1

INTRODUCTION TO SOUND

1.1 INTRODUCTION

In our daily life, we have conversation amongst ourselves. We hear the chirping of the birds or horn of the vehicles or mewing of the cat. They are of so many types, tones, and levels of sound. In fact, we can recognize a person by just his or her voice. We use sound waves (which are acoustic/ mechanical waves) in talking, while electromagnetic radio waves in sending voice through the radio set or telephone. In this lesson, you are going to study about the details of sound. Let us learn about the basics of sound, elements of sound, nature, characteristics of sound, principles of sound- propagation, refraction, reflection, transmission and absorption of sound.

1.2 OBJECTIVES

After reading this lesson, the learner will be able to :

- define sound
- discuss the basics, elements, nature and characteristics of sound
- recognize the principles, propagation, refraction and transmission of sound
- illustrate the absorption of sound

1.3 INTRODUCTION TO SOUND

Sound is a result of vibration. The vibration is produced by a source, travels in the medium, as a wave and is ultimately sensed through the ear - drum. Let's try to discuss it better by an activity. A simple activity can be done to show the association between vibration and sound.

Take a aluminum wire about 30 cm (in length) or simply a metallic hanger, such as of aluminum and bend it so as to shape it like a bow. Take a rubber band or an elastic string of sufficient length. You may also use small twig, tie a thread or elastic string such as rubber band to both the ends of bow, such that string remains under tension. Ask your colleague to record that :

(i) If you pluck the string, you can hear some sound. You may have to adjust the curve of the bow to be able to hear the sound. You'd notice that the sound vanishes if you hold the string after plucking. If you look carefully, you can realize that the sound comes only as long as the string vibrates.

(ii) You can check the vibrations. Take a small paper strip (about a cm in length and 2 to 3 mm in breadth), bend it in the middle to form a V and place it over the string. You may try the same with string instruments like guitar, sitar, and ektara or even use powder on percussion instruments like tabla, drum or dhol.

If you leave a little powder or dust on the tabla, and cause the membrane to vibrate, you may be able to 'see' the vibrations. A gentle touch with finger tips will also tell you that vibrations are associated with sound in all these cases. If you strike a steel tumbler with a spoon, hear the sound and then hold the tumbler with firm hand, the vibrations will cease and so will the sound.

Discuss the observations with your friends. Can you now conclude that the sound has an association with vibrations? These vibrations are transmitted in a medium mechanically and that is how sound travels. It travels like a wave. A medium is a must for mechanical waves like sound to travel. We speak and expect to be heard. But it will surprise you to learn that without some aid, we can't converse on moon, as we do here. This is because there is no air on moon (actually there is some but very little) and sound needs a medium to travel. In contrast, we can receive electromagnetic waves from distant stars and artificial satellites in space as electromagnetic waves need no medium to travel. A wave involves a periodic motion, movement that repeats itself. It also transports energy. Let us understand waves better.

What happens if you throw a stone in a pool of water? You will see a disturbance of a circular shape moving, from the point of fall of the stone, outwards. We also observe that the disturbance is made up of a raised ring in water, which seems to travel outward. Soon there is another similar circular feature originating at the same centre and moving outward. This goes on for quite some time. Even though there appears to be a movement of material, actually it is only the position of the disturbance that is changing. This is a wave and is made up of the raised part (crest) and low part (trough). So crest and trough are essential components of a wave. A wave transfers energy from one point to the other without the medium particles moving from one point to the other. Thus wave is clearly different from particle. Sound is a vibration that propagates, as a mechanical wave of pressure and displacement, through some medium. Sometimes sound refers to only those vibrations with frequencies that are within the range of hearing for human or for a particular animal.

Understanding the nature of sound requires observations. We observe a flute playercontinuously shifting fingers, over holes to produce different notes, while playing a tune. Similarly, a sitar player also keeps pressing the string at different points touching different frets (*parda* in Hindi). When you strike an empty and a water filled glass with a spoon and different notes are produced. The science of sound helps us in understanding the reasons behind such things. Besides, the understanding of sound has enabled scientists to devise gadgets which are very useful. These include hearing aids, sound instruments like speakers, sound recording and sound amplifying devices etc. We shall also learn about various technological tools that have been developed to improve communication. By improvement we mean, we can communicate to more people, at greater distances, and with more clarity. Therefore, in a nutshell it can be said that all sounds are vibrations travelling through the air as sound waves. Sound waves are caused by the vibrations of objects and radiate outward from their source in all directions. A vibrating object *compresses* the surrounding air molecules (squeezing them closer together) and then *rarefies* them (pulling them farther apart). Although the fluctuations in air pressure travel outward from the object, the air molecules themselves stay in the same average position. As sound travels, it reflects off objects, in its path, creating further disturbances in the surrounding air. When these changes in air pressure vibrate your eardrum, nerve signals are sent to your brain and are interpreted as sound.

1.4 NATURE OF SOUND

Sound is a longitudinal, mechanical wave. Sound can travel through any medium, but it cannot travel through a vacuum. There is no sound in outer space. Sound is a variation in pressure. A region of increased pressure on a sound wave is called compression (or condensation). A region of decreased pressure on a sound wave is called rarefaction (or dilation).

Representing a wave

We need to describe a friend by name, height, colour, gender for identifying. Similarly, we have to specify some qualities that we shall call parameters, for wave description. A wave is represented in terms of its wavelength, amplitude, frequency and time period.

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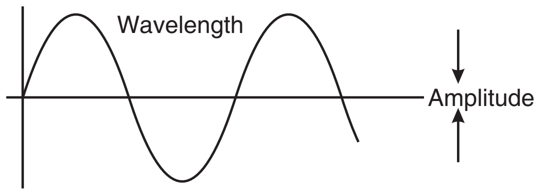

Fig. 1.1: A representation of wave

Consider a simple pendulum . It has a bob, a thread and a hinge to fasten it.

Pick up the bob to some height by pulling it tangentially and drop it . You can observe the bob falls down and rises up to the same height in the opposite direction and then reverses and traces the same path. This phenomenon repeats for long. This phenomenon is called as periodic wave , since a bob traces a point after a regular period of time . If we trace the distance for the lowest height of the bob with time, a periodic wave form will be drawn as follows :

1.4.1 Amplitude (Am)

It is basically a measurement of the vertical distance of the trough(C) or crest(A) of a wave from the average(B) as illustrated in diagram above.

1.4.2 Wavelength (λ)

The distance between adjacent troughs or adjacent crests, measured in unit of length such as meters and expressed by symbol λ (lambda). For longitudinal wave, it will be distance between two successive rarefactions or compressions.

1.4.3 Time Period (T)

This defines the time it takes for one complete wave to pass a given point, measured in seconds (s) (WL = T).

1.4.4 Frequency (n)

The number of complete waves that pass a point in one second , measured in Hertz (Hz). In simple words , the number of times the bob reaches appoint in (say A) in one second determines its frequency or repetitivity .

1.4.5 Speed or velocity (v)

The speed of the wave is proportional to the magnitude of the frequency . Wave speed is defined as the distance travelled by a wave disturbance in one second and is measured in meters/second ms^{-1} or m/s. Speed is scalar quantity while velocity is a vector quantity.

Not all of these properties are independent; one can relate some. Period is inversely related to the frequency. This means if the frequency is high, the period will be low. This is understandable because frequency is number of times a wave completes a set of up and down movements (or a set of crests and troughs) in 1 second. If these occur more frequently, it has to be done in very short time. Mathematically one may say period

$$T = 1/n$$

Where 'n' is frequency. We just said that wavelength is equal to the distance between two successive crusts or troughs. In one second this distance is covered a number of times given by frequency.

So, $\quad \text{Velocity} = \text{frequency} \times \text{wavelength}$

or $\quad V = n \times \lambda$

The waves that produce a sense of sound for living beings are called sound waves or audible waves. Only those waves that have frequencies lying in the range of 16 Hz to 20,000 Hz are audible to human beings. However, this range is an average and will slightly vary from individual to individual. Sound waves with frequencies below 16 Hz are called infrasonic waves and those above 20 kHz are ultrasonic waves. Animals like bats are able to produce and sense waves beyond the range of human audibility and use it for 'seeing' in the dark.

INTEXT QUESTIONS 1.1

1. Which sound wave will have its crests farther apart from each other - a wave with frequency 100 Hz or a wave with frequency 500 Hz?
2. If the velocity of sound is 330 meters per second (ms^{-1}), what will be wavelength if the frequency is 1000 Hertz?
3. What is the approximate audible range of frequency for humans?

1.5 CHARACTERISTICS OF SOUND

A sound can be characterized by the following three quantities pitch , quality and loudness which are explained below:

Pitch is the frequency of a sound as perceived by human ear. A high frequency gives rise to a high pitch note and a low frequency produces a low pitch note. Fig. 1.2 shows the frequencies of some common sounds.

A pure tone is the sound of only one frequency, such as that given by a tuning fork or electronic signal generator. Generally the pure tone part of sound is called fundamental frequency (fo)

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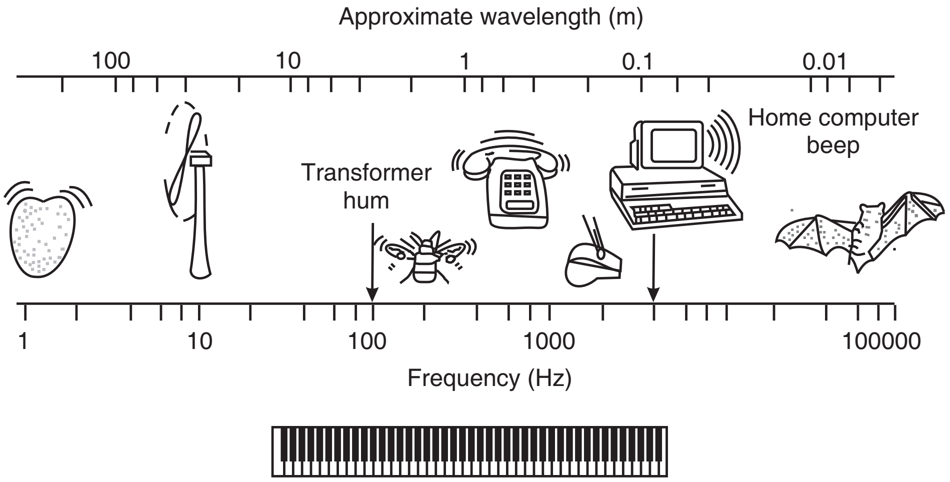

Fig. 1.2: Frequency and Wavelength of Everyday Sound

The fundamental note has the greatest amplitude and is heard predominantly because it has a larger intensity. The other frequencies such as 2fo, 3fo, 4fo, ... are called ***overtones*** or ***harmonics*** and they determine the ***quality*** of the sound.

Loudness is a physiological sensation. It depends mainly on sound pressure but also on the spectrum of the harmonics and the physical duration.

1.6 PRINCIPLES OF SOUND

1. Sound is produced by a vibrating body and travels in the form of a wave.
2. Sound wave travels through materials by vibrating the particles that makes up the materials.
3. The pitch of the sound is determined by the frequency of the wave and loudness by its amplitude.

1.7 PROPAGATION

Sound is a sequence of waves of pressure which propagates through compressible media such as air or water. (Sound can propagate through solids as well, but there are additional modes of propagation). During their propagation, waves can be reflected, refracted, or attenuated by the medium.

All media have three properties which affect the behaviour of sound propagation in them:

1. A relationship between density and pressure. This relationship, affected by temperature, determines the speed of sound within the medium.

2. The motion of the medium itself, e.g., wind. Independent of the motion of sound through the medium, if the medium is moving, the sound is further transported.

3. The viscosity of the medium. This determines the rate at which sound is attenuated. For many media, such as air or water, attenuation due to viscosity is negligible.

Sound waves travel in fluids and solids as longitudinal waves. A longitudinal wave is a wave in which vibration or the displacement takes place in the direction of the propagation of the wave. Sound moves due to difference in pressure. If a sound is produced in air, it compresses the adjacent molecules. Due to the compression, the air pressure increases. This causes the compressed molecules to move in the direction of the pressure that is the direction of the wave. But displacement of the molecules causes fall in pressure in the place they left. If the wave is continuing then another rush of molecules comes in, fills the empty or rarified space. This process is repeated and the disturbance propagates. Thus a chain of compressions and rarefactions is generated due to sound. They travel and transport energy. If there is no medium, then produced sound will not be able to push any medium-molecules and sound will not move. That is the reason why we can't hear on moon; there is no air in moon's atmosphere and sound can't travel.

Table 1.1: Velocity of sound in different materials

Medium	Velocity
Steel	5200 m/s
Water	1520 m/s
Air	330 m/s
Glass	4540 m/s
Silver	3650 m/s

Such difference in the velocities of light and sound means if there is an event in the sky, which produces light and sound both, we shall see the light almost instantly but it will be a while before we hear it. When there is a lightening in the sky, we see the light before we hear the sound. Mechanical wave can be either transverse or longitudinal while the electromagnetic wave is only transverse. The transverse wave is one in which the motion of wave and of the particles are perpendicular to each other. In a longitudinal wave, the motions are in the same direction. The sound wave can be of two types- transverse and longitudinal.

We can try to visualize transverse wave by tying one end of a rope to a hook or peg in a vertical wall (or to a door-handle) and holding the other end such that the rope remains loose. We can demonstrate a transverse wave travelling along the rope if we quickly give up- and down- jerk (or even in horizontal plane) to the rope at our end. We see the wave travelling between our hand and the peg while the points on the rope move perpendicular to the rope and wave. This is a transverse wave, as the particles of the medium move perpendicular to the direction of wave movement. In the example of wave when we throw a stone in stationary water in a pond, it is more complex but here we confine to what happens on the surface. We see that on water surface the wave moves from the centre to the shore. If we see a duck or a small paper boat there, it oscillates up and down with water that is goes up temporarily after which they come back to their mean positions without shifting the position horizontally. That makes it a transverse wave.

In a longitudinal wave, the displacement of the particles and propagation of the wave are in the same direction. For instance, if we blow a horn, speak, or quickly move an object in air we are pushing the air molecules. These molecules, in turn, push the adjacent molecules which impart their energy to the next ones. After losing energy in the interaction, the molecule is back to its original (mean) position. This results in formation of compressions and rarefactions. So it's the compression (or rarefaction) which is travelling and not the molecules. Just like the distance between two successive crests or troughs is a measure of wavelength for transverse waves, the distance between two successive compressions or rarefactions is termed wavelength of the longitudinal wave.

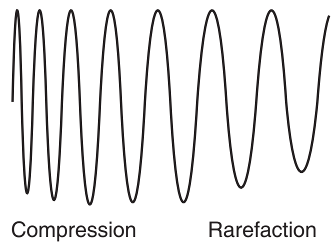

Fig. 1.3: Formation of rarefactions and compressions in air

While transverse waves form only in fluids (air and liquid), the longitudinal waves can form in all the three media viz. solid, liquid and gas. One way to visualize a longitudinal wave is to take a spring, fix it between two ends and then pull or press it on one end along the length. Compressions and rarefactions can be seen moving and rebounding along the axis of the spring.

1.8 REFRACTION OF SOUND

Refraction is the bending of waves when they enter a medium where their speed is different. Refraction is not so important a phenomenon with sound as it is with

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light where it is responsible for image formation by lenses, the eye, cameras, etc. But bending of sound waves does occur and is an interesting phenomenon in sound.

1.9 REFLECTION OF SOUND

The reflection of sound follows the law "angle of incidence equals angle of reflection", sometimes called the law of reflection. The same behaviour is observed with light and other waves, and by the bounce of a billiard ball off the bank of a table. The reflected waves can interfere with incident waves, producing patterns of constructive and destructive interference. This can lead to resonances called standing waves in rooms. It also means that the sound intensity near a hard surface is enhanced because the reflected wave adds to the incident wave, giving pressure amplitude that is twice as great in a thin "pressure zone" near the surface. This is used in pressure zone microphones to increase sensitivity. The doubling of pressure gives a 6 decibel increase in the signal picked up by the microphone. Reflection of waves in strings and air columns are essential to the production of resonant standing waves in those systems.

1.10 TRANSMISSION OF SOUND

As a sound wave travels across a room and touches a wall, a reflective wave is produced that will reintroduce a portion of that wave back into the room. The balance of the original sound will attempt to pass through the wall to the adjoining room. The energy that survives this transfer is called Sound Transmission.

1.11 SOUND ABSORPTION

When a sound wave strikes one of the surfaces of a room, some of the sound energy is reflected back into the room and some penetrates the surface. Parts of the sound wave energy are absorbed by conversion to heat energy in the material, while the rest is transmitted through. The level of energy converted to heat energy depends on the sound absorbing properties of the material.

A material's sound absorbing properties are expressed by the sound absorption coefficient, α, (alpha), as a function of the frequency. α ranges from 0 (total reflection) to 1.00 (total absorption) and is determined by :

1. Transmitted energy
2. Converted energy
3. Incident energy
4. Reflected energy

and is determined by :

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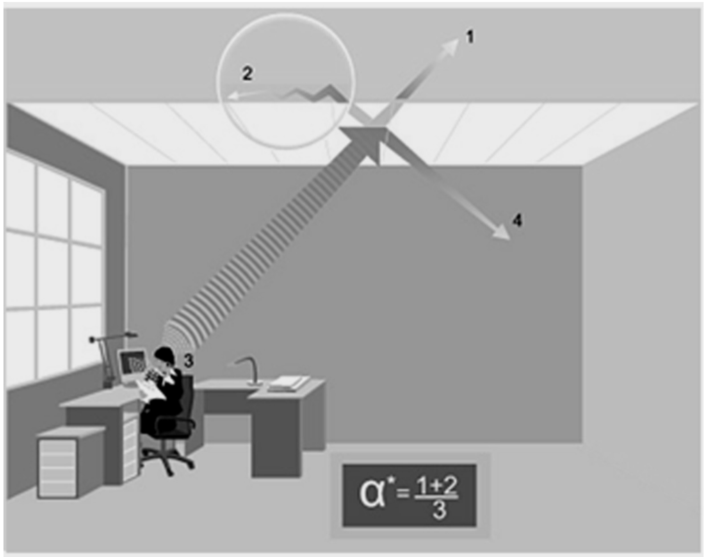

Fig. 1.4: Absorption coefficient

1.12 MUSIC AND NOISE

Music is a set of sound that is pleasing to hear and is not random. It refers to the quality of sound as well as the tune. Noise is random and irritates while music has periodicity whether in beats, or rhythm. For instance, in a song, you'd notice that the same tune is repeated after certain period. After a stanza, the singer comes back to the same tune (combination of notes). If we plot sound pressure with time, we'd notice that it is sweet if it changes in a regular fashion. Noise, in contrast, changes in an irregular fashion and irritates. Sound is evaluated by musicians in 3 terms: quality, pitch and loudness. Two sounds may have the same loudness, may be at the same pitch but can still have different quality/timbre. That is how we can distinguish the sounds from Sitar and guitar even when the loudness and the pitch are the same.

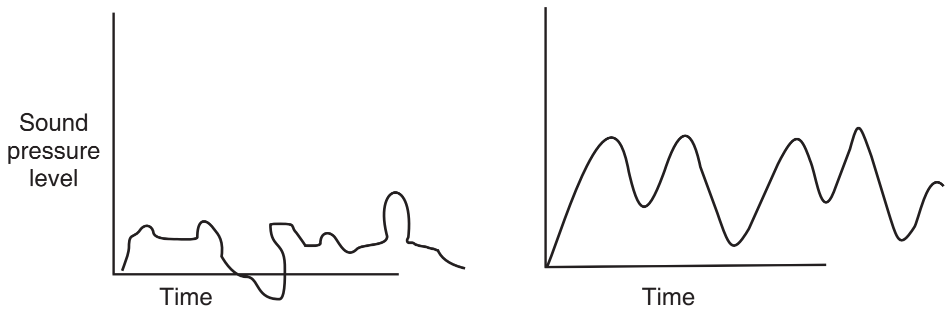

Fig. 1.5 : Graphical representation of changes in sound pressure with time in musical and noisy sound

1.13 WHAT YOU HAVE LEARNT

- Sound results from vibration and needs a medium to travel, be it gas (like air), solid or liquid. It is faster in solids than in liquids and is the slowest in the gases.
- A wave is described in terms of wavelength, frequency and amplitude. Velocity is equal to the product of wavelength and frequency.
- Noise is random while music is periodic. Music is pleasing to hear but it is also subjective. Sustained exposure to noise and even music at high decibel harms.
- The functioning of musical instruments like Tabla, Sitar and flute (Baansuri) can be understood as vibrations in membranes, strings and organ pipe.
- In telecommunicati/broadcasting they all work through the conversion of sound wave/text into electromagnetic waves at transmission end and reconversion to sound wave/text at the receiver's end.

1.14 TERMINAL QUESTIONS

1. Discuss the elements of sound.
2. Why cannot we hear each other on Moon?
3. Describe two experiments to show that sound has vibrations associated with it.
4. What is the relationship among velocity, wavelength and frequency?
5. What are the differences between longitudinal and transverse sound waves?
6. Will sound move faster in solid or air?
7. What is the basic difference between noise and music?
8. What are the features of sound?
9. Explain the 'transmission of sound'.
10. Illustrate sound absorption

1.15 ANSWERS TO INTEXT QUESTIONS

1.1

1. 500 2. 330 mm 3. 20 Hz to 20 kHz

Notes

1.16 REFERENCES

1. Science and Technology (Secondary): Sound and Communication, NIOS Publication.

2. Sound and recording: application and theory: Francis Rumsey and Tim McCommick