Sound

Waves - Transverse and Longitudinal

Waves

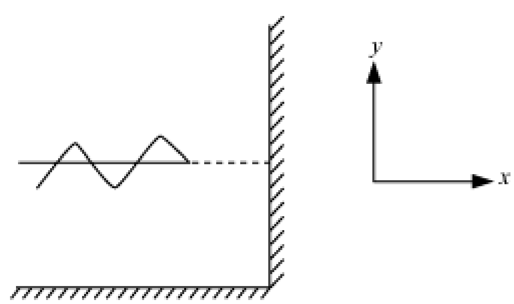
Continuous disturbance that transfers energy without any net displacement of the medium particles

Types of Wave

- **Mechanical wave**
- Requires a material medium for propagation
- Examples − sound waves, water waves, etc.
- **Electromagnetic wave**
- Does not require any material medium
- Examples − light wave, X-rays, etc.
- **Matter wave**
- Associated with electrons, protons, neutrons, atoms

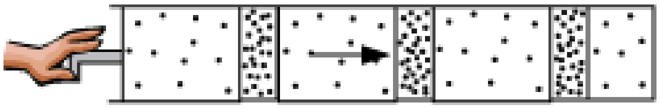
Types of Mechanical Wave

- **Transverse wave**
- Medium particles oscillate perpendicular to the direction of propagation of wave.



- Transverse waves are transmitted through solids and not through liquids and gases as the latter does not possess any internal transverse restoring force (shear strength).

- **Longitudinal waves**
- Medium particles oscillate along the direction of propagation of wave.



- Longitudinal waves can propagate through solids, liquids, and gases.

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 repetition of sound caused by its reflection off a hard surface is known as **echo**. If you shout once in an auditorium, then you will hear the original sound at first and then the reflected sound. This reflected sound is the echo of the original 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.

Solved Examples

Medium

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
⇒ s = 346 × 3

∴ 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*.

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

Medium

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:

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

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

Hard

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:

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

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

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,

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

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:

$$v = \frac{2\times525}{3}$$

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

Uses of Echo

- For determination of speed of sound:
  - $v = \frac{\text{Total distance travelled by the sound}}{\text{Time interval in which echo reaches the place from where the sound was produced}} = \frac{2d}{t}$
- Bats and dolphins use echo to detect obstacle or enemy in their path Also, they use it to hunt their prey.

- Bats and dolphins can produce and hear ultrasonic sound i.e sound of very high frequency of about 100 KHz. Thus, they have very high audible limit. Bats and dolphins produce high frequency sound waves which on striking any obstacle or prey on their path get reflected and start travelling towards them. On hearing these reflected sound waves (the echoes of the waves produced by them), they detect the obstacles or the preys in their path. In this way, they protect them from colliding with the obstacles or hunt their preys. This process of detecting obstacles is known as **sound ranging.**

- 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:

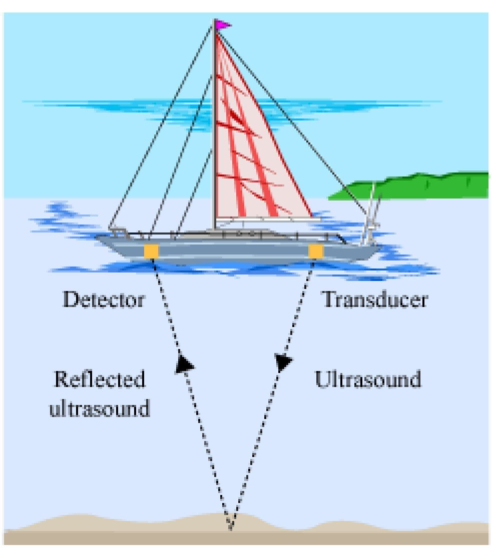
  $2d = v \times t$

  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**.



- In medical field: Here, echo method of ultrasonic waves is used to view human organs and any foreign body inside it.

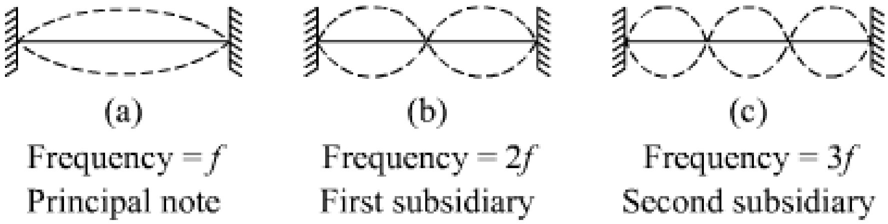
Natural, Damped and Forced Vibration; Resonance

Natural vibrations

The periodic vibrations of a body in the absence of any external force on the body are known as natural or free vibrations. The frequency of the body in natural vibrations is called its natural frequency.

Few examples of natural or free vibrations:

- Simple pendulum: It starts vibrating with its natural frequency when its bob is displaced from its mean position. Its frequency depends upon length *l* of the pendulum and acceleration due to gravity *g* and is given by $f = \frac{1}{2\pi}\sqrt{\frac{g}{l}}$.
- A load and spring system: Its frequency is given by $f = \frac{1}{2\pi}\sqrt{\frac{K}{m}}$, where *K* is force constant and *m* is the mass of the spring.
- Tuning fork when struck hard on a rubber pad starts vibrating with natural frequency.
- On plucking the strings of instruments like sitar, guitar, violin, etc, vibrations of a definite natural frequency are produced. This natural frequency is given as $f = \frac{1}{2l}\sqrt{\frac{T}{\pi r^2 d}}$, where *d* is the density of the material and $\pi r^2 d$ is the mass of the unit length of the string. The frequency *f* of vibrations in a stretched string is
- inversely proportional to length and radius of the string
- directly proportional to the square root of the tension (*T*) in the string
- A string of a given length stretched between its ends under a given tension can be made to vibrate in different modes by plucking the string at different points.



Different modes of vibrations in a string

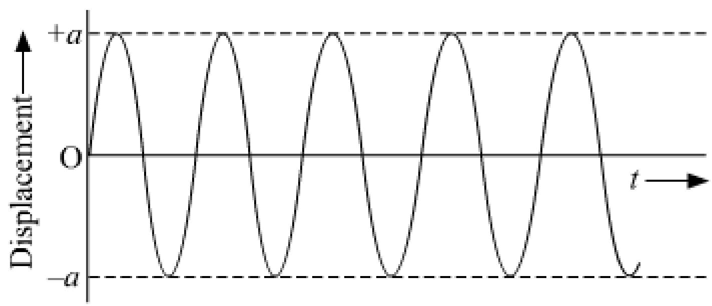
In figure (a), the string of length *l* is stretched in the middle because of which it vibrates in one loop. This vibration is known as principle note of frequency *f*. When the same string is plucked at its 1/4 length from one end, it vibrates in two loops (figure (b)).

Similarly, when it is plucked at its 1/6 length from one end, it vibrates in three loops (figure (c)).The wavelength of different modes in figure (a), (b) and (c) is 2*l*, 2*l*/2 and 2*l*/3, respectively.

Nature of natural vibrations

The natural vibrations are the simple harmonic vibrations under the influence of restoring force for which the amplitude and frequency continue to remain constant. These natural vibrations are possible only in vacuum.

In actual practice, it is impossible to achieve natural vibrations as the surrounding always has some form of medium which offers resistance to the motion or vibrations of a body because of which the amplitude of vibrations goes on decreasing. The frequency of natural vibration depends on the shape and size of the vibrating body.



Displacement-time graph for natural or free vibration (in vacuum)

Damped vibrations

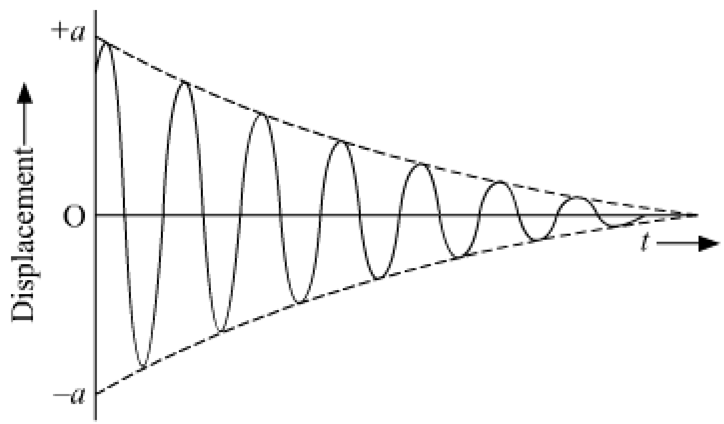
The periodic vibrations of a body of decreasing amplitude in the presence of any resistive force are called damped vibrations. Two forces which take part in damped vibrations are:

- the restoring force

- the frictional or resistive force

The reason for damped vibrations is the frictional or resistive force due to the surrounding medium. This resistive force has the tendency to oppose the motion of a body and, at any instant, is proportional to the velocity of the body (*=mv/t*). Thus, the energy of vibrating body continuously gets dissipated for overcoming this resistive force due to which the amplitude of its vibrations goes on decreasing. Ultimately, the body stops vibrating when it loses all its energy. The rate of decrease of amplitude of vibrations depends on

- nature of the medium
- shape and size of the body in vibrations



Displacement-time graph for the damped vibrations

Few examples of damped vibrations:

- Thin branch of a tree when pulled and released produces damped vibrations.
- Tuning fork when struck on a rubber pad in the presence of air produces damped vibrations.
- Simple pendulum oscillating in air produces damped vibrations.
- Vibrations of a loaded spring in air are damped vibrations.

Forced vibrations

The vibrations of a body which take place under the influence of an external periodic force acting on it, are called the forced vibrations. The forces which take part in forced vibrations are:

- the restoring force
- the frictional or resistive force
- the external periodic force or driving force

In forced vibration, the body vibrates with the frequency of the applied force and not with its natural frequency. The amplitude of forced vibrations depends on the frequency of the driving force. The amplitude of forced vibrations will be very large if the frequency of driving force is exactly equal to the natural frequency of the body and if these two frequencies are different, then the amplitude of forced vibration will be small.

Few examples of forced vibrations:

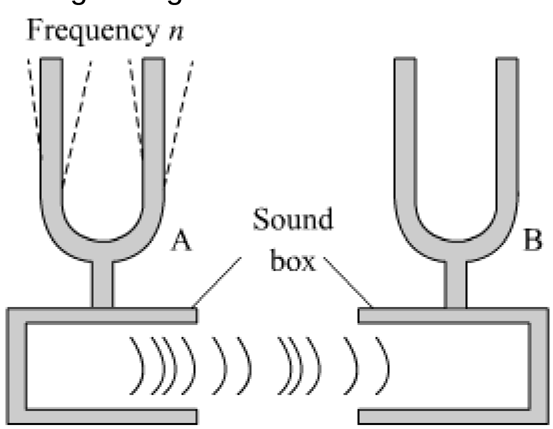
- Vibrations produced in the table top when a vibrating tuning fork is pressed against it are forced vibrations.
- Vibrations produced in the microphone's diaphragm with the frequencies corresponding to the speech of the speaker is an example of forced vibrations.
- In string instruments like guitar, an artist applies the periodic force on the strings to produce forced vibration in them.

Resonance

It is a special case of forced vibration in which the frequency of the externally applied periodic force on an object is equal to its natural frequency. In this case, the body begins to vibrate with an increased amplitude. This phenomenon is known as resonance.

Demonstration of resonance

(1) Resonance achieved using tuning forks and sound boxes



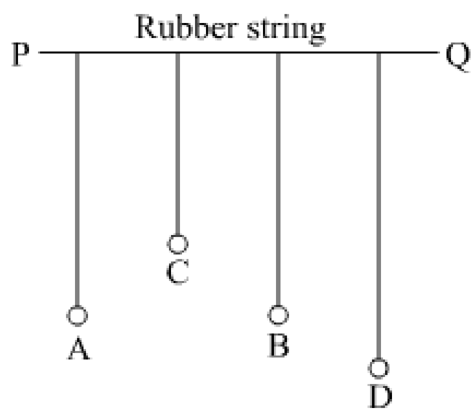
Resonance with tuning forks

In the above set up, two tuning forks A and B of same frequency are mounted on two separate sound boxes with their open ends facing each other. Now, when the prong of one of the forks say, A strikes on a rubber pad, then it starts vibrating. Then it passes its forced vibration to the air column of the sound box placed below it.

These vibrations are of large amplitude because of large surface area in the sound box. Gradually vibrations produced by the sound box of fork A get communicated to the sound box of fork B. Now, the sound box of fork of B starts vibrating with the frequency of fork A. Since, the frequency of these vibrations is same as the natural frequency of the fork B.

The fork B picks up these vibrations and starts vibrating under resonance. Hence, the two sound boxes help in communicating the vibrations and in increasing the amplitude of vibrations.

(2) Forced and resonant vibrations of pendulums



Forced and resonant vibrations of pendulums

We have a set up in which four pendulums are suspended from a rubber string of length PQ. Pendulum A and B are of the same length so that their natural frequency of vibration is same. The pendulum C is shorter than A and B and pendulum D is longer than A and B. Hence, the natural frequency of C is higher than that of A and B and natural frequency of D is lower than that of A and B.

Initially, the pendulum A is set into vibration by displacing its bob to one of its side. We will observe that pendulum B which is of the same length as of pendulum A also starts vibrating with some small amplitude initially and then gradually acquires the same amplitude as of pendulum A.

The vibrations produced in pendulum A are communicated as forced vibration to the other pendulums through the rubber string PQ. But the pendulum C and D remain in the state forced vibrations while pendulum B comes in the state of resonance.

This happens because the length of pendulum A and B are same which results in the same natural frequency of both the pendulums. And therefore there is an exchange of energy only between A and B and thus the resonance takes place between them.

Few examples where resonance can be seen:

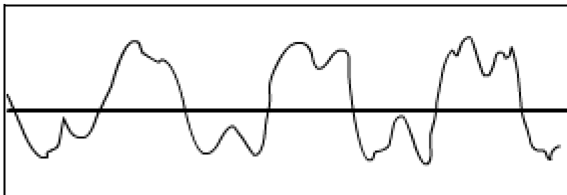
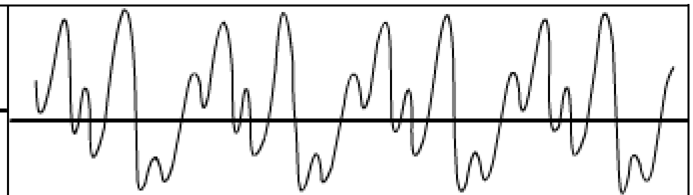
- in machine parts
- in a bridge

- in radio and TV receivers

Characteristics of Sound Waves

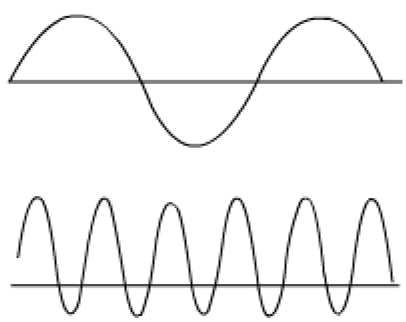
Characteristics of Sound: An Overview

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?

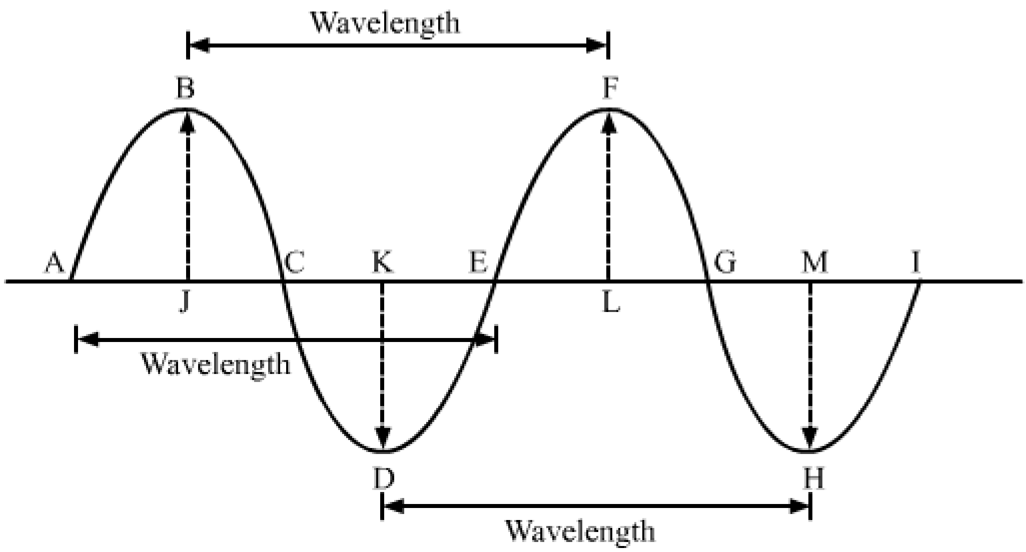
Two sounds with the same loudness, pitch and speed can be distinguished by their quality or timbre. If a sound is pleasant to hear, then it is said to have a rich timbre. An unpleasant sound has a poor timbre.

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

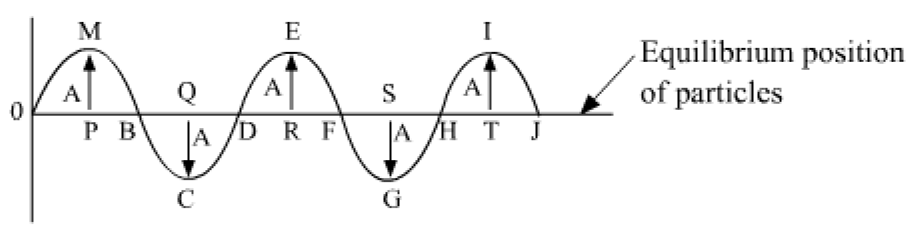
These five characteristics are demonstrated in the following figure with the help of a **transverse wave**. Note that the **crests** and **troughs** in a transverse wave are equivalent to the compressions and rarefactions in a longitudinal wave, respectively.



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.

Whiz Kid

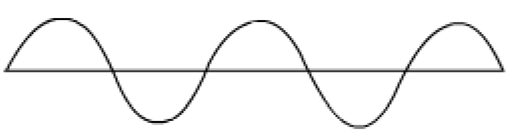
Loudness and Intensity

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

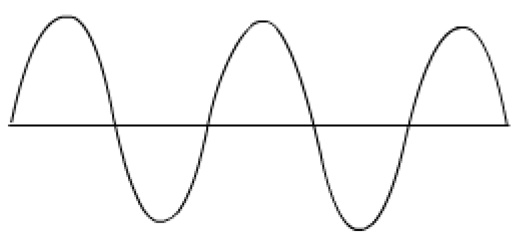
Loudness is the measure of the human ear's response to a sound. In contrast, intensity is the amount of energy passing per unit area per unit time.

•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?

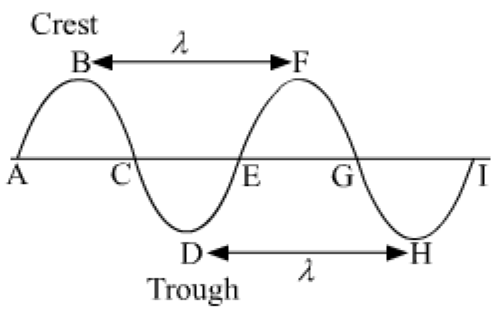


Sound wave A



Sound wave B

Wavelength (λ)

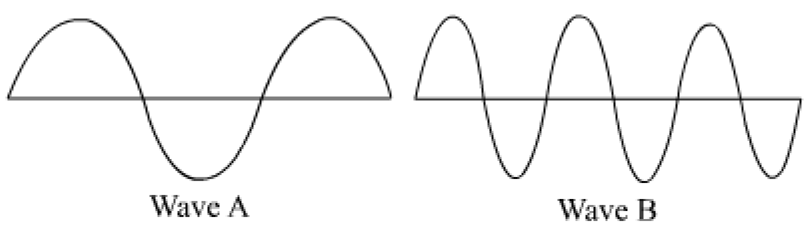


The distance between two consecutive compressions or rarefactions of a sound wave is its **wavelength** (*λ*). In case of a transverse wave, wavelength is the distance between two consecutive crests or troughs.

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

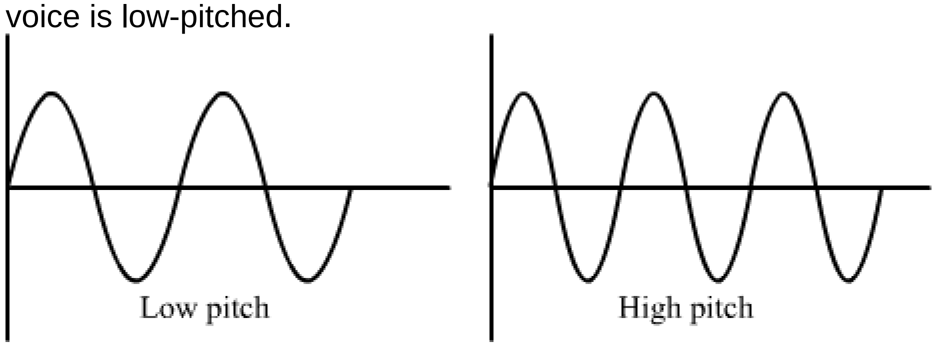
Pitch is defined as the shrillness of a sound. This highness or lowness of a sound is proportional to the frequency of the sound.

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.

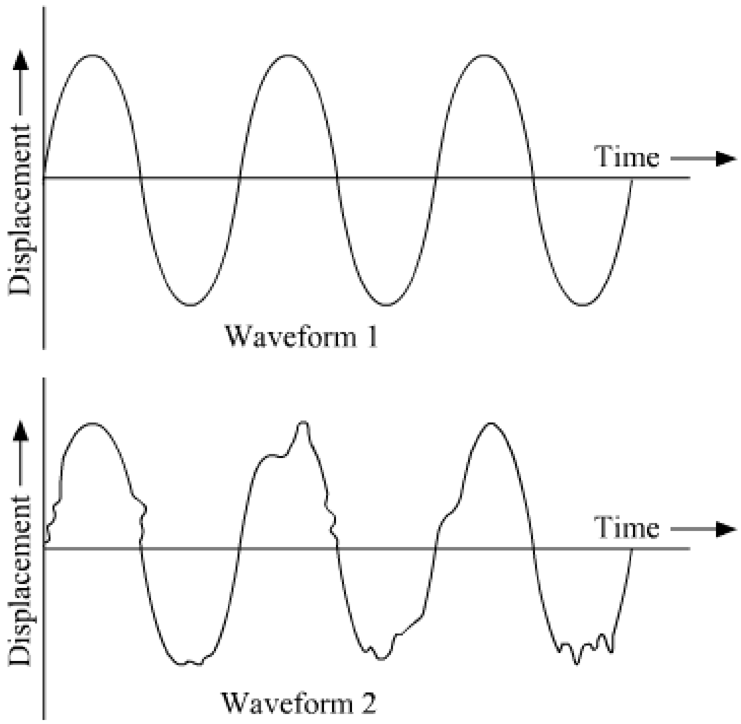
Tone is defined as a sound that has a single frequency.

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.

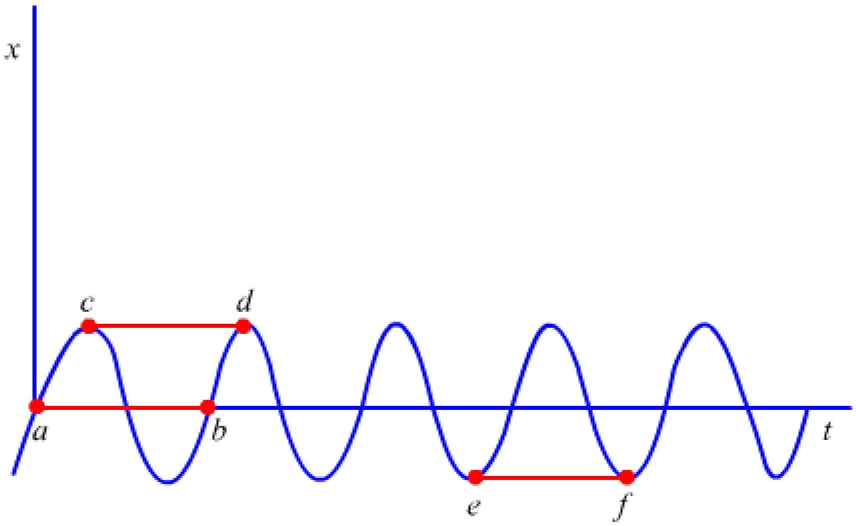
Sonic Boom

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,

$$T = \frac{1}{f}$$
$$= \frac{1}{400}$$
$$= 0.0025 \text{ s}$$

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

$$v = f \times \lambda$$

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

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

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

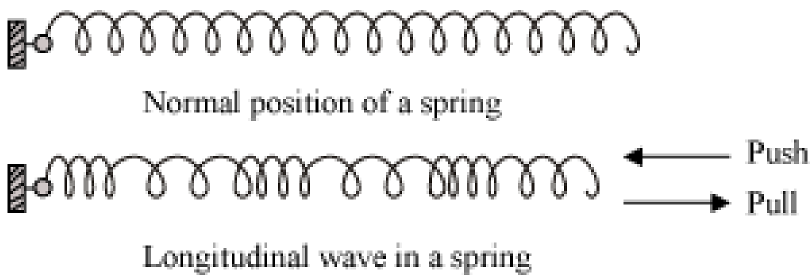
$$\lambda = \frac{v}{f}$$

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

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

Whiz 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.

Solved Examples

Easy

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.

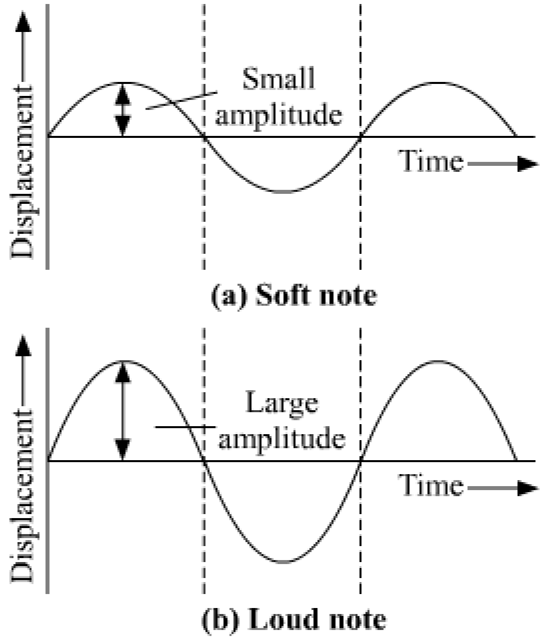
Advantages of a diatonic scale

- 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.

Loudness and Intensity

Loudness of sound

Loudness is the characteristic of sound by virtue of which a loud sound can be distinguished from a feeble one, both having the same pitch and timbre. It depends upon the amplitude of the wave. The unit of loudness is phon and decibel (dB).



Soft and loud notes

On comparing the waves of the above graphs, which are produced on striking a tuning fork with a rubber band first gently and then strongly, we observe two waves have same frequency (i.e. same pitch) and same waveform (i.e. same quality or timbre) , but they differ in amplitude. Evidently, the loud sound corresponds to the wave of the large amplitude.

Loudness of sound

- is directly proportional to the square of amplitude
- inversely varies with the square of distance from the source
- is directly proportional to the surface area of vibrating body
- is directly proportional on the density of the medium
- increases with the presence of resonating bodies near the vibrating body

Intensity of sound

It is the amount of sound energy passing per second normally through the unit area around a point in a medium. Its unit is watt per meter^2 .

The intensity of sound wave is proportional to

- square of the amplitude of vibration
- square of the frequency of vibration

- density of air

Subjective nature of loudness and objective nature of intensity

The loudness of a sound depends on (1) intensity and (2) sensitivity of the ears of the listener i.e. the sound of the same intensity may appear to be of different loudness to different persons.

Moreover, two sounds of the same intensity but of different frequencies may differ in loudness to the same listener because listeners' ears are sensitive to different frequencies.

Thus, loudness is subjective in nature but intensity is objective in nature as it being a measurable quantity.

Relationship between loudness and Intensity

According to the Weber and Fechner, relationship between loudness and intensity is given as

$$L = K \log_{10} I$$

Here, K is the constant of proportionality.

For an equally loud pure sound of frequency 1 kHz, the loudness of a sound in phon is the loudness in decibel.

Let I_1 and I_0 be the intensities of two sounds of loudness L_1 and L_0, respectively. Using the relation between loudness and intensity, we have

$L_1 = K \log_{10} I_1$ and $L_0 = K \log_{10} I_0$

If taking L as the difference of loudness of two sounds, then

$$L = L_1 - L_0 = K (\log_{10} I_1 - \log_{10} I_0)$$

$$L = K \log_{10} \frac{I_1}{I_0} \left(\mathrm{dB}\right)$$

Noise pollution

Noise pollution is the disturbance produced by noise which has harmful impact on humans and animals. When sounds of level above 120 dB is produced from various sources such as loudspeakers, moving vehicles etc., then such sounds are reffered as noise. Now, when these sounds of level above 120 dB are constantly heard, then these can cause severe headache or permanent damage to the ears of listeners. Sounds with such level also have adverse effects on various birds and animals.