

COMPREHENSIVE QUESTIONS

Give an extended response to the following questions

- 1 What is Simple Harmonic Motion (SHM)? What are the conditions for an object to oscillate with SHM?
- 2 Show that the mass spring system executes Simple Harmonic Motion (SHM).
- 3 What is simple pendulum? Diagrammatically show the forces acting on simple pendulum. Also show that simple pendulum executes simple harmonic motion.
- 4 What is wave motion? How waves can be categorized?
- 5 How waves transport energy without carrying the material medium? Also describe the connection between oscillatory motion and waves.
- 6 Prove the relation between wave speed, wavelength and frequency of wave.
- 7 Using ripple tank explain reflection, refraction and diffraction of waves.

NUMERICAL QUESTIONS

- 1 A mass hung from a spring vibrates 15 times in 12 s. Calculate (a) the frequency and (b) the period of the vibration.
- 2 A spring requires a force of 100.0 N to compress it to a displacement of 4 cm. What is its spring constant?
- 3 A second pendulum is a pendulum with period of 2.0 s. How long must a second pendulum be on the Earth ($g = 9.81 \text{ m/s}^2$) and Moon (where $g = 1.62 \text{ m/s}^2$)? What is the frequency of second pendulum at earth and on Moon?
- 4 Calculate the period and frequency of a propeller on a plane if it completes 250 cycles in 5.0 s.
- 5 Water waves with wavelength 2.8 m, produced in a ripple tank, travel with a speed of 3.80 m/s. What is the frequency of the straight vibrator that produced them?
- 6 The distance between successive crests in a series of water waves is 4.0 m, and the crests travel 9.0 m in 4.5 s. What is the frequency of the waves?
- 7 A station broadcasts an AM radio wave whose frequency is $1230 \times 10^3 \text{ Hz}$ (1230 kHz on the dial) and an FM radio wave whose frequency is $91.9 \times 10^6 \text{ Hz}$ (91.9 MHz on the dial). Find the distance between adjacent crests in each wave.

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How does the bat's detection system work, and how can a moth 'jam' the system or otherwise reduce its effectiveness?

Unit
11

SOUND

After studying this chapter you should be able to

- ✓ explain how sound is produced by vibrating sources and that sound waves require a material medium for their propagation.
- ✓ describe the longitudinal nature of sound waves (as a series of compressions and rarefactions).
- ✓ define the terms pitch, loudness and quality of sound.
- ✓ describe the effect of change in amplitude on loudness and the effect of change in frequency on pitch of sound.
- ✓ define intensity and state its SI unit.
- ✓ describe what is meant by intensity level and give its unit.
- ✓ explain that noise is a nuisance.
- ✓ describe how reflection of sound may produce echo.
- ✓ describe audible frequency range.
- ✓ describe the importance of acoustic protection.
- ✓ solve problem based on mathematical relations learnt in this unit.

STUDENT LEARNING OUTCOME

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- 11.1 Sound waves
- 11.2 Characteristics of sound
- 11.3 Sound Intensity
- 11.4 Speed of sound
- 11.5 Reflection of sound and echo
- 11.6 Acoustics
- 11.7 Audible frequency range
- Key Points and Projects
- Exercise

Hearing is perhaps the one sense we take for granted the most. We often do not realize the different sounds that goes through our ears on minute-to-minute basis. It's probably the first thing we experience when we wake up in the morning – when we hear birds chirping or our alarm clock bleeping away. Sound fills our days with excitement and meaning, when people talk to us, when we

listen to music, or when we hear interesting programs on the radio and TV.

At times it may be displeasing in the form of noise, but that is the lively world around us. In this unit we will describe sound as waves, its characteristics, speed and reflection.

11.1 SOUND WAVES

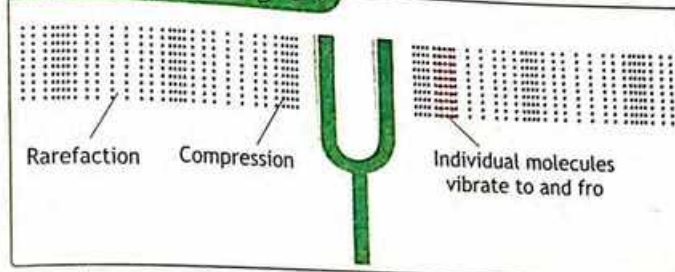
Sound waves are longitudinal waves traveling through a medium, such as air.

Sound wave is created by a vibrating object, such as a guitar string, the human vocal cords, or the diaphragm of a loudspeaker. Moreover, sound can be transmitted only in a medium, such as a gas, liquid, or solid. As we will see, the particles of the medium must be present for the creation of disturbance and the sound wave to move from place to place. Sound cannot exist in a vacuum.

For example, consider a tuning fork, a common device for producing pure musical notes. A tuning fork consists of two metal prongs, or tines, that vibrate when struck. Their vibration disturbs the air near them, as shown in Figure 11.1. When a tine swings to the right, the molecules in an element of air are forced closer together than normal. Such a region of high molecular density and high air pressure is called a *compression*. When the tine swings to the left, the molecules in an element of air to the right of the tine spread apart, and the density and air pressure in this region are then lower than normal. Such a region of reduced density is called a *rarefaction*. The rarefaction itself therefore moves, following the previously produced compression. As the tuning fork continues to vibrate, a succession of compressions and rarefactions forms and spreads out from it.

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FIGURE 11.1 - Tuning Fork



11.1.1: Production of Sound: Some disturbance and vibration is needed for the production of sound, as seen in the tuning fork experiment. As shown in figure 11.2 similar observations can be made from buzzing sound of bees or mosquitoes; the sound is produced due to rapid vibrations of their wings. Sound in sitar or guitar is produced by vibration of the stretched string. The sound of school bell is produced by vibrations in its steel gong (half-sphere) when it is struck by a spring-loaded arm.

FIGURE 11.2 - Examples of sound by vibrations



11.1.2 Transmission of sound: Since sound is a longitudinal mechanical wave it also requires the transmitting medium. In tuning fork experiment, the compressions and rarefactions that were produced in air were used to carry sound. However, sound can be transmitted through other media (such as other gases and even liquids and solids). For example, children at play may discover that sound travels very easily along a metal fence. Swimmers notice that they can hear sound travels very easily along a metal fence. Swimmers notice that they can hear a distant motorboat better with their ears under the water than in the air. In both these examples, sound is traveling in a material other than air.

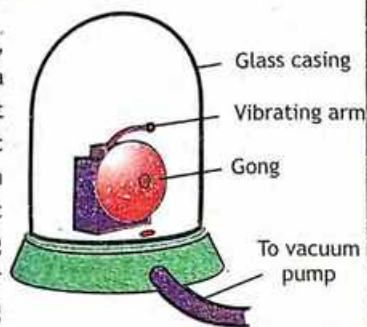
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Nevertheless sound does require a material medium for its propagation and it cannot travel through vacuum.

ACTIVITY

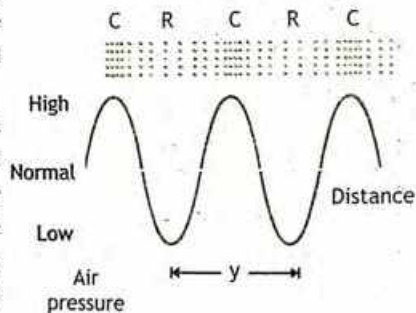
The bell in jar experiment is shown in figure, it demonstrates that sound does require a material medium for its propagation and it cannot travel through vacuum. An electric bell is sealed inside a bell jar and a vacuum pump to remove the air. When the electric bell is turned on, it produces a loud ringing sound. As the vacuum pump removes the air from the bell jar, the loudness of the ringing decreases.

If the vacuum pump is a good one, the sound of the bell will almost be eliminated.



SOUND PROPAGATION

Sound, like all waves, travels at a certain speed and has the properties of frequency ' f ' and wavelength ' λ '. Figure shows a graph of air pressure as a function of distance from a source. There are crests in the sinusoidal wave at points where the sound wave has compressions and troughs where the sound wave has rarefactions.



11.1.3 Detection of sound: Sound can be detected by various means, ear is one such biological organ. Ear converts sound waves into perception of hearing. Perception is commonly defined to be awareness through the senses, a typically circular definition of higher level processes in living organisms.

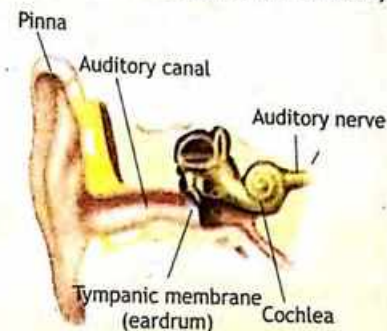
Microphones detect sound by converting it to electrical signals. The persons impaired of hearing detects the sound with artificial hearing devices.

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PHYSICS OF HEARING

The hearing mechanism involves some interesting physics. Figure shows the anatomy of the ear with its division into three parts: the outer ear or ear canal; the middle ear, which runs from the eardrum to the cochlea; and the inner ear, which is the cochlea itself. The body part normally referred to as the ear is technically called the pinna.

The sound wave that enters our ear is a pressure wave, which sets eardrum into motion. Oscillation of ear drum causes oscillation in the fluid-filled inner ear; the motion of the fluid disturbs hair cells within the inner ear, which transmit nerve impulses to the brain with the information that a sound is present.



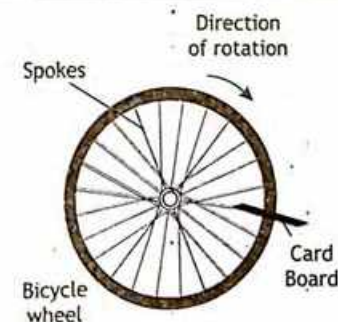
11.2 CHARACTERISTICS OF SOUND

Few characteristics on which one sound can be distinguished from another are pitch, loudness and quality (or timber).

11.2.1 Pitch: Pitch distinguishes shrill sound from grave sound. The pitch of a note depends on the frequency of the sound wave reaching the ear. A high-pitched note has a high frequency and a short wavelength. A low pitched note has a low frequency and a long wavelength.

ACTIVITY

Support a bicycle on its stand and rotate its rear wheel. Hold a piece of cardboard in your hand with its free end touching the spokes of the rotating wheel. The sound will be produced, as you increase the speed of rotation the spokes touching per unit time to the cardboard will increase, which will increase the frequency. As a result, sound produced will become shriller (of a higher pitch).



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For example the sound produced by man, dogs, frogs etc are of low pitch whereas the sound produced by women, birds, cats etc are of high pitch. Pitch is like colour in light; both depend on the frequency.

11.2.2 Loudness: The greater the sound energy, the louder is the sound. The loudness depends upon the amplitude (height) of the sound wave.

Loudness depends upon the following factors:

- **The area of vibrating body:** Larger the area of vibration larger will be amplitude of sound produced.
- **Distance from the source of sound:** The farther away, the smaller the amplitude.
- **Material through which sound is traveling:** Amplitude of sound wave is different in different materials such as water and air.

For example, a drum produces loud sound if its membrane is struck strongly. This is because the vibrating body starts to oscillate with larger amplitude and therefore the sound it produces also has a larger amplitude and as a result the sound is louder.

ACTIVITY

Support a ruler under a heavy load or book as shown in the figure. Twang the ruler with your hand, sound will be produced. Notice that when you gently twang the ruler, faint sound is produced and when you twang it hard, loud sound is produced. Thus by increasing the amplitude of vibration the loudness increases.



11.2.3 Quality: The property of sound by which two sounds of the same loudness and pitch are distinguished from each other. The same note on different instruments sounds different; we say the notes differ in quality or timbre.

For example, when a piano and a flute are made to produce sound of same loudness and pitch, we can easily distinguish between the overall sound from piano and flute.

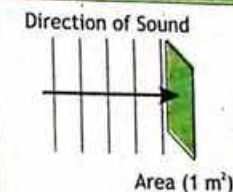
11.3 SOUND INTENSITY

Intensity is a measure of the amount of sound energy reaching a unit of area in unit time (power per unit area).

In equation form, intensity I is

$$I = \frac{E}{A \times \Delta t} = \frac{P}{A} \quad \text{11.1}$$

FIGURE 11.3 - Intensity



In equation 11.1, 'P' is Power (the rate at which energy 'E' is transferred by the wave per unit time ' Δt ') and 'A' is the area through which sound energy is measured. Sound intensity is measured in units of picowatts per square metre (pW/m^2). (Note that 1.0 pW is $1.0 \times 10^{-12} \text{ W}$.)

Intensity is an objective property of the sound wave – in fact, it is related to the square of the wave amplitude, and does not depend on the particular characteristics of a person's ears. Loudness, on the other hand, is a subjective property of the sound that depends on the human ear, the sensitivity of the ear to the frequency of the sound, and the distance from the source of the sound.

10.3.1 Intensity Level: An average human ear can detect sounds with an intensity as low as 10^{-12} W/m^2 and as high as 1 W/m^2 (and even higher, although above this, it is painful). This is an incredibly wide range of intensity, spanning a factor of 10^{12} from lowest to highest. To permit comparison of values which vary so greatly in magnitude, it is most convenient to express them in terms of their logarithms - the power to which 10 must be raised to equal the number.

Table 11.1 LOGARITHMIC INTENSITY LEVELS AND SOUND INTENSITY

Intensity level (dB)	Intensity level (B)	Intensity (pW/m^2)
0	0	1
10	1	10
20	2	100
30	3	1000
50	5	100000
100	10	10000000000

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If L is the loudness and I is the sound intensity in W/m^2 , then mathematically

$$L \propto \log I \quad \text{or} \quad L = k \log I \quad \text{--- (1)}$$

Where ' k ' is the constant of proportionality. If ' L_0 ' represents the loudness of faintest audible sound of intensity ' I_0 ' such that $I_0 = 10^{-12} \text{ W/m}^2$ equation 1 can be written as:

$$L_0 = k \log I_0 \quad \text{--- (2)}$$

Subtracting equation 2 from equation 1, we get

$$L - L_0 = k \log I - k \log I_0 \quad \text{or} \quad L - L_0 = k (\log I - \log I_0)$$

$$L - L_0 = k \log \frac{I}{I_0}$$

The difference between the loudness of these two loudness of sound ($L - L_0$) is called intensity level or intensity level (β) and is given as

$$\beta = k \log \frac{I}{I_0} \quad \text{--- (3)}$$

Since β is defined in terms of a similar quantities ratio, it is unit-less. The value of k depends not only on the units of I and I_0 but also on the unit of intensity level. If the intensity of any sound is ten times greater than the intensity I_0 of the faintest audible sound ($I = 10 I_0$), then intensity level of such a sound is taken as unit called bel and value of k becomes 1. Substituting $k = 1$, equation 3 becomes

$$\beta = \log \frac{I}{I_0} \quad (\text{bels})$$

P **O** **I** **N** **T** **T** **O** **P** **O** **N** **D** **E** **R** **I** **T** **'** **S** **Z** **E** **R** **O** **N** **O** **T** **H** **I** **N** **G** **H** **I** **N** **G**! A sound intensity level of 0 dB does not indicate that the sound wave has no intensity or amplitude. An intensity level of 0 dB corresponds to an intensity of $10^{-12} = 1 \text{ pW/m}^2$.

The sound intensity level scale is similar to the Celsius temperature scale — it can have negative values. A sound intensity level of -1 dB corresponds to a sound intensity of 10^{-11} or 0.1 pW/m^2 . Similarly, an intensity level of -2 dB corresponds to an intensity of 0.01 pW/m^2 .

When our teacher hear us whispering with friend in class it is 20 dB, when teacher is demonstrating in the class the sound is 50 dB and when whole class is working on assignment it is 60 dB. Some values are given in table 11.2.

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Table 11.2 LOGARITHMIC INTENSITY LEVELS AND SOUND INTENSITY

Source	Intensity level (dB)	Intensity (W/m^2)
threshold of hearing	0	10^{-12}
normal breathing	10	10^{-11}
average whisper at 2 m	20	10^{-10}
empty theatre	30	10^{-9}
residential area at night	40	10^{-8}
quiet restaurant	50	10^{-7}
two-person conversation	60	10^{-6}
busy street traffic	70	10^{-5}
vacuum cleaner	80	10^{-4}
loud stereo in average room	90	10^{-3}
maximum level in concert hall (13th row)	100	10^{-2}
pneumatic chisel	110	10^{-1}
maximum level at some rock concerts	120	10^0
propeller plane taking off	130	10
threshold of pain	140	10^{-2}
military jet taking off	150	10^{-3}
wind tunnel	160	10^{-4}
instant perforation of the eardrum	170	10^{-5}

Since bel is a large unit, the intensity of sound is often expressed in a smaller unit called decibel (dB). Such that

$$\beta = 10 \log \frac{I}{I_0} \quad (\text{dB}) \quad \text{--- (11.2)}$$

It must be remembered that 1 bel = 10 decibels.

The comparison values for different intensity levels in decibel (dB), Bel (B) and intensity in pW/m^2 is given in table 11.2.

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DECIBEL SCALE

One convenient feature of the logarithmic scale is that an increase of X decibels corresponds to an increase by a particular multiplicative factor in intensity, no matter where you start from. The relative sound level, $\Delta\beta$, is the difference between two sound levels:

$$\Delta\beta = \beta_2 - \beta_1$$

$$\text{or } \Delta\beta = 10 \log \frac{I_2}{I_0} - 10 \log \frac{I_1}{I_0}$$

$$\text{or } \Delta\beta = 10(\log I_2 - \log I_0) - 10(\log I_1 - \log I_0)$$

$$\text{Hence } \Delta\beta = 10 \log I_2 - 10 \log I_0 - 10 \log I_1 + 10 \log I_0$$

$$\text{or } \Delta\beta = 10 \log I_2 - 10 \log I_1$$

$$\text{Therefore } \Delta\beta = 10 \log \frac{I_2}{I_1} \quad \text{11.3}$$



A sound level metre is a measuring instrument used to assess sound levels by measuring air pressure.

Equation 11.3 enable us to find the relative sound levels of the loudest and the quietest sounds produced by a source called dynamic range. The larger the dynamic range, the greater the range of sound intensities a device can produce or record.

Manufacturers list the dynamic range for all high-end loudspeakers and headphones as well. In general, the higher the dynamic range, the better the sound quality. However, the price usually increases with the dynamic range.

EXAMPLE 11.1:

Show that if one sound is twice as intense as another. About what factor is the sound level (in dB) higher?

GIVEN

Intensity ' I_1 ' = I

Intensity ' I_2 ' = $2I$

REQUIRED

Intensity level ' $\Delta\beta$ ' = ?

SOLUTION: the difference between two sound levels is $\Delta\beta = 10 \log \frac{I_2}{I_1}$

$$\text{Putting values } \Delta\beta = 10 \log \frac{2I}{I} \quad \text{or } \Delta\beta = 10 \log 2.0$$

$$\text{or } \Delta\beta = 10 \times 0.301$$

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Hence

$$\Delta\beta = 3.01$$

Answer

This means that the two sound intensity levels differ by 3.01 dB. Note that because only the ratio I_2 / I_1 is given (and not the actual intensities), this result is true for any intensities that differ by a factor of two.

For example, a 56.0 dB sound is twice as intense as a 53.0 dB sound, a 97.0 dB sound is half as intense as a 100 dB sound, and so on.

EXTENSION EXERCISE 11.1

If an increase of 3 dB means "twice as intense," what does an increase of 6 dB mean?

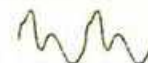
ASSIGNMENT 11.1:

Suppose that when a certain sound intensity level (in dB) triples, the sound intensity (in W/m^2) also triples. Determine this sound intensity level.

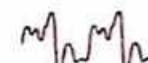
MUSIC AND NOISE



The sound that produces a pleasing sensation in the ear is called musical sound. The wave form of such sound is composed of regular and uniform vibrations as shown in figure (a) and (b), the violin and clarinet music is having regular and uniform pattern. On the other hand, the sound which produces a displeasing effect on the ear is called noise. The wave form of such sound is of irregular and disordered vibrations as shown in figure (c). The excessive displeasing sound which disrupts the balance or activity of humans or other living things is called noise pollution.



(a) Violin Music



(b) Clarinet Music



(c) Noise

11.4 SPEED OF SOUND WAVES

The speed of sound is the distance traveled per unit time by a sound wave as it propagates through a medium. Sound, like all waves, travels at a certain speed and has the properties of frequency and wavelength. At 20 °C, the speed of sound in air is 343 m/s. Sound can be transmitted through any medium—gas, liquid, or solid. The speed of sound depends on the material through which it is passing.

Children at play may discover that sound travels very easily along a metal fence. Swimmers notice that they can hear a distant motorboat better with their ears under the water than in the air.

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In both examples, sound is traveling in a material other than air. You may have watched distant lightning and noticed the time lapse before the sound of thunder reaches you. This is an example of the relatively slow speed of sound compared to the speed of light. The speed of sound in water is almost five times faster than its speed in air. Sound travels most rapidly in certain solids, less rapidly in many liquids, and quite slowly in most gases. Some values are given in Table 11.3. The speed of sound 'v' can be found by dividing distance 'S' by time 't' as:

$$\text{speed} = \frac{\text{distance}}{\text{time}}$$

$$\text{or } v = \frac{S}{t} \quad \text{11.4}$$

EXAMPLE 11.2:

You are standing at 1.5 km from the cannon with a stop watch. You start the stopwatch when you see the cannon flash and stop it when the sound is heard. The time recorded on your stopwatch is 4.4 s, what is the speed of sound? What is this speed in km/hr?

GIVEN

Distance 'S' = 1.5 km = 1500 m

Time 't' = 4.4 s

REQUIRED

Speed of sound 'v' = ?

SOLUTION: speed is defined as $v = \frac{S}{t}$

TABLE 11.3 THE SPEED OF SOUND

State	Material	Speed at 0°C (m/s)
Solid	aluminum	5104
	glass	5050
	steel	5050
	maple wood	4110
	bone (human)	4040
	pine wood	3320
Solid/liquid	brain	1530
Liquid	fresh water	1493 (at 25°C)
	sea water	1470
	alcohol	1241
Gas (at atmospheric pressure)	hydrogen	1270
	helium	970
	nitrogen	350 (at 20°C)
	air	332
	oxygen	317
	carbon dioxide	258

Putting values $v = \frac{1500 \text{ m}}{4.4 \text{ s}}$

Hence $v = 340.9090 \text{ m/s} = 341 \text{ m/s}$ — **Answer**

To convert m/s into km/h we apply the conversion factor

$$v = 341 \times \frac{3600}{1000} \text{ km/h}$$

$$v = 341 \times 3.6 \text{ km/h}$$

$$v = 1227.6 \text{ km/h} = 1228 \text{ km/h}$$
 — **Answer**

The speed of sound is 341 m/s or 1228 km/h.

ASSIGNMENT 11.2: LIGHTNING

If the time between seeing lightning and hearing the thunder is 5.0 s. The speed of sound is 343 m/s, how far away is the lightning?

11.4.1 The Speed of Sound in Air: The speed of sound in air depends upon the density of air and its compressibility (how easy it is to squeeze). As temperature increases, these properties change causing the speed of sound in air to increase with temperature. At a temperature of 0°C and a pressure of 101 kPa (1 atm pressure), the speed of sound in dry air is 331 m/s, and for each 1°C rise in temperature, the speed of sound increases approximately by 0.6 m/s. Mathematically

$$v = 331 + 0.6T \quad \text{11.5}$$

where T is the temperature in °C. Unless stated otherwise, we will assume in this Chapter that $T = 20^\circ\text{C}$, so $v = [331 + (0.60)(20)] \text{ m/s} = 343 \text{ m/s}$.

The general wave equation also applies to sound waves as

$$v = f\lambda \quad \text{11.6}$$

It should be noted that wide range of frequencies observed in sound, and the speed of sound is the same for all frequencies. Thus, in the relation 11.6 the speed v remains fixed. For example, if the frequency of a wave is doubled, its wavelength is halved, so that the speed v stays the same.

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EXAMPLE 11.3: WAVELENGTH CALCULATION

What is the wavelength of the sound in dry air if its frequency is 590 Hz on a hot day with temperature of 40 °C?

GIVEN

Temperature $T = 40^\circ\text{C}$

Frequency ' f ' = 590 Hz

REQUIRED

Wavelength ' λ ' = ?

SOLUTION: Since speed of sound at 0°C is 331 m/s and for each one degree celsius rise in temperature, the speed of sound increases by 0.6 m/s. Therefore

$$v = 331 + 0.6T \quad \text{or} \quad v = [331 + 0.6 \times 40] \text{ m/s}$$

$$\text{or} \quad v = [331 + 24] \text{ m/s} \quad \text{Hence} \quad v = 355 \text{ m/s}$$

Now by general wave equation $v = f\lambda$ or $\lambda = \frac{v}{f}$

Putting values $\lambda = \frac{355 \text{ m/s}}{590 \text{ Hz}}$ or $\lambda = \frac{355 \text{ m/s}}{590 \text{ 1/s}}$

$\lambda = 0.6 \text{ m}$ — **Answer**

Thus, the wavelength of wave is 0.6 m

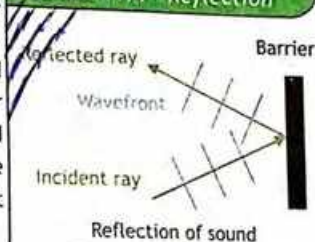
ASSIGNMENT 11.3: FREQUENCY CALCULATION

What is the frequency of sound with wavelength 0.25 m in air with temperature of 32 °C?

11.5 REFLECTION OF SOUND WAVES AND ECHO

When a wave front strikes a boundary that is parallel to the front, the wave may be absorbed, be transmitted, or undergo reflection, depending on the nature of the boundary medium, or the wave may be partly absorbed, partly transmitted, partly reflected, or any combination thereof. Sound wave reflect like other kind of waves.

The bouncing back of sound waves when it strikes a surface is called reflection of sound.

FIGURE 11.4 - Reflection

Just like reflection of water waves in ripple tank, sound waves can also be made to bounce back as shown in figure 11.4. Some materials, such as hard, smooth surfaces, reflect sound waves more than they absorb them. Other materials, such as soft curtains, absorb sound waves more than they reflect them. Figure shows a sound wave with a plane wave front reflecting from a flat surface.

Some people claim that their singing voice is better in the shower than anywhere else. This may be true as a result of the many sound reflections that occur in a small room. Sound due to multiple reflections is called a **reverberation**. The continuation of many reflections causes a tone to gain in volume. Thus reverberation adds to gain in volume of tone.

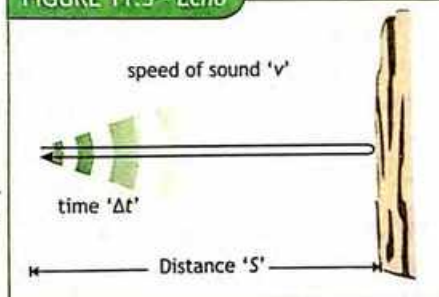
11.5.1 Echo: A reflected sound that can be distinguished from the original is called an echo. If a reflected sound arrives after 0.10 s, the human ear can distinguish the reflected sound from the original sound. *Thus, a reflected sound that arrives before 0.10 s is perceived as an increase in volume and is called a reverberation, but a sound that arrives after 0.10 s is perceived as an echo.*

Besides the hearing of your words repeated, echoes can be used to estimate the distance of an object and the velocity of sound itself. Since the sound covers a distance ' S ' twice ' $S = 2S$ ' i.e for going and receiving in time ' Δt ' as shown in figure 11.5. The speed ' v ' is

$$v = \frac{2S}{\Delta t}$$

or $S = \frac{v\Delta t}{2}$ — **11.7**

This means that we can calculate the minimum distance for the echo to be heard.

FIGURE 11.5 - Echo

For example, the speed of sound at room temperature of 20°C is $v = 343 \text{ m/s}$ and the sound reaches the ear in time $\Delta t = 0.1 \text{ s}$, the distance S can be calculated as

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$$S = \frac{343 \frac{\text{m}}{\text{s}} \times 0.1 \text{ s}}{2} \quad \text{or} \quad S = \frac{34.3 \text{ m}}{2}$$

$$S = 17.15 \text{ m}$$

So the minimum distance required for an echo to be heard when the speed of sound is 343 m/s is 17.15 m. The change in temperature can effect this distance because the speed of sound changes with temperature.

EXAMPLE 11.4: ECHO

During a winter school camp on Pipe Line Track from Donga Gali to Ayubia, Aalia shouts at a cliff and hears her echo after 1.5 s. She record the temperature on her personal thermometer as 3 °C. How far is the cliff from her?

GIVEN

time $\Delta t = 1.5 \text{ s}$

Temperature $T = 3^\circ\text{C}$

REQUIRED

distance 'S' = ?

SOLUTION: First we would calculate the speed of sound at 3 °C. Since speed of sound at 0 °C is 331 m/s and for each one degree Celsius rise in temperature, the speed of sound increases by 0.6 m/s. Therefore for increase in 4 degrees we have

$$v = 331 + 0.6T \quad \text{or} \quad v = [331 + 0.6 \times 3] \frac{\text{m}}{\text{s}}$$

$$\text{or} \quad v = [331 + 1.8] \frac{\text{m}}{\text{s}} \quad \text{so} \quad v = [331 + 2] \frac{\text{m}}{\text{s}}$$

$$\text{Hence} \quad v = 333 \frac{\text{m}}{\text{s}}$$

$$\text{Now using the equation for echo} \quad S = \frac{v \Delta t}{2}$$

$$\text{Putting values} \quad S = \frac{333 \frac{\text{m}}{\text{s}} \times 1.5 \text{ s}}{2}$$

$$S = 249.75 \text{ m} = 250 \text{ m} \quad \text{--- Answer}$$

The cliff is approximately 250 m far from her.

ASSIGNMENT 11.4: DOUBLE CLIFF ECHO

A man stands in between two parallel cliffs and fires a gun, he hears two successive echoes after 3 s and 5 s. What is the distance between cliffs?

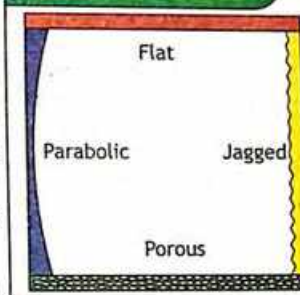
NOT FOR SALE**11.6 ACOUSTICS**

Acoustics is the study of waves, vibrations and sound. Echoes are easily observed in a large, empty room, but when rugs and furniture are put in the room, the acoustics change; because such materials absorb the sound more than they reflect. If the reflective surfaces are too absorbent, the sound level will be low and the room will sound dull and lifeless.

Reflection of sound in a room makes it sound lively and full. The acoustics of a room depend on the shape of the room, the contents of the room, and the composition of the walls, ceiling, and floor. The designer of an auditorium, must find a balance between reverberation and absorption. It is often advantageous to place highly reflective surfaces behind the stage to direct sound out to an audience.

Architectural acoustics is about achieving a good quality of speech in a theater, or recording studio, or suppressing noise to make offices and homes more comfortable and peaceful places to work and live. Flat surfaces reflect, parabolic surfaces focus, porous surfaces absorb while jagged surfaces disperse the sound as shown in figure 11.6.

It is often advantageous to place highly reflective surfaces behind the stage to direct sound out to an audience. Reflecting surfaces are suspended above the stage in some theaters.

FIGURE 11.6 - Acoustics

P A good acoustic design will provide a better and comfortable environment in the mosque in term of sound audibility and speech intelligibility. Unfortunately, architects nowadays often focus more on designing a building based on its looks or form, and the main function of space most often neglected. To ensure good listening conditions acoustical needs must be considered in the design phase of the mosque.

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11.6.1 Acoustic protection: Acoustic protection is the application of soft and porous material to protect individuals against undesirable sounds and noises. Acoustic protection is employed not only for physical health, but for psychological well being as well. Animals and birds have also been reported to express discomfort due to higher noise and sound levels. Acoustic protection is also necessary to minimize stress levels generated due to high noise. Acoustic protection may also be required to protect structures against vibrations generated by objects, such as trains and earthquakes. This is also required to control the noise generated during construction and/or development activities.

TipBits

Noise Pollution: The excessive displeasing sound which disrupts the balance or activity of humans or other living things is called noise pollution. The first type of noise pollution involves noises that are so loud they put the sensitive parts of the ear. Prolonged exposure to sounds of about 85 dB can begin to damage hearing irreversibly. Certain sounds above 120 dB can cause immediate damage.

The sound level produced by a jet engine from a few meters away is about 140 dB. The workers working in noisy areas like an airport use 'headphones' to prevent the hearing loss brought on by damage to the inner ear.



The second kind of noise pollution involves noises that are considered annoyances, these sounds are irritating and sometimes becomes intolerable. Studies have found that long-term exposure to noise can cause potentially severe health problems in addition to hearing loss, especially for young children. Constant levels of noise (even at low levels) can be enough to cause stress, which can lead to high blood pressure, insomnia, and psychiatric problems, and can even impact memory and thinking skills in children.

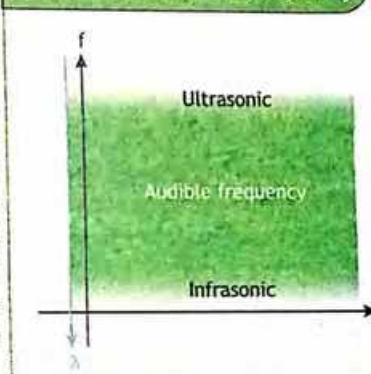
Animals and plants are also victims of noise pollution. It is observed that in animals it damages the nervous system and reproductive system. While in plants growth defects are observed. The World Health Organization has recommended that noise during sleep should be limited to a level of 35 dB.

11.7 AUDIBLE FREQUENCY RANGE

There are both upper and lower limits to the sound frequencies that humans can hear. A healthy young person can typically hear frequencies in a range from about 20 Hz (Recall that 1 Hz is 1 cycle per second) to 20,000 Hz (20 kHz). The upper limit decreases with age.

Physicists have established a three-part classification of sound, based on the range of human hearing. Sound frequencies lower than 20 Hz are referred to as infrasonic, those in the 20 Hz to 20,000 Hz range are audible, and those higher than 20,000 Hz are ultrasonic as shown in figure 11.7. Different animal have varying hearing ranges. You may have experienced a dog whistle that seems to produce no sound at all when blown, but still brings your pet dog back.

FIGURE 11.7 - Audible frequency



The frequency of the sound produced by these whistles is higher than 20 kHz. While it is outside the audible range for humans, it is obviously not outside the audible range for dogs. The top end of a dog's hearing range is about 45 kHz, while a cat's is 64 kHz.

11.7.1 Infra-sound: Whales, elephants and rhinoceroses are known to use infra-sound to communicate over long distances. The infra sounds from elephants and whales can be extremely loud (around 117 dB), allowing communication for many kilometres, with a possible maximum range of around 10 km for elephants, and potentially hundreds or thousands of kilometers for some whales.

FIGURE 11.8 - Infra-sounds



Elephants and whales use infrasounds to communicate.

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Infrasounds can be generated by human processes such as explosions, or by machinery such as diesel engines, wind turbines. Certain specialized loudspeaker designs are also able to reproduce extremely low frequencies; these include large-scale rotary woofer models of subwoofer loudspeaker. Some human singers can also produce sounds in infra sonic range.

11.7.2 Ultra-sound: Bats use ultrasonic ranging (echolocation - by listening to the echoes of their calls) technique to detect their prey. They can detect frequencies beyond 100 kHz, possibly up to 200 kHz. To avoid bats, many insects have good ultrasonic listening. This includes many groups of moths, beetles, praying mantids and lacewings. Upon hearing a bat, these insects move to escape before being prey for echo-locating bat. Whales and dolphins can hear ultrasound and use such sounds in their navigational system to orient and capture prey.

FIGURE 11.9 - Ultra-sonics



The praying mantis and moths has a specialized ultrasound receptor on its abdomen that allows them to take cover in response to an approaching bat.

Apart from animals, humans have also used ultrasound to their advantage.

- i. **Automatic door opener:** A common ultrasound application is an automatic door opener, where an ultrasonic sensor detects a person's approach and opens the door. Ultrasonic sensors are also used to detect intruders; the ultrasound can cover a wide area from a single point.
- ii. **Nondestructive Testing:** Ultrasonic testing is a type of nondestructive testing commonly used to find flaws in materials and to measure the thickness of objects.
- iii. **SONAR:** A common use of ultrasound is in underwater range finding; this use is also called SONAR (Sound Navigation and Ranging).

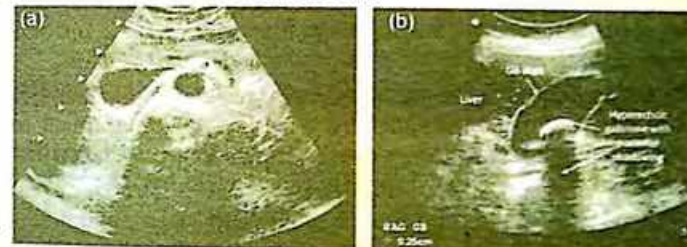
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An ultrasonic pulse is generated in a particular direction. If there is an object in the path of this pulse, part or all of the pulse will be reflected back to the transmitter as an echo and can be detected through the receiver path. By measuring the difference in time between the pulse being transmitted and the echo being received, it is possible to determine the distance.

iv. Ultrasonic cleaners: Jewelry, machined parts and other objects that have odd shapes are immersed in a cleaning fluid that is agitated with ultrasound typically about 40 kHz in frequency. The intensity is great enough to cause cavitation, which is responsible for most of the cleansing action. Because cavitation-produced shock pressures are large and well transmitted in a fluid, they reach into small crevices where even a low-surface-tension cleaning fluid might not penetrate.

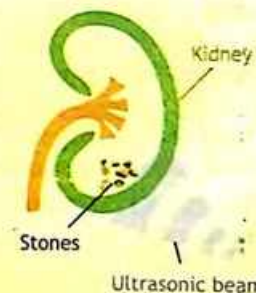
MEDICAL APPLICATIONS OF ULTRA SOUND

Perhaps the most familiar is the ultrasound scan that is used to image a particular part of the body. By sending bursts of ultrasound into the body and measuring the time delay of the resulting echoes – it is possible to map out the location of structures that lie hidden beneath the skin.



(a) Abdominal ultrasound reveals normal liver and gallbladder. There is no abnormal echo in the gallbladder. (b) A gallbladder stone is seen in the image.

In addition to imaging the interior of a body, ultrasound can also produce changes within the body that would otherwise require surgery. For example, in a technique called shock wave lithotripsy (SWL), an intense beam of ultrasound is concentrated onto a kidney stone that must be removed. After being hit with as many as 1000 to 3000 pulses of sound (at 23 joules per pulse), the stone is fractured into small pieces that the body can then eliminate on its own.



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Sound: A disturbance of matter that is transmitted from its source outward
Loudness: The perception of sound intensity
Pitch: The perception of the frequency of a sound
Quality: Number and relative intensity of multiple sound frequencies
Musical sound: The sound that is pleasant and harmonious
Noise: Any loud, discordant, or disagreeable sound
Intensity: The power per unit area carried by a wave
Sound intensity level: A unitless quantity telling you the level of the sound relative to a fixed standard
Reflection of sound: The bouncing back of sound when it strikes a surface
Reverberation: Sound due to multiple reflections
Echo: A reflected sound that can be distinguished from the original sound
Audible frequency range: Range of frequency from 20 Hz to 20000 Hz.

GROUP A 'HEARING DISABILITIES': Interview members of the medical profession to learn about human hearing. What are some types of hearing disabilities? How are hearing disabilities related to disease, age, and occupational or environmental hazards? What procedures and instruments are used to test hearing? How do hearing aids help? What are the limitations of hearing aids? Make a chart to present your findings to the class.

GROUP B 'LECTURE ROOM DESIGN': Assess your classroom acoustics, try to place different sound reflectors and experimentally determine the best design for your classroom. Write a research article to be published in school magazine.

GROUP C 'SOUND LEVEL': Obtain a sound-level metre, and measure the noise level at places where you and your friends might be during an average week. Also make some measurements at locations where sound is annoyingly loud. Be sure to hold the metre at head level and read the metre for 30s to obtain an average. Identify sources of noise in their environment and suggest how such noise can be reduced to an acceptable level. Present your findings to the class in a graphic display.

GROUP D 'ANIMALS HEARING ABILITIES': Research how animals have adopted their hearing abilities to survive and effectively communicate with each other. Prepare a chart to be displayed in the classroom.

GROUP E 'ULTRASOUND': Research how ultrasound techniques are used in medical and industry. Write an article to be published in school magazine.

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EXERCISE

- ① The intensity of a sound wave increases by 1000 W/m^2 . What is this increase equal to in decibels?
A. 10 B. 20 C. 30 D. 40
- ② An echo occurs when a sound wave is ...
A. absorbed B. transmitted C. refracted D. reflected
- ③ Compared with a sound of 60 decibels, a sound of 80 decibels has an intensity _____ times greater.
A. 10 B. 100 C. 1000 D. 10000
- ④ The loudness of a sound is most closely related to its _____.
A. frequency B. period C. wavelength D. amplitude
- ⑤ Various instruments sound different even when they play the same note due to difference in
A. pitch B. loudness C. quality D. intensity
- ⑥ Humans can hear sound that is
A. less than 20 Hz B. between 20 Hz and 20 kHz
C. greater than 20 kHz D. None
- ⑦ The speed of sound on a warm day when the outdoor temperature is 38°C is
A. 331 m/s B. 345 m/s C. 354 m/s D. 362 m/s
- ⑧ Minimum echo distance is reduced in
A. summer B. winter C. spring D. space
- ⑨ Which of the following cannot transmit sound?
A. solid B. liquid C. gas D. vacuum

CONCEPTUAL QUESTIONS

Give a brief response to the following questions

- ① Why sound produced by a simple pendulum is not heard?
- ② If a ringing bicycle bell is held tightly by hand, it stops producing sound. Why?
- ③ Why is the intensity of an echo less than that of the original sound?
- ④ In which medium air or water, an echo is heard sooner? Why?
- ⑤ Why sound cannot be heard on the moon?

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- 6 If a person places his ear on rails of railroad for determination of coming train. Why is this done, and how does it work?
- 7 When you watch a thunderstorm, you see the lightning first, and you hear the thunder afterward. Why is the thunder delayed?
- 8 If the speed of sound is dependent on frequency, would music from marching band be enjoyed?
- 9 Why does your voice sound fuller in the shower?
- 10 Why is it so quiet after a snowfall?

COMPREHENSIVE QUESTIONS

Give an extended response to the following questions

- 1 What is sound? How it is produced, transmitted and received?
- 2 What is audible frequency range?
- 3 What is the speed of sound?
- 4 Describe the terms loudness, pitch and quality. Explain each by giving an example.
- 5 What is intensity level? Describe the decibels scale for the intensity of different sound levels.
- 6 What is noise? Explain why noise is nuisance?
- 7 How sound is reflected? Describe the difference between echo and reverberation.
- 8 What is acoustic protection? Why is it important?

NUMERICAL QUESTIONS

- 1 The sound intensity 3 m from a jackhammer is $8.20 \times 10^{-2} \text{ W/m}^2$. What is the sound intensity level in decibels? (Use the usual reference level of $I_0 = 1.00 \times 10^{-12} \text{ W/m}^2$).
- 2 A ship is anchored where the depth of water is 120 m. An ultrasonic signal sent to the bottom of the lake returns in 0.16 s. What is the speed of sound in water?
- 3 A gunshot from a .22 rimfire rifle has an intensity of about $I = (2.5 \times 10^{13}) I_0$. Do we need to wear ear protection? (Considering that prolonged exposure to sounds above 85 decibels can cause hearing damage or loss).
- 4 What sound intensity level in dB is produced by earphones that create an intensity of $4.00 \times 10^{-2} \text{ W/m}^2$? (Use the usual reference level of $I_0 = 1.00 \times 10^{-12} \text{ W/m}^2$.)

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- 5 What is the speed of sound in air at -20°C ?
- 6 Army man wearing binoculars see the flash from enemy tank fire 5 s before the fire is heard, he records 26°C temperature on his personal thermometer. What is the distance of the tank from him?
- 7 Calculate the wavelengths of sounds at the extremes of the audible range, 20 Hz and 20,000 Hz, at normal room temperature of 20°C ?
- 8 Ishfaq stands between two high rise buildings A and B, such that he is at 33 m distance from building A. When he blows the whistle, he hears the first echo after 0.2 s and second echo after 0.8 s. Calculate (a) the speed of sound and (b) distance of building B from him.

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