Chapter 11

SOUND

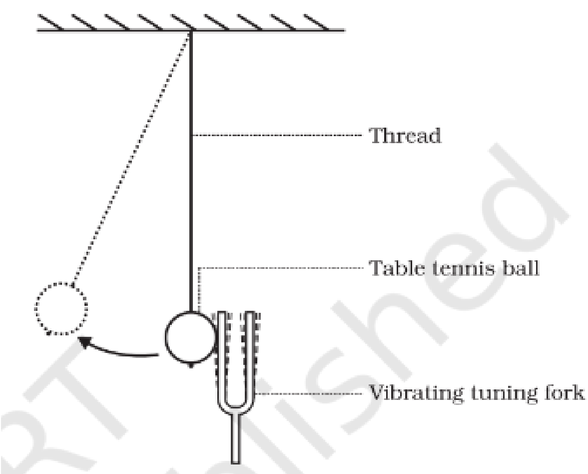
Everyday we hear sounds from various sources like humans, birds, bells, machines, vehicles, televisions, radios etc. Sound is a form of energy which produces a sensation of hearing in our ears. There are also other forms of energy like mechanical energy, light energy, etc. We have talked about mechanical energy in the previous chapters. You have been taught about conservation of energy, which states that we can neither create nor destroy energy. We can just change it from one form to another. When you clap, a sound is produced. Can you produce sound without utilising your energy? Which form of energy did you use to produce sound? In this chapter we are going to learn how sound is produced and how it is transmitted through a medium and received by our ears.

11.1 Production of Sound

Activity (11.1)

- Take a tuning fork and set it vibrating by striking its prong on a rubber pad. Bring it near your ear.
- Do you hear any sound?
- Touch one of the prongs of the vibrating tuning fork with your finger and share your experience with your friends.
- Now, suspend a table tennis ball or a small plastic ball by a thread from a support [Take a big needle and a thread, put a knot at one end of the thread, and then with the help of the needle pass the thread through the ball]. Touch the ball gently with the prong of a vibrating tuning fork (Fig. 11.1).
- Observe what happens and discuss with your friends.

Fig. 11.1: Vibrating tuning fork just touching the suspended table tennis ball.



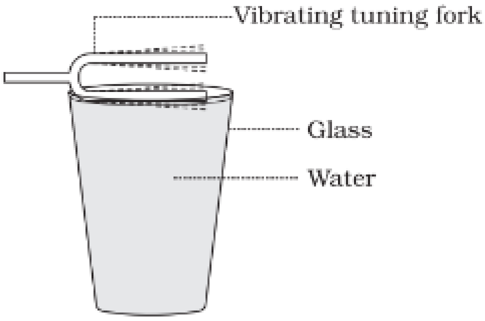
The image depicts an educational experiment where a tuning fork, struck to produce vibrations, is just touching a table tennis ball suspended from a thread. As the fork vibrates, it intermittently contacts the ball, transferring energy to it. This causes the ball to move or bounce away with each touch. The experiment is designed to visually demonstrate the energy transfer from the sound waves generated by the vibrating tuning fork to the physical motion of the table tennis ball.

Activity (11.2)

Fill water in a beaker or a glass up to the brim. Gently touch the water surface with one of the prongs of the vibrating tuning fork, as shown in Fig. 11.2.

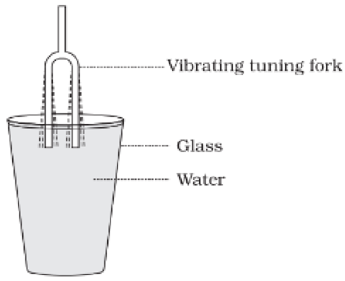
• Next dip the prongs of the vibrating tuning fork in water, as shown in Fig. 11.3.
• Observe what happens in both the cases.
• Discuss with your friends why this happens.

Fig. 11.2: One of the prongs of the vibrating tuning fork touching the water surface.



The image illustrates an experiment involving a vibrating tuning fork with one of its prongs touching the surface of the water in a glass. The vibration of the tuning fork, once struck and set into motion, is partly transmitted to the water, causing ripples or waves to emanate from the point of contact. This setup is used to demonstrate how vibrational energy can be transferred from one medium (the tuning fork) to another (water), creating a visible pattern of motion on the water's surface that corresponds to the frequency of the tuning fork's vibration.

Fig. 11.3: Both the prongs of the vibrating tuning fork dipped in water



The image shows a physics demonstration where both prongs of a vibrating tuning fork are immersed in a glass of water. When the tuning fork is struck and starts to vibrate, these vibrations are transmitted to the water, creating a pattern of waves that can be observed on the surface. This setup serves as an educational tool to illustrate the transmission of vibrational energy from the solid tuning fork to the liquid medium, and the consequent formation of wave patterns in the water due to the disturbance caused by the tuning fork's vibrations.

From the above activities what do you conclude? Can you produce sound without a vibrating object?

In the above activities we have produced sound by striking the tuning fork. We can also produce sound by plucking, scratching, rubbing, blowing or shaking different objects. As per the above activities what do we do to the objects? We set the objects vibrating and produce sound. Vibration means a kind of rapid to and fro motion of an object. The sound of the human voice is produced due to vibrations in the vocal cords. When a bird flaps its wings, do you hear any sound? Think how the buzzing sound accompanying a bee is produced. A stretched rubber band when plucked vibrates and produces sound. If you have never done this, then do it and observe the vibration of the stretched rubber band.

Activity (11.3)

• Make a list of different types of musical instruments and discuss with your friends which part of the instrument vibrates to produce sound.

11.2 Propagation of Sound

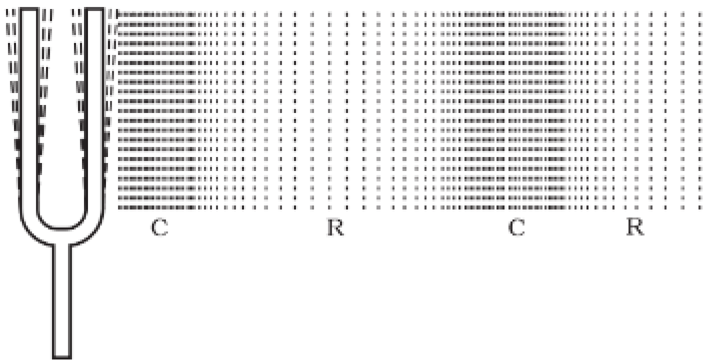
Sound is produced by vibrating objects. The matter or substance through which sound is transmitted is called a medium. It can be solid, liquid or gas. Sound moves through a medium from the point of generation to the listener. When an object vibrates, it sets the particles of the medium around it vibrating. The particles do not travel all the way from the vibrating object to the ear. A particle of the medium in contact with the vibrating object is first displaced from its equilibrium position. It then exerts a force on the adjacent particle. As a result of which the adjacent particle gets displaced from its position of rest. After displacing the adjacent particle the first particle comes back to its original position. This process continues in the medium till the sound reaches your ear. The disturbance created by a source of sound in the medium travels through the medium and not the particles of the medium.

A wave is a disturbance that moves through a medium when the particles of the medium set neighbouring particles into motion. They in turn produce similar motion in others. The particles of the medium do not move forward themselves, but the disturbance is carried forward. This is what happens during propagation of sound in a medium, hence sound can be visualised as a wave. Sound waves are characterised by the motion of particles in the medium and are called mechanical waves.

Air is the most common medium through which sound travels. When a vibrating object moves forward, it pushes and compresses the air in front of it creating a region of high pressure. This region is called a compression (C), as shown in Fig. 11.4. This compression starts to move away from the vibrating object. When the vibrating object moves backwards, it creates a region of low pressure called rarefaction (R), as shown in Fig. 11.4. As the object moves back and forth rapidly, a series of compressions and rarefactions is created in the air. These make the sound wave that propagates through the medium.

Compression is the region of high pressure and rarefaction is the region of low pressure. Pressure is related to the number of particles of a medium in a given volume. More density of the particles in the medium gives more pressure and vice versa. Thus, propagation of sound can be visualised as propagation of density variations or pressure variations in the medium.

Fig. 11.4: A vibrating object creating a series of compressions (C) and rarefactions (R) in the medium.



The image presents a visual representation of sound waves being generated by a vibrating tuning fork in a medium, which is typically air. The tuning fork, once struck, oscillates and produces alternating regions of compressions (C) and rarefactions (R). Compressions are areas where the air molecules are pushed closer together, and rarefactions are areas where the molecules are spread further apart. This pattern of compression and rarefaction moves away from the fork, creating sound waves that propagate through the medium. This illustration serves as an educational tool to show how sound waves travel in a sequence of high-pressure and low-pressure zones, corresponding to the vibratory motion of the source.

Question

1. How does the sound produced by a vibrating object in a medium reach your ear?
Answer: The sound produced by a vibrating object in a medium reaches your ear through a process involving the vibration of the object, which sets the particles of the medium around it into vibration. These particles, in turn, displace adjacent particles, creating a chain reaction that propagates the sound waves through the medium until they reach your ear. This transmission involves successive compressions (areas of high pressure) and rarefactions (areas of low pressure) in the medium, allowing the energy of the sound to travel from the source to your ear without the actual movement of particles over the entire distance.

2. Explain how sound is produced by your school bell.
Answer: Sound is produced by your school bell through the process of striking it, which sets it into vibration. These vibrations cause the air particles around the bell to vibrate as well, creating sound waves. These waves are longitudinal, meaning the particles of the medium (air, in this case) move parallel to the direction of the wave propagation. The bell, by vibrating, essentially compresses and rarefies the air around it, producing sound waves that propagate through the air and reach your ears, allowing you to hear the bell.

3. Why are sound waves called mechanical waves?
Answer: Sound waves are called mechanical waves because they require a medium (solid, liquid, or gas) to travel through. These waves are created by the vibration of an object, which causes the particles of the medium to move in a to-and-fro motion (parallel to the direction of wave propagation) and transmit energy from one place to another. This mechanical movement of particles characterizes sound waves as mechanical waves, distinct from electromagnetic waves, which can travel through the vacuum of space.

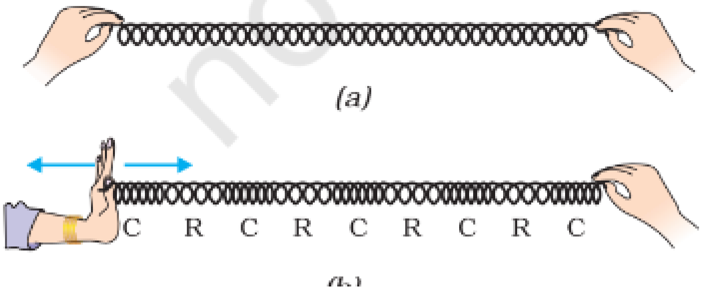
4. Suppose you and your friend are on the moon. Will you be able to hear any sound produced by your friend?
Answer: If you and your friend are on the moon, you would not be able to hear any sound produced by your friend through the conventional means of sound traveling through air. This is because the moon has no atmosphere to serve as a medium for the sound waves to propagate through. Sound requires a material medium for its transmission, and in the vacuum of space (or the moon's surface), there is no medium to carry the sound waves from your friend to you.

11.2.1 SOUND WAVES ARE LONGITUDINAL WAVES

Activity (11.4)

• Take a slinky. Ask your friend to hold one end. You hold the other end. Now stretch the slinky as shown in Fig. 11.5(a). Then give it a sharp push towards your friend.
• What do you notice? If you move your hand pushing and pulling the slinky alternatively, what will you observe?
• If you mark a dot on the slinky, you will observe that the dot on the slinky will move back and forth parallel to the direction of the propagation of the disturbance.

Fig. 11.5: Longitudinal wave in a slinky.



The image depicts a slinky being used to demonstrate a longitudinal wave, which is a type of wave where the displacement of the medium is parallel to the direction of wave propagation. In part (a), two hands hold the slinky stretched out to show its natural state. In part (b), one hand quickly pushes and pulls one end of the slinky, creating a series of compressions (C), where the coils are close together, and rarefactions (R), where the coils are spread apart. This alternating sequence of compressions and rarefactions moves along the length of the slinky, mimicking the way sound waves propagate through a medium, making this a useful hands-on representation for understanding the mechanics of longitudinal waves.

The regions where the coils become closer are called compressions (C) and the regions where the coils are further apart are called rarefactions (R). As we already know, sound propagates in the medium as a series of compressions and rarefactions. Now, we can compare the propagation of disturbance in a slinky with the sound propagation in the medium. These waves are called longitudinal waves. In these waves the individual particles of the medium move in a direction parallel to the direction of propagation of the disturbance. The particles do not move from one place to another but they simply oscillate back and forth about their position of rest. This is exactly how a sound wave propagates, hence sound waves are longitudinal waves.

There is also another type of wave, called a transverse wave. In a transverse wave particles do not oscillate along the direction of wave propagation but oscillate up and down about their mean position as the wave travels. Thus, a transverse wave is the one in which the individual particles of the medium move about their mean positions in a direction perpendicular to the direction of wave propagation. When we drop a pebble in a pond, the waves you see on the water surface is an example of transverse wave. Light is a transverse wave but for light, the oscillations are not of the medium particles or their pressure or density— it is not a mechanical wave. You will come to know more about transverse waves in higher classes.

11.2.2 CHARACTERISTICS OF A SOUND WAVE

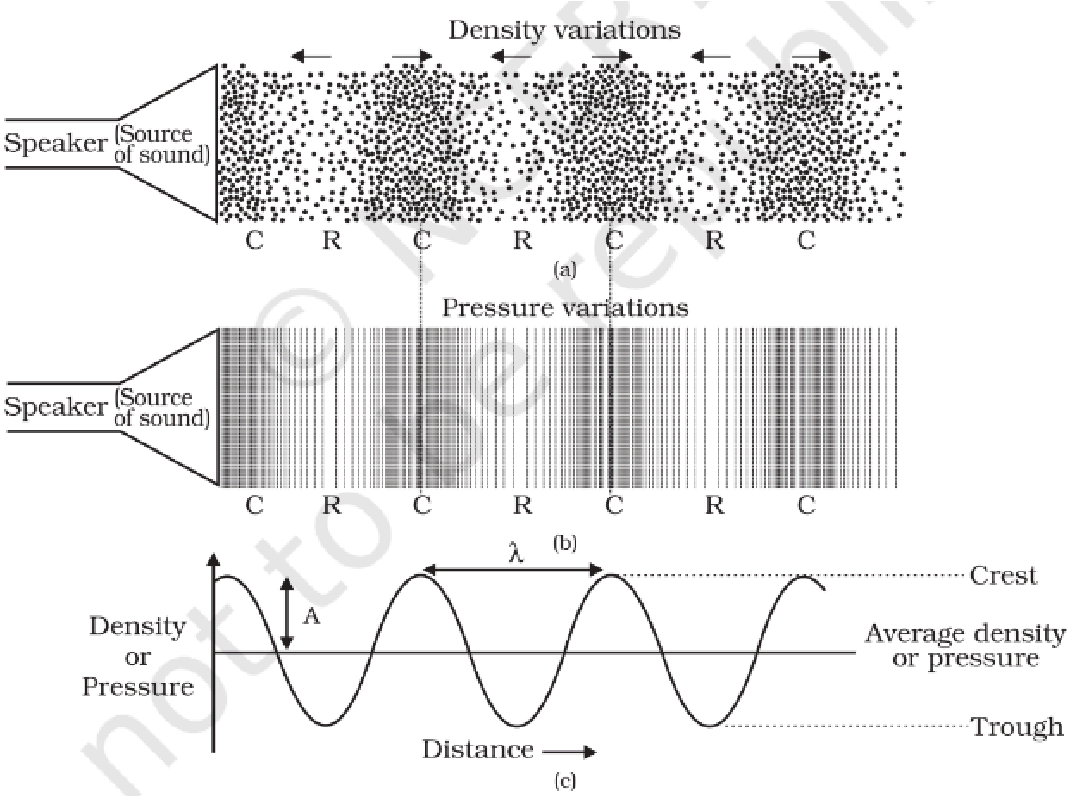
We can describe a sound wave by its
- frequency
- amplitude and
- speed.

A sound wave in graphic form is shown in Fig. 11.6(c), which represents how density and pressure change when the sound wave moves in the medium. The density as well as the pressure of the medium at a given time varies with distance, above and below the average value of density and pressure. Fig. 11.6(a) and Fig. 11.6(b) represent the density and pressure variations, respectively, as a sound wave propagates in the medium.

Compressions are the regions where particles are crowded together and represented by the upper portion of the curve in Fig. 11.6(c). The peak represents the region of maximum compression. Thus, compressions are regions where density as well as pressure is high. Rarefactions are the regions of low pressure where particles are spread apart and are represented by the valley, that is, the lower portion of the curve in Fig. 11.6(c). A peak is called the crest and a valley is called the trough of a wave.

The distance between two consecutive compressions (C) or two consecutive rarefactions (R) is called the wavelength, as shown in Fig. 11.6(c), The wavelength is usually represented by λ (Greek letter lambda). Its SI unit is metre (m).

Fig. 11.6: Sound propagates as density or pressure variations as shown in (a) and (b), (c) represents graphically the density and pressure variations.



The image displays three different representations of sound waves as they propagate from a speaker, which acts as the source of the sound.

(a) Illustrates how sound waves create density variations in the air. The particles are shown more densely packed in the compression regions (C) and less densely packed in the rarefaction regions (R).

(b) Depicts pressure variations corresponding to the density variations, with compressions being areas of higher pressure and rarefactions being areas of lower pressure. The alternation of dense and less dense lines represents these pressure changes.

(c) Is a graphical representation of the sound waves, showing how density and pressure change over distance. The graph plots these variations as a sinusoidal wave, with crests representing areas of high pressure (compressions) and troughs representing areas of low pressure (rarefactions). The amplitude (A) of the wave indicates the magnitude of the density or pressure change, and the wavelength (λ) is the distance between two consecutive compressions or rarefactions.

This figure serves as a comprehensive educational illustration of how sound travels as a longitudinal wave, manifesting as sequential compressions and rarefactions in the medium through which it moves.

H. R. Hertz

In the image, H. R. Hertz appears to have a neutral expression. His mouth is closed and straight, indicating a calm or neutral mood, and he is facing slightly to the side. His eyes are looking off to the side as well, which can suggest contemplation or focus. There are no strong indicators of a smile or frown, and his facial muscles are relaxed, supporting the neutral expression interpretation.

Heinrich Rudolph Hertz was born on 22 February 1857 in Hamburg, Germany and educated at the University of Berlin. He confirmed J.C. Maxwell's electromagnetic theory by his experiments. He laid the foundation for future development of radio, telephone, telegraph and even television. He also discovered the photoelectric effect which was later explained by Albert Einstein. The SI unit of frequency was named as hertz in his honour.

Frequency tells us how frequently an event occurs. Suppose you are beating a drum. How many times you are beating the drum in unit time is called the frequency of your beating the drum. We know that when sound is propagated through a medium, the density of the medium oscillates between a maximum value and a minimum value. The change in density from the maximum value to the minimum value, then again to the maximum value, makes one complete oscillation. The number of such oscillations per unit time is the frequency of the sound wave. If we can count the number of the compressions or rarefactions that cross us per unit time, we will get the frequency of the sound wave. It is usually represented by v (Greek letter, nu). Its SI unit is hertz (symbol, Hz).

The time taken by two consecutive compressions or rarefactions to cross a fixed point is called the time period of the wave. In other words, we can say that the time taken for one complete oscillation is called the time period of the sound wave. It is represented by the symbol T. Its SI unit is second (s). Frequency and time period are related as follows:

$$v = \frac{1}{T}$$

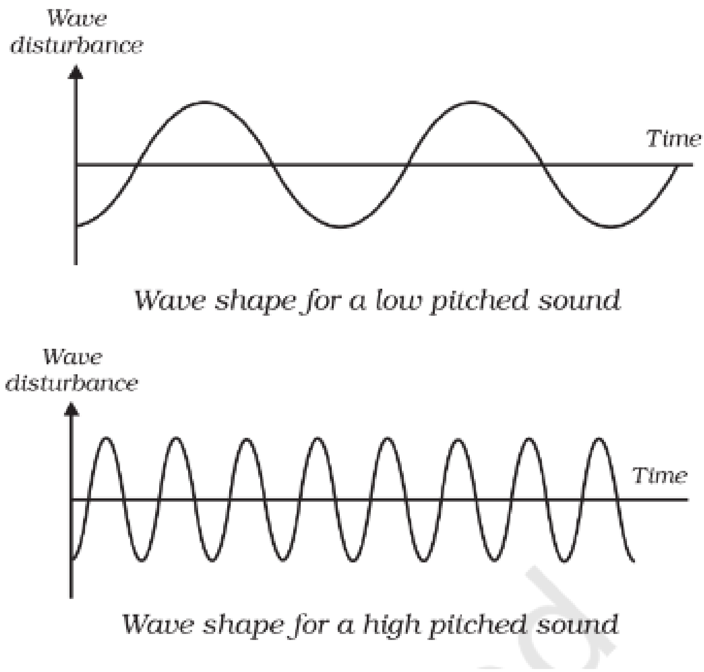
A violin and a flute may both be played at the same time in an orchestra. Both sounds travel through the same medium, that is, air and arrive at our ear at the same time. Both sounds travel at the same speed irrespective of the source. But the sounds we receive are different. This is due to the different characteristics associated with the sound. Pitch is one of the characteristics.

How the brain interprets the frequency of an emitted sound is called its pitch. The faster the vibration of the source, the higher is the frequency and the higher is the pitch, as shown in Fig. 11.7. Thus, a high pitch sound corresponds to more number of compressions and rarefactions passing a fixed point per unit time.

Objects of different sizes and conditions vibrate at different frequencies to produce sounds of different pitch.

The magnitude of the maximum disturbance in the medium on either side of the mean value is called the amplitude of the wave. It is usually represented by the letter A, as shown in Fig. 11.6(c). For sound its unit will be that of density or pressure.

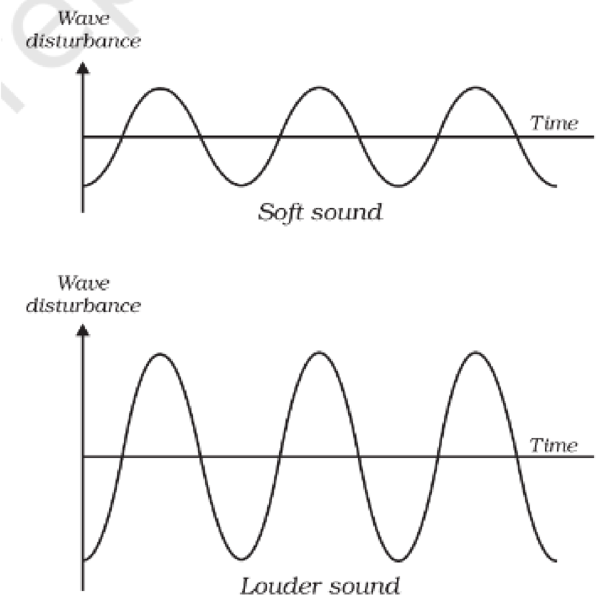
Fig. 11.7: Low pitch sound has low frequency and high pitch of sound has high frequency.



The image illustrates two waveforms corresponding to different sound pitches. The top waveform, labeled as a low pitched sound, shows a sound wave with a lower frequency, indicated by the longer wavelengths between each peak. The bottom waveform, representing a high pitched sound, has a higher frequency, as evidenced by the shorter wavelengths and more frequent peaks in the same period of time. This visual comparison effectively shows that the pitch of a sound is related to its frequency: low pitch correlates with low frequency, and high pitch with high frequency. The vertical axis represents the amplitude, or intensity, of the wave disturbance, while the horizontal axis represents time.

The loudness or softness of a sound is determined basically by its amplitude. The amplitude of the sound wave depends upon the force with which an object is made to vibrate. If we strike a table lightly, we hear a soft sound because we produce a sound wave of less energy (amplitude). If we hit the table hard we hear a louder sound. Can you tell why? A sound wave spreads out from its source. As it moves away from the source its amplitude as well as its loudness decreases. Louder sound can travel a larger distance as it is associated with higher energy. Fig. 11.8 shows the wave shapes of a loud and a soft sound of the same frequency.

Fig. 11.8: Soft sound has small amplitude and louder sound has large amplitude.



The image compares two waveforms to illustrate the relationship between amplitude and perceived volume of a sound. The top waveform, labeled "Soft sound," shows a sound wave with a small amplitude, meaning the peaks and troughs are relatively close to the central axis, which corresponds to a quieter sound. The bottom waveform is labeled "Loud sound" and has a larger amplitude; its peaks and troughs are farther from the central axis, indicating a sound that is perceived as louder. Both waveforms are plotted with amplitude on the vertical axis and time on the horizontal axis, clearly demonstrating that the amplitude of a sound wave affects the volume or loudness of the sound we hear.

The quality or timber of sound is that characteristic which enables us to distinguish one sound from another having the same pitch and loudness. The sound which is more pleasant is said to be of a rich quality. A sound of single frequency is called a tone. The sound which is produced due to a mixture of several frequencies is called a note and is pleasant to listen to. Noise is unpleasant to the ear! Music is pleasant to hear and is of rich quality.

Questions

1. Which wave property determines (a) loudness, (b) pitch?

Answer: The wave properties that determine:

- (a) Loudness: The amplitude of the wave. A higher amplitude means a louder sound, and a lower amplitude means a softer sound.
- (b) Pitch: The frequency of the wave. A higher frequency results in a higher pitch, and a lower frequency results in a lower pitch.

2. Guess which sound has a higher pitch: guitar or car horn?
Answer: Generally, a car horn is designed to produce a high pitch to attract attention quickly and effectively from a distance, which means it has a higher frequency. So, between a guitar and a car horn, the car horn typically has a higher pitch.

The speed of sound is defined as the distance which a point on a wave, such as a compression or a rarefaction, travels per unit time. We know, speed, $$v = distance / time = λ /T$$

Here λ is the wavelength of the sound wave. It is the distance travelled by the sound wave in one time period (T) of the wave. Thus,

$$v = \lambda \nu \left(\because \frac{1}{T} = \nu \right)$$

or $$v = \lambda \nu$$

The image presents a mathematical equation related to wave physics. The equation is \(v = \lambda \cdot \nu \), which is a fundamental equation where:

- $$\(v \)$$ is the wave speed (the speed at which the wave propagates through the medium),
-$$ \(\lambda \) (lambda)$$ is the wavelength (the distance between successive points of the wave in one cycle, such as crest to crest),
- $$\(\nu \) (nu)$$ is the frequency of the wave (the number of cycles that pass a point per unit of time).

The equation shows that the speed of a wave is equal to the product of its wavelength and frequency. This relationship is fundamental to understanding how waves behave in different media and is key to numerous applications in physics, including acoustics and optics. The part of the equation in the parentheses,$$ \(1/T \)$$, is defining frequency as the inverse of the period (T), which is the time it takes to complete one cycle. This further emphasises that the wave speed is directly proportional to the frequency and wavelength of the wave.

That is, $$speed = wavelength × frequency$$. The speed of sound remains almost the same for all frequencies in a given medium under the same physical conditions.

Example 11.1 A sound wave has a frequency of 2 kHz and wave length 35 cm. How long will it take to travel 1.5 km?

Solution:

Given,
Frequency, v = 2 kHz = 2000 Hz
Wavelength, λ = 35 cm = 0.35 m
We know that speed, v of the wave
= wavelength × frequency
v = λ v
= 0.35 m 2000 Hz = 700 m/s
The time taken by the wave to travel a distance, d of 1.5 km is

$$t = \frac{d}{v} = \frac{1.5 \times 1000 \text{ m}}{700 \text{ m s}^{-1}} = \frac{15}{7} \text{ s} = 2.1 \text{ s.}$$

The image contains a calculation for the time it takes a sound to travel a certain distance. It uses the formula $t = \frac{d}{v}$, where:

- t represents time,
- d represents distance,
- v represents velocity (speed of sound in this context).

In the calculation provided:

- The distance d is given as 1.5 kilometers, which is converted to meters (1.5 x 1000 m).
- The speed of sound v is given as 700 meters per second.

By substituting the given values, the calculation is as follows:

$t = \frac{1.5 \times 1000 \text{ m}}{700 \text{ m/s}}$

Which simplifies to:

$t = \frac{1500}{700}$

And further simplifies to:

$t = \frac{15}{7}$

Which results in approximately:

$t \simeq 2.1$ seconds.

So,the image shows a calculation of the time it takes for sound to travel a distance of 1.5 kilometers when the speed of sound is 700 meters per second. The result of the calculation is approximately 2.1 seconds, which means that if you hear a sound that originated 1.5 kilometers away, it would take about 2.1 seconds to reach you.

Thus sound will take 2.1 s to travel a distance of 1.5 km.

Questions

1. What are wavelength, frequency, time period and amplitude of a sound wave?

Answer: Wavelength, Frequency, Time Period, and Amplitude of a Sound Wave:

- Wavelength (λ): The distance between two consecutive compressions or rarefactions in a sound wave. It is the spatial period of the wave—the distance over which the wave's shape repeats.
- Frequency (v): The number of complete oscillations or cycles a wave undergoes per unit time. It determines the pitch of the sound and is measured in Hertz (Hz).
- Time Period (T): The time taken for one complete cycle of the wave to pass a given point. It is the inverse of the frequency (T = 1/v) and is measured in seconds.
- Amplitude: The magnitude of the maximum disturbance in the medium during one cycle of a wave. For sound, this corresponds to how much the medium (air, for instance) gets compressed or rarefied, determining the loudness of the sound.

2. How are the wavelength and frequency of a sound wave related to its speed?

Answer: Relationship between Wavelength, Frequency, and Speed:

- The speed of a sound wave (v) is directly proportional to both its wavelength (λ) and its frequency (v), according to the equation
- $$v=λv$$
- v=λv. This means that the speed of a wave in a medium is equal to the product of its wavelength and frequency. Therefore, if you know two of these properties, you can calculate the third.

3. Calculate the wavelength of a sound wave whose frequency is 220 Hz and speed is 440 m/s in a given medium.

Answer: The wavelength of a sound wave whose frequency is 220 Hz and speed is 440 m/s in a given medium is 2.0 meters.

4. A person is listening to a tone of 500 Hz sitting at a distance of 450 m from the source of the sound. What is the time interval between successive compressions from the source?

Answer: The time interval between successive compressions from the source for a tone of 500 Hz is 0.002 seconds, or 2 milliseconds.

The amount of sound energy passing each second through unit area is called the intensity of sound. We sometimes use the terms “loudness” and “intensity” interchangeably, but they are not the same. Loudness is a measure of the response of the ear to the sound. Even when two sounds are of equal intensity, we may hear one as louder than the other simply because our ear detects it better.

Question

1. Distinguish between loudness and intensity of sound.

Answer: Loudness and intensity of sound are related but distinct concepts in the study of sound waves.

- Intensity of Sound: Intensity refers to the amount of sound energy passing through a unit area in a unit time. It is a physical and objective measure, quantified in watts per square meter (W/m²). Intensity depends on the sound wave's amplitude and the distance from the source, as well as the medium through which the sound is traveling. A higher amplitude of the sound wave results in a higher intensity.

- Loudness: Loudness, on the other hand, is a subjective perception of the intensity of sound by the human ear. It is how humans perceive the strength or weakness of a sound and is measured in decibels (dB). The perception of loudness can vary significantly between different people and depends on the sensitivity of the human ear to various frequencies. For instance, the human ear is more sensitive to sounds in the frequency range of 2,000 to 5,000 Hz, meaning sounds within this range may be perceived as louder compared to sounds of the same intensity but with frequencies outside this range.

In summary, intensity is a measure of the sound wave's energy, while loudness is how our ears perceive that energy.

11.2.3 SPEED OF SOUND IN DIFFERENT MEDIA

Sound propagates through a medium at a finite speed. The sound of a thunder is heard a little later than the flash of light is seen. So, we can make out that sound travels with a speed which is much less than the speed of light. The speed of sound depends on the properties of the medium through which it travels. You will learn about this dependence in higher classes. The speed of sound in a medium depends on temperature of the medium. The speed of sound decreases when we go from solid to gaseous state. In any medium as we increase the temperature, the speed of sound increases. For example, the speed of sound in air is 331 m s–1 at 0oC and 344 m s–1 at 22 oC. The speeds of sound at a particular temperature in various media are listed in Table 11.1. You need not memorise the values.

Table 11.1: Speed of sound in different media at 25 ºC

State	Substance	Speed in m/s
Solids	Aluminium	6420
	Nickel	6040
	Steel	5960
	Iron	5950
	Brass	4700
	Glass (Flint)	3980
Liquids	Water (Sea)	1531
	Water (distilled)	1498
	Ethanol	1207
	Methanol	1103
Gases	Hydrogen	1284
	Helium	965
	Air	346
	Oxygen	316
	Sulphur dioxide	213

The image is a table titled "Table 11.1: Speed of sound in different media at 25 °C" that categorizes various materials by their states of matter—solids, liquids, and gases—and lists the speed of sound through each material in meters per second.

In the solids category, the speed of sound is highest in aluminum at 6420 m/s, and it varies among other metals like nickel (6040 m/s), steel (5960 m/s), iron (5950 m/s), and brass (4700 m/s). Glass, specifically flint glass, has a speed of sound of 3980 m/s, which is the lowest among the listed solids but still considerably higher than in liquids or gases.

For liquids, sea water has a sound speed of 1531 m/s, which is slightly higher than distilled water at 1498 m/s. The speeds in other liquids like ethanol and methanol are lower, with 1207 m/s and 1103 m/s respectively.

In the gases category, hydrogen has the highest speed at 1284 m/s. Helium's speed is 965 m/s, and air follows at 346 m/s. Oxygen has a slightly lower sound speed of 316 m/s, and sulfur dioxide has the lowest speed listed among the gases at 213 m/s.

The information provided in the table reflects that the speed of sound varies not just with the state of matter but also with the specific substances, being generally fastest in solids and slowest in gases, with liquids falling in between. The variation is due to differences in the elasticity and density of the materials.

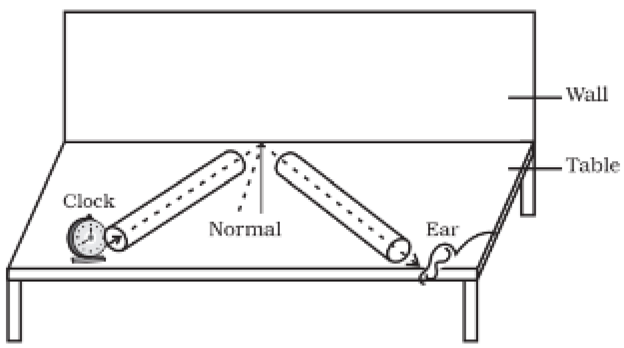
Question
1. In which of the three media, air, water or iron, does sound travel the fastest at a particular temperature?
Answer: Sound travels the fastest in iron, among the three media (air, water, and iron) at a particular temperature. This is because sound speed in a medium is generally faster in solids than in liquids, and faster in liquids than in gases. Iron, being a solid, has particles that are closely packed together, allowing sound waves to be transmitted more quickly through the medium due to the efficient transfer of vibrational energy between the tightly packed particles.

11.3 Reflection of Sound

Sound bounces off a solid or a liquid like a rubber ball bounces off a wall. Like light, sound gets reflected at the surface of a solid or liquid and follows the same laws of reflection as you have studied in earlier classes. The directions in which the sound is incident and is reflected make equal angles with the normal to the reflecting surface at the point of incidence, and the three are in the same plane. An obstacle of large size which may be polished or rough is needed for the reflection of sound waves.

Activity (11.5)
• Take two identical pipes, as shown in Fig. 11.9. You can make the pipes using chart paper. The length of the pipes should be sufficiently long as shown.
• Arrange them on a table near a wall.
• Keep a clock near the open end of one of the pipes and try to hear the sound of the clock through the other pipe.
• Adjust the position of the pipes so that you can best hear the sound of the clock.
• Now, measure the angles of incidence and reflection and see the relationship between the angles.
• Lift the pipe on the right vertically to a small height and observe what happens. (In place of a clock, a mobile phone on vibrating mode may also be used.)

Fig. 11.9: Reflection of sound



The image shows a simple diagram depicting an experiment to illustrate the reflection of sound. A clock, which is likely used as a source of ticking sound, is placed on one end of a table. On the opposite side, an ear is positioned close to the table surface, indicating that someone is listening for the sound. The line from the clock to the wall and then to the ear represents the path of the sound waves.

The sound waves emitted by the clock travel to the wall, hit it, and then reflect off it—following the law of reflection where the angle of incidence is equal to the angle of reflection (illustrated by the dotted lines labeled "Normal" at the point of reflection). The reflected sound waves then travel to the person's ear.

This setup could be used to demonstrate how sound can bounce off surfaces and how its direction can be changed by reflection, similar to the way light behaves. It can also be an illustration of how sound can reach a listener by more than one path, potentially causing an echo if the timing between the direct and reflected sound is perceptible.

11.3.1 ECHO

If we shout or clap near a suitable reflecting object such as a tall building or a mountain,we will hear the same sound again a little later. This sound which we hear is called an echo. The sensation of sound persists in our brain for about 0.1s. To hear a distinct echo the time interval between the original sound and the reflected one must be at least 0.1s. If we take the speed of sound to be 344 m/s at a given temperature, say at 22 oC in air, the sound must go to the obstacle and reach back the ear of the listener on reflection after 0.1s. Hence, the total distance covered by the sound from the point of generation to the reflecting surface and back should be at least (344 m/s) × 0.1 s = 34.4 m. Thus, for hearing distinct echoes, the minimum distance of the obstacle from the source of sound must be half of this distance, that is, 17.2 m. This distance will change with the temperature of air. Echoes may be heard more than once due to successive or multiple reflections. The rolling of thunder is due to the successive reflections of the sound from a number of reflecting surfaces, such as the clouds and the land.

11.3.2 REVERBERATION

A sound created in a big hall will persist by repeated reflection from the walls until it is reduced to a value where it is no longer audible. The repeated reflection that results in this persistence of sound is called reverberation. In an auditorium or big hall excessive reverberation is highly undesirable. To reduce reverberation, the roof and walls of the auditorium are generally covered with sound-absorbent materials like compressed fibreboard, rough plaster or draperies. The seat materials are also selected on the basis of their sound absorbing properties.

Example 11.2 A person clapped his hands near a cliff and heard the echo after 2 s. What is the distance of the cliff from the person if the speed of the sound, v is taken as 346 m s–1?

Solution:
Given,
Speed of sound, v = 346 m s–1
Time taken for hearing the echo, t = 2 s
Distance travelled by the sound

= v × t = 346 m s–1 × 2 s = 692 m
In 2 s sound has to travel twice the distance between the cliff and the person. Hence, the distance between the cliff and the person
= 692 m/2 = 346 m.

Question
1. An echo is heard in 3 s. What is the distance of the reflecting surface from the source, given that the speed of sound is 342 m s–1?

11.3.3 USES OF MULTIPLE REFLECTION
OF SOUND
1. Megaphones or loudhailers, horns, musical instruments such as trumpets and shehanais, are all designed to send sound in a particular direction without spreading it in all directions, as shown in Fig 11.10. In these instruments, a tube followed by a conical opening reflects sound successively to guide most of the sound waves from the source in the forward direction towards the audience.

Fig 11.10: A megaphone and a horn.

The image shows two devices used to amplify sound. The top part of the image features a person speaking into a megaphone. The megaphone is a cone-shaped device that takes the sound from the person's mouth and directs it in a focused beam toward the audience, making the sound louder by channeling and projecting it over a greater distance.

The bottom part of the image depicts a hand squeezing a bulb attached to a horn, often referred to as a bulb horn. When the bulb is squeezed, it forces air through the horn, producing a loud sound. The horn amplifies this sound by funneling the air vibrations through its shape, increasing their amplitude and therefore their volume as they exit the horn's wide end.

Both images illustrate how the shape of an object can be used to amplify sound without the need for electronic amplification. The megaphone uses passive acoustic amplification, while the horn relies on the mechanical action of squeezing the bulb to create sound.

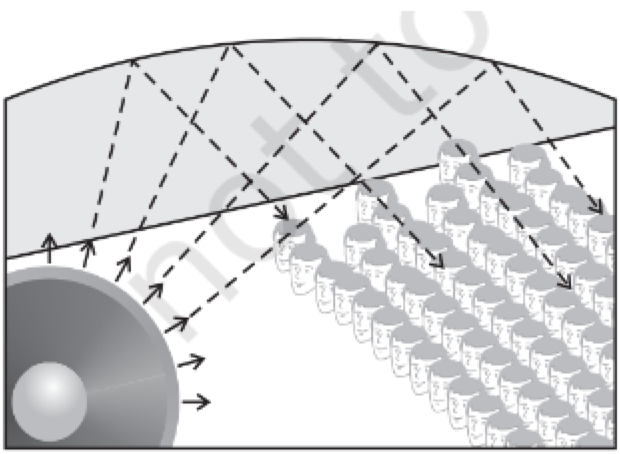
2. Stethoscope is a medical instrument used for listening to sounds produced within the body, mainly in the heart or lungs. In stethoscopes the sound of the patient’s heartbeat reaches the doctor’s ears by multiple reflection of sound, as shown in Fig.11.11 .

Fig.11.11: Stethoscope

The image appears to capture a moment between a doctor and a child. The doctor is using a stethoscope to listen to the child's chest, which is a common medical practice to check the sounds of the heart and lungs. On the right side of the image, there is an illustration of sound waves, depicted by concentric arcs, which could symbolize the sound of the heartbeat being transmitted through the stethoscope to the doctor's ears. This image could be part of educational material illustrating how a stethoscope is used in medical examinations to amplify internal sounds of a patient's body for diagnostic purposes.

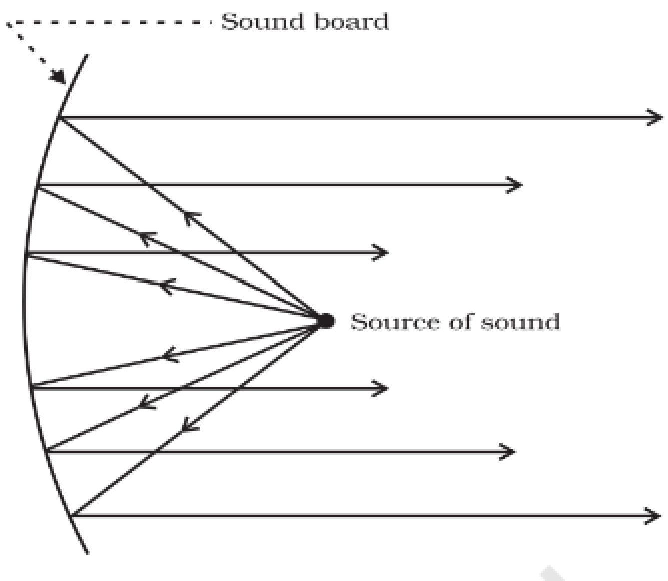
3. Generally the ceilings of concert halls, conference halls and cinema halls are curved so that sound after reflection reaches all corners of the hall, as shown in Fig 11.12. Sometimes a curved soundboard may be placed behind the stage so that the sound, after reflecting from the sound board, spreads evenly across the width of the hall (Fig 11.13).

Fig. 11.12: Curved ceiling of a conference hall.



The image depicts a loudspeaker emitting sound waves, which are represented by the dashed lines spreading out from the speaker. The pattern shows how the sound waves propagate in space, moving outward in all directions from the source. The illustration seems to emphasize the directivity and dispersion of sound waves in an environment, demonstrating how sound travels through air. Additionally, the image includes human figures in rows, suggesting the audience in the path of the sound waves, which is possibly used to show how sound reaches listeners in a given setting, such as a concert or public address scenario. The concentric arcs illustrate the wavefronts of sound, showing the crests of the waves which radiate outward from the speaker.

Fig. 11.13: Sound board used in a big hall.



The image shows a diagram representing how a sound board, or a reflector, is used to direct sound waves from a source. The source of sound is located at a focal point, and the sound waves are represented by arrows emanating from this point. The sound board has a dotted line indicating its edge, and the sound waves reflect off this board, demonstrating how it can be angled to direct the sound towards a specific area or audience. This is a common technique used in auditoriums and theaters to ensure that sound from the stage is projected throughout the venue. The diagram effectively shows the concept of sound reflection and direction, which is important for optimizing acoustics in a space.

Question
1. Why are the ceilings of concert halls curved?
Answer: The ceilings of concert halls are curved to enhance the acoustics by evenly distributing sound throughout the hall. The curvature helps to reflect sound waves from the stage into various parts of the audience area, ensuring that everyone hears the performance clearly, regardless of their seating position. This design prevents sound from being absorbed in one spot or creating echoes and reverberation that can distort the quality of the music. Essentially, the curved ceiling acts as a reflector, directing sound waves in a manner that optimizes the auditory experience for the audience, balancing both the volume and clarity of sound across the hall.

11.4 Range of Hearing
The audible range of sound for human beings extends from about 20 Hz to 20000 Hz (one Hz = one cycle/s). Children under the age of five and some animals, such as dogs can hear up to 25 kHz (1 kHz = 1000 Hz). As people grow older their ears become less sensitive to higher frequencies. Sounds of frequencies below 20 Hz are called infrasonic sound or infrasound. If we could hear infrasound we would hear the vibrations of a pendulum just as we hear the vibrations of the wings of a bee. Rhinoceroses communicate using infrasound of frequency as low as 5 Hz. Whales and elephants produce sound in the infrasound range. It is observed that some animals get disturbed before earthquakes. Earthquakes produce low-frequency infrasound before the main shock waves begin which possibly alert the animals. Frequencies higher than 20 kHz are called ultrasonic sound or ultrasound. Ultrasound is produced by animals such as dolphins, bats and porpoises. Moths of certain families have very sensitive hearing equipment. These moths can hear the high frequency squeaks of the bat and know when a bat is flying nearby, and are able to escape capture. Rats also play games by producing ultrasound.

Hearing Aid: People with hearing loss may need a hearing aid. A hearing aid is an electronic, battery operated device. The hearing aid receives sound through a microphone. The microphone converts the sound waves to electrical signals. These electrical signals are amplified by an amplifier. The amplified electrical signals are given to a speaker of the hearing aid. The speaker converts the amplified electrical signal to sound and sends to the ear for clear hearing.

Questions
1. What is the audible range of the average human ear?
Answer: The audible range of the average human ear extends from about 20 Hz to 20,000 Hz (20 kHz).

2. What is the range of frequencies associated with
(a) Infrasound?
(b) Ultrasound?

Answer: The range of frequencies associated with:

- (a) Infrasound: Frequencies below 20 Hz.
- (b) Ultrasound: Frequencies above 20,000 Hz (20 kHz).

11.5 Applications of Ultrasound

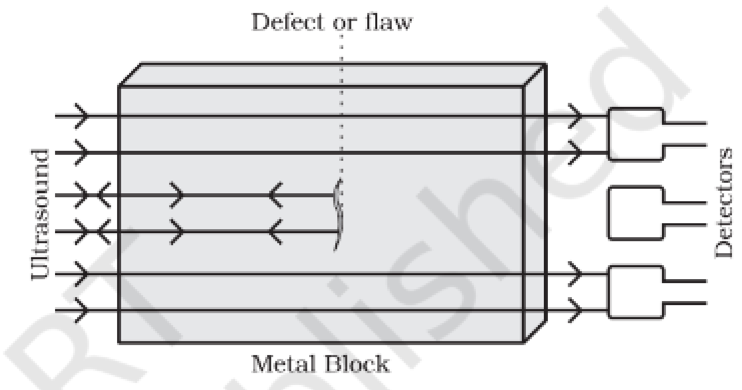
Ultrasounds are high frequency waves. Ultrasounds are able to travel along well- defined paths even in the presence of obstacles. Ultrasounds are used extensively in industries and for medical purposes.

• Ultrasound is generally used to clean parts located in hard-to-reach places, for example, spiral tube, odd shaped parts, electronic components, etc. Objects to be cleaned are placed in a cleaning solution and ultrasonic waves are sent into the solution. Due to the high frequency, the particles of dust, grease and dirt get detached and drop out. The objects thus get thoroughly cleaned.

• Ultrasounds can be used to detect cracks and flaws in metal blocks.

in construction of big structures like buildings, bridges, machines and also scientific equipment. The cracks or holes inside the metal blocks, which are invisible from outside reduces the strength of the structure. Ultrasonic waves are allowed to pass through the metal block and detectors are used to detect the transmitted waves. If there is even a small defect, the ultrasound gets reflected back indicating the presence of the flaw or defect, as shown in Fig. 11.14.

Fig 11.14: Ultrasound is reflected back from the defective locations inside a metal block.



The image illustrates a process known as ultrasonic testing, a non-destructive testing method used to detect defects or flaws within a metal block. Ultrasonic waves are sent through the metal from one side, and detectors are placed on the opposite side to receive the waves. When the waves encounter any discontinuities, such as defects or flaws, they are reflected back and do not reach the detectors as they normally would. The presence of these reflected waves can be used to locate and characterize the flaw within the metal. This technique is widely used in various industries for material testing, quality control, and maintenance inspections.

Ordinary sound of longer wavelengths cannot be used for such purpose as it will bend around the corners of the defective location and enter the detector.
• Ultrasonic waves are made to reflect from various parts of the heart and form the image of the heart. This technique is called 'echocardiography'.

• Ultrasound scanner is an instrument which uses ultrasonic waves for getting images of internal organs of the human body. A doctor may image the patient's organs, such as the liver, gall bladder, uterus, kidney, etc. It helps the doctor to detect abnormalities, such as stones in the gall bladder and kidney or tumours in different organs. In this technique the ultrasonic waves travel through the tissues of the body and get reflected from a region where there is a change of tissue density. These waves are then converted into electrical signals that are used to generate images of the organ. These images are then displayed on a monitor or printed on a film. This technique is called 'ultrasonography'. Ultrasonography is also used for examination of the foetus during pregnancy to detect congenial defects and growth abnormalities.

Ultrasound may be employed to break small 'stones' formed in the kidneys into fine grains. These grains later get flushed out with urine.

What you have learnt

• Sound is produced due to vibration of different objects.
• Sound travels as a longitudinal wave through a material medium.
• Sound travels as successive compressions and rarefactions in the medium.
• In sound propagation, it is the energy of the sound that travels and not the particles of the medium.
• The change in density from one maximum value to the minimum value and again to the maximum value makes one complete oscillation.
• The distance between two consecutive compressions or two consecutive rarefactions is called the wavelength, λ.
• The time taken by the wave for one complete oscillation of the density or pressure of the medium is called the time period, T.
• The number of complete oscillations per unit time is called the frequency (v), v = .1/T
• The speed v, frequency v, and wavelength λ, of sound are related by the equation, v = λv.
• The speed of sound depends primarily on the nature and the temperature of the transmitting medium.
• The law of reflection of sound states that the directions in which the sound is incident and reflected make equal angles with the normal to the reflecting surface at the point of incidence and the three lie in the same plane.
• For hearing a distinct sound, the time interval between the original sound and the reflected one must be at least 0.1 s.
• The persistence of sound in an auditorium is the result of repeated reflections of sound and is called reverberation.
• Sound properties such as pitch, loudness and quality are determined by the corresponding wave properties.

• Loudness is a physiological response of the ear to the intensity of sound.
• The amount of sound energy passing each second through unit area is called the intensity of sound.
• The audible range of hearing for average human beings is in the frequency range of 20 Hz – 20 kHz.
• Sound waves with frequencies below the audible range are termed “infrasonic” and those above the audible range are termed “ultrasonic”.
• Ultrasound has many medical and industrial applications.

The image shows a young person sitting at a desk, deeply engaged in writing or drawing in a notebook. The individual appears focused on the task at hand, with their attention directed towards the contents of the page. It’s a simple, colorful illustration, likely intended for an educational context to depict study, homework, or classroom activities. The orange bar at the top may suggest a header or title space, possibly for educational material or a section in a textbook.

Exercises
1. What is sound and how is it produced?
Answer: Sound is a form of energy that produces a sensation of hearing in our ears. It is produced by the vibration of objects. When an object vibrates, it causes the air particles around it to move, creating pressure waves that propagate through the medium (air, water, or solid) and are detected by our ears.

2. Describe with the help of a diagram, how compressions and rarefactions are produced in air near a source of sound.
Answer: Imagine a vibrating tuning fork. As it moves forward, it pushes air particles closer together, creating a high-pressure area known as a compression. As it moves back, it creates a low-pressure area by allowing the air particles to spread out, known as a rarefaction. This forward and backward motion continues, creating alternating compressions and rarefactions that propagate through the air as sound waves.

3. Why is sound wave called a longitudinal wave?
Answer: A sound wave is called a longitudinal wave because the movement of the particles of the medium is parallel to the direction of the wave's propagation. The particles vibrate

back and forth in the same direction the sound is moving, creating compressions and rarefactions.

4. Which characteristic of the sound helps you to identify your friend by his voice while sitting with others in a dark room?
Answer: The timbre (quality) of the sound helps you identify your friend's voice. Timbre is the characteristic that allows us to distinguish between different sounds having the same pitch and loudness. It is influenced by the sound's harmonic content and other qualities.

5. Flash and thunder are produced simultaneously. But thunder is heard a few seconds after the flash is seen, why?
Answer: This is because light travels much faster than sound. The speed of light is approximately 299,792 kilometers per second, while the speed of sound in air is about 344 meters per second (at 20°C). Thus, we see the flash of lightning almost instantly, but the sound of thunder, which travels much slower, reaches our ears later.

6. A person has a hearing range from 20 Hz to 20 kHz. What are the typical wavelengths of sound waves in air corresponding to these two frequencies? Take the speed of sound in air as 344 m s–1
Answer:

7. Two children are at opposite ends of an aluminium rod. One strikes the end of the rod with a stone. Find the ratio of times taken by the sound wave in air and in aluminium to reach the second child.
Answer: For this, we would need the speed of sound in aluminium and in air, then calculate the time taken for both cases and find their ratio. The speed of sound in aluminium is much higher than in air, implying that sound travels faster in aluminium.

8. The frequency of a source of sound is 100 Hz. How many times does it vibrate in a minute?
Answer: In one minute (60 seconds), a 100 Hz sound source vibrates 100 times per second * 60 seconds = 6,000 times.
9. Does sound follow the same laws of reflection as light does? Explain.
Answer: Yes, sound follows the same laws of reflection as light does. When sound waves hit a surface, they can be reflected. The angle of incidence (the angle between the incoming wave and a perpendicular line to the surface) is equal to the angle of reflection (the angle between the reflected wave and the same perpendicular line).

10. When a sound is reflected from a distant object, an echo is produced. Let the distance between the reflecting surface and the source of sound production remains the same. Do you hear echo sound on a hotter day?
Answer: Yes, sound travels faster in warmer air, so the time interval for an echo to return might be slightly reduced on a hotter day, but the echo can still be heard as long as the conditions for creating an echo are met.

11. Give two practical applications of reflection of sound waves.

Answer: Sonar (Sound Navigation and Ranging), used in submarines and ships to detect underwater objects by sending out sound waves and measuring the time it takes for the echoes to return.

- Architectural design, such as in concert halls and theaters, where sound reflection principles are applied to improve acoustics, ensuring sound is evenly distributed throughout the space.

12. A stone is dropped from the top of a tower 500 m high into a pond of water at the base of the tower. When is the splash heard at the top? Given, g = 10 m s–2 and speed of sound = 340 m s–1
Answer:

13. A sound wave travels at a speed of 339 m s–1. If its wavelength is 1.5 cm, what is the frequency of the wave? Will it be audible?
Answer: The frequency of the sound wave, given its speed of 339 m/s and a wavelength of 1.5 cm (0.015 m), is calculated to be 22,600 Hz. This frequency is above the typical audible range for humans, which is from 20 Hz to 20,000 Hz. Therefore, this sound would not be audible to most humans as it is considered ultrasound.

14. What is reverberation? How can it be reduced?
Answer: Reverberation is the persistence of sound in a particular space after the original sound is produced, caused by the sound waves reflecting off surfaces and continuing to bounce around. It can be reduced by using sound-absorbing materials on walls, ceilings, and floors, such as acoustic panels, curtains, and carpets, which absorb the sound waves instead of reflecting them.

15. What is loudness of sound? What factors does it depend on?
Answer: Loudness is a subjective perception that indicates how strong or weak a sound seems to a listener. It depends on the sound wave's amplitude (the higher the amplitude, the louder the sound), the frequency of the sound (certain frequencies are perceived as louder at the same amplitude), and the listener's hearing sensitivity.

16. How is ultrasound used for cleaning?
Answer: Ultrasound cleaning uses high-frequency sound waves to create cavitation bubbles in a liquid cleaner. When these bubbles collapse, they produce a strong force that removes dirt, grease, and other contaminants from objects submerged in the cleaning solution, even in hard-to-reach places.

17. Explain how defects in a metal block can be detected using ultrasound.
Answer: Ultrasound waves are sent through a metal block, and detectors on the other side pick up the waves. If there are defects within the block, such as cracks or voids, the ultrasound waves will reflect off these imperfections and be detected by the receivers. By analyzing these reflections, it's possible to locate and identify defects within the metal without damaging it, a process known as non-destructive testing (NDT).

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