Simple Harmonic Motion (SHM) **CHAPTER-O7, PART-I**

By the end of this chapter we will be able to-

• Understand the conditions under which simple harmonic oscillations take place.
• Describe simple harmonic oscillations graphically.
• Describe waves and wave motion.
•explain the characteristics of waves.
• Classify waves as transverse and longitudinal.
• Describe the nature of electromagnetic waves.
• Set a **mathematical** relation with wavelength, frequency, period and wave speed (**the quantities related to waves)**/The wave equation.
• Solve problems with wavelength, frequency, period and wave speed.
• Identify wavelength, frequency and period from graphs of displacement against distance or time AND use the concept to solve problems.
• Solve problems using the concepts of intensity and amplitude and the inverse square law.

Simple Harmonic Motion and related terms

Simple harmonic oscillations take place whenever we have a system (The mass–spring system and the simple pendulum) that is displaced from its fixed equilibrium position and:

- the acceleration is in the opposite direction to the displacement
- the acceleration is proportional to the displacement.

We can express these two conditions into one equation:

$$a = -\omega^2 x \quad \Rightarrow a \propto -x$$

The **minus sign** shows that the acceleration is in the opposite direction to the displacement, so that the force tends to bring the system back towards its equilibrium position.

The defining property of all simple harmonic oscillations is that the magnitude of the acceleration of the body that has been displaced away from equilibrium is proportional to the displacement and the direction of the acceleration is towards the equilibrium position. (Since $F = ma$, this is equivalent to saying that the restoring force is proportional to and opposite to the displacement.)

Therefore, in general, to check whether SHM will take place, we must check that:

- there is a fixed equilibrium position
- when the particle is moved away from equilibrium, the acceleration of the particle is both proportional to the amount of displacement and in the opposite direction to it.

Examples of oscillations include:

• the motion of a mass at the end of a horizontal or vertical spring after the mass is displaced away from its equilibrium position
• the motion of a ball inside a round-bottomed bowl after it has been displaced away from its equilibrium position at the bottom of the bowl
• the vertical motion of a body floating in a liquid under the action of wind and waves (e.g. an iceberg)
• a tight guitar string that is set in motion by plucking the string
• the motion of a tree branch or a skyscraper under the action of the wind.

Hooke's law: The Hooke's law states, if the spring constant is k, mass is m and position is x, then the applied force on it,

$$F = -kx$$

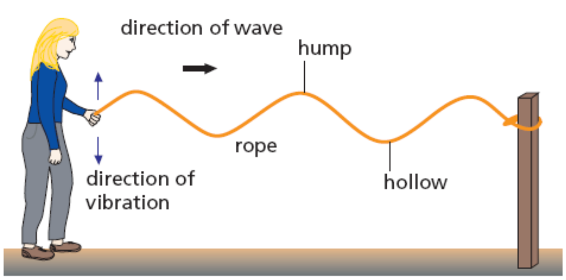
The harmonic or Oscillatory motion that obeys Hooke's law is called simple harmonic motion.
In your book, there is no scope of deducing it, but there is no harm in knowing it.
If the spring constant of a spring is k and m is the attached mass, then the time period of the mass is,

$$T = 2\pi\sqrt{\frac{m}{k}}$$

If instead of being a spring, it would be a pendulum hanging from a string and if the length of the string is *l* and gravitational acceleration is g, then the time period is:

$$T = 2\pi\sqrt{\frac{l}{g}}$$

(No, there is no mistake, whether you hang a light mass or a heavy mass, the time period will be the same, it does not depend on the mass.)
Question: Hang a stone of mass 10 gm from a string 1 m long. What is its time period?
The time period remains the same whether the mass of the stone is 10 gm or not



Waves

All of us have seen waves,

-when a stone is thrown into water then waves spread out in all directions from that point.

-When a bulb is switched on in the room, the light that spreads in the room is also a wave.

-When we talk, the sound that reach from one place to another place is also a wave.

-When a compressed spring is released, the deformation that propagates through it is a kind of a wave too.

In short, we can say, we can realize what a wave is. But what will we say if we want to give a nice definition for it in terms of physics?

What is a wave?

A wave is a disturbance that travels in a medium (which can be a vacuum in the case of electromagnetic waves) transferring energy (and momentum) from one place to another. The direction of propagation of the wave is the direction of energy transfer.

There is no large-scale motion of the medium itself as the wave passes through it.

Characteristics of Waves

Here, we will discuss all the characteristics of waves, specially the mechanical waves.

i. For mechanical waves a medium is necessary.

ii. When a wave propagates through a medium, the particles of the medium oscillate (vibrate or go up-down) about its own position but are not displaced permanently with the wave.

iii. Energy can be transferred from one place to another through waves. The more the energy, the more the amplitude of the wave.. Energy is proportional to the amplitude of the Wave. If the amplitude is doubled, energy is increased four times.

$$E \propto a^2$$

iv. Every wave has a velocity; this velocity depends on the nature of the medium,
In air, the velocity of sound is 330 m/s, in water this velocity is 1439 m/s.
The velocity of a wave in a tight rope (under tension will be more than the velocity of the wave in a loose rope.

v. Reflection or refraction occurs for waves, at the time of travelling from one medium to another medium, if part of a wave returns back to the first medium, it is called reflection .When a wave travels from the first medium to the second, it is refraction When we hear an echo of sound, it is reflection. If we hear external sound when we are submerged under water it is due to refraction.

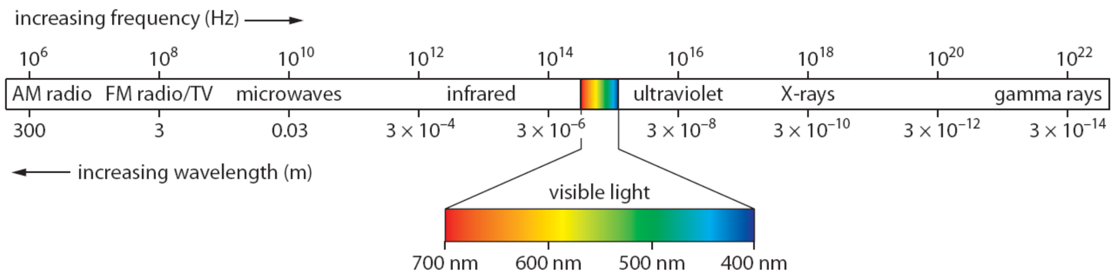
vi. Superposition occurs for waves, the two waves, can reinforce one another or can destroy each other.

There **are many types of waves, f**or which this **definition may not** be perfectly correct. For propagation of wave we talked about a medium, but when light reaches the earth from the sun, there is no need for a medium then. Light is an electromagnetic wave.

The scientists are talking about a new type of wave called gravity wave, which they have observed; it also does not need any medium.

In quantum mechanics, an amazing branch of physics, deals with **another type of wave known as wave function which is even m**ore spectacular; there the wave cannot be seen directly, only its effect can be experienced.

Electromagnetic waves



The electromagnetic spectrum

What all EM waves have in common is that they move at the speed of light in a **vacuum**. That speed is (exactly) c = 299 792 458 m s^{-1} or approximately **3.00 × 10^8 ms^{-1}**

Mechanical Waves:

Mechanical waves are **produced by a disturbance**, such as a vibrating object, in a material medium and are **transmitted by the particles** of the medium vibrating to and fro. Such waves can be seen or felt and include waves on a rope or spring, water waves and sound waves in air or in other materials.

Progressive wave: A progressive or travelling wave is a disturbance which carries energy from one place to another without transferring matter.

Types of Waves: There are two types, transverse and longitudinal.

Longitudinal waves:

All longitudinal waves require a medium in which the wave travels.

In a **longitudinal** wave the displacement is parallel to the direction of energy transfer.

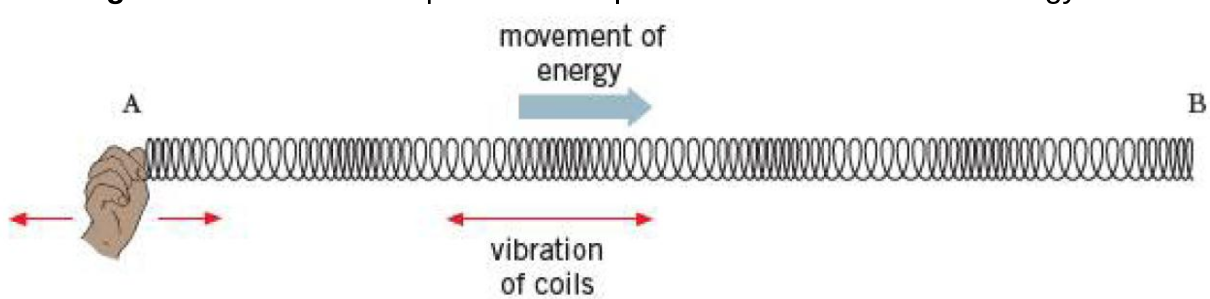


Figure: Imagine the left end of a slinky is pushed in and out as in Figure, the coils of the slinky move in a direction that is parallel to that of the wave.

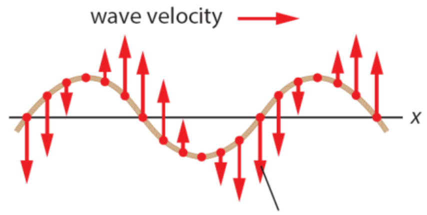
A longitudinal wave is one in which the direction of the vibrations of the particles in the wave is along the direction in which the energy of the wave is travelling.

Transverse waves:

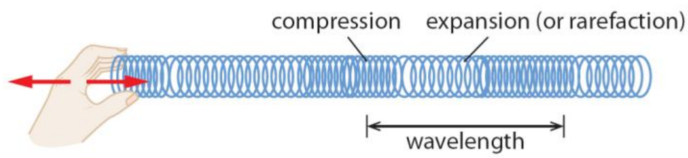
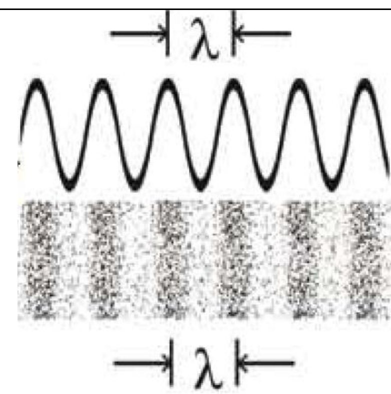
We call a wave transverse if the displacement is at **right angles** to the direction of energy transfer.

OR,

A transverse wave is one in which the vibrations of the particles in the wave are at right angles to the direction in which the energy of the wave is travelling.



A snapshot of the wave

Longitudinal wave	Transverse wave
When a wave propagates through a spring, the wave moves forward by contraction and expansion of the spring. The wave formed in the spring was of contraction and expansion, the direction of contraction and expansion of the spring and the direction of wave is the same. The name of this wave is longitudinal wave. Sound is this type of a longitudinal wave.	When we produce a wave in the rope by shaking it, there the vibration of the rope does not take place along the direction of the velocity of the wave. The direction of vibration i.e. up and down of the rope, is perpendicular to the direction of the velocity of the wave. The name of this type of a wave is a transverse wave. The wave produced in water is an example.
	

What is time period?

The time to create one complete oscillation is known as the period of the wave. The symbol for period is T. If the period of wave is T = 0.25 s, for example, then the number of oscillations produced in one second is 4.

Frequency:

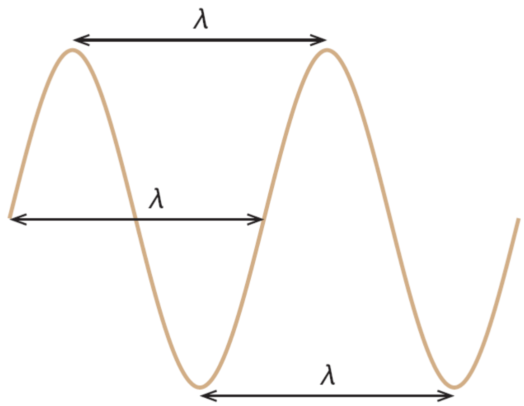
The number of oscillations per second is called the frequency f of the wave. In general if the period is T then the frequency is the inverse:

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

The unit of frequency is the inverse second, which is given the name hertz (Hz).

Wavelength: The length of a complete oscillation is known as the wavelength of the wave. The symbol for wavelength is λ.

It is also the distance from crest to crest or trough to trough (Figure). (A crest is the highest point on the wave and a trough the lowest.)

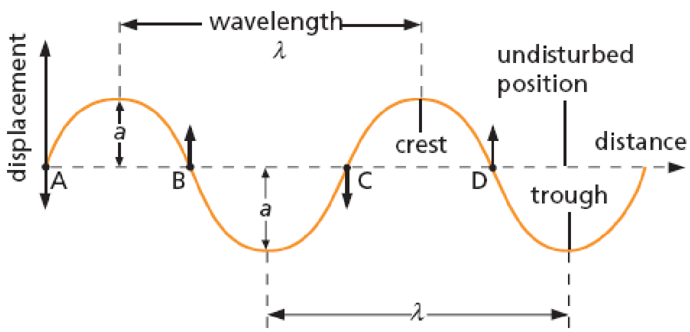


Three distances that all give the WAVELENGTH

Phase: A term used to describe the relative positions of the crests or troughs of two different waves of the same frequency is phase.

When the crest**s** and trough**s** of the two waves are aligned, the waves are said to be in phase. When crests and troughs are not aligned the waves are said to have a phase difference. When **a** crest and **a** trough of two waves are aligned the waves are said to be in antiphase.

The qualitative **measure of phase difference** has the unit of angle (radians or degrees).

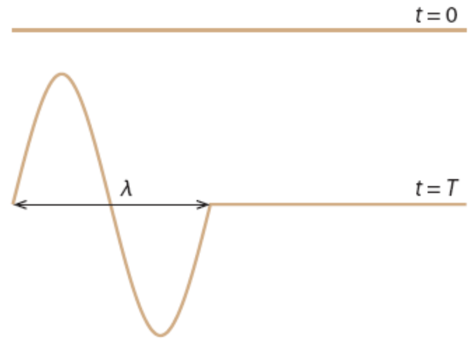


The parts at A and C have the same speed in the same direction and are **in phase**. At B and D the parts are also in phase with each other but they are **out of phase** with those at A and C because their directions of vibration are opposite.

The wave equation:

Speed of wave = frequency · wavelength

Figure: In a time of one period the wave has moved forward a distance of one wavelength.



So suppose we have a wave on a rope, of wavelength λ, period T and frequency f. Figure shows the rope at time zero when we have not yet produced any oscillations and at time T where we have produced one oscillation.

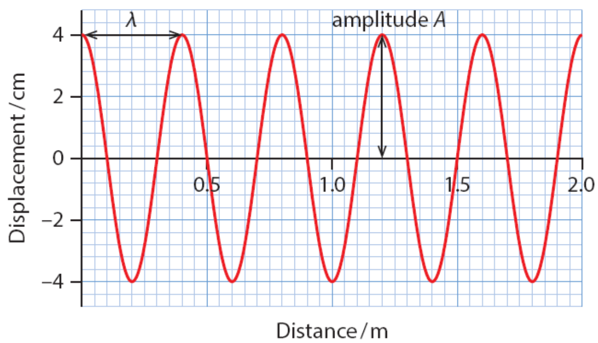
The wave has moved a distance equal to one wavelength in a time equal to one period and the speed of the wave is:

$$v = \frac{distance\ for\ one\ oscillation}{time\ for\ one\ oscillation} = \frac{\lambda}{T} = f\lambda, \quad since, f = \frac{1}{T}$$

The speed of the wave depends only on the properties of the medium and not on how it is produced.

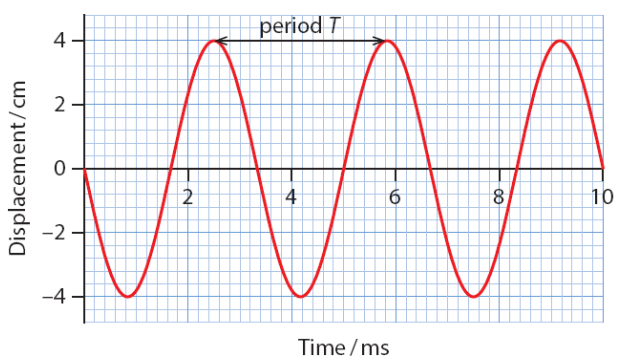
Question:

Important pieces of information from i. displacement–distance graph and ii. Displacement–time graph



A graph of displacement versus position

Find the i. amplitude, ii. wavelength and iii. the number of wavelength



Find the i. amplitude, ii. time period and iii. frequency

Spring wave is longitudinal wave-Explain.

The particles of transverse wave are in periodic motion.-Explain.

Which quantity does change when a wave travels from one medium to another?

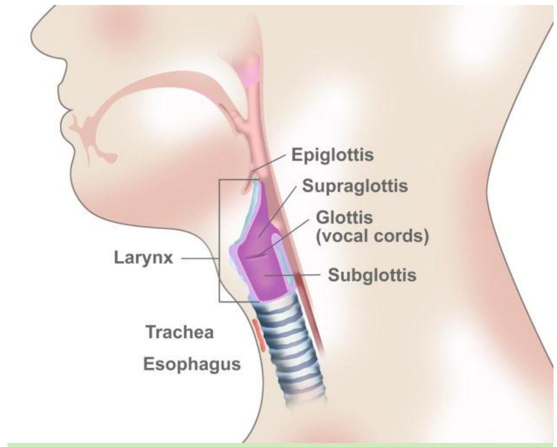
Ans.: When a wave travels from one medium to another medium, then change of its velocity occurs.

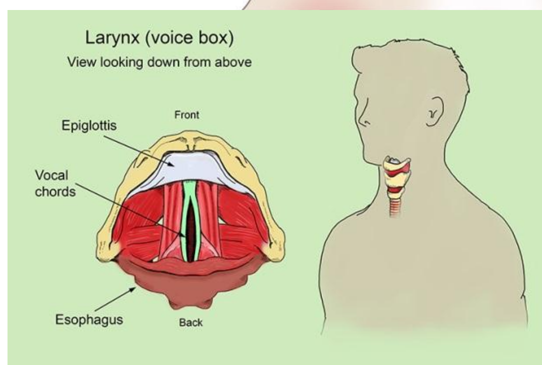
Since the frequency always remains the same, so when a wave travels from one medium to another then its wavelength changes.

Therefore, when waves propagate through different medium, its velocity or wavelength changes, but frequency or time period never changes.

SOUND WAVES
CHAPTER-O7, PART-II

By the end of this chapter we will be able to-
-Describe the nature of sound waves.
-explain the range of hearing and its uses
-explain the characteristics of sound waves
-explain the change of velocity of sound
-explain creation of an echo
-explain the uses of echo in our daily lives
-set up the mathematical relation among the velocity of sound, frequency, and wavelength and measure these quantities.
-explain the pitch and intensity of sound
-explain the reasons and consequences of sound pollution and the techniques to prevent it.





Sound Wave

To produce sound waves
-a source is needed
-a medium to send it through
and any type of receiver to receive that sound.

Characteristics of sound wave:

-Sound is a mechanical wave, because sound wave is produced due to the vibration of body, and for its transmission an elastic medium is needed.

-This is a longitudinal wave, because the direction of propagation of the wave and the direction of vibration is the same.
-The velocity of sound depends on the property of the medium, In gaseous mediums its velocity is low, in liquids greater, and in solids it is much more.
-The velocity of sounds depends on the temperature and humidity of the medium.
-The intensity of sound is proportional to the square of the amplitude of the wave. Therefore, if the amplitude of a wave is high, the intensity of the sound will be high and if the amplitude is low, the intensity will be low.

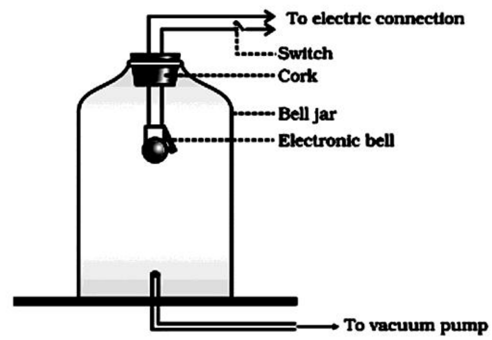
The most familiar source is our throat; sound is created by the **vibration of the vocal cord** when air flows through it in our throat. We will feel the vibration if we touch our throat during conversation. When we make a sound then air comes out through throat from our lungs. In our throat there is a wind pipe through which air enters the lungs and come out from the lungs. To produce sound larynx is situated upon it. There are two membranes which work as valves, called the vocal cords. These vibrate during the flow of air and produce sound

Why the voice of a male does is deep and the voice of female and children is sharp?

The vocal cords of males become **stiff** with the increasing of age, whereas for female it remains **soft.** This is why males produce sound of low frequency or pitch and females produce sound of high frequency or pitch. Due to this, the voice of males is **deep** and that of the females is sharp.

Sound waves cannot travel through a vacuum:

To show that sound cannot propagate without a medium; we keep a calling bell as shown in Figure in the laboratory. The calling bell can **be** sounded by supplying electricity from **outside.** The sound of the calling bell will be slowly dulled if it is evacuated gradually by a pump. If the bell jar is completely emptied of air, though the bell will vibrate inside but it seems from outside that there is no sound.



Conclusion: Without air in the bell jar, no sound waves can be travelled through.

Range of audibility:

AUDIBLE SOUND The sound that can be heard has frequency between 20 Hz to 20,000 Hz or 20 kHz.The human ear can easily detect frequencies between 20 Hz and 20 KHz. Hence sound waves with frequency ranging from 20 Hz to 20 KHz is known are audible sound.(Usually hearing capability decreases due to continuously listening to songs with head phones or staying in sound polluted areas.)

INFRASONIC SOUND: If the frequency of sound is less than 20 Hz, it is called infrasound. Many animals can hear sounds of low frequency. Before earthquakes, sounds of low frequency are generated, and often hearing this sound animals panic and leave the area.

ULTRASOUND: If the frequency of sound is greater than 20 kHz it is called ultrasound. We cannot hear the sound produced by the bat; because the sound is ultrasound i.e. frequency of the sound is beyond our hearing range. Bats can produce sound of frequency 100 kHz or more.

Ultrasound cleaner: Ultrasound cleaner is used when we need to clean small instruments perfectly in the laboratory. The small instruments are immersed in a liquid, and subjected to the ultrasound wave, the vibrations of which remove the dirt.

If frequency less than 20 Hz or greater than 20 kHz is generated, then the movement created in air will not be heard by us. To detect such sounds we can use a special type of **microphone or receiver**

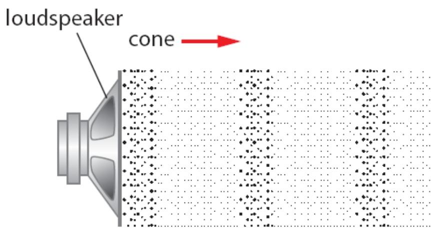
Male voice is harsh but child and female voice is shrill. Explain.
Why is the voice of women sharp whereas that of adult men is deep? Explain.

The nature of sound waves

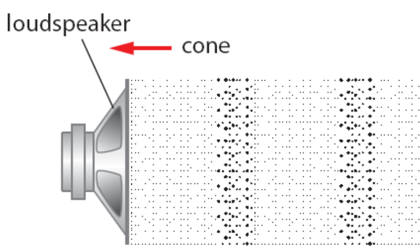
A loudspeaker sends sound waves through the air because its surface pushes and pulls repeatedly on the air. When the waves reach your ears, your eardrums vibrate so you hear sound..

Explanation:

As the surface vibrates, it moves forwards then backwards repeatedly.



Each time it moves forwards into the surrounding air, it sends **a compression** wave through the surrounding air as a result of pushing the nearby air molecules forwards, so they bump into air molecules further away pushing them forwards,, so they bump into air molecules further away pushing them forward ...and so on.



Each time a vibrating surface moves backwards away from the surrounding air, it sends **a rarefaction** wave, the opposite of a compression wave, through the surrounding air as a result of:

- leaving a space which is then filled by nearby air molecules moving in, so
- they leave a space which is then filled by air molecules further away moving backwards,
- these air molecules leave space which is then filled by air molecules even further away moving in ... and so on. The result is that as the surface vibrates, it repeatedly sends a compression wave followed by a rarefaction wave into the surrounding air.

How does a bat fly?

Bats have eyes and pretty good eye sight, yet they use echo during flight. While flying a bat uses its throat to produce sound, if there is an obstacle in the front, the sound returns after reflection, and the bat can estimate the distance from the time of the returning sound. For this reason, the bat can fly even in dark without being obstructed.

Previously we could not see from outside the fetus that grows in the womb of a pregnant mother, which is now possible with the help of a process called ultrasonography

Why sound is one kind of wave? Explain.

Sound waves are longitudinal waves that can travel in gases and liquids as well as solids. Sound is a longitudinal wave of compression and rarefaction created by the pressure in air. A sound wave consists of a series of compressions and rarefactions in the medium in which it is travelling. A vibrating loudspeaker produces compressions when the cone moves to the right and expansions when it moves to the left. These compressions and expansions move through air as a wave called sound.

Variation of Velocity of Sound

Sound is a mechanical wave. The velocity of sound does not depend on the air pressure. It depends on the **elasticity** of the medium.

The nature of liquid and solid is different from air and naturally the velocity of sound is different there.

In liquid the velocity of sound is more than that in air and in solid velocity of sound is even more than in liquid.

But it is **inversely proportional to the square root of the density** of air. So if there is water vapor in the air, its density decreases, hence velocity increases.

In air, velocity of sound is proportional to the square root of temperature.

i.e. $v \propto \sqrt{T}$ **, here T is the temperature in Kelvin**

Important:

$v_\theta = 332 + 0.6\theta$	$v = v_0\sqrt{\frac{T}{T_0}}$	$\frac{v_2}{v_1} = \sqrt{\frac{T_2}{T_1}}$

Question: Explain the relation between the velocities of sound with the nature of medium.

Question: Why is sound heard faster in monsoon than winter?

Question: Velocity of sound in water is more than that in air medium, Explain.

Question: Why velocities of sound depend on humidity of air? Explain.

Question: What is the velocity of sound more during daytime than night?

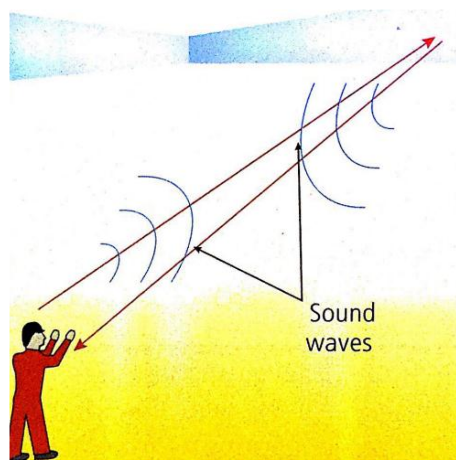
Question: Which quantity does change when a wave travels from one medium to another?

Sound of frequency 1 kHz is produced by a tuning fork. It was allowed to pass through air, water and iron.

Medium⇒	air	water	iron
Frequency	1000Hz	1000Hz	1000Hz
Velocity	334 *m/s*	1493 m/s	5130 m/*s*
Wavelength	0.334m	1.49m	5.13m

Echo: Reflection of sound from a smooth surface. Since sound is one type of wave, it can have reflection.

Echoes can be heard in a large hall or gallery which has bare smooth walls or in a cave with smooth walls.
For example, if you clap your hands in a large hall, you should be able to hear an echo of the clap.
The echo is due to sound waves created when you clap your hands reflecting off the wall and returning to you.
The further away you are from the wall, the longer the sound waves take to travel to the wall and back to you, so the longer the delay between the clap and the echo..



Minimum distance to hear an echo:

When we hear something the feeling persist for around 0.1s, so to hear two sounds separately, it needs separation of 0.1 s differences between two sounds. Velocity of sound is 330 m/s, therefore to create a difference of 0.1 s, sound has to travel at least 33 m.

$$d = \frac{vt}{2}$$

If we stand in front of a big wall, a building, or a high hill at least half of this distance (16.5 m), the sound will take 0.1 s to come back after being reflected and we will hear the reflection of sound or echo.

Why can all reflected sound not to be heard?

If someone speaks in a big empty building it creates a reverberating sound. This is due to reflection. Within the building the distance is not enough to hear the sound separately.

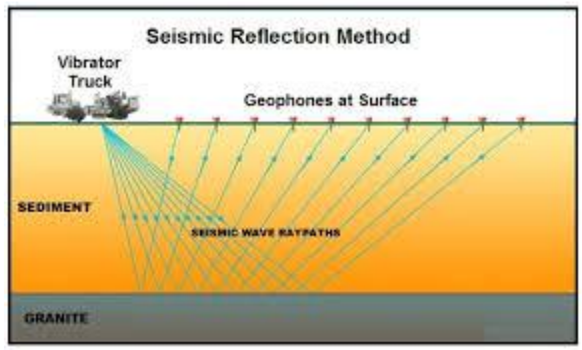
Unwanted echoes in buildings and halls can be eliminated by:

• covering the walls in soft fabric, which absorbs sound waves instead of reflecting them so no echoes will be heard

• making the wall surface uneven not smooth, so reflected sound waves are scattered (i.e. 'broken up') so they cannot cause echoes.

Uses of Sound :

Three dimensional Seismic Surveys: Seismic Survey is done to explore whether gas or oil is present below the earth. To do this, a small blast is done a little below the earth, Sound of the blast hits the different layers of the soil and returns after reflection. The reflected wave is detected by a special type of receiver named a geophone (Figure). Analyzing all information a perfect three dimensional picture of the soil is formed, from which gas or oil is present or not is determined. Since we know the position of the source of sound and the geophone, the distance of the different layers of soil can be calculated accurately from the time required for the sound to reach from source to geophone.



Musical Sound: The sweet sounds are the sounds of musical instruments.

Among the many characteristics of musical sound, the important three are:

Intensity: Intensity is a measure of how loudly a musical sound can be heard. Therefore, the amount of sound energy that flows per second per unit area is called the intensity. The unit of intensity is Wm.

Pitch: The characteristic of musical sound by which the sound of the same intensity is sometimes heard dull and sometimes sharp is called pitch.

Timber: The characteristics of sound by which we can differentiate the sound produced from different musical instrument is called timber or quality of sound.

Different types of musical instruments that are used to produce melodious sound, can be divided into three groups:

Musical instrument made of wire: Ektara (Monochord), Violin, Sitar

Musical instruments based on air flow: Flute, Harmonium

Musical instrument made of percussion: Dhol, Tabla

Now-a-days melodious sounds are produced using electronics in a completely different way.

INTENSITY OF SOUND: Sound intensity, also known as acoustic **intensity**, is defined as the power carried by **sound** waves per unit area in a direction perpendicular to that area.

The SI unit of **sound intensity** is watt per square meter (W/m^2).

What is meant by intensity of sound 25 Wm^{-2}?

Sound Pollution:

Sound is essential in our life, but excessive sound makes our life intolerable. Those who live in cities, especially those who live besides a road observe that the sound produced from engines of **bus, car, truck and of continuous horn**s goes beyond our tolerance limit very often. Most of the time we are used to living in such types of pollution for a long time. Due to sound pollution, we are losing our hearing capability. To intensify the problem many of us listen to songs using headphones in the ears.

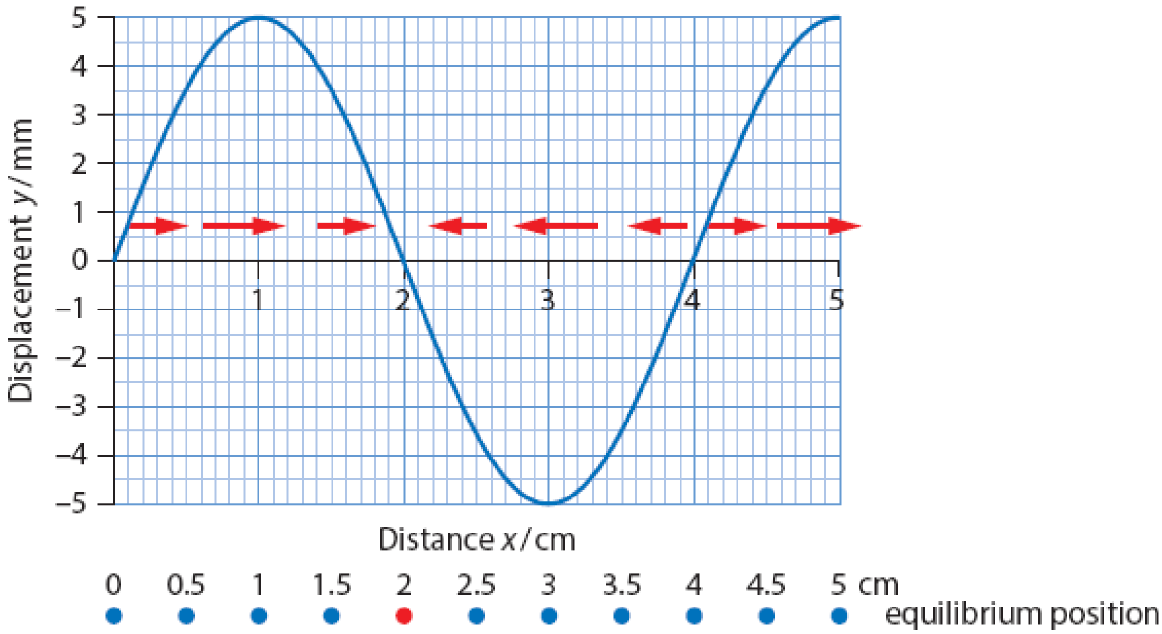
To reduce sound pollution the first step is to make laws against it. The second step is to make public awareness. This issue has to be clarified to all, using horns while in cars as little as possible, installation of sound absorbing machine in the industry, making less uses of loud speaker, using vehicles of less sound etc. In addition, steps be taken of plantation of trees in the empty places in cities.

Table: Intensity of sound of different types

Jet engine	**-140 dB**
Traffic	**80-90 dB**
Car	**60-80 dB**
Television	**50-60 dB**
Conversation	**40-60 dB**
Breathing	**10 dB**
Sound of mosquito	**0 dB**

$T = \frac{1}{f}$	$v = f\lambda$ $v = \frac{d}{t}$		$d = \frac{vt}{2}$ $t = \frac{2d}{v}$
$v_\theta = 332 + 0.6\theta$	$v = v_0\sqrt{\frac{T}{T_0}}$	$\frac{v_2}{v_1} = \sqrt{\frac{T_2}{T_1}}$	$\frac{v_w}{v_a} = \frac{\lambda_w}{\lambda_a}$

TIPS: You cannot tell whether a wave is transverse or longitudinal by looking at displacement–distance graphs. The graphs look the same for both.



Molecules to the left of that at x = 2.0 cm move to the right, while the neighbours to the right move left. This means that the region at x = 2.0 is the Centre of a compression.

Since a compression is a region where molecules crowd together, the pressure and density of the medium in a compression is higher than normal. To give an idea of the differences in pressure involved, a sound of frequency 1000 Hz can be heard by the human ear when the pressure of air at the eardrum exceeds atmospheric pressure by just 20 μPa. (Normal atmospheric pressure is 105 Pa.) The amplitude of oscillations for air molecules under these conditions is about 10−11 m, or a tenth of the diameter of the hydrogen atom! In a rarefaction the reverse is true, with the molecules moving farther apart so that the density and pressure are a bit less than normal.

To understand physics perfectly we need have a clear idea about some topics, one of them is wave. There are three large classes of wave: mechanical waves (e.g. sound), electromagnetic waves (e.g. light) and matter waves (e.g. electron motion in atoms).

In terms of physics, we can say in simple harmonic motion the phase that develops at any instant, after one time period, this phase returns again.

Therefore, for the time is being we will limit our discussions only to those waves which require mediums like solids, liquids or gases. The name of this type of wave is mechanical wave.