Sound

Propagation of Sound

Production and Propagation of Sound: An Overview

An age-old philosophical question goes something like this: 'If a tree falls in the woods and there is no one to hear it, does it make a sound?' Common sense tells us, 'Yes, it does make a sound.' But what about sound itself? What is it? How is it produced? And how does it reach our ears?

This lesson will introduce you to the basics of sound.

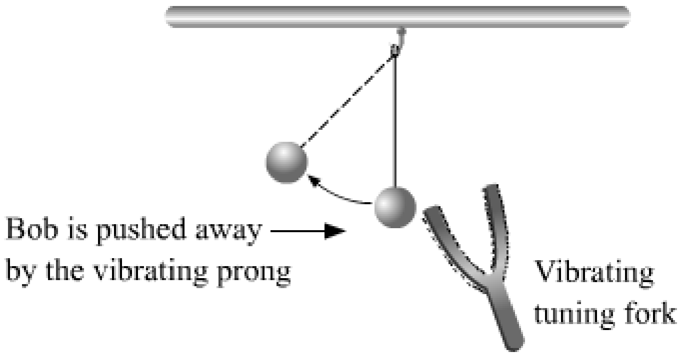
Did You Know?

The rattlesnake, commonly found in the deserts of the United States, makes a loud rattling sound by using its tail. It produces this sound by beating the tail rapidly on the ground. This sound is generally produced in order to ward off its enemies.

Sound Production

Sound is produced by vibrating objects. Let us see how sound is produced by **vibration**.

A bob touching a vibrating tuning fork



Take a tuning fork, a rubber hammer and a bob with a thread attached to it. Suspend the bob from the ceiling by the thread. Strike a prong of the fork with the rubber hammer. The tuning fork will start to vibrate. Bring it close to your ear. **Do you hear any sound?** Bring one of the vibrating prongs in contact with the suspended bob. This will cause the bob to be pushed away and start oscillating. **Can you say why?**

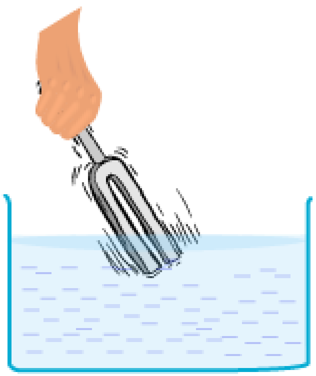
This activity helps us conclude that the tuning fork vibrates to produce sound. Any vibrating object can produce sound. Sound can be produced by plucking a stretched string, scratching a rough surface, rubbing our hands together and by blowing an object. Our voices are the result of the vibrating vocal cords present in our throat. The sound of the guitar is the result of the vibrations of its plucked strings.

Example: **A bicycle bell stops ringing when you cover it with your hands. Can you say why?**

Solution: When you cover a ringing bicycle bell with your hands, the sound energy is transferred from the bell to your hands. As a result, the bell stops vibrating. Consequently, the ringing sound stops.

Sound is a form of energy that is produced when an object or a membrane vibrates to and fro about a mean position. **Therefore, we can produce a sound by producing vibrations in an object**. These vibrations create sound waves which travel through a medium (air, water, etc.) before reaching our ears.

Fill a bathtub with water up to its brim. Strike a tuning fork against a hard surface to make it vibrate. Bring the vibrating tuning fork in contact with the surface of the water in the tub. **Do you observe the ripples formed on the surface of water?** Next, dip the vibrating prongs in water. **What do you observe in it?**



A vibrating tuning fork dipped in water

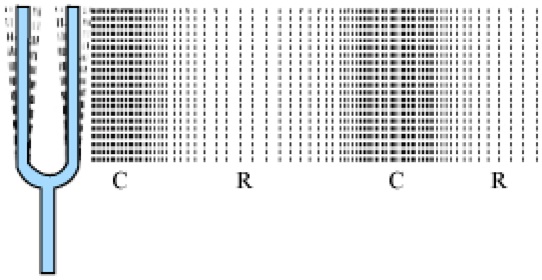
Propagation of Sound

The phenomenon of sound wave propagation has two main features. These are:

- The particles of a medium (like air) move and change its density (due to the vibration in the source of sound).
- The change in density corresponds to a change in pressure.

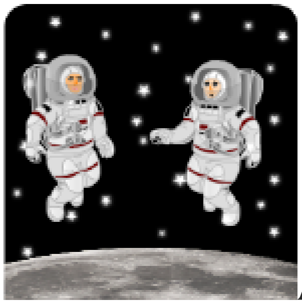
Air is the most common medium through which sound travels. When you beat a drum, the neighbouring air particles are set into vibration. As they move forward, they push the air particles in front of them. Consequently, a high-pressure region called **compression** (C) is created. As the vibrating air particles move forward, a contrasting low-pressure region gets created. This is called **rarefaction** (R). A series of compressions and rarefactions are produced when an object rapidly moves to and fro. These compressions and rarefactions of the air particles allow the sound wave to propagate through it.

Pressure is directly proportional to the number of medium particles present in a given volume of the medium, i.e., the higher the density of particles in a given volume of the medium, the higher is the pressure, and vice versa. These pressure variations in the medium enable sound to propagate.



Compressions and rarefactions

Did You Know?



Astronomers cannot communicate on the moon by means of sound. This is because the moon has no atmosphere and sound waves cannot travel in vacuum. Instead, they communicate through walkie-talkies using radio waves.

Nature of Sound Wave

Types of Waves

There are two types of waves in nature.

- **Longitudinal wave**: This type of wave manifests alternate regions of **compressions** and **rarefactions** while travelling through a medium.
- **Transverse wave**: This type of wave manifests alternate regions of **crests** and **troughs** while travelling through a medium.

Sound is a longitudinal and **mechanical wave**. Mechanical waves are those waves which require medium for their propagation. If a wave does not require medium for its propagation, then it is said to be non-mechanical wave. An example of non-mechanical wave is visible light.

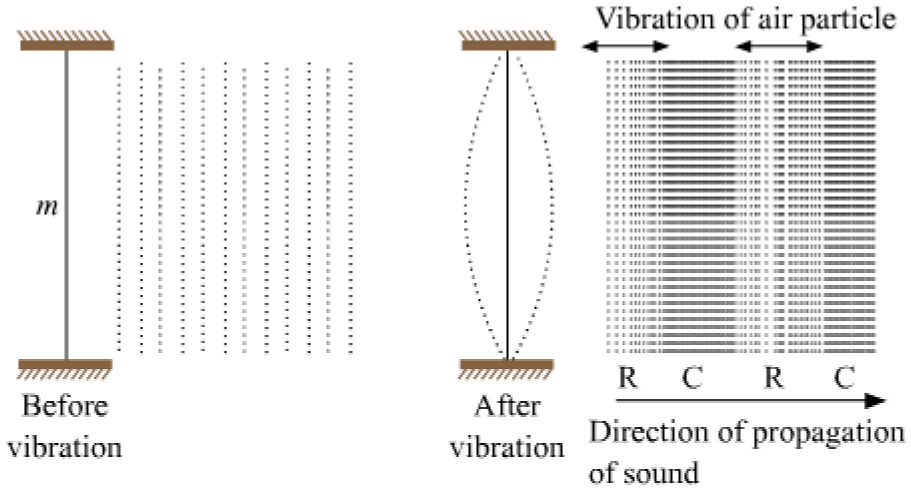
Sound requires a medium for its **propagation**. The medium particles vibrate to and fro. They do not move with the wave. Air is the most common medium present around us everywhere.

The speed of sound is determined by the properties of the medium (air, water, etc.) it travels through. The **frequency** or **amplitude** of sound does not influence its speed.

Whiz Kid

Why is sound wave longitudinal?

We can understand this with the help of the following diagram.



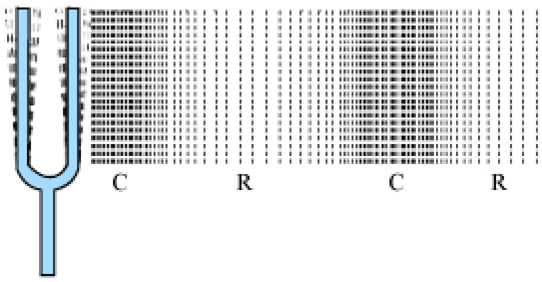
Here, the sound wave is propagated along the direction of the **vibration** of the medium particles; so, it is a longitudinal wave.

Longitudinal Wave

How are rarefactions and compressions created inside a medium?

Sound waves are longitudinal in nature. When a sound wave passes through air, air particles vibrate back and forth, parallel to the direction of the propagation of sound. Thus, when a sound wave travels horizontally, the particles of the medium also vibrate back and forth horizontally. Consequently, the sound wave creates regions of compressions and rarefactions along its propagation.

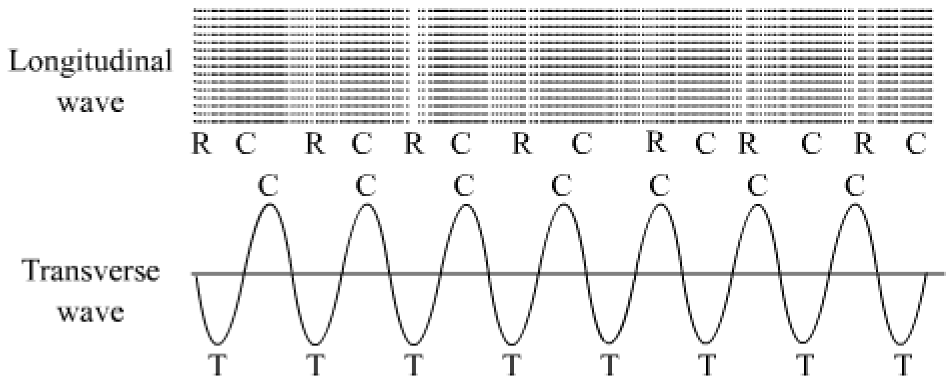
Compressions are high-pressure regions in the medium wherein the particles are closer to one another than they normally are. At these points, the volume of the medium becomes reduced. Rarefactions, on the other hand, are low-pressure regions in the medium wherein the particles are farther apart than they normally are. At these points, the volume of the medium becomes increased.



Transverse Wave

If the particles of a medium oscillate up and down about their rest positions in a direction perpendicular to the direction of propagation of the wave, then the wave is a **transverse wave**. **Light is a transverse wave.** The following diagram shows the transverse wave equivalent of a longitudinal wave.

Transverse waves can propagate through vacuum or a medium.



- When the vibrating particles move upward, they form hump-like shapes called **crests** (C).These are transverse equivalents of compressions (C).
- Similarly, when the vibrating particles move downward, they form valley-like shapes called **troughs** (T). These are transverse equivalents of rarefactions (R).

Did You Know?
You can view transverse waves by plucking a stretched string or dropping a pebble in still water.

In a crowded stadium, spectators make a transverse wave by alternately standing and sitting in small groups. This is popularly known as a **Mexican wave.**

Know More

Longitudinal waves require a medium to propagate whereas transverse waves can propagate through a medium or vacuum depending on the source.

Distinguishing Longitudinal and Transverse Waves

Longitudinal wave	Transverse wave
Longitudinal waves are those in which the particles of the medium oscillate parallel to the propagation of the wave.	Transverse waves are those in which the particles of the medium oscillate perpendicular to the propagation of the wave.
Longitudinal waves always need a medium to propagate. These are mechanical waves.	Depending on the source, transverse waves can propagate through a medium or vacuum. A transverse wave that needs a medium to propagate is a mechanical wave.
Waves propagating along the length of a spring and sound waves are longitudinal in nature.	Water waves and electromagnetic waves are transverse in nature.

Example 1: **Ashok ties one end of a string to a pole and gently moves the other end up and down. Which type of wave is produced because of this action?**

Solution: Transverse waves are formed in the string because of Ashok's action. In case of a transverse wave, the particles of the medium vibrate up and down at right angles to the direction in which the wave is moving.

Example 2: **Which type of wave will be formed if you stretch and compress a spring by pulling and pushing its one end alternately?**

Solution: On stretching and compressing one end of a spring, alternate regions of rarefactions and compressions will be formed in the spring. This is the characteristic of longitudinal waves.

Example 3: **Why is sound able to travel through oxygen gas? What type of wave does it manifest while travelling through the gas?**

Solution: Sound requires a medium to travel. Oxygen gas can act as a medium for sound. Hence, sound can travel through it. Sound is a longitudinal wave; so, it will propagate through oxygen gas by creating alternate regions of compressions and rarefactions.

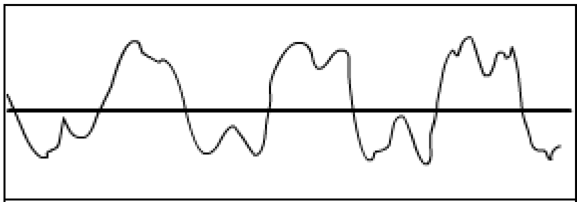
Distinguishing Sound and Light Waves

Sound wave	**Light wave**
Sound is a mechanical wave.	Light is not a mechanical wave.
Sound is a longitudinal wave.	Light is a transverse wave.
Sound needs a medium to travel.	Light does not require any medium to travel.
Sound propagates by disturbing the medium particles.	Light propagates on its own.

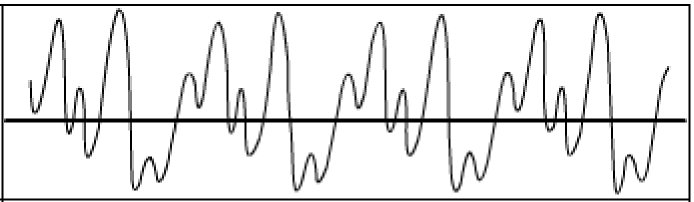
Characteristics of Sound Waves

Characteristics of Sound: An Overview

We can distinguish the sounds made by two men, two women, two musical instruments, two animals, etc. This is because sound waves differ in their quality or timbre. Quality is a characteristic of sound that enables us to distinguish between sounds with the same loudness and pitch. The following figures show the sound waves produced by a violin and a flute.



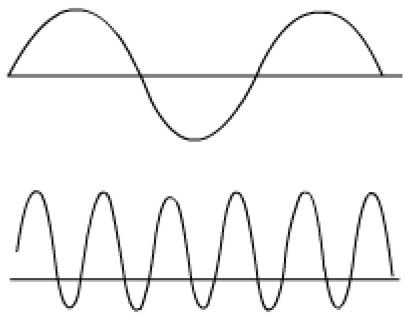
Sound wave produced by a flute



Sound wave produced by a violion

A pleasant sound has a rich quality. The sound of a violin is more pleasant than that of a flute. This is evident from their respective sound waves.

These sound waves depict the voices of a boy and girl. **Can you identify the girl's sound wave?**



Did You Know?

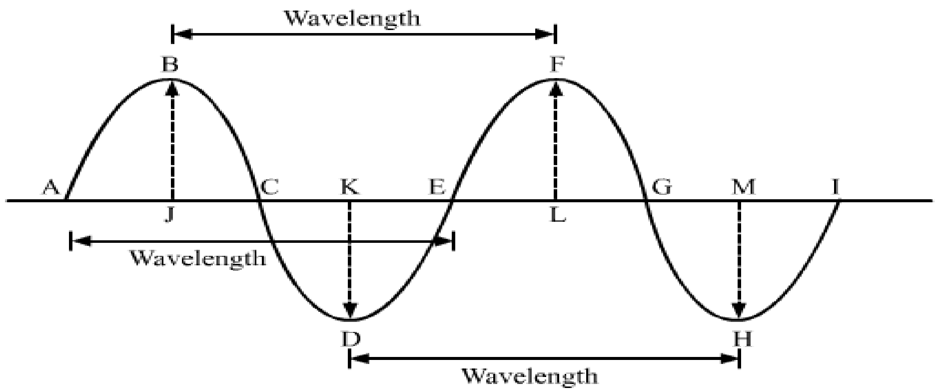
Two sounds with the same loudness, pitch and speed can be distinguished by their quality or timbre. If a sound is pleasant to hear, then it is said to have a rich timbre. An unpleasant sound has a poor timbre.

Characteristics of Sound

Sound is a **longitudinal wave**. A longitudinal wave manifests alternate regions of **compressions** and **rarefactions** while travelling through a medium. A longitudinal wave can be described by the five characteristics listed below.

- Amplitude
- Wavelength
- Frequency
- Time period
- Speed

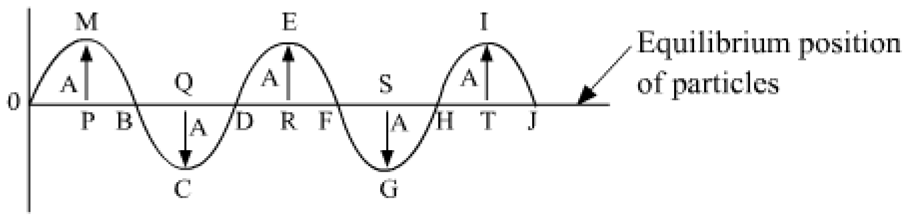
These five characteristics are demonstrated in the following figure with the help of a **transverse wave**. Note that the **crests** and **troughs** in a transverse wave are equivalent to the compressions and rarefactions in a longitudinal wave, respectively.



Wave characteristics

Amplitude (A)

The **amplitude** (A) of a wave is the maximum displacement of the medium particles on either side of their original, undisturbed position. In the following figure, the transverse equivalent of a longitudinal sound wave is shown.



The maximum displacement of the medium particles is represented by the maximum heights MP, ER and IT, and the maximum depths QC and SG. This maximum displacement is the amplitude of the wave, i.e. MP = ER = IT = QC = SG = Amplitude of the wave.

•The SI unit of amplitude is metre (m).

•The loudness of a sound is directly related to its amplitude. The amplitude of a loud sound is larger than that of a soft sound.

•The amplitude of a sound wave determines the amount of energy it carries.

Did You Know?

The loudness of a sound is directly related to the amplitude of the wave. It is the measure of our ears' response to a sound. Our ears detect louder sounds better than softer ones. A loud sound has greater amplitude than a soft sound.

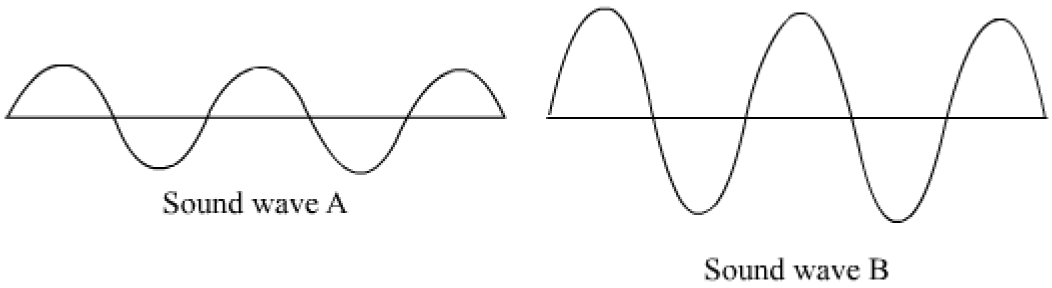
Loudness and Intensity

It is quite common to use the terms 'loudness' and 'intensity' interchangeably. However, the two are not the same.

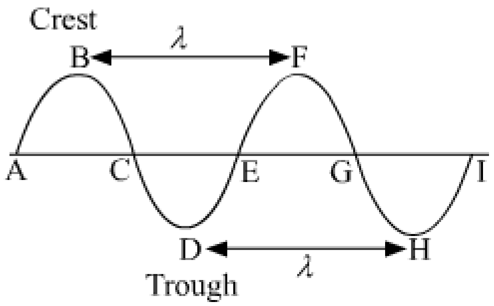
Loudness is the measure of the human ear's response to a sound. In contrast, intensity is the amount of energy passing per unit area per unit time.

•A sound may be louder than another owing to a difference in their intensities.

Can you say which sound wave corresponds to the louder sound?



Wavelength (λ)

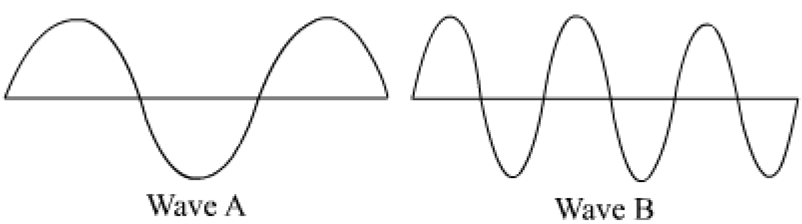


The distance between two consecutive compressions or rarefactions of a sound wave is its **wavelength** (λ). In case of a transverse wave, wavelength is the distance between two consecutive crests or troughs.

In the figure, the distances BF and DH represent the wavelength of the wave.

The SI unit of wavelength is metre (m).

Can you say which of these two waves has the longer wavelength ?



Frequency (f)

The **frequency** (f) of a source of sound is the number of cycles or vibrations produced by it per second. It is the rate at which sound wave is produced by the source.

If five crests of a wave pass through a fixed point in one second, then the frequency of the wave is five cycles per second.

The SI unit of frequency is hertz (Hz).

One hertz is equal to one vibration per second. Sometimes a bigger unit of frequency—called kilohertz (kHz)—is used.

1 kHz = 1000 Hz

The frequency (*f*) of a wave is the reciprocal of its time period *T*, i.e.

$F = 1/T$

Note that the frequency of a wave is the same as the frequency of the vibrating body that produces the wave. For example, the frequency of a tuning fork is marked as 256 Hz. This means that it can produce a sound wave of frequency 256 Hz.

The frequency of a wave remains constant in any medium, but its speed and wavelength depend upon the nature of the medium.

Did You Know?

Pitch, Tone and Note

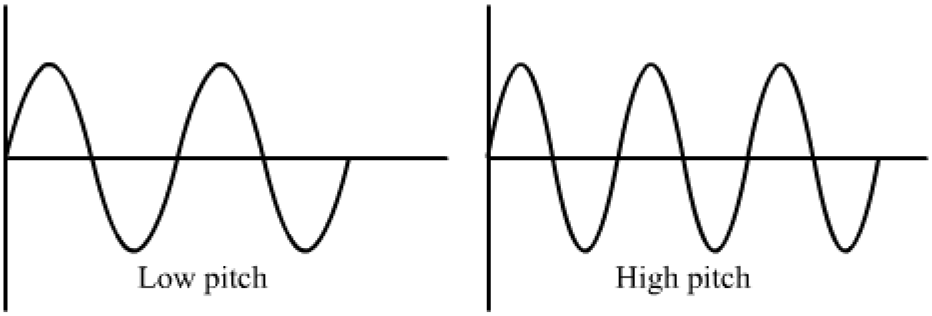
Pitch is defined as the shrillness of a sound. This highness or lowness of a sound is proportional to the frequency of the sound.

The sound produced by a flute is of a higher pitch compared to the sound produced by a drum. This is because the frequency of the former is higher than that of the latter. Similarly, women produce higher-pitched sounds than men.

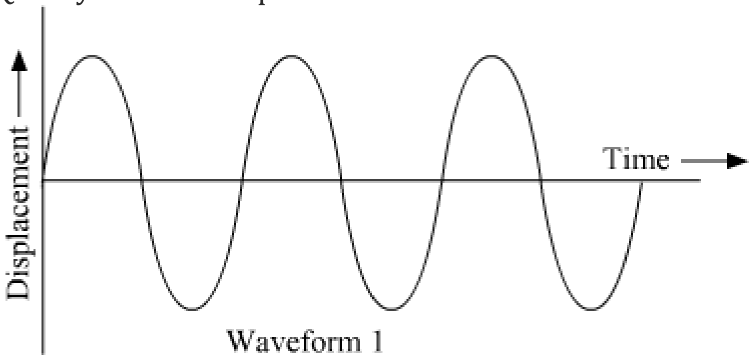
Tone is defined as a sound that has a single frequency.

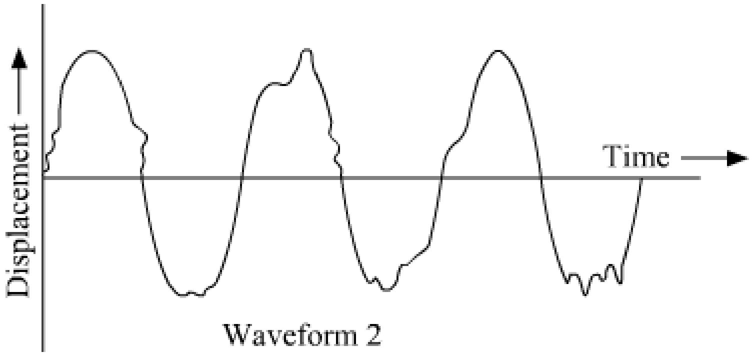
Note is defined as a sound that has a mix of different frequencies.

Suppose two sounds, produced from two different sources, have the same amplitude and speed. In this case, one sound can be distinguished from the other by its pitch, which is directly related to its frequency. The female voice is high-pitched while the male voice is low-pitched.



Quality or Timbre is that characteristic of a sound that helps in distinguishing various types of sounds having same amplitude and frequency, but emitted from different sources. Quality of sound depends on its waveform.





Both the sounds shown above have different quality as their waveforms are different.

Whiz Kid

Take a wide tub filled with water. Drop a pebble at the centre of the tub from a height. You will observe ripples moving outwards in a transverse-wave-like motion. Count the number of crests that hit a particular side of the tub. Note the time using a stopwatch. Then, calculate the frequency of this wave. Share your result with friends.

Know Your Scientist

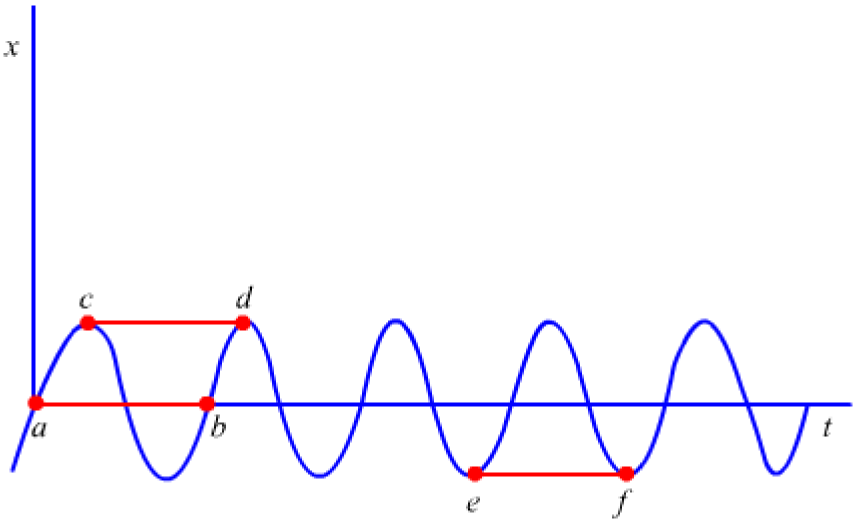
Heinrich Rudolph Hertz (1857-1894) was a German scientist. He was educated at the University of Berlin. He confirmed James Clark Maxwell's electromagnetic theory through his experiments. He laid the foundation for the future development of the radio, telephone, telegraph and television. He died quite young, less than a month before his thirty-seventh birthday. The SI unit of frequency is named in his honour.

Sonic boom occurs when an aircraft breaks the sound barrier. An aircraft travelling with a supersonic speed will produce a pressure wave of sound in the shape of a cone whose vertex will be formed at nose of the aircraft and its base will be behind the aircraft. So, when the edge of the cone intersects with our ears, we hear a loud sound known as sonic boom.

Time Period (*T*)

The time required to complete one complete oscillation or cycle is called the **time period** (*T*). It is also defined as the time interval between two consecutive crests or troughs of a wave.

- The SI unit of time period is second (s).
- It is the inverse of the frequency of a wave, i.e. $T = 1/f$

- 

  A flat sound is a low-pitched sound.
- This is a periodic wave. Its time period is represented by length on the time axis, e.g. *ab*, *cd* and *ef*.
- **Solved Examples**
- **Easy**
- **Example 1:**
- **The frequency of a source of sound is 400 Hz. Calculate the number of times the source vibrates in one minute. Also calculate the time period.**
- **Solution:**
- Frequency of the source of sound = 400 Hz
- Number of vibrations of the source per second = 400
- Number of vibrations of the source per minute = 400 × 60 = 24000
- We know that time period (*T*) is the inverse of frequency (*f*). So,
  T = 1/f

=1/400

=0.0025 s

Speed

The distance travelled by a wave in a given interval of time is called its **speed** (*v*). Its SI unit is metre per second (m/s). Hence, we can write:

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

Suppose a wave can travel a distance λ in *T* seconds with a speed *v*. Then, these terms are related as follows:

$$v = \frac{\lambda}{T}$$

We know that

f = 1/T

So,

$v = f \times \lambda$

Therefore, speed is the product of frequency and wavelength.

Now, the sound travels with much greater speed in solids than in liquids and than in gases.

Medium	Speed of sound (m/s)
Solid (Iron or steel)	5000
Liquid (Water)	1500
Gas (Air)	330

Did You Know?

According to Albert Einstein's special theory of relativity, nothing can travel faster than the speed of light. The speed of light in air (3×10^8 m/s) is about 10,00,000 times greater than the speed of sound in air (344 m/s).

Solved Examples

Easy

Example 1: **What is the speed of sound with frequency 20 Hz and wavelength 0.2 m?**

Solution:

Speed (v) = Frequency (f) × Wavelength (λ)

= 20 × 0.2 = 4 m/s

Example 2: **If twenty pulses are produced per second, then what is the frequency of the wave in hertz?**

Solution:

The frequency of a wave in hertz is equal to the number of pulses produced per second.

Number of pulses produced by the wave per second = 20

Frequency of the wave = 20 Hz

Medium

Example 3: A sound wave travelling at a speed of 330 ms^{-1} has a wavelength of 2 cm. Calculate the frequency of the wave. Will it be audible to humans?

Solution:

Speed of the sound wave = 330 m/s

Wavelength = 2 cm = 0.02 m

We know that

$$v = f \times \lambda$$
$$f = \frac{v}{\lambda}$$
$$= \frac{330}{0.02} = 16500 \text{ Hz} = 16.5 \text{ kHz}$$

Hence, the frequency of the sound wave is 16.5 kHz.

Now, we know that human hearing ranges from 20 Hz to 20 kHz. Since the frequency of the given sound wave is 16.5 kHz, it will be audible to humans.

Example 4: Sound waves travel at a speed of 330 m/s. Calculate the frequency of a sound wave whose wavelength is 0.75 m.

Solution:

- **Distance from the source**

Given:

Speed (v) of the wave= 330 m/s

Wavelength λ = 0.75 m

We have to find the frequency (f) of the wave.

We know that
$v = f \times \lambda$

$v = f \times \lambda$

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

$$= \frac{330}{0.75} = 440 \text{ Hz}$$

Hence, the frequency of the sound wave is 440 Hz.

Hard

Example 5: A wave pulse on a string moves a distance of 10 m in 0.05 s. Find the velocity of the pulse and the wavelength of the wave if its frequency is 300 Hz.

Solution:

We know that

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

In the given case:

Distance travelled = 10 m

Time taken = 0.05 s

$$v = \frac{10}{0.05}$$

$$\therefore v = 200 \text{ m/s}$$

Therefore, the speed or velocity of the pulse is 200 m/s.

We also know that
Speed = frequency × wavelength

In the given case:

Frequency = 300 Hz

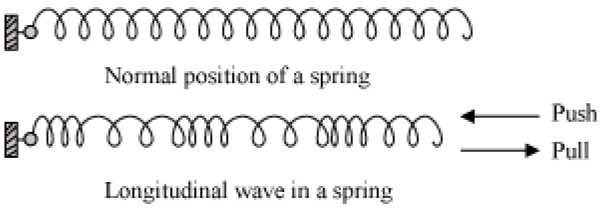
$$\lambda = \frac{v}{f}$$

$$= \frac{200}{300} = 0.67 \text{ m}$$

Therefore, the wavelength of the wave is 0.67 m.

Whiz Kid

Attach one end of a coiled spring to a wall. Compress the spring and then release it. You will observe a longitudinal wave produced in the spring, with alternating compressions and rarefactions. Count the number of compressions or rarefactions passing from the fixed point. Note the time using a stopwatch. Then, calculate the frequency of this wave .



Factors Affecting the Speed of Sound

We know that sound waves require a medium to travel. The temperature, humidity and nature of a medium affect the speed of sound travelling through it. Let us see how.

Temperature

The temperature of a medium is directly related to the speed of sound travelling through it. The speed of sound increases with an increase in the temperature and decreases with a decrease in the temperature. For example, the speed of sound in air at 0°C is about 332 m/s whereas its speed in air at 25°C is about 346 m/s.

Humidity

Like temperature, humidity is directly related to the speed of sound. For example, the speed of sound in dry air is 334 m/s; in moist air, it is 338 m/s.

Nature

The speed of sound varies according to the nature of the medium it travels through. The speed of sound in a gaseous medium is less than that in a liquid medium. Also, the speed of sound in a liquid medium is less than that in a solid medium. For example, at 25°C, the speeds of sound in hydrogen, water and iron are about 1284 m/s, 1500 m/s and 5130 m/s respectively. Hence, we can conclude that

$v_g < v_l < v_s$

Here, v_g = Speed of sound in a gaseous medium; v_l = Speed of sound in a liquid medium; v_s = Speed of sound in a solid medium

KWhiz Kid

The given table lists the speeds of sound in various materials at different temperatures.

Medium	Temperature (°C)	Speeds of sound (in m/s)
Dry air	0	332
Dry air	20	344
Dry air	25	346
Hydrogen	0	1280
Hydrogen	25	1284
Distilled water	20	1498
Sea water	37	1531
Blood	20	1570
Copper	20	3750
Aluminium	20	5100
Aluminium	25	6420
Iron	20	5130
Glass	20	5170

Did You Know?

Here is an interesting natural phenomenon related to the speed of sound. When lightning strikes, the flash is seen a few seconds before the sound is heard. **Why does this happen?**

This happens because the speed of sound in air (332 m/s) is much less than that of light (300000000 m/s). Hence, there is a difference between the time taken by the two to cover the same distance.

Here are two other phenomena indicating that light travels faster than sound.

1. When a cracker bursts, we first observe the light and then hear the sound.
2. When a gun is fired from a distance, we first notice the flash of the gun and then hear the gunshot.

Example 1: **A person hears a thunder four seconds before the flash of lightning. What is the distance between the person and the point where lightning occurs in the sky? (Speed of sound in air = 330 m/s)**

Solution:

We know that

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

In this case:

Speed = 330 m/s

Time = 4 s

Distance = Speed × Time

= 330 × 4 = 1320 m

Hence, the distance between the person and the point of lightning in the sky is 1320 m or 1.32 km.

Hard

Example 2: Ravinder throws a stone vertically upward with a velocity of 50 m/s. It hits a bell hanging at a height of 125 m. The bell rings as the stone hits it. How long after his throw will Ravinder hear the ring of the bell? (Take the speed of sound as 344 m/s and acceleration due to gravity as 10 m/s^2.)

Solution:

Let us first calculate the time taken (t) by the stone to reach a height of 125 m.

We have the following motion relation:

$$s = ut + \frac{1}{2}at^2$$

Where, u = 50 m/s and s = 125 m

Hence, we can write:

$$125 = 50t - \frac{1}{2} \times 10t^2$$
$$\Rightarrow t^2 - 10t + 25 = 0$$
$$\Rightarrow t^2 - 5t - 5t + 25 = 0$$
$$\Rightarrow t(t-5) - 5(t-5) = 0$$
$$\Rightarrow (t-5) = 0$$
$$\Rightarrow t = 5 \text{ s}$$

Now, let us calculate the time taken (t') by the sound of the ring to reach the ground. We can do so by dividing the height of the bell by the speed of sound.

$$t' = \frac{125}{344} = 0.36$$

Hence, Ravinder will hear the sound of the ring 5.36 (5 + 0.36) seconds after his throw.

Musical Sound

Sound maybe of two types: noise and musical sound. Musical sounds are produced by musical instruments like flute, guitar, violin, etc. They produce a pleasant effect on the listener. On the other hand, noise is produced by a person's shouts, thunderstorm etc. They produce an unpleasant effect on the listener.

Characteristics of musical sound:

(i) Loudness - This characteristic property of sound distinguishes two sounds of same frequency. It depends upon the intensity of vibration, which is proportional to the square of amplitude. So, larger the amplitude, louder is the sound. Loudness also depends on the following factors:

- Density of air
- Sensitivity of the ear
- Distance from the source
- Velocity and direction of wind

(ii) Pitch - Pitch is the characteristic of sound which differentiates the notes. Pitch of the sound depends on the frequency of the sound. A sound is said to have high pitch or is shrill if it is produced by a vibrating body of high frequency. If a body vibrates with low frequency, then it produces a flat sound. For example, a male voice is flat while a female voice is shrill.

(iii) Quality - Quality is the characteristic of sound that differentiates two sounds of same pitch and loudness. The sound produced by the musical instruments are made up of waves of definite frequency but contain a series of tones of different frequencies. They are called **Overtones** and the tone of smallest frequency is called the fundamental tone. Larger the number of overtones, higher is the quality of sound.((i

Musical scale:
When two notes are sounded simultaneously and produce a pleasant sensation in the ear, then it is a **concord** or a **consonance**.
If the notes produce an unpleasant sound in the ear, then it is a **dischord** or a **dissonance**.

Harmony - Harmony is the pleasant effect produced due to concord, when two or more notes are sounded together.

Melody - Melody is the pleasant effect produced by two or more notes, when they are sounded one after the another.

Musical intervals - Musical interval is the ratio of frequencies of two notes in the musical scale.

Musical scale - Musical scale is the series of notes separated by a fixed musical interval.
Keynote is the starting note of a musical scale.
A **diatonic** scale contains a series of eight notes.
An **octave** is the interval between the keynote and the last tone.

Advantages of a diatonic scale

- This scale provides the same order and duration of chords and intervals, which succeed each other, that are required for a musical effect.
- This scale can produced a musical composition with the lower and higher multiples of frequencies of the notes.

Echo and Reverberation

Reflection of Sound

When you sing in the bathroom or shout in an open field, your sound gets reflected off various obstacles. This reflection of sound results in echo and reverberation. There is an old wives' tale that a duck's quack has no echo. The tale would be true if the duck quacks in your living room. However, in suitable conditions, a duck's quack will surely echo.

When sound falls on a hard surface (solid or liquid), it bounces and changes its direction—just like light or a rubber ball. This bouncing back of sound on striking a surface is called **reflection of sound**. Hard surfaces such as a metal box and concrete wall are good reflectors of sound waves. Soft surfaces such as a cushion are bad reflectors of sound because they absorb sound.

Laws of reflection of sound:

(i)The incident sound wave, the reflected sound wave and the normal to the surface at the point of incidence, all lie in the same plane, i.e., reflection is a two-dimensional phenomenon.

(ii)The angle of reflection of sound is always equal to the angle of incidence.

Quick Questions

Question 1: Is the law of reflection of sound similar to the law of reflection of light?

Solution: Yes, the two laws are similar.

Question 2: Does the frequency of sound change after reflecting off a surface?

Solution: No, it does not. The frequency of sound depends only on the source of sound.

Echo

The sensation of a sound exists in the human brain for about 0.1 s. This means that if two sounds reach our ears within one-tenth of a second, then we will not hear them as separate sounds. So, if a reflected sound is to be heard separately from the original sound, there needs to be a time interval of at least one-tenth of a second (i.e., 0.1 s) between them

Now, we know that:

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

The speed of sound in air at 20°C is about 344 m/s.

The minimum time difference needed between a sound and its reflection for the echo to be heard is 0.1 s.

Therefore, the total distance travelled by the sound and its reflection to produce the echo is given as:

Total distance = Speed × Time

= 344 × 0.1 = 34.4 m

So, the sound travels 34.4 m during the time between which it is transmitted and the echo is heard. This distance is twice the actual distance between the source of the sound and the reflector of the sound. Therefore, the actual distance between the source of the sound and the reflector of the sound is 17.2 m.

Project Ideas

Visit your school auditorium with a friend. One of you should stand at a corner and the other should stand at the adjacent corner that is farther from it. One of you should clap. The other should measure the time interval between the clap and its echo using a stopwatch. Then, taking the speed of sound to be 330 m/s, calculate the distance between the two of you. Find out the actual length of the auditorium and compare it with the distance calculated.

Example 1: **A person is standing between two vertical cliffs. He is 540 m away from the nearest cliff. He shouts and hears the first echo after 3 s. Calculate the speed of sound in air.**

Solution: Total distance covered by the sound and its reflection = 2 × 540 m

Time taken for the echo to be heard = 3 s

Let the speed of sound in air be *v*.

We know that:

$$\text{Speed} = \frac{\text{Distance}}{\text{Time}}$$
$$\Rightarrow v = \frac{2 \times 540}{3}$$
$$\therefore v = 360 \text{ m/s}$$

Example 2: **Rajeev claps his hands near a mountain and hears the echo of the sound after 6 s. If the speed of sound in air is 346 m/s, then calculate the distance between Rajeev and the mountain.**

Solution:

Time taken for the echo to be heard = 6 s

The time taken by the sound to reach the mountain is half of the time taken for the echo to be heard, i.e., 3 s.

Speed of sound in air = 346 m/s

Let the distance between Rajeev and the mountain be *s*.

We know that:
Distance = Speed × Time

$\Rightarrow s = 346 \times 3$

$\therefore s = 1038$ m

Reverberation

A sound produced in an auditorium exists for some time because it undergoes multiple reflections off the walls, ceiling and floor. This is called **reverberation**. The duration of an echo in this case is so short that several echoes overlap with the original sound. If the reverberation is too long, then the sound becomes distorted, noisy and confusing.

Solved Examples

Easy

Example 1: **A fishing boat using sonar detects a school of fish 150 m below it by transmitting an ultrasound signal. How much time elapses between the transmission of the signal and its return to the boat? (Speed of sound in sea water = 1500 m/s)**

Solution:

It is given that:

Speed of sound in sea water = 1500 m/s

Distance between the boat and the fish = 150 m

Distance covered by the ultrasound signal = (2 × 150) m = 300 m

Let the time taken by the signal to return to the boat be *t*.

We know that:

$$\text{Time} = \frac{\text{Distance}}{\text{Speed}}$$
$$\Rightarrow t = \frac{300}{1500}$$
$$\therefore t = 0.2 \text{ s}$$

Example 2: **A man standing at a point between two parallel walls fires a pistol. He hears the first echo after 0.5 s and the second one after 0.7 s. Find the distance between the walls. (Speed of sound in air = 340 m/s)**

Solution:

It is given that:

Speed of sound in air = 340 m/s

Time taken for the first echo to be heard = 0.5 s

Let the distance between the man and one of the walls be *x*. The sound and its echo travel double this distance.

We know that:
Distance = Speed × Time

$$\Rightarrow 2x = 340 \times 0.5$$
$$\Rightarrow x = \frac{340 \times 0.5}{2}$$
$$\therefore x = 85 \text{ m}$$

Now,

Time taken for the second echo to be heard = 0.7 s

Let the distance between the man and the other wall be *y*. The sound and its echo travel double this distance.

So,
Distance = Speed × Time

$$\Rightarrow 2y = 340 \times 0.7$$
$$\Rightarrow y = \frac{340 \times 0.7}{2}$$
$$\therefore y = 119 \text{ m}$$

Thus, distance between the two walls = $x + y$ = 85 m + 119 m = 204 m

Example 3: **A woman, standing at a distance from a hill, fires a gun. She hears its echo after 3 s. Then, moving 350 m away from the hill, she fires again. This time she hears the echo after 5 s. Calculate the speed of sound in air.**

Solution:

It is given that the first echo is heard after 3 s.

Let the distance between the woman and the hill be *x*. The sound and its echo travel double this distance.

Let the speed of sound in air be *v*.

We know that:

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

$$\Rightarrow v = \frac{2x}{3} \text{ m/s} \qquad \text{...(i)}$$

The woman then moves 350 m away and fires again. The time taken for the this echo to be heard is 5 s.

Let the new distance between the woman and the hill be *x* + 350. The sound and its echo travel double this distance.

So,

$$v = \frac{2(x+350)}{5} \text{ m/s} \qquad \text{...(ii)}$$

On comparing expressions (i) and (ii), we obtain:

$$\frac{2x}{3} = \frac{2(x+350)}{5}$$

$$\therefore x = 525 \text{ m}$$

On substituting the value of *x* in expression (i), we obtain:

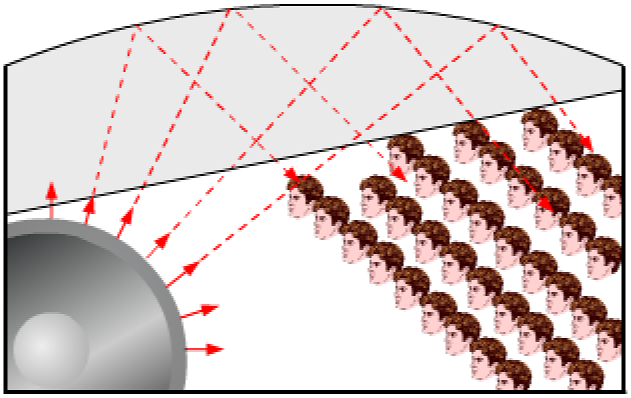
$$v = \frac{2 \times 525}{3}$$

$$\therefore v = 350 \text{ m/s}$$

Application of Reflection of Sound

Multiple Reflections of Sound

Bat is the only mammal that can fly. Unlike birds, bats do not use their eyes to navigate. They use sound to find their way and to locate their prey. Have you ever heard a bat scream? Well, you wouldn't have. This is because a bat's screaming sound cannot be detected by the human ear. There are scientific instruments, too, which use the bat's technique.

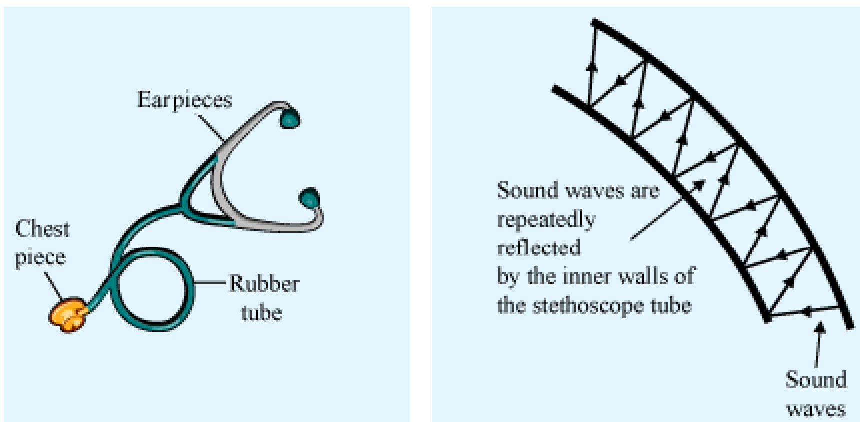


Curved ceiling of a conference hall

The principle of reflection of sound is used in making sound-producing devices such as the megaphone and bulb horn, and other devices such as the stethoscope and soundboard. All these devices involve multiple reflections of sound waves.

Stethoscope

It is a medical instrument used for checking the pulse rate and heartbeat. It comprises a chest piece and a pair of earpieces connected to one another by a rubber tube. The chest piece consists of a sensitive membrane that vibrates when brought in contact with the chest. As a result of the vibration caused in the membrane, the air particles within the rubber tube vibrate with the frequency of its source, i.e., the heartbeat. Sound waves undergo multiple reflections inside the rubber tube before reaching the earpieces.



(a) Stethoscope

(b) Multiple reflections of sound waves in the stethoscope tube

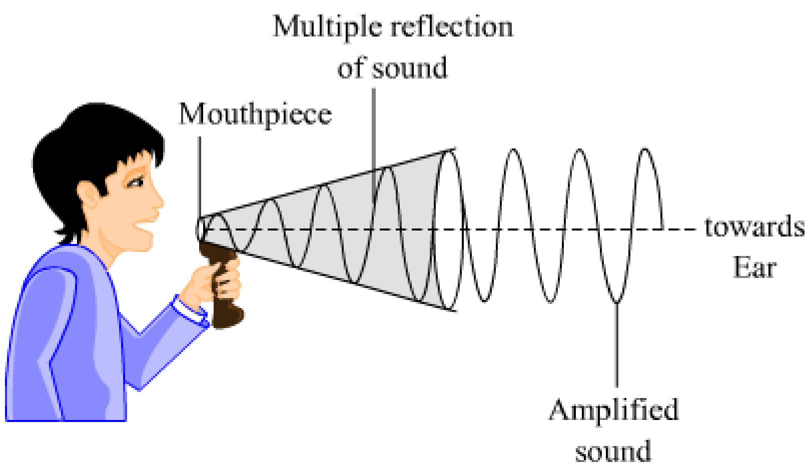
The stethoscope was invented in 1816 by a French doctor named Rene Laennec. The purpose of his invention was to hear the sound made by the heartbeat and the lungs.

Know Your Scientist

Rene-Theophile-Hyacinthe Laennec (1781–1826) was a French physician. He studied medicine in Paris under many famous doctors such as Dupuytren and Nicolas Corvisart desMarest. He is known for the invention of the stethoscope in 1816 while working at Hopital Necker(a hospital for sick children). He died in 1826 because of tuberculosis. At the time of his death, he was working as a professor at the College de France.

Loudspeaker

The loudspeaker or the megaphone is an instrument that amplifies and enhances incoming sound waves through multiple reflections. It is a cone-shaped device designed to send sound in a particular direction. Its narrower end acts as the mouthpiece. Amplified sound is sent out from the wider end. The multiple reflections of sound inside the funnel enable the speaker's voice to be heard across a large distance.



As shown in the figure, the multiple reflections of sound move through the loudspeaker and out from it in the form of transverse waves. It is clear from the figure that the sound heard by the listener will be louder than the one produced by the speaker near the mouthpiece. This is because the amplitude of the sound is greater near the wider end than it is near the narrower end.

Whiz Kid

Have you ever wondered as to why the ceilings of big halls such as concert halls, cinema halls and auditoriums are curved?

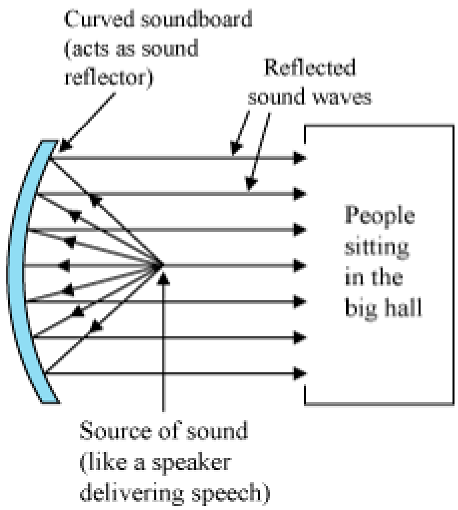
Sound waves transmitted by the source in a big hall get absorbed by the walls, floor, seats and even the clothes of the crowd sitting inside the hall. Hence, the ceiling of the hall is curved to reduce this problem.

The working of several musical instruments such as the trumpet and *shehanai* is based on the multiple reflections of sound.

Can you explain why one of the ends of the bulb horn is wider than the other?

Soundboard

In a big hall like an auditorium, the ceiling and the walls cause sound to undergo multiple reflections before reaching the audience. This hampers the quality of the produced sound. A soundboard, placed behind the source of sound, is used for countering this problem. The source of sound is located at the focus of the concave soundboard. The concave surface reflects the produced sound waves towards the audience, thereby preventing sound from spreading in various directions. Consequently, the audience gets a parallel beam of powerful sound.



Go to your school auditorium and check the measures employed there to reduce the absorption of sound. Discuss the findings with your friends.

Hearing Range of Humans and Other Organisms

Hearing Range

Whether it is a falling leaf or a falling apple, a collapsing building or a flying bat—everything around us that can vibrate makes sound. But how many of these sounds can we actually hear? We can hear only those sounds whose frequencies lie in the range 20 Hz–20000 Hz. This range is also known as the **hearing range of humans**.

If the frequency of a sound is greater than 20000 Hz, then it is called **ultrasound**. If the frequency of a sound is less than 20 Hz, then it is called **infrasound**.

Organisms	**Hearing ranges (Hz)**
Humans	20–20000
Elephants	16–12000
Cows	23–35000
Rats	200–76000
Bats	2000–110000
Horses	55–33500
Dogs	67–45000
Rabbits	360–42000

Did You Know?

Children can hear ultrasound having frequency up to 25000 Hz. As humans grow older, their sensitivity towards ultrasound decreases. In adults, the upper limit of hearing frequency is about 20000 Hz.

Hearing Range in Humans

'A Day in My Life' is a famous song by The Beatles. Paul McCartney, a band member, recorded the sound of an ultrasonic whistle at the end of this song for his dog. This is because, unlike humans, dogs can hear sounds of this frequency.

As humans grow older, their hearing range changes. The given table lists the hearing range of humans at different stages of their life.

Childhood	15 Hz–25000 Hz
Adulthood	20 Hz–20000 Hz

Old age	50 Hz–8000 Hz

The most sensitive hearing range of humans is 1,000 Hz to 4,000 Hz.

Animals using sound beyond human's audible range:

Infrasound Communication

Rhinoceroses can produce sounds of frequency as low as 5 Hz. They use these low-frequency sound waves to communicate among themselves.

Sensory Antennae of Animals

Dolphins, bats and porpoises are mammals that can produce ultrasound. It helps them in navigation and finding the exact location of food.

Hearing Aid

A hearing aid is a device that amplifies sound and compensates for the poor hearing ability of the hearing-impaired. It consists of a microphone, an amplifier and a speaker.The functions of these parts are tabulated below.

Parts of a hearing aid	Functions
Microphone	Converts sound into electrical signal
Amplifier	Amplifies the electrical signal
Speaker	Converts the amplified electrical signal back into sound

A hearing aid does not cure hearing loss or restore hearing to normal. It only improves a person's hearing and speech comprehension.

Properties and Applications of Ultrasound

Properties of Ultrasound

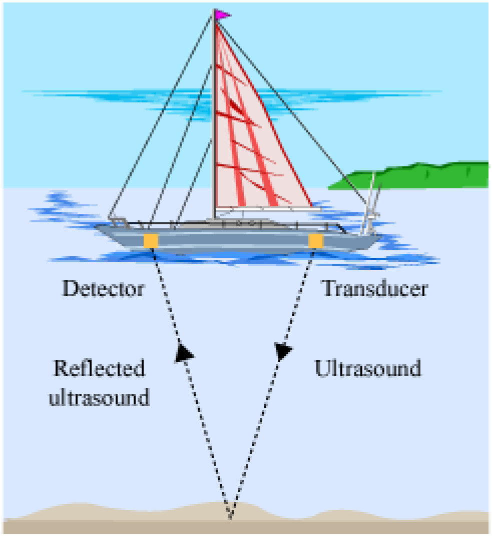
We have studied in our previous classes that sound is produced by vibrating matters. Sound waves is an example of longitudinal wave which needs material to propagate, we hear sound because the sound from source reaches our ear by travelling through air. The wave speed is described in terms of frequency (f), wavelength (λ) and velocity (v) which are related as,

$$v = f\lambda$$

Sound waves which have frequencies ranging from 20 Hz to 20 000 Hz are audible to human and known as audible sound. Sound wave of frequency less than 20 Hz are termed as infrasound waves and those which have frequency more than 20 000 Hz are ultrasound waves.

Ultrasonic waves are high-frequency sound waves that cannot be heard or sensed by humans. These waves carry so much energy that they can penetrate human muscles. Ultrasonic waves can be used for various practical purposes.

Sonar



Sonar is the acronym for **SO**und **NA**vigation and **R**anging. It is an acoustic instrument installed in ships to measure depth, direction and speed of underwater objects such as icebergs, sea rocks, shipwrecks and spy submarines. It uses high-frequency ultrasound for this purpose and works on the principle of echo.

Sonar consists of two main parts—the **transducer** and the **detector**. The former produces and transmits ultrasonic sound, while the latter receives the ultrasound reflected from the bottom of the sea or an underwater object. Sonar measures the echo of the ultrasound and calculates the depth or distance of underwater objects using the relation:

$2d = v \times t$

Where, d = Distance between the ship and the underwater object

v = Speed of ultrasound in water

t = Time taken by the echo to return from the object

This method of measuring distance is known as **echo ranging**.

Example 1: **A sonar attached to a ship produces ultrasonic waves which get reflected off the sea floor. If the device records the reflection in six seconds, what is the depth of the sea? (Speed of sound in water = 1500 m/s)**

Solution: The time taken by the ultrasonic waves to travel from the ship to the sea floor and back to the ship is six seconds. Hence, the time taken by the waves to reach the sea floor is three seconds.

Distance = Speed × Time

Speed = 1500 m/s

Time = 3 s

∴ Distance = 1500 × 3

= 4500 m

Hence, the depth of the sea is 4500 m.

Medium

Example 2: **A ship on the surface of the sea transmits a signal to an underwater submarine and receives it back after 5 seconds. Calculate the distance between the submarine and the ship. (Speed of sound in water = 1500 m/s)**

Solution: We have the formula:

$2d = v \times t$

Where, d = Distance between the submarine and the ship = ?

v = Speed of sound in water = 1500 m/s

t = Time taken by the signal to return to the ship = 5 s

⇒2d = 1500 × 5 = 7500 m

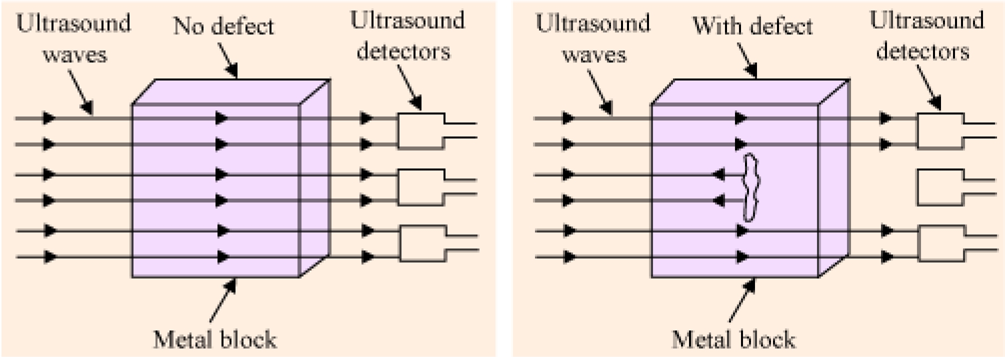
⇒ d = 3750 = 3.75 km

Hence, the distance between the submarine and the ship is 3.75 km.

Detecting Flaws

Ultrasonic waves are used in industries to detect cracks and flaws in objects (such as metal blocks) without damaging them. The frames of big buildings, bridges, machines, etc., are made up of metals. Any flaws within the frames can reduce the strength of these structures. Ultrasound cannot pass through such cracks and flaws; this, consequently, helps in detecting the defects. Let us understand how this happens.

Suppose we have two metal blocks and one of them has a flaw. Ultrasonic waves are allowed to pass through the blocks. Ultrasound detectors are placed on the other side of each block.



The detectors next to the block without any defect will detect an ultrasound of the same strength as the one made to pass through. However, the detectors next to the defective block will detect an ultrasound of reduced strength. This is because the flaw prevents some of the waves from passing through to the other end.

Note that short-frequency sound waves are not used for detecting flaws in metals. This is because they can bend around the edges of flaws and pass through to the other end. Consequently, the presence or absence of flaws cannot be ascertained.

Other Applications of Ultrasound

Cleaning

Ultrasound is used in industries to clean parts of machines that are difficult to reach. Spiral tubes, electronic components, odd-shaped machines, etc., are cleaned using ultrasound. The process involves dipping the object to be cleaned in a cleansing solution and using ultrasound waves to stir the solution. The stirring causes dust particles, grease, etc., to vibrate with very high frequency. As a result, they become loose and fall into the solution.

Ultrasound in the medical industry

- Doctors use ultrasound to view abnormalities in internal human organs such as the liver, gall bladder, uterus and kidney. In this, a probe and a gel are used. To make a proper contact between the skin and the probe, the gel is applied to the skin outside the internal organ which needs to be studied. The probe passes ultrasonic wave through the body. These waves get reflected off the regions where abnormalities such as stones and tumour are present. The reflected waves are received by a computer, which then generates pictures of the organs subjected to the test. This technique is known as **ultrasonography**.

- **Echocardiography** is the technique of studying the structure and motion of the heart using ultrasound. The collected information is used for finding out if a flaw exists in the heart.

- Ultrasound is also used to monitor the different developmental stages of the foetus inside a womb.

- Since the frequency of ultrasound is very high, it can break the stones present in the gall bladder and kidney using Lithotripsy medical process. The broken down pieces can then be eliminated from the body through urine.

- **Did You Know?**
- **How a bat finds its path of movement despite its eyesight being weak**
- Like sonar, a bat detects its prey using the technique of **echo ranging**. It emits high-frequency ultrasound that gets reflected off obstacles such as walls, trees and insects. The nature of the reflected waves helps the bat detect and recognize the objects.

- **Ultrasound is used for making desired holes and cuts of a specific shape in materials like glass.**

RADAR

Radar is an acronym which stands for **Ra**dio **D**etection and **R**anging. It is an object detecting system which is used to determine the altitude, direction or range of fixed or moving objects. It is similar to SONAR but it uses electromagnetic waves instead of ultrasonic waves.
A pulse of electromagnetic wave is sent by the Radar, which is reflected back as it bounces off the target.
This reflected wave is detected and by knowing the speed of radio wave and the time taken by the radio wave to bounce off the target, the distance of the object can be detected.

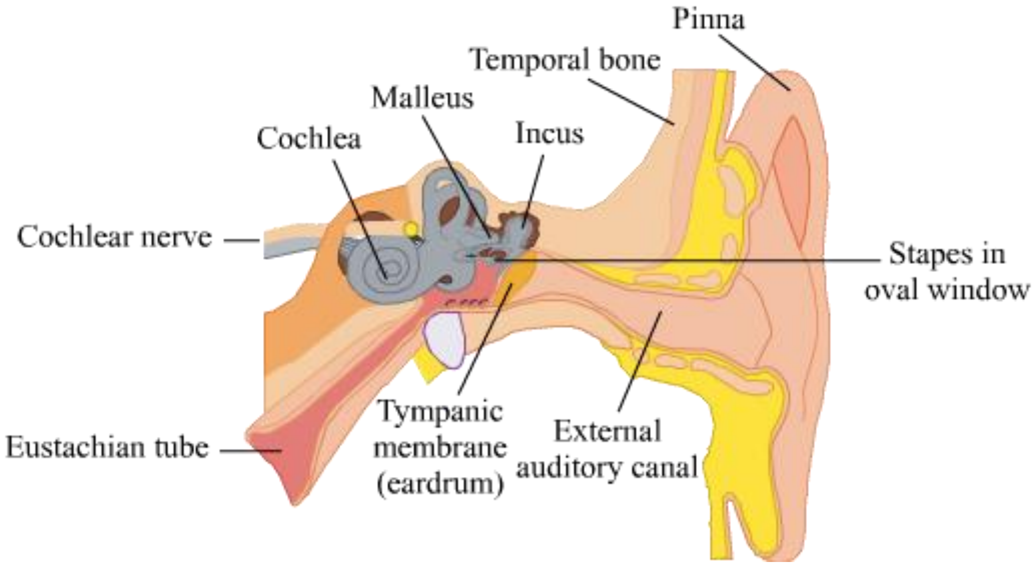
Radar is used to track aircrafts, artificial satellites and motor vehicles. Radar Gun is an instrument used to detect the crossing speed limit of vehicles.

The Human Ear

We have two ears to hear the different sounds that are around us—the soft purring of a cat, the loud barking of a dog, the tinkling of a bell, the blaring of a horn, etc. Our ears detect all types of sounds lying in the hearing range and send sound signals to the brain. In this lesson, we will learn about the working of the human ear.

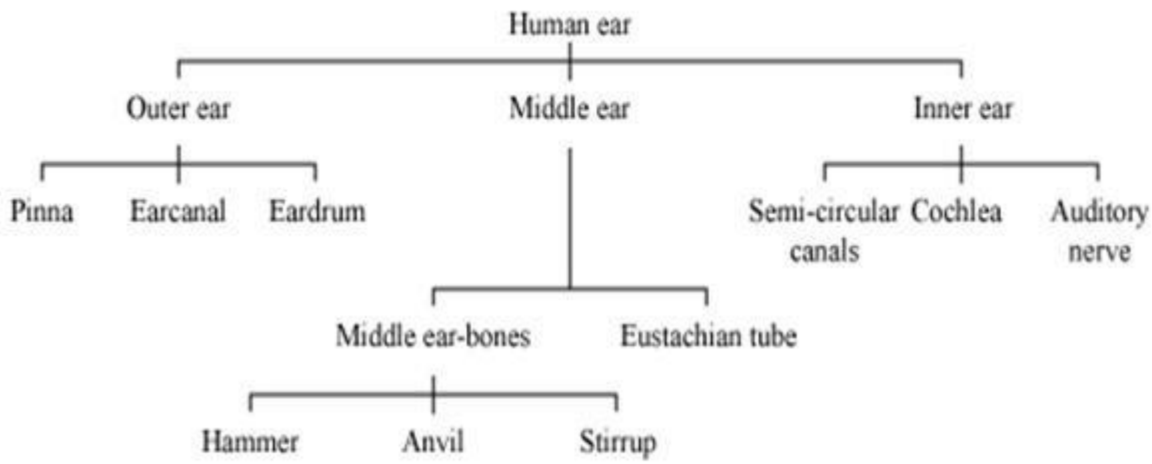
Structure of the Human Ear

The ear is one of the five sensory organs of the human body. It can sense sound waves from various sources. Take a look at this figure to know the various parts of the human ear.



The Human Ear

The human ear consists of three main parts—the outer ear, the middle ear and the inner ear. The following chart shows these three parts and their sub-parts.



- The eardrum is the intersection of the outer ear and the middle ear.
- The oval window is the intersection of the middle ear and the inner ear.

The stirrup bone of the middle ear is the smallest bone in the human body.

Parts of the Human Ear with Their Functions

The following table lists the functions of the different parts of the human ear.

Ear parts	**Sub-parts**	**Functions**
Outer ear	Pinna	Collects and sends sound to the ear canal
	Ear canal	Provides passage for sound to reach the eardrum
	Eardrum or tympanic membrane	Vibrates in response to sound; very sensitive membrane
Middle ear	Middle ear bones	Transfer sound energy to the cochlea
	Eustachian tube	Connects the middle ear to the throat
Inner ear	Semi-circular canals	Send messages to the brain for balancing
	Cochlea	Sends sound messages in the form of electrical impulses to the brain
	Auditory nerve	Conducts electrical messages to the brain where sound is then heard

Know More

The cochlea is a circular or snail-shaped, fluid-filled bone containing hair cells. Sound vibrations in the cochlea cause the hair cells to bend. As a result, electrical impulses get generated. These are then are carried to the brain by the auditory nerve. Consequently, sound is heard.

The Eustachian tube allows the middle ear fluids to drain and enables air to enter it from the throat.

Hearing Loss

Sounds above 85 dB can damage the eardrum. This may lead to hearing loss. Decibel (dB) is the unit of the intensity of sound. The following table lists the intensity of sound corresponding to various sounds and sources of sound.

Sources of sound	**Intensity levels (dB)**
Blowing leaves	10
Whisper	20
Mosquito buzz	40
Normal conversation	60
Busy city traffic	80
Large orchestra	100
Leaf blower	110
Jackhammer	120
Jet plane	140

The diaphragm of the eardrum may break or perforate at the sound intensity level equal to or greater than 160 dB.

Disclaimer: The sources of sound produce different noise level at different distances.