Propagation of Sound Waves

Production of Sound

If somebody calls you from behind, you will quickly turn around. **What makes you do so?**

We turn back in response to a call because of the sound heard by us. We are able to talk to each other because of the sound produced by us. We are able to predict the distance of a train only by listening to the sound it produces. Similarly, we can distinguish between different musical instruments because of the sounds they produce.

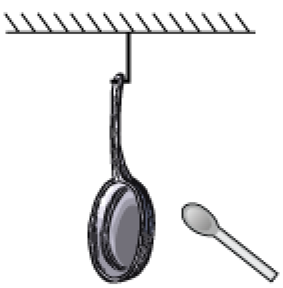
How do you realize that an alarm bell is ringing?

So, what is sound?

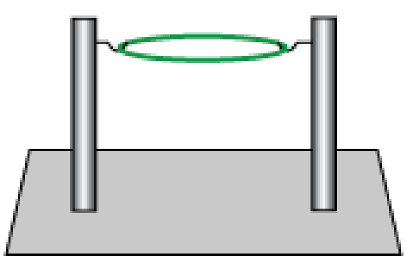
Sound is a form energy that produces the sensation of hearing in our ears and vibrating bodies produce sound.

Do you know how a sound is produced? To find out, let us perform the following activities.

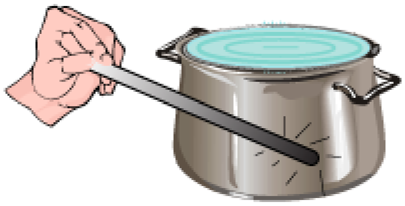
Take a frying pan and suspend it in air with the help of support. Hit the pan with a metal spoon. Now, touch the pan. **Can you feel the vibrations?** When you beat an object, you can feel its vibrations with the help of your sense of touch. Touch the pan when it is not producing any sound. **Can you feel the vibrations now?**



Take a rubber band and stretch it between two poles (as shown in the given figure). Now, pluck the rubber band in the middle. **Can you hear any sound? Does the rubber band vibrate when it produces a sound?** On plucking a stretched rubber band or a stretched string, it vibrates rapidly and produces a sound.



Take a cooking utensil and pour some water in it. Now, beat the utensil with a rod. You will hear a sound. Carefully, observe the surface of water in the utensil**. Do you see concentric circles moving on the water surface?** These are vibrations in water, produced by vibrations of the utensil body, on beating.



Therefore, it can be concluded that a vibrating body produces sound.

The back and forth movement of an object produces sound. An object moving back and forth is said to be in vibration. Hence, sound is produced by vibrating objects.

Sound Requires Medium for Propagation

We are able to hear the bursting of crackers even when we are standing at a distance. **How is it possible? How does the sound produced by a cracker reach us?**

The sound of a bursting cracker reaches us through air. It shows that sound can travel through air.

Let us try to understand this better.

A material medium is necessary for the propagation of sound. Vacuum is devoid of any material. Hence, sound cannot travel through vacuum.

Outer space is devoid of any material medium. Hence, no sound can be heard in outer spaces. To communicate in such areas, astronauts use walkie-talkies. A walkie-talkie is an instrument, which uses radio waves for the transportation of messages.

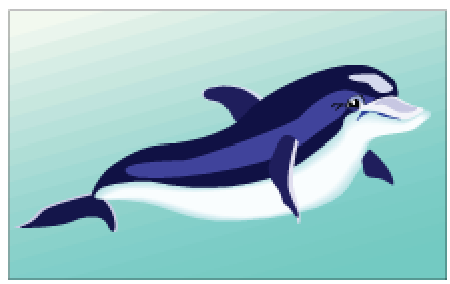
Can sound travel through liquids?

To find out whether sound can travel through liquids, let us perform the following activity.

Take a metal plate and spoon. Place them inside a bucket filled with water. Hit the plate with the spoon in such a way that it does not touch the body of the bucket.

Now, carefully place your ear near the surface of water. **Are you able to hear the sound produced?**

You can hear the produced sound. Sound reaches your ear after travelling through water. Hence, we can say that sound travels through liquids.

Dolphins communicate with each other by sending high pitched squalls. It shows that sound can travel through water.	

Can sound travel through solids?

Place your ear on one end of a long table. Ask your friend to tap the table from the other end. **Do you hear any sound?**

You can hear the produced sound. Sound reaches your ear after travelling through the table. This indicates that sound can travel through solids.

Stethoscope is an example of sound travelling through solids. Doctors use stethoscopes to listen to your heartbeat.	

Sound can travel in solids, liquids, and gases. However, sound cannot travel in vacuum.

Propagation of Sound

Production and Propagation of Sound: An Overview

This lesson will introduce you to the basics of sound.

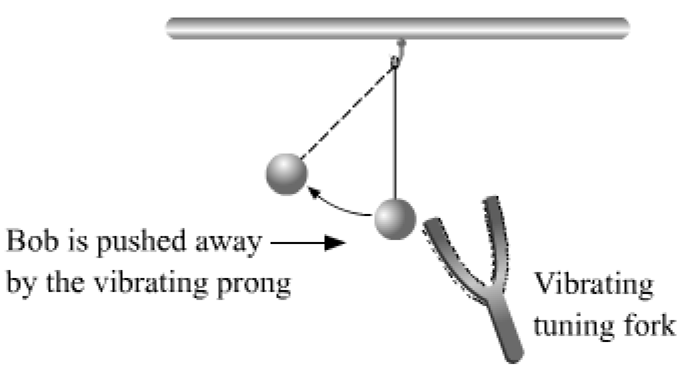
Did You Know?

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.

Solved Examples

Medium
Example:

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

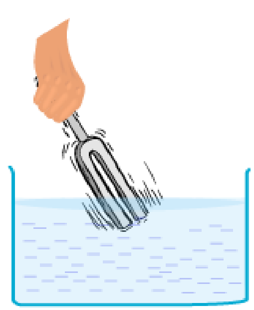
Solution:

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.

Whiz Kid

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.

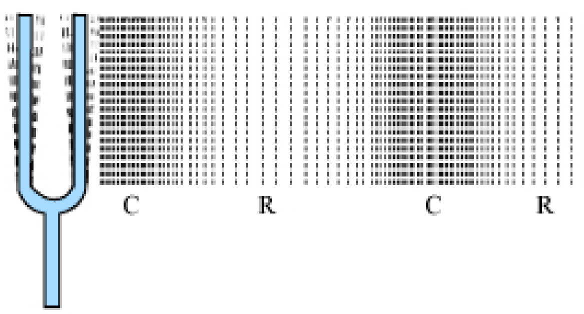
Air is the most common medium through which sound travels. When you beat a drum, the neighbouring air particles are set into vibration. As they move forward, they push the air particles in front of them. Consequently, a high-pressure region called **compression** (C) is created.

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.

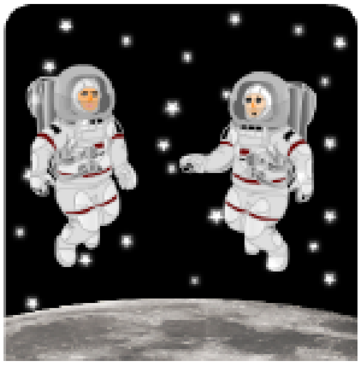
Pressure is directly proportional to the number of medium particles present in a given volume of the medium, i.e., the higher the density of particles in a given volume of the medium, the higher is the pressure, and vice versa.

These pressure variations in the medium enable sound to propagate.



Compressions and rarefactions

Did You Know?

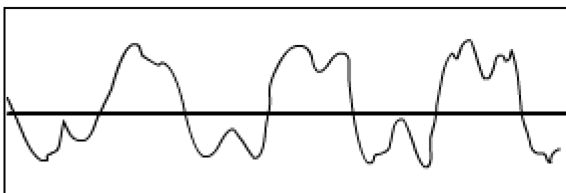
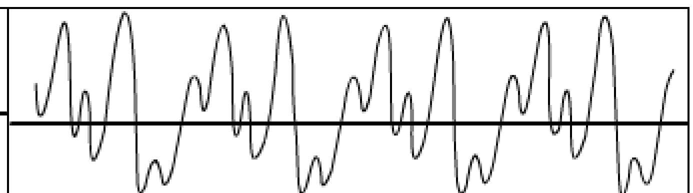


Astronomers cannot communicate on the moon by means of sound. This is because the moon has no atmosphere and sound waves cannot travel in vacuum. Instead, they communicate through walkie-talkies using radio waves.

Characteristics of Sound Waves

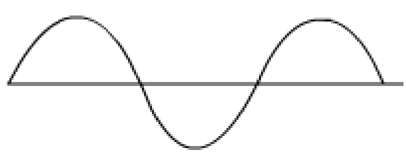
Characteristics of Sound: An Overview

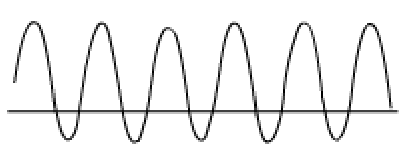
We can distinguish the sounds made by two men, two women, two musical instruments, two animals, etc. This is because sound waves differ in their quality or timbre. Quality is a characteristic of sound that enables us to distinguish between sounds with the same loudness and pitch. The following figures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

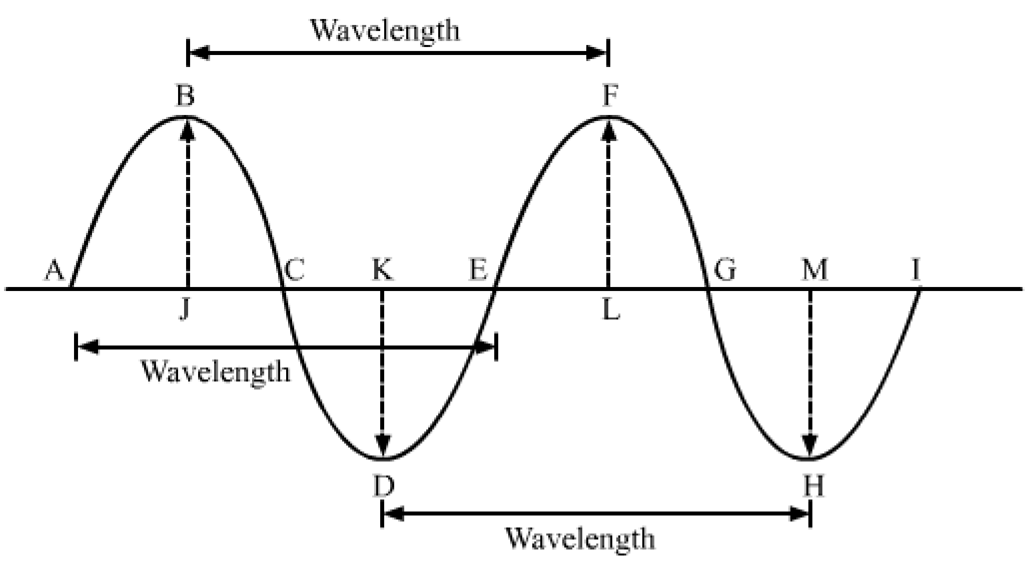
Two sounds with the same loudness, pitch and speed can be distinguished by their quality or timbre. If a sound is pleasant to hear, then it is said to have a rich timbre. An unpleasant sound has a poor timbre.

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

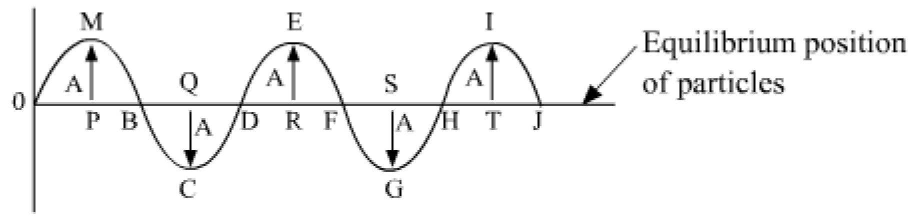
These five characteristics are demonstrated in the following figure with the help of a **transverse wave**. Note that the **crests** and **troughs** in a transverse wave are equivalent to the compressions and rarefactions in a longitudinal wave, respectively.



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

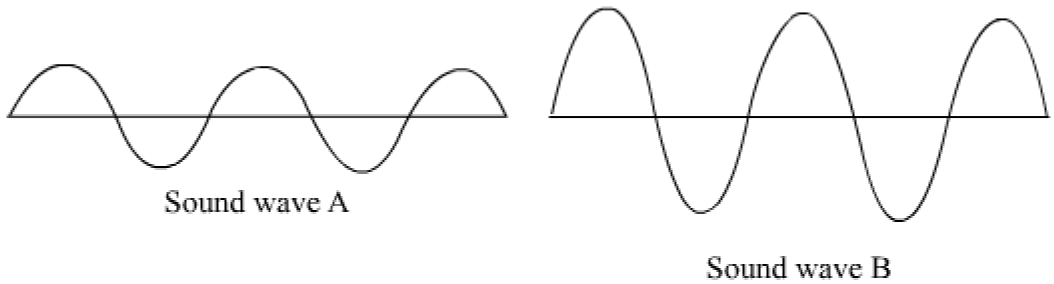
Loudness and Intensity

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

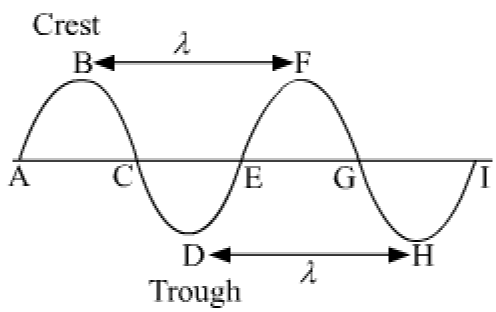
Loudness is the measure of the human ear's response to a sound. In contrast, intensity is the amount of energy passing per unit area per unit time.

•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?



Wavelength (*λ*)

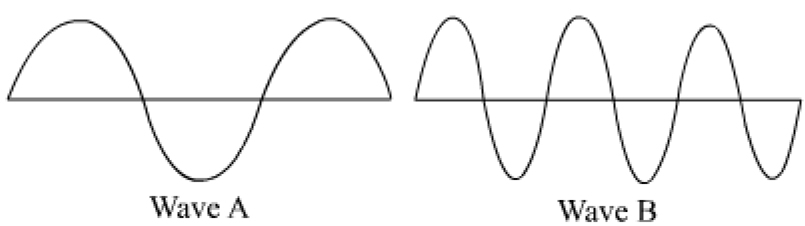


The distance between two consecutive compressions or rarefactions of a sound wave is its **wavelength** (*λ*). In case of a transverse wave, wavelength is the distance between two consecutive crests or troughs.

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.

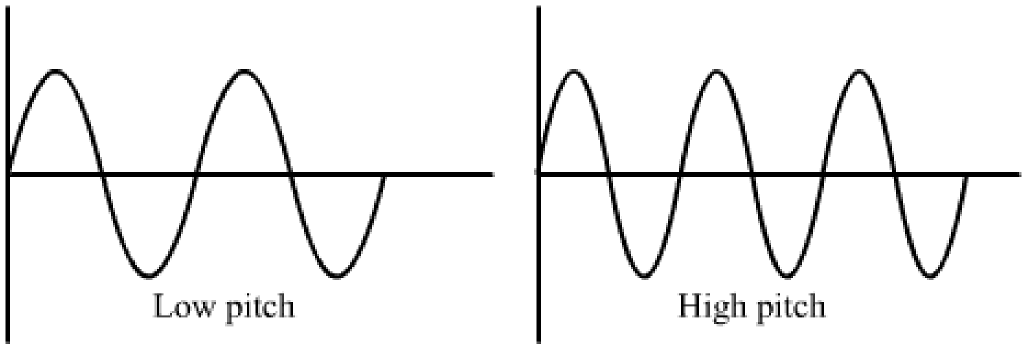
Similarly, women produce higher-pitched sounds than men.

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

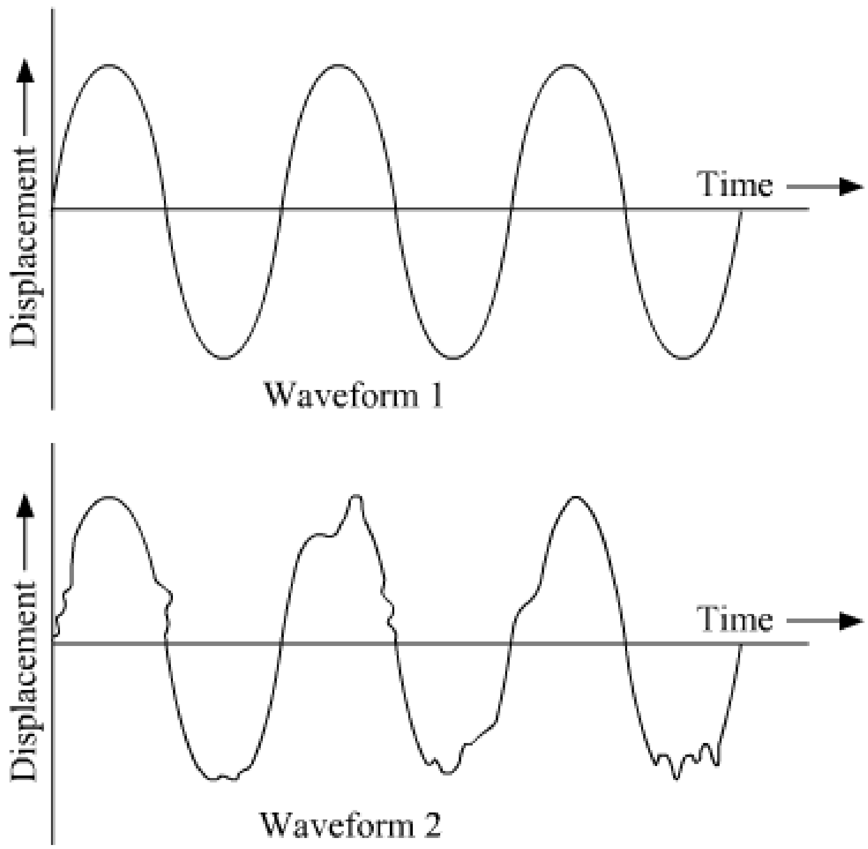
Note is defined as a sound that has a mix of different frequencies.

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

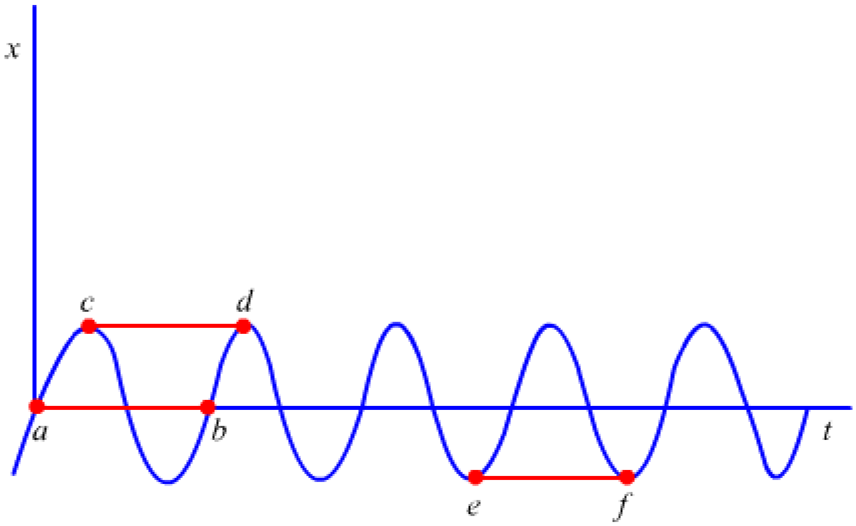
Sonic boom occurs when an aircraft breaks the sound barrier. An aircraft travelling with a supersonic speed will produce a pressure wave of sound in the shape of a cone whose vertex will be formed at nose of the aircraft and its base will be behind the aircraft.

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 = 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

$$v = f \times \lambda$$
$$f = \frac{v}{\lambda}$$
$$= \frac{330}{0.75} = 440 \text{ Hz}$$

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:

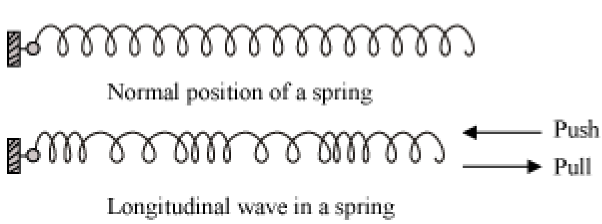
$$\lambda = \frac{v}{f}$$

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

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.

Speed of Sound in Different Media

We must have noticed that the sound produced at a place takes some time to reach us. For instance, the sound of a cracker is heard after some time of its explosion. This signifies that sound does not reach us instantly. This is because sound travels in a medium with some fixed speed. The speed of sound (*v*) in a medium depends upon the following factors:

1. E, elasticity of the medium
2. ρρ, density of the medium

Relation between speed of sound, elasticity of the medium and density of the medium

$$v = \sqrt{\frac{E}{\rho}} \text{ .....(1)}$$

where *E* is the elasticity of the medium (Young's modulus of elasticity in solid and bulk modulus for fluids).

For gas, *E* = *P* (pressure)

This is because when sound travels in a gas, the temperature of the gas does not change. Thus, the propagation of sound in gases is an isothermal change and for isothermal change, modulus of elasticity is equal to the pressure.

$$v = \sqrt{\frac{P}{\rho}} \text{ .....(2)}$$

Using equation (2), the speed of sound in air at normal temperature and pressure (N.T.P.) is found to be 279.5 m s^{-1}. But, experimentally the speed of sound in air is found to be 330 m s^{-1}. This means that the speed of sound found using equation (2) is lower than the experimental value. This lead us to a relation as shown below.

$$v = \sqrt{\frac{\gamma P}{\rho}} \text{ where } E = \gamma P \text{ and } \gamma = \frac{C_p}{C_v},$$

(γγ is the ratio of the specific heat at constant temperature to the specific heat at constant volume).

This relation was introduced by Laplace. According to him, when sound travels in a gas, during the formation of compression and rarefaction, there is no exchange of heat in the medium, i.e., the propagation of sound is an adiabatic change and for such change *E* = γγ*P.*
γγ depends upon the nature of the medium. For air, γγ = 1.4. The Laplace relation gave the correct value of speed of sound in air at N.T.P.

Speed of sound in different media

Medium		**Speed of sound (in m s^{-1})**
Gases	Air	330
	Hydrogen	1270
	Carbon dioxide	260
Liquids	Alcohol	1210
	Turpentine	1325
	Water	1450
Solids	Copper	3560
	Steel	5100
	Glass	5500
	Granite	6000

Can you list down few examples where speed of sound in steel is more than that in air?

Factors affecting the speed of sound in gas

1. Density
2. Temperature
3. Humidity
4. Direction of wind

Effect of density: From the relation v = $\sqrt{\frac{\gamma P}{\rho}}$, we can clearly see that speed of sound is inversely proportional to the density of the gas i.e. v∝ $\sqrt{\frac{1}{\rho}}$. Thus, the speed of sound increases with decrease in density of the gas and vice versa.

Effect of temperature: The speed of sound increases with increase in temperature of the gas because as the temperature increases the density of the gas decreases.

In fact, the speed of sound is related to temperature (*T*) of the medium as $v \propto \sqrt{T}$ where T is in Kelvin. The speed of sound in air increases by a factor of 0.61 m s^{-1} for each ^oC rise in temperature (provided the rise in temperature is not be very large) i.e.

$$v_t = v_0 + 0.61t,$$

where v_t is the speed of sound at temperature *t* and v_0 is the speed of sound at 0°.

Effect of humidity: The speed of sound increases with increase in humidity of air because the density of water vapour is 5/8 times the density of dry air at ordinary temperature. Thus, increase of moisture in air tends to decrease the density of air. Hence, the speed of sound in humid air is greater than the speed of sound in dry air.

Effect of direction of wind: The speed of sound increases or decreases in accordance with the direction of the wind. If the direction of propagation of sound is along the direction of wind, then its speed increases otherwise the speed of sound decreases.

$v + w$ is the total speed of sound if the wind is blowing in the direction of propagation of sound.(where v is the speed of sound in still air and w is the speed of wind)
$v - w$ is the total speed of sound when the direction of wind is opposite to the direction of propagation of sound.

Factors not affecting the speed of sound in gas

1. Pressure
2. Amplitude of wave
3. Wavelength or frequency of wave

Effect of Pressure: The speed of sound does not depend on pressure. In $v = \sqrt{\frac{\gamma P}{\rho}}$,
the ratio PρPρ remains unchanged with increase in pressure. For instance, if pressure of a gas is doubled, volume becomes half, so density gets doubled as mass is constant. Thus, P/ρ does not change.

Effect of amplitude of wave: The speed of sound is independent of the amplitude of sound wave.

Effect of wavelength or frequency: The speed of sound does not depend on the wave length or frequency of sound wave.

Difference between sound wave and light wave

Sound Waves	Light Waves
They can not travel in vacuum.	They can travel in vacuum.
They can travel in air at a speed of 330 m s^{-1} .	They can travel in air at a speed of 3 × 10^8 m s^{-1}.
There speed increases with increase in density of the optical medium.	There speed decreases with increase in density of the optical medium.
These are longitudinal mechanical waves.	These are transverse electromagnetic waves.

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

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

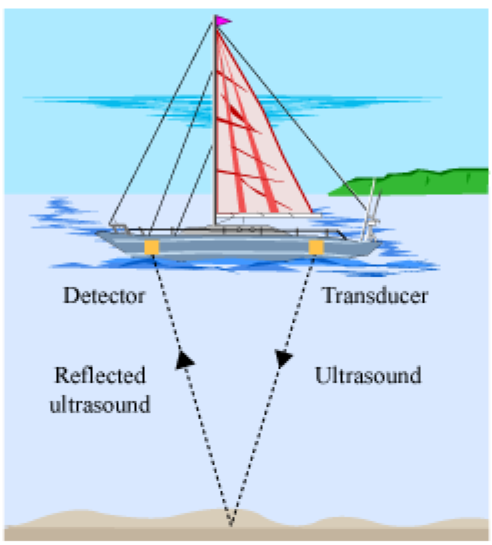
We have studied in our previous classes that sound is produced by vibrating matters. Sound waves is an example of longitudinal wave which needs material to propagate, we hear sound because the sound from source reaches our ear by travelling through air. The wave speed is described in terms of frequency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

Solved Examples

Easy

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

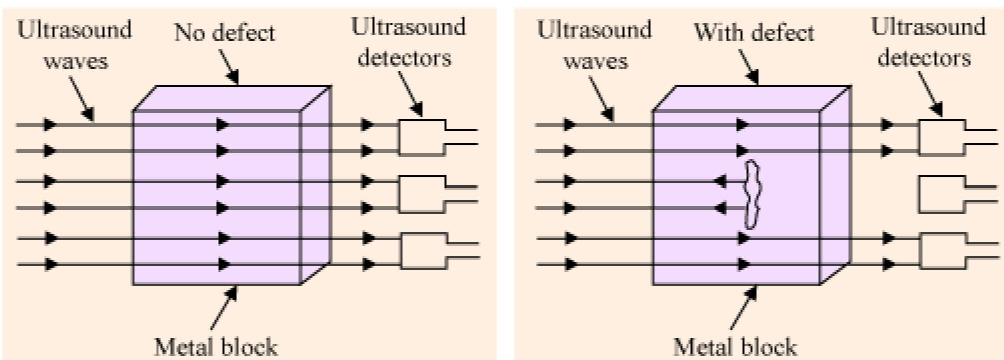
t = Time taken by the signal to return to the ship = 5 s

$$\Rightarrow 2d = 1500 \times 5 \ = 7500 \text{ m}$$
$$\Rightarrow d = 3750 = 3.75 \text{ km}$$

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.

Detecting Flaws

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.

Other Applications of Ultrasound

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.