8 PROPAGATION OF SOUND WAVES

Syllabus :

(i) *Nature of sound waves, Requirement of a medium for sound waves to travel; propagation and speed in different media; comparison with speed of light.*

Scope – Sound propagation, terms — frequency (f), wavelength (λ), velocity (V), relation $V = f\lambda$ (simple numerical problems), effect of different factors on the speed of sound; comparison of speed of sound with speed of light, consequences of the large difference in these speeds in air, thunder and lightning.

(ii) *Infrasonic, sonic, ultrasonic frequencies and their applications.*

Scope – Elementary ideas and simple applications only. Difference between ultrasonic and supersonic.

(A) PRODUCTION AND PROPAGATION OF SOUND WAVE

8.1 SOUND AND ITS PRODUCTION FROM VIBRATIONS

Everyday we hear sounds from various sources. For example, we hear sound of morning alarm, church bell, school bell, horn of a car (or bus), barking of dog, music from different instruments, *etc*. Although we do not see sound coming to us, but sound reaches our ears in the form of waves formed due to the vibrations of particles of the medium. The waves carry the mechanical energy of the vibrating particles with them so as to produce a sensation of hearing in our ears. Thus

Sound is a form of energy that produces the sensation of hearing in our ears.

Sound is produced by vibrations

Sound is produced when a body vibrates. Following experiments demonstrate this fact.

Experiment (1) : Stretch a string by holding one end in mouth between the teeth and the other end in one hand as shown in Fig. 8.1. Pluck it by the other hand near the middle.

It is noticed that the string starts vibrating and simultaneously a sound is heard. After some time when the string stops vibrating, no sound is heard.

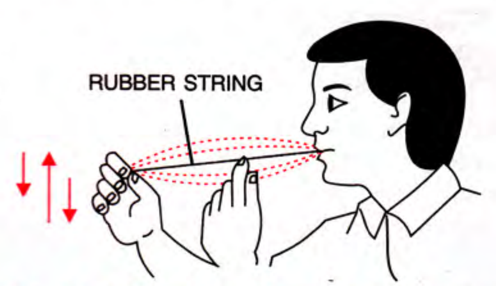

Fig. 8.1 A vibrating rubber string produces sound

Experiment (2) : Take a thin wire and stretch it between the two nails about a metre apart. Place a small bit of paper as rider near the middle of the wire and pluck the wire near the rider as shown in Fig. 8.2.

It is observed that the rider flies off as the wire starts vibrating and a sound is heard. After some time when the wire stops vibrating (*i.e.*, when the paper rider placed on the wire, does not fly off), no sound is heard.

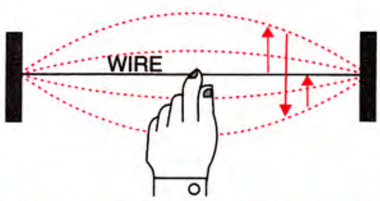

Fig. 8.2 A vibrating wire produces sound

Experiment (3) : Take a tuning fork which is a rectangular rod of steel (or aluminium) bent in the U shape, with a metallic stem at the bend. Strike its one arm on a rubber pad and bring it near a table tennis ball suspended by a thread as shown in Fig. 8.3.

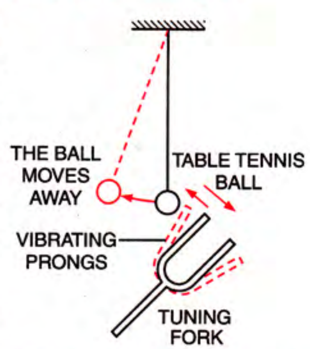

Fig. 8.3 A vibrating tuning fork producing sound

It is noticed that as the arm of vibrating tuning fork is brought close to the ball, it jumps to and fro and sound of the vibrating tuning fork is heard. When its arms stop vibrating, the ball becomes stationary and no sound is heard.

Experiment (4) : Take a drum and beat it. The membrane vibrates which can be felt by touching it and the sound of drum is heard. As the membrane stops vibrating, no sound is heard. This shows that the vibrating drum produces sound.

Experiment (5) : If the string of a sitar (or guitar) is plucked, the string starts vibrating and its sound is heard.

Similarly on blowing a whistle, the air in whistle starts vibrating and a sound is heard.

From the above experiments, it is concluded that sound is produced when a body vibrates. As it stops vibrating, the sound produced by it ceases. Thus

A vibrating body is a source of sound.

Sound is a form of energy : Mechanical energy is required to start vibrations in a body producing sound. The vibrations of body are transmitted in medium in form of waves from that point to the next and so on. These waves on reaching our ears, produce vibrations in the ear drum which are perceived as sound by us. Thus, sound is a form of energy.

8.2 SOUND PROPAGATION REQUIRES A MATERIAL MEDIUM

Sound produced by a vibrating body travels from one place to other through the mechanical vibrations of the medium particles in form of waves. Thus a material medium is required for the propagation of sound. This can easily be demonstrated by the following experiment.

Experiment (Bell jar experiment) : Take an electric bell and an air tight glass bell jar. The electric bell is suspended inside the bell jar. The bell jar is connected to a vacuum pump as shown in Fig. 8.4. As the circuit of electric bell is completed by pressing the key, the

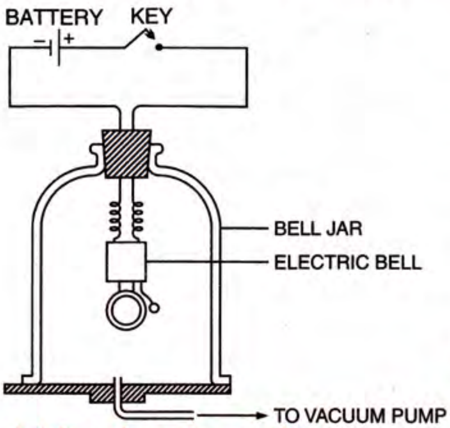

Fig.8.4 Sound requires medium (bell jar experiment)

hammer of the electric bell is seen to strike the gong repeatedly and the sound of bell is heard.

Now keeping the key pressed, air is gradually withdrawn from the jar by starting the vacuum pump. It is noticed that the loudness of sound goes on decreasing as the air is taken out from the bell jar and finally no sound is heard when the entire air from the jar has been drawn out. *The hammer of electric bell is still seen striking the gong repeatedly* which means that the gong is still vibrating to produce sound (as hammer strikes the gong), but it is not heard.

Explanation : When hammer of the bell hits the gong, sound is produced due to the vibrations of gong which travels through air to the wall of jar. This causes the wall of jar to vibrate due to which the air outside the jar is also set in vibration. Thus sound is heard by us. But when air has been removed from the jar, sound produced due to vibrations of gong could not travel to the wall of jar, so wall could not vibrate and no sound is heard. This clearly demonstrates that sound requires a material medium for its transmission and it cannot travel through vacuum. Thus,

A material medium is necessary for the propagation of sound from one place to another.

Requisites of the medium

The medium required for propagation of sound must possess the following *three* properties :

(i) *The medium must be elastic* so that its particles may come back to their initial positions after displacement on either side.

(ii) *The medium must have inertia* so that its particles may store mechanical energy.

(iii) *The medium should be frictionless* so that there is no loss of energy in propagation of sound through it.

Sound can propagate not only in gases, but also in solids and liquids. Some materials such as air, water, iron etc., can easily transmit sound through them from one place to another. On the other hand, blanket, thick curtains etc., absorb most of the sound incident on them and transmit or reflect only a small fraction of it.

Sound cannot travel in vacuum. On moon, there is no medium, therefore on moon, one can not hear the sound produced by the others.

Note : The light does not require any material medium for its propagation and it can therefore propagate through vacuum as well.

8.3 PROPAGATION OF SOUND IN A MEDIUM

When a source of sound vibrates, it creates a periodic disturbance in the medium near it (*i.e.*, the state of particles of medium changes). The distrubance then travels in the medium in form of waves. This can be understood by the following examples.

Example 1 : Take a thin metal strip. Keeping it vertical, fix its lower end. Push its upper end to one side and then release it. As it vibrates (*i.e.* moves alternately to the right and left) sound is heard.

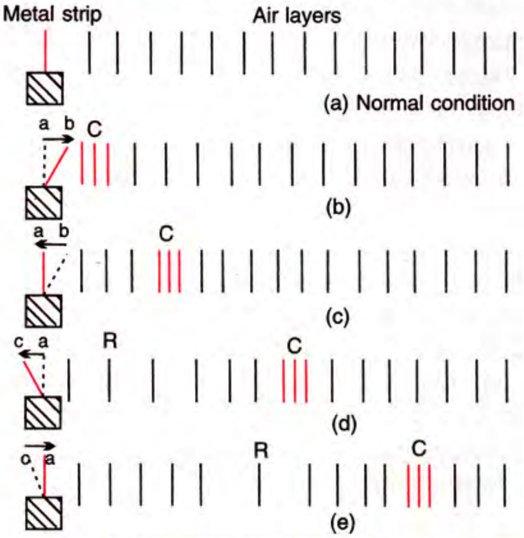

Fig.8.5 Propagation of disturbance in air

Fig. 8.5(a) shows the undisturbed or normal position of the metal strip and the air layers on the right side near the strip in their undisturbed (or normal) position.

As the strip moves to the right from *a* to *b* in Fig. 8.5(b), it pushes the particles of air in layers in front of it. So the particles of air in these layer get closer to each other *i.e.*, air of these layers gets compressed (or *compression* is formed at *C*). The particles of these layers while moving towards right, push and compress the layers next to them, which then compress the next layers and so on. Thus the disturbance moves forward in form of compression. The particles of the medium get displaced, but they do not move along with the compression.

As the metal strip starts returning from *b* to *a* in Fig. 8.5(c) after pushing the particles in front, the particles of air near the strip starts returning back to their mean positions due to the elasticity of the medium.

When the strip moves to the left from *a* to *c* in Fig. 8.5(d), it pushes back the layers of air near it towards its left and thus produces a space of very low pressure on its right side. The air layers on the right side of the strip expand in this region thus forming the rarefied air layers. This region of low pressure is called the *rarefaction R*.

When the strip returns from *c* to its normal position *a* in Fig. 8.5(e), it pushes the rarefaction *R* forward and the air layers near the strip again pass through their mean positions due to the elasticity of the medium.

In this manner, as strip moves to the right and left repeatedly, the compression and rarefaction regions are produced one after the other which carry the disturbance with it with a definite speed depending on the nature of the medium. Gradually due to friction, the strip loses its energy to the medium and the disturbance dies out.

One complete to and fro motion of the strip forms one compression and one rarefaction which together constitute one wave. This wave in which the particles of medium vibrate about their mean positions, in the direction of propogation of sound is called the *longitudinal wave*. Thus *sound travels in air in form of longitudinal waves.* Actually the longitudinal waves can be produced in solids, liquids as well as gases. At compressions, the density and pressure of the medium is maximum, while at rarefaction the density and pressure of the medium is minimum.

Example 2 : In the above example, formation of waves in air could not be seen. The formation of waves can easily be seen on the surface of water. If we drop a piece of stone in the still water of a pond, we hear the sound of stone striking the water surface. Actually a disturbance is produced in water at the point where the stone strikes it. This disturbance spreads in all directions radially outwards in form of circular waves (or ripples) on the surface of water as shown in Fig. 8.6.

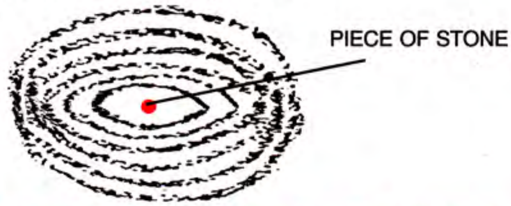

Fig.8.6 Ripples (or waves) formed on the surface of water on dropping a piece of stone in it

Now if we place a piece of cork on the water surface at some distance away from the point where the stone strikes the water, we notice that the *cork does not move ahead, but it moves up and down, while the wave moves ahead.* The reason is that the particles of water (or medium) start vibrating up and down at the point where the stone strikes. These particles then transfer their energy to the other neighbouring particles and they themselves come back to their mean positions. This process continues and thus the disturbance moves ahead on the water surface in form of waves as shown in Fig. 8.7. The waves die out as soon as the energy imparted by stone gets dissipated. However, it is possible to obtain a continuously travelling wave if a periodic disturbance is produced at the point of striking the stone on the water surface.

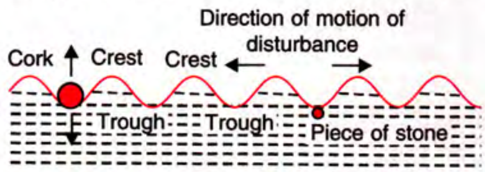

Fig. 8.7 Propagation of disturbance on the surface of water.

The wave in which the particles of medium vibrate about their mean positions, in a direction perpendicular to the direction of propagation of the wave, is called the *transverse wave*. A transverse wave is composed of *crest* and *trough*. The position of maximum upward displacement is called crest, while the position of maximum downward displacement is called trough. The transverse waves can only be produced in solids and on the surface of liquids. They can not be produced inside liquids and in gases.

Characteristics of wave motion : (1) A wave is produced by *the periodic disturbance* at a point in the medium.

(2) Due to propagation of wave in a medium, the particles of medium vibrate about their mean positions (without leaving their positions) and energy is transferred with a constant speed from one place of medium to the other place.

8.4 SOME TERMS RELATED TO WAVE MOTION

(i) Amplitude : *When a wave passes through a medium, the maximum displacement of the particle of medium on either side of its mean position, is called the amplitude of wave.* It is denoted by the letter a. Its S.I. unit is metre (m).

(ii) Time period : *The time taken by a particle of medium to complete its one vibration is called the time period of wave.* It is denoted by the letter T. Its S.I. unit is second (s).

(iii) Frequency : *The number of vibrations made by a particle of medium in one second is called the frequency of wave. It is same as the number of waves passing through a point in one second.* It is denoted by the letter f, n or υ (neu). Its S.I. unit is second^{-1} (symbol s^{-1}) or hertz (symbol Hz).

The frequency f and time period T are related as

$$\boxed{f = \frac{1}{T}} \qquad \text{..... (8.1)*}$$

The frequency of a wave is equal to the frequency of vibration of its source. It is the characterstic of its source which produces the disturbance. It does not depend on the amplitude of vibration or on the nature of medium in which the wave propagates.

(iv) Wavelength : *The distance travelled by the wave in one time period of vibration of particle of the medium, is called its wavelength.* It is denoted by the letter λ (lambda). Its S.I. unit is metre (m). It depends on the medium in which the wave travels.

In a longitudinal wave, the distance between two consecutive compressions or between two consecutive rarefactions is equal to one wavelength, while in a transverse wave, the distance between two consecutive crests or between two consecutive troughs is equal to one wavelength.

(v) Wave velocity : *The distance travelled by a wave in one second is called its wave velocity or wave speed.* It is the speed with which *energy is transferred from one place to the other place by wave motion.* It is not the velocity of an individual particle vibrating about its mean position. It is denoted by the letter V. Its S.I. unit is metre per second (m s^{-1}).

It may be noted that the wave velocity is constant for a given medium. It depends on the elasticity and the density of the medium. It changes when the wave passes from one medium to the other medium.

Displacement-time graph : Fig. 8.8 shows the variation of displacement with time for a particle of the medium *at a given position*, when a wave propagates through the medium. It is called **displacement-time graph**. In Fig. 8.8, the amplitude is represented by the letter a and time period is represented by the letter T. Note that each particle of the medium goes through such motion, not simultaneously, but one after another as the wave moves in the medium.

*** In time T s, number of vibrations = 1**

$\therefore$ In 1 s, number of vibrations = $1/T = f$

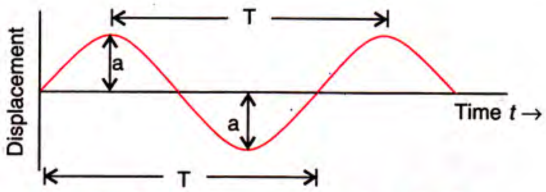

Fig.8.8 Displacement – time graph of a particle of a wave

Displacement-distance graph : Fig. 8.9 shows the displacement-distance graph of a transverse wave *at an instant*. Here amplitude of particles of wave is shown by the letter *a* and wavelength is shown by the letter λ. The curve shows the displaced positions of particles of medium from their mean positions at an instant when wave propagates through the medium. It is also called snap-shot of a wave.

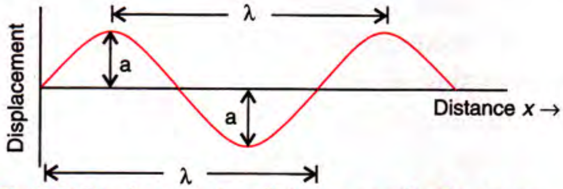

Fig.8.9 Displacement – distance graph of a wave

8.5 RELATIONSHIP BETWEEN THE WAVELENGTH, WAVE VELOCITY AND FREQUENCY

Let velocity of a wave be V, time period T, frequency f and wavelength λ. By the definition of wavelength,

Wavelength λ = Distance travelled by the wave in one time period *i.e.*, in T second
= Wave velocity × Time period
= $V \times T$

or $$\boxed{VT = \lambda} \qquad \text{....(8.2)}$$

But $$T = \frac{1}{f}$$

∴ From eqn. (8.2),

$$V \times \left(\frac{1}{f}\right) = \lambda$$

or $$\boxed{V = f\lambda} \qquad \text{...(8.3)}$$

Therefore,

$$\boxed{\text{Wave velocity} = \text{Frequency} \times \text{Wavelength}}$$

8.6 SPEED OF SOUND IN DIFFERENT MEDIA

It is our common experience while standing at some distance from a blacksmith that when a blacksmith strikes his hammer on an iron piece, the sound produced on striking the hammer is heard a short-while after the hammer is seen striking. Similarly the sound of a cracker is heard only a little later than it has exploded (*i.e.*, when flash is seen). This indicates that the sound does not reach us instantaneously but it travels in a medium with a finite speed and it takes some time to reach us from the place where it is produced.

The speed of sound in a medium depends on the following *two* factors :

(i) the elasticity E of the medium, and
(ii) the density ρ of the medium.

The speed of sound in a medium is given by the relation

$$\boxed{V = \sqrt{\frac{E}{\rho}}} \qquad \text{...(8.4)}$$

where E is the modulus of elasticity (Young's modulus in case of solids or bulk modulus in case of fluids*) and ρ is the density of the medium.

Newton assumed that when sound travels in a gas, the temperature of gas does not change (*i.e.*, the propagation of sound is an *isothermal change*). For isothermal change, modulus of elasticity is equal to the pressure *i.e.*, $E = P$. Thus from eqn. (8.4), speed of sound in a gas is given as

$$\boxed{V = \sqrt{\frac{P}{\rho}}} \qquad \text{...(8.5)}$$

For air at normal temperature and pressure (N.T.P.), $P = 1{\cdot}01 \times 10^5\ \text{N m}^{-2}$, $\rho = 1{\cdot}293\ \text{kg m}^{-3}$, so V comes out to be $279{\cdot}5\ \text{m s}^{-1}$. But experimentally the speed of sound in air is found to be nearly $330\ \text{m s}^{-1}$. Thus speed of sound calculated by using eqn. (8.5) is found to be lower than the experimental value.

Later on, the scientist Laplace applied a correction to the above relation. According to Laplace, 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*. For an adiabatic change, modulus of elasticity $E = \gamma P$ where γ is the ratio of the specific heat at constant pressure to the specific heat at constant volume ($\gamma = C_p / C_v$) and P is the pressure of the gas.

Hence from eqn. (8.4), the speed of sound in a gas is given as

$$\boxed{V = \sqrt{\frac{\gamma P}{\rho}}} \qquad \text{...(8.6)}$$

The value of γ depends on the nature of the medium. For air, γ is 1·4.

* **Fluids include liquids and gases.**

This modified formula (eqn. 8.6) gave the correct value of the speed of sound. At N.T.P. in air, taking $\gamma = 1{\cdot}4$, $P = 1{\cdot}01 \times 10^5$ N m^{-2} and $\rho = 1{\cdot}293$ kg m^{-3}. V comes out to be nearly $330{\cdot}7$ m s^{-1} which agrees with the experimental value.

The speed of sound is different in different media. The speed of sound is more in solids, less in liquids and least in gases (since solids are much more elastic than the liquids and gases). The speed of sound is nearly 5100 m s^{-1} in steel, 1450 m s^{-1} in water and 330 m s^{-1} in air at 0°C.

Table below gives the speed of sound in different media at 0°C.

Speed of sound in some media

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

Examples showing that the speed of sound in steel is more than that in air

(1) If sound is produced at one end of a very long steel bar, two sounds are heard at the other end. One which reaches first, is propagated through steel and the other which is heard later, is through air.

(2) A person living near the railway track often presses his ear against the steel rail to guess whether a train is coming or not. The reason is that the vibrations produced by the moving wheels of train, travel much faster through the steel rail than through air. So sound is heard through track much before it is heard through air. Thus the person by hearing sound through the steel rail gets an indication of coming of train well before its sound is heard..

8.7 FACTORS AFFECTING THE SPEED OF SOUND IN A GAS

The speed of sound in a gas is affected by the change in (i) density, (ii) temperature, (iii) humidity, and (iv) direction of wind.

(i) *Effect of density* : From relation $V = \sqrt{\dfrac{\gamma P}{\rho}}$, it is clear that $V \propto \dfrac{1}{\sqrt{\rho}}$ *i.e.*, the *speed of sound is inversely proportional to the square root of density of the gas.* The density of oxygen is 16 times the density of hydrogen, therefore the speed of sound in hydrogen is four times the speed of sound in oxygen*.

(ii) *Effect of temperature* : *The speed of sound in a gas increases with the increase in temperature of the gas.* The reason is that with the increase in temperature, the density of gas decreases and consequently the speed of sound increases. In fact, the speed of sound is directly proportional to the square root of temperature of the medium *i.e.*, $V \propto \sqrt{T}$ where T is the temperature of the gas on the Kelvin scale.

The speed of sound in air increases by about $0{\cdot}61$ m s^{-1} (or 61 cm per second) for each degree celsius rise in temperature (provided that the rise in temperature is not very large). *i.e.*,

$$\boxed{V_t = V_0 + 0{\cdot}61\, t} \qquad \ldots(8.7)$$

Example : The speed of sound in the dry still air at 0°C is 330 m s^{-1}. At 25°C, the speed of sound in this air will be

$$V_{25} = V_0 + 0{\cdot}61\, t = 330 + 0{\cdot}61 \times 25 = 345{\cdot}25 \text{ m s}^{-1}.$$

(iii) *Effect of humidity* : *The speed of sound in air increases with the increase in humidity in air.* The density of water vapour is about $\frac{5}{8}$th times the density of dry air at ordinary temperature, therefore the increase of moisture in air tends to decrease the density of air. Hence the speed of sound in the humid air is greater than the speed of sound in dry air. In other words, *the sound travels faster in humid air than in dry air.*

(iv) *Effect of direction of wind* : *The speed of sound increases or decreases according to the direction of travel of wind.* If wind is blowing in the direction of propagation of sound, the speed of sound increases, while if it is blowing

* $\dfrac{\text{Velocity of sound in hydrogen}}{\text{Velocity of sound in oxygen}} = \sqrt{\dfrac{\text{Density of oxygen}}{\text{Density of hydrogen}}}$

or $\dfrac{V_{H_2}}{V_{O_2}} = \sqrt{\dfrac{16}{1}} = 4$

in a direction opposite to that of sound, the speed of sound decreases.

If V is the speed of sound in still air and W is the speed of wind, the speed of sound becomes $V + W$ when wind blows in the direction of travel of sound and the speed of sound becomes $V - W$ when wind blows in the direction opposite to the direction of travel of sound.

Example : The sound of a distant music is quickly and loudly heard if it is coming with the wind. On the other hand, it is difficult to hear if the wind blows in opposite direction.

8.8 FACTORS NOT AFFECTING THE SPEED OF SOUND IN A GAS

The speed of sound in a gas is not affected by the change in (i) pressure, (ii) amplitude of wave, and (iii) wavelength or frequency of wave.

(i) *Effect of pressure* : *The speed of sound in a gas is independent of pressure.* In the formula $V = \sqrt{\frac{\gamma P}{\rho}}$, the ratio $\frac{P}{\rho}$ remains unchanged with the change in pressure. When pressure increases, volume decreases, but mass remains unchanged, so density increases, such that the ratio P/ρ remains constant. For example, if pressure P of a gas is doubled, volume becomes half, so density ρ gets doubled (mass is constant). As a result, the ratio P/ρ does not change. Thus, the speed of sound in a gas is independent of pressure.

(ii) *Effect of amplitude of wave* : *The speed of sound does not depend on the amplitude of sound wave.*

(iii) *Effect of wavelength (or frequency) of wave* : *The speed of sound does not depend on the wavelength (or frequency) of sound wave.*

8.9 COMPARISON OF SPEED OF SOUND WITH SPEED OF LIGHT

There are the following *four* points of distinction between the propagation of sound and light waves.

(1) The light waves can travel in vacuum, but the sound waves can not travel in vacuum.

(2) Ths speed of light waves is 3×10^8 m s^{-1} in air which is about a million times greater than the speed of sound waves in air (*i.e.*, 330 m s^{-1} at 0°C).

(3) The speed of light waves decreases in an optically denser medium (speed of light in water is $2{\cdot}25 \times 10^8$ m s^{-1}, in glass is 2×10^8 m s^{-1}), while the speed of sound waves is more in solids, less in liquids and still less in gases (speed of sound in steel is nearly 5100 m s^{-1}, in water is nearly 1450 m s^{-1} and in air is nearly 330 m s^{-1}).

(4) The light waves are transverse electromagnetic waves while the sound waves in air are the longitudinal mechanical waves.

Consequences of the large difference in the speed of sound and that of light

(1) **Thunder and lightning :** *In thunder, light is seen much earlier than the sound of thunder is heard, although they are produced simultaneously.* The reason is that light takes almost negligible time in comparison to sound in reaching us from the place of thunder because speed of light is much more (= 3×10^8 m s^{-1}) than the speed of sound (= 330 m s^{-1}).

(2) When the starter in an athletic event fires a gun, a spectator sitting at a distance hears the sound of fire a little later while the smoke is instantaneously seen. The reason is that $V_{\text{light}} >> V_{\text{sound}}$.

(3) The spectators watching the cricket game hear the sound of stroke a little later than the batsman is seen actually making it. The reason is that $V_{\text{light}} >> V_{\text{sound}}$.

8.10 EXPERIMENTAL DETERMINATION OF SPEED OF SOUND IN AIR

The fact that light travels in air about a million times faster than sound, can be used to determine the speed of sound in air.

Experiment : Choose two places A and B at high altitudes facing each other, at a known distance d apart (say, about 1 km), in still air. The distance d is noted. At each place, there is an observer with a gun and a stop watch. First the observer at place A fires the gun, while the observer at place B starts his stop watch immidiately on seeing the flash of fire at A and stops it when he hears the sound of fire. The observer at B by his watch thus finds the time interval t_1 taken by the sound to travel from A to B.

Now the observer at place B fires the gun. The observer at place A starts his stop watch when he sees the flash of fire at B and stops it when he hears the sound of fire. Thus the observer A by his watch finds the time interval t_2 taken by sound to travel from B to A.

The average of the two time intervals is $t = \frac{t_1 + t_2}{2}$. This is the time taken by sound to travel the distance d between the places A and B. The speed of sound is then calculated by using the formula

$$\boxed{V = \frac{\text{Distance}}{\text{Time}} = \frac{d}{t} \text{ m s}^{-1}} \quad ...(8.8)$$

Note : In this experiment, we measure the time interval two times, first for sound to travel from place A to place B and then from place B to place A so as to eliminate the error arising due to flow of wind. However, the speed of sound so determined is not still very accurate because of the personal error of the two observers and the variation in temperature and humidity of air in between the places A and B.

EXAMPLES

1. A bat can hear sound of frequencies up to 120 kHz. Determine the minimum wavelength of sound which it can hear. Take speed of sound in air to be 344 m s^{-1}.

Given, $f = 120$ kHz $= 120 \times 10^3$ Hz, $V = 344$ m s^{-1}.

From relation $V = f\lambda$,

$$\text{Wavelength } \lambda = \frac{V}{f} = \frac{344}{120 \times 10^3}$$

$$= \mathbf{2{\cdot}87 \times 10^{-3}\ m\ (or\ 2{\cdot}87\ mm)}$$

i.e., the bat can hear sound of minimum wavelength 2·87 mm.

2. Ocean waves of time period 10 s have wave velocity 15 m s^{-1}. Find : (i) the wavelength of these waves, (ii) the horizontal distance between a wave crest and its adjoining wave trough.

Given, $T = 10$ s, $V = 15$ m s^{-1}

(i) From relation $V = \frac{\lambda}{T}$,

Wavelength of wave $\lambda = V \times T$

or $\lambda = 15 \times 10 = \mathbf{150\ m}$

(ii) The distance between a wave crest and its adjoining wave trough

$$= \frac{\lambda}{2} = \frac{1}{2} \times 150 \text{ m} = \mathbf{75\ m.}$$

3. A wave pulse of frequency 200 Hz, on a string moves a distance 8 m in 0·05 s. Calculate : (a) the velocity of pulse, and (b) the wavelength of wave on string.

Given, $d = 8$ m, $t = 0{\cdot}05$ s, $f = 200$ Hz

(a) The velocity of pulse $V = \frac{\text{Distance moved } d}{\text{Time taken } t}$,

or $V = \frac{8 \text{ m}}{0{\cdot}05 \text{ s}} = \mathbf{160\ m\ s^{-1}}$

(b) Wave velocity on string V

= velocity of wave pulse on it = 160 m s^{-1}

From relation $V = f\lambda$,

$$\text{Wavelength of wave } \lambda = \frac{V}{f} = \frac{160}{200} = \mathbf{0{\cdot}8\ m.}$$

4. Compare approximately the speed of sound in air and steel.

The speed of sound in air is nearly 330 m s^{-1} and in steel is nearly 5100 m s^{-1}. Thus, the ratio of speed of sound in air and steel is

$$\frac{\text{Speed of sound in air}}{\text{Speed of sound in steel}} = \frac{330 \text{ m s}^{-1}}{5100 \text{ m s}^{-1}} = \frac{\mathbf{1}}{\mathbf{15}} \textbf{ nearly.}$$

5. The smoke from the gun barrel is seen 2 second before the explosion is heard. If the speed of sound in air is 340 m s^{-1}, calculate the distance of observer from gun. State the approximation used.

Given : Speed of sound = 340 m s^{-1}, time = 2 s

$$\text{Speed} = \frac{\text{distance travelled}}{\text{time taken}}$$

$$\therefore \text{ Distance} = \text{speed} \times \text{time}$$

$$= 340 \times 2 = \mathbf{680\ m.}$$

Approximation :

The speed of light ($= 3 \times 10^8$ m s^{-1}) is much larger in comparison to the speed of sound ($= 340$ m s^{-1}), therefore we can assume that the light takes negligible time and sound takes 2 s to reach the observer.

6. The speed of sound in air is 330 m s^{-1} and in water is 1650 m s^{-1}. It takes 2 s for sound to

reach a certain distance from the source placed in air. (a) Find the distance. (b) How much time will it take for sound to reach the same distance when the source is in water ?

(a) Given, in air $V = 330 \text{ m s}^{-1}$, $t = 2$ s

From relation $V = \frac{d}{t}$

Distance travelled by sound in air,

$$d = V \times t = 330 \times 2 = \mathbf{660 \text{ m}}$$

(b) In water, $V = 1650 \text{ m s}^{-1}$, $d = 660$ m

$\therefore$ Time taken by sound to travel the distance d in water will be

$$t = \frac{d}{V} = \frac{660 \text{ m}}{1650 \text{ m s}^{-1}} = \mathbf{0{\cdot}4 \text{ s.}}$$

EXERCISE 8 (A)

1. What causes sound ?
   Ans. Sound is caused due to vibrations of a body.
2. What is sound ? How is it produced ?
3. Complete the following sentence :
   Sound is produced by a .... body.
   Ans. Vibrating
4. Describe a simple experiment which demonstrates that the sound produced by a tuning fork is due to vibrations of its arms.
5. Describe in brief, with the aid of a labelled diagram, an experiment to demonstrate that a material medium is necessary for the propagation of sound.
6. There is no atmosphere on moon. Can you hear each other on the moon's surface ? **Ans.** No.
7. State *three* characteristics of the medium required for propagation of sound ?
8. Explain with an example, the propagation of sound in a medium.
9. Choose the correct word/words to complete the following sentence :
   When sound travels in a medium ...... (the particles of the medium, the source, the disturbance, the medium) travels in form of a wave. **Ans.** the disturbance
10. Name the *two* kinds of waves in form of which sound travels in a medium.
11. What is a longitudinal wave ? In which medium: solid, liquid or gas, can it be produced ?
12. What is a transverse wave ? In which medium: solid, liquid or gas, can it be produced ?
13. Explain meaning of the terms compression and rarefaction in relation to a longitudnal wave.
14. Explain the terms crest and trough in relation to a transverse wave.
15. Describe an experiment to show that in wave motion, only energy is transferred, but particles of medium do not leave their position.
16. Define the term amplitude of a wave. Write its S.I. unit.
17. What do you mean by the term frequency of a wave ? State its S.I. unit.
18. How is the frequency of a wave related to its time period ? **Ans.** Frequency = 1/time period
19. Define the term wave velocity. Write its S.I. unit.
20. Draw displacement-time graph of a wave and show on it the amplitude and time period of wave.
21. Draw a displacement-distance graph of a wave and mark on it, the amplitude of wave by the letter a and wavelength of wave by the letter λ.
22. How are the wave velocity V, frequency f and wavelength λ of a wave related ? Derive the relationship.
23. State *two* properties of medium on which the speed of sound in it depends.
    Ans. (i) Elasticity (ii) density.
24. Arrange the speed of sound in gases V_g, solids V_s and liquids V_l in an ascending order.
    Ans. $V_g < V_l < V_s$
25. State the speed of (i) light and (ii) sound in air ?
    Ans. (i) Speed of light = $3 \times 10^8 \text{ m s}^{-1}$
    (ii) Speed of sound = 330 m s^{-1}.
26. Compare approximately the speed of sound in air, water and steel. **Ans.** 1 : 4 : 15
27. Answer the following :
    (i) Can sound travel in vacuum ?
    (ii) How does the speed of sound differ in different media ?
    Ans. (i) No (ii) Speed of sound is maximum in solids, less in liquids and least in gases.
28. Flash of lightning reaches us earlier than the sound of thunder. Explain the reason.
    Ans. Light travels much faster than sound
29. If you place your ear close to an iron railing which is tapped some distance away, you hear the sound twice. Explain why ?
    Ans. Sound travels in iron faster than in air, so first the sound through iron rail is heard and then the sound through air is heard.

30. The sound of an explosion on the surface of a lake is heard by a boat man 100 m away and by a diver 100 m below the point of explosion.
   (i) Who would hear the sound first : boat man or diver ?
   (ii) Give a reason for your answer in part (i).
   (iii) If sound takes time t to reach the boat man, how much time approximately does it take to reach the diver ?
   Ans. (i) diver (ii) sound travels faster in water than in air (iii) $0{\cdot}25\ t$.

31. How do the following factors affect, if at all, the speed of sound in air :
   (i) frequency of sound, (ii) temperature of air,
   (iii) pressure of air, (iv) moisture in air ?
   Ans. (i) No effect (ii) Speed of sound increases with the increase in temperature (iii) No effect (iv) Speed of sound increases with the increase of moisture in air.

32. How does the speed of sound change with change in (i) amplitude and (ii) wavelength, of sound wave ? **Ans.** (i) No change (ii) No change.

33. In which medium the speed of sound is more : humid air or dry air ? Give a reason to your answer.
   Ans. In humid air. **Reason :** Density of air decreases with the increase of moisture and $V \propto \frac{1}{\sqrt{\rho}}$.

34. How does the speed of sound in air vary with temperature ?
   Ans. The speed of sound increases by $0{\cdot}61\ m\ s^{-1}$ for each 1°C rise in temperature.

35. Describe a simple experiment to determine the speed of sound in air. What approximation is made in the method described by you ?

36. Complete the following sentences :
   (a) Sound can not travel through ....,but it requires a ....
   (b) When sound travels in a medium, the particles of medium .... but the disturbance ....
   (c) A longitudinal wave is composed of compression and ....
   (d) A transverse wave is composed of crest and ....
   (e) Wave velocity = ... × wavelength.
   Ans. (a) vacuum, medium (b) do not move, moves (c) rarefaction (d) trough (e) frequency.

Multiple choice type :

1. The correct statement is :
   (a) Sound and light both require medium for propagation
   (b) Sound can travel in vacuum, but light can not
   (c) Sound needs medium, but light does not need medium for its propogation
   (d) Sound and light both can travel in vacuum.
   Ans. (c) Sound needs medium, but light does not need medium for its propogation.

2. Sound in air propagates in form of :
   (a) longitudinal wave
   (b) transverse wave
   (c) both longitudinal and transverse waves
   (d) neither longitudinal nor transverse wave.
   Ans. (a) longitudinal wave

3. The speed of sound in air at 0°C is nearly :
   (a) $1450\ m\ s^{-1}$ (b) $450\ m\ s^{-1}$
   (c) $5100\ m\ s^{-1}$ (d) $330\ m\ s^{-1}$
   Ans. (d) $330\ m\ s^{-1}$

4. The speed of light in air is :
   (a) $3 \times 10^8\ m\ s^{-1}$ (b) $330\ m\ s^{-1}$
   (c) $5100\ m\ s^{-1}$ (d) $3 \times 10^{10}\ m\ s^{-1}$
   Ans. (a) $3 \times 10^8\ m\ s^{-1}$

Numericals :

1. The heart of a man beats 75 times a minute. What is its (a) frequency and (b) time period ?
   Ans. (a) $1{\cdot}25\ s^{-1}$, (b) $0{\cdot}8$ s

2. The time period of a simple pendulum is 2 s. Find its frequency. **Ans.** 0·5 Hz

3. The separation between two consecutive crests in a transverse wave is 100 m. If wave velocity is $20\ m\ s^{-1}$, find the frequency of wave.
   Ans. 0·2 Hz

4. A longitudinal wave travels at a speed of $0{\cdot}3\ m\ s^{-1}$ and the frequency of wave is 20 Hz. Find the separation between the two consecutive compressions.
   Ans. $1{\cdot}5 \times 10^{-2}$ m (or 1·5 cm)

5. A source of wave produces 40 crests and 40 troughs in 0·4 s. What is the frequency of the wave ? **Ans.** 100 Hz

6. An observer A fires a gun and antoher observer B at a distance 1650 m away from A hears its sound. If the speed of sound is $330\ m\ s^{-1}$, find the time when B will hear the sound after firing by A.
   Ans. 5 s

7. The time interval between a lightning flash and the first sound of thunder is 5 s. If the speed of sound in air is $330\ m\ s^{-1}$, find the distance of flash from the observer. **Ans.** 1650 m

8. A boy fires a gun and another boy at a distance hears the sound of fire 2·5 s after seeing the flash. If speed of sound in air is 340 m s^{-1}, find distance between the boys. **Ans.** 850 m

9. An observer sitting in line of two tanks, watches the flashes of two tanks firing at each other at the same time, but he hears the sounds of two shots 2 s and 3·5 s after seeing the flashes. If distance between the two tanks is 510 m, find the speed of sound. **Ans.** 340 m s^{-1}

10. How long will sound take to travel in (a) an iron rail and (b) air, both 3·3 km in length ? Take speed of sound in air to be 330 m s^{-1} and in iron to be 5280 m s^{-1}.
Ans. (a) 0·625 s, (b) 10 s

11. Assuming the speed of sound in air equal to 340 m s^{-1} and in water equal to 1360 m s^{-1}, find the time taken to travel a distance 1700 m by sound in (i) air and (ii) water.
Ans. (i) 5 s (ii) 1·25 s

(B) INFRASONIC, SONIC AND ULTRASONIC FREQUENCIES

8.11 INFRASONIC, SONIC AND ULTRASONIC FREQUENCES

The human ear is able to hear sound in a frequency range of about 20 Hz to 20,000 Hz (or 20 kHz) *i.e., the audible range of frequency is* 20 Hz *to* 20 kHz. We can not hear sounds of frequencies less than 20 Hz or more than 20 kHz. Actually the audible range of frequency varies from person to person and it also varies with the age of the person. The audible range of frequency of a person decreases as he gets older since his ears lose the hearing sensitivity to the high frequencies. Children can hear sounds of some what higher frequencies say up to 30 kHz, while an old person can hear sound only up to frequencies 12 kHz. Hence the audible range of frequency for an average person is considered to be from 20 Hz to 20 kHz. Even in the audible range, the human ear is not equally sensitive to all frequencies. *The human ear is most sensitive in the range* 2000 Hz *to* 3000 Hz, *where it can hear even a very feeble sound.*

The sound of frequencies in the range 20 Hz to 20 kHz is called the *sonic* or *audible sound*; the sound of frequency less than 20 Hz is known as *infrasonic sound* (or simply *infrasonic*), while the sound of frequency greater than 20 kHz is known as *ultrasound* (or *ultrasonic*).

Animals can produce and hear sounds of frequencies below 20 Hz as well as above 20 kHz. Different animals have different ranges of audible frequencies. Elephants and whales can produce infrasonic sounds of frequencies less than 20 Hz. Some fishes can hear sounds of frequencies in the range of 1 Hz to 25 Hz. Some animals can produce ultrasonic sounds and communicate in them. A dog can hear sounds of frequencies up to nearly 50 kHz, a bat up to about 100 kHz, while Dolphins can hear sounds of even higher frequencies up to 150 kHz.

Frequency ranges for hearing and speaking by human and animals

Object	Frequency range of hearing and speaking
1. Bat	10 Hz – 100 kHz
2. Cat	80 Hz – 60 kHz
3. Dog	20 Hz – 50 kHz
4. Dolphins	200 Hz – 150 kHz
5. Grasshopper	90 Hz – 1·0 kHz
6. Human	20 Hz – 20 kHz

8.12 ULTRASOUND AND ITS APPLICATIONS

We have read that the sound of frequencies above 20,000 Hz, is called the ultrasound. Ultrasound can travel quite freely in solids and liquids, but in gases its intensity falls. In a medium, it travels with the same speed with which the audible sound travels. In air, the speed of ultrasound is 330 m s^{-1}.

Properties of ultrasound

Ultrasound has all properties similar to that of ordinary sound, but because of high frequencies, ultrasound has the following *two* additional properties which the audible sound does not possess.

(i) The energy carried by ultrasound is very high.

(ii) The ultrasound can travel along a well defined straight path. It does not bend appreciably at the edges of an obstacle because of its small wavelength (*i.e.*, it has high directivity).

The above two properties of ultrasound makes it very useful to us for many purposes.

Applications of ultrasound

Few applications of ultrasound are given below.

(1) Bats avoid obstacles in their path by producing and hearing the ultrasound. They produce ultrasound which returns after striking an obstacle in their way. By hearing the reflected sound, they can judge the direction where the obstacle is in their way and from the time interval (when they produce ultrasound and then receive them back), they can judge the distance of the obstacle.

(2) Ultrasound is used for drilling holes or making cuts of desired shape in materials like glass.

(3) For cleaning the minute objects such as the parts of watches and electronic components, ultrasound is used. The objects are placed in a cleaning solution and the ultrasonic waves are sent into the solution. This causes high frequency vibrations in the solution and makes the cleaning easier.

(4) For detection of defects in metals, ultrasound is used. Ultrasound will pass through the object if there is no defect (such as crack or cavity), in the object. But if there is some defect, a part of ultrasound will get reflected back.

(5) For imaging the human organs, ultrasound is widely used. *Ultrasonography* is used to obtain the images of patient's organs (such as liver, gall bladder, uterus *etc.*). It helps to detect stones, tumors *etc.* in them. *Echo cardiography* is used to obtain the image of the heart.

(6) Ultrasound is used in surgery to remove cataract and in kidneys to break the small stones into fine grains.

(7) In SONAR (abbreviated form of sonographic navigation and ranging) to detect and find the distance of objects under water, ultrasound is used.

Difference between ultrasonic and supersonic

The word ultrasonic is used for ultrasound (*i.e.*, sound of frequency above 20 kHz), while supersonic is used for object which travels with a speed greater than the speed of sound in air (*i.e.*, 330 m s^{-1}) *e.g.* concord jet planes and fighter planes.

EXERCISE 8 (B)

1. What do you mean by the audible range of frequency ?
   Ans. The range of frequency within which the sound can be heard by a human being is called the audible range of frequency.
2. What is the audible range of frequency for human ? **Ans.** 20 Hz to 20 kHz
3. For which range of frequencies, human ears are most sensitive ? **Ans.** 2000 Hz to 3000 Hz
4. Which has the higher frequency – ultrasonic sound or infrasonic sound ? **Ans.** Ultrasonic sound.
5. Complete the following sentences :
   (a) An average person can hear sound of frequencies in the range .... to ....
   (b) Ultrasound is of frequency ....
   (c) Infrasonic sound is of frequency ....
   (d) Bats can produce and hear .... sound.
   (e) Elephants produce .... sound.

Ans. (a) 20 Hz, 20 kHz (b) above 20 kHz (c) below 20 Hz (d) ultrasonic (e) infrasonic.

6. Name the sounds of the frequencies given below:
   (a) 10 Hz (b) 100 Hz (c) 1000 Hz (d) 40 kHz
   Ans. (a) infrasonic (b) audible (c) audible (d) ultrasonic.
7. Can you hear the sound produced due to vibrations of a seconds' pendulum ? Give reason.
   Ans. No. **Reason :** The frequency of sound produced due to vibrations of seconds' pendulum is 0·5 Hz which is infrasonic sound.
8. What is ultrasound ?
   Ans. Sound of frequency above 20 kHz.
9. State the approximate speed of ultrasound in air.
   Ans. 330 m s^{-1}
10. State *two* properties of ultrasound that make it useful to us.
    Ans. (i) High energy content, (ii) high directivity.
11. Explain how do bats locate the obstacles and prey in their way.
12. State *two* applications of ultrasound.

Multiple choice type :

1. A man can hear the sound of frequency :
   (a) 1 Hz (b) 1000 Hz
   (c) 200 kHz (d) 5 MHz **Ans.** (b) 1000 Hz
2. The properties of ultrasound that make it useful, are :
   (a) high power and high speed
   (b) high power and good directivity
   (c) high frequency and high speed
   (d) high frequency and bending around the objects.
   Ans. (b) high power and good directivity
3. Sonar makes use of :
   (a) infrasonic sound (b) ultrasound
   (c) ordinary sound (d) light.
   Ans. (b) ultrasound