles which are in the same phase of vibration.

- distance travelled by the wave during the time taken by each particle in the medium to complete one vibration
- The distance between two consecutive crests or two consecutive troughs is also considered as the wavelength of a transverse wave
- The distance between two consecutive compressions or two consecutive rarefactions is considered as the wavelength of a longitudinal wave
- The unit of wavelength is metre (m)

Speed of wave

The speed of a wave is the distance travelled by the wave in one second. The unit of speed of a wave is m/s.

If a wave travels 700 m in 2 s, what is the speed of the wave?

$$\text{Speed} = \frac{Distance}{Time}$$

Distance = 700 meters, Time = 2 seconds

$$\text{Speed} = \frac{700m}{2s} = 350 \text{ m/s}$$

$$v = \frac{2D}{t}$$

relation between frequency and wavelength

When the speed is constant, frequency of the wave is inversely proportional to the wavelength

$$f \propto \frac{1}{\lambda}$$

The relation between the speed of wave, frequency and wavelength

$$v = f\lambda \qquad f = \frac{v}{\lambda} \qquad \lambda = \frac{v}{f}$$

v is the speed of the wave (in meters per second, m/s)

f is the frequency (in hertz, Hz)

λ (lambda) is the wavelength (in meters, m)

If the frequency of a longitudinal wave travelling at a speed of 350 m/s in the air is 35 Hz,
a) What is the distance between two consecutive compressions of this wave?
b) What about the distance between two consecutive rarefactions?

Speed v = 350 m/s

Frequency f = 35Hz

$$\lambda = \frac{v}{f} = \frac{350}{35} = 10 \text{ m}$$

Rarefactions are regions where particles are farthest apart. Just like compressions, the distance between two consecutive rarefactions is also one wavelength.

A sound wave with a frequency of 175 Hz has a wavelength of 2 m. Calculate the speed of sound.

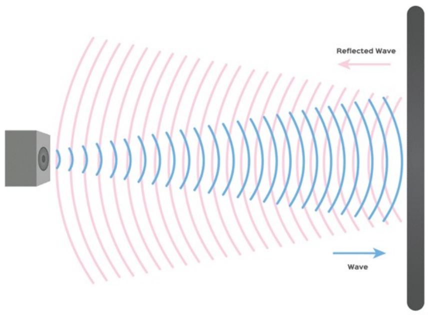
Frequency f = 175 Hz

Wavelength λ = 2 m

$$v = f\lambda = 175 \times 2 = 350 \text{ m/s}$$

Reflection of Sound

When a sound wave hits a surface, it bounces back, just like light reflecting off a mirror



Smooth surfaces reflect sound more effectively than rough surfaces

Reflection of sound is utilised in:

- Soundboards
- Curved ceilings in halls

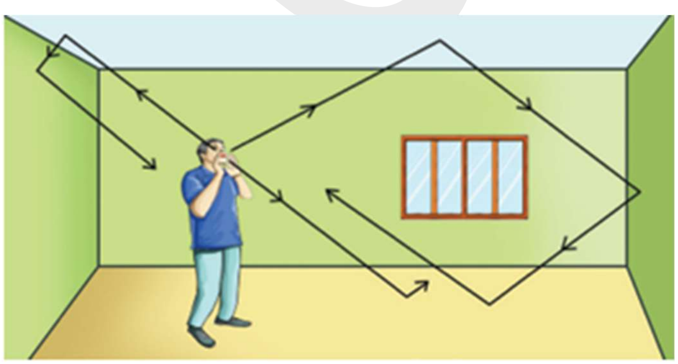
Soundboards

- Found in places like auditoriums, theatres, or behind musical instruments like pianos.
- They reflect sound toward the audience to amplify and spread it more evenly.
- This ensures that even people in the back rows hear the sound clearly

Curved Ceilings in Halls

- Curved (concave) ceilings focus sound waves and direct them to specific areas
- This helps enhance clarity and eliminate dead spots where sound might otherwise be too quiet
- Used in concert halls, churches, and lecture rooms

Multiple Reflection of Sound

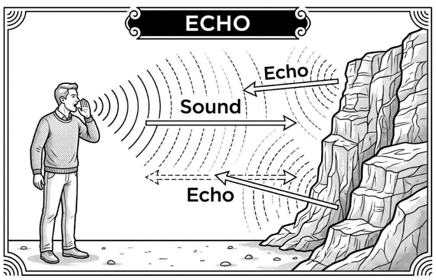


when a sound wave reflects off several surfaces one after another. Instead of just one bounce (like an echo), it keeps bouncing, often inside an enclosed space. Reflected sound waves get reflected again. This is multiple reflection of sound

- Stethoscope
- Whispering Galleries

Echo

Echo is the sound heard after a while due to the reflection of the initial sound.



Persistence of hearing

The auditory experience produced by a sound persists for about 1/10 of a second. This characteristic is known as persistence of hearing.

- Sound travels at about 343 m/s in air.
- If a sound wave reflects off a distant surface and comes back after a short delay, you hear it as an echo.
- Your ears can distinguish two separate sounds if the delay is 0.1 seconds or more.

Minimum distance for echo

To hear an echo, the minimum distance between the source and the reflecting surface must be:

$$\text{Distance} = \frac{v \times t}{2} = \frac{343 \times 0.1}{2} = 17.15 \text{ meters}$$

What should be the minimum distance between the source and the reflecting surface to hear the echo in water? (Consider the speed of sound in water as 1480 m/s)

Distance = $\frac{(v \times t)}{2}$

v = 1480 m/s (speed of sound in water)

t = 0.1 s (minimum time gap to hear an echo)

$$\text{Distance} = \frac{1480 \times 0.1}{2} = \frac{148}{2} = 74 \text{ meters}$$

Reverberation

Reverberation is the lingering of sound, even after the original sound has ceased. It is due to the multiple reflection of sound and the boom fades away gradually.

It's a result of multiple reflections of sound.

When the reflected sound reaches you before the original fades, it creates a prolonged effect.

Eg - Gol Gumbaz in Bijapur, Karnataka

Why are the walls of large halls like cinema theatres made rough?

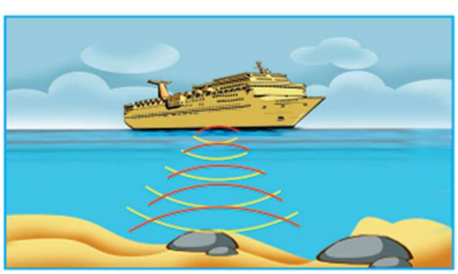
- To prevent echoes and sound distortion
- Smooth walls reflect sound strongly and uniformly, which can cause clear echoes or overlapping sounds
- Rough surfaces scatter the sound waves in many directions (this is called diffused reflection)
- These spaces also use acoustic panels, carpets, and curtains to absorb sound and reduce reverberation

Limits of audibility

For a person with normal hearing, the lower limit of audible sound is about 20 Hz and the upper limit is about 20000 Hz (20 kHz)

- Sound with a frequency below 20 Hz is infrasonic. e.g., earthquakes, elephant communication
- Sound with frequency more than 20000 Hz is ultrasonic. dog whistles, bats, ultrasound scans

Uses of Ultrasonic Waves



Medical field

- To crush small stones in the kidneys.
- In physiotherapy
- To take images of internal organs such as kidney, liver, gall bladder and uterus - ultra sonography
- Ultrasonic waves that travel through body tissues strike and reflect at areas of varying density in the tissues. These waves are converted into electric signals to form an image of the organ. This technique is ultra sonography

Industrial field

- For cleaning spiral tubes, irregular machine parts, electronic components etc.
- In the device called SONAR which is used to find the distance to the underwater objects

If an ultrasonic wave emitted by a transmitter, installed on a ship on the surface of the water, strikes a rock at the bottom of the sea and returns after 0.2 s, what is the distance from the ship to the rock? Consider the speed of ultrasonic waves in seawater as 1522 m/s

The wave travels to the rock and back, so the total distance covered is twice the depth.

$$\text{Distance} = \frac{v \times t}{2}$$

$$\text{Distance} = \frac{1522 \times 0.2}{2} = \frac{304.4}{2} = 152.2 \text{ meters}$$

Seismic Waves and Tsunami

- Seismic waves are those which travel through the Earth's crust as a result of earthquakes, volcanic eruptions, and massive explosions.
- Seismology is the study of seismic waves.
- The intensity of earthquakes is determined by the Richter scale.

TSUNAMI WAVES

Earthquakes that occur at the bottom of oceans or along coastal areas can sometimes trigger tsunami waves.

Tsunami is a series of gigantic ocean waves caused by the displacement of large volumes of water in the sea