

WAVES

LEARNING OBJECTIVE

At the end of this chapter the students will be able to:

Recall the generation and propagation of waves.

Describe the nature of the motions in transverse and longitudinal waves.

Understand and use the terms wavelength, frequency and speed of wave.

Understand and use the equation $v = f\lambda$.

Understand and describe Newton's formula of speed of sound.

Derive Laplace correction in Newton's formula of speed of sound.

Derive the formula $v = v_o + 0.61t$.

Explain and use the principle of superposition.

Understand the terms interference and beats.

Understand and describe reflection of waves.

Explain the formation of a stationary wave using graphical method.

Understand the terms node and anti-node.

Understand and describe modes of vibration of string.

Understand and describe Doppler's effect and its causes.

Waves transport energy without transporting matter. The energy transportation is carried by a disturbance, which spreads out from a source. We are well familiar with different types of waves such as water waves in the ocean, or gently formed ripples on a still pond due to rain drop. When a musician plucks a guitar-string, sound waves are generated which on reaching our ear, produce the sensation of music. Wave disturbances may also come in a concentrated bundle like the shock waves from an aeroplane flying at supersonic speed. Whatever may be the nature of waves, the mechanism by which it

oscillations. The waves which propagate by the oscillation of material particles are known as mechanical waves.

There is another class of waves which, instead of material particles, propagate out in space due to oscillations of electric and magnetic fields. Such waves are known as electromagnetic waves. We will undertake the study of electromagnetic waves at a later stage. Here we will consider the mechanical waves only. The waves generated in ropes, strings, coil of springs, water and air are all mechanical waves.

So far we have been considering motion of individual particles but in case of mechanical waves, we study the collective motion of particles. An example will help us here. If you look at a black and white picture in a newspaper with a magnifying glass, you will discover that the picture is made up of many closely spaced dots. If you do not use the magnifier, you do not see the dots. What you see is the collective effect of dots in the form of a picture. Thus what we see as mechanical wave is actually the effect of oscillations of a very large number of particles of the medium through which the wave is passing.

Do You Know?

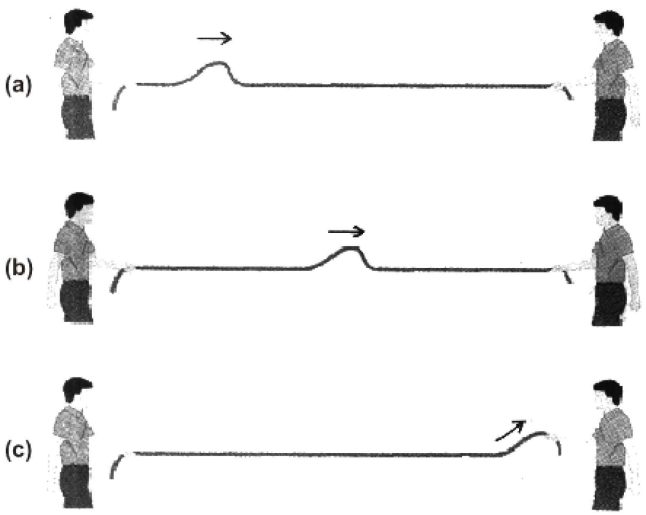
Ultrasonic waves are particularly useful for undersea communication and detection systems. High frequency radio waves, used in radars travel just a few centimetres in water, whereas highly directional beams of ultrasonic waves can be made to travel many kilometres.

PROGRESSIVE WAVES

Drop a pebble into water. Ripples will be produced and spread out across the water. The ripples are the examples of progressive waves because they carry energy across the water surface. A wave, which transfers energy by moving away from the source of disturbance, is called a progressive or travelling wave. There are two kinds of progressive waves – transverse waves and longitudinal waves.

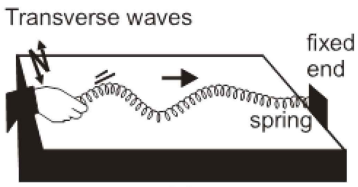
Transverse and Longitudinal Waves

Consider two persons holding opposite ends of a rope or a hosepipe. Suddenly one person gives one up and down jerk to the rope. This disturbs the rope and creates a hump in it which travels along the rope towards the other person (Figure a and b).



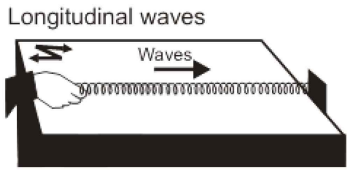
When this hump reaches the other person, it causes his hand to move up (Figure c). Thus the energy and momentum imparted to the end of the rope by the first person has reached the other end of the rope by travelling through the rope i.e., a wave has been set up on the rope in the form of a moving hump. We call this type of wave a pulse. The forward motion of the pulse from one end of the rope to the other is an example of progressive wave. The hand jerking the end of the rope is the source of the wave. The rope is the medium in which the wave moves.

A large and loose spring coil (slinky spring) can be used to demonstrate the effect of the motion of the source in generating waves in a medium. It is better that the spring is laid on a smooth table with its one end fixed so that the spring does not sag under gravity.



(a)

If the free end of the spring is vibrated from side to side, a pulse of wave having a displacement pattern shown in figure (a) will be generated which will move along the spring.



(b)

If the end of the spring is moved back and forth, along the direction of the spring itself as shown in figure (b), a wave with back and forth displacement will travel along the spring. Waves like those in figure (a) in which displacement of the spring is perpendicular to the direction of the waves are called transverse waves. Waves like those in figure (b) in which displacements are in the direction of propagation of the waves are called longitudinal waves. In this example the coil of spring is the medium, so in general we can say that

Transverse waves are those in which particles of the medium are displaced in a direction perpendicular to the direction of propagation of waves and longitudinal waves are those in which the particles of the medium have displacements along the direction of propagation of waves.

Both types of waves can be set up in solids. In fluids, however, transverse waves die out very quickly and usually cannot be produced at all. That is why, sound waves in air are longitudinal in nature.

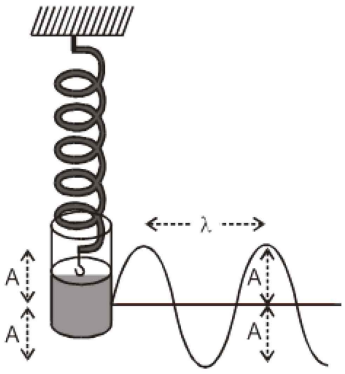
PERIODIC WAVES

Upto now we have considered wave in the form of a pulse which is set up by a single disturbance in a medium like the snapping of one end of a rope or a coil spring. Continuous, regular and rhythmic disturbances in a medium result from periodic vibrations of a source which cause periodic waves in that medium. A good example of a periodic vibrator is an oscillating mass-spring system (figure a). We have already studied in the previous chapter that the mass of such a system executes SHM.



Transverse Periodic Waves

Imagine an experiment where one end of a rope is fastened to a mass spring vibrator. As the mass vibrates up and down, we observe a transverse periodic wave travelling along the length of rope (figure b). The wave consists of crests and troughs. The crest is a pattern in which the rope is displaced above its equilibrium position, and in troughs, it has a displacement below its equilibrium position.

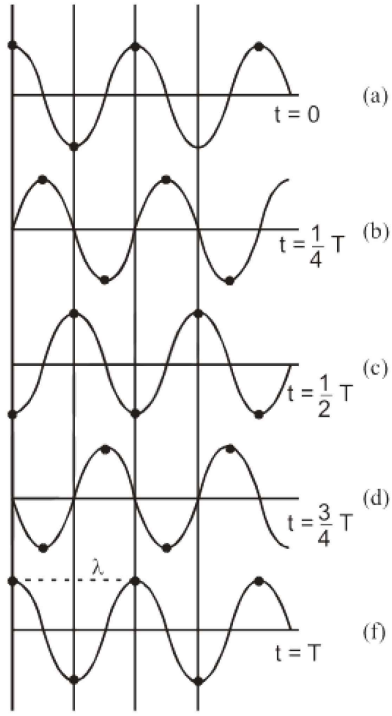


As the source executes harmonic motion up and down with amplitude A and frequency f, ideally every point along the length of the rope executes SHM in turn, with the same amplitude and frequency. The wave travels towards right as crests and troughs in turn, replace one another, but the points on the rope simply oscillates up and down. The amplitude of the wave is the maximum value of the

letter lambda λ (figure b).

In principle, the speed of the wave can be measured by timing the motion of a wave crest over a measured distance. But it is not always convenient to observe the motion of the crest. As discussed below, however, the speed of a periodic wave can be found indirectly from its frequency and wavelength.

As a wave progresses, each point in the medium oscillates periodically with the frequency and period of the source. Figure illustrates a periodic wave moving to the right, as it might look in photographic snapshots taken every 1/4 period. Follow the progress of the crest that started out from the extreme left at t = 0. The time that this crest takes to move a distance of one wavelength is equal to the time required for a point in the medium to go through one complete oscillation. That is the crest moves one wavelength λ in one period of oscillation T. The speed v of the crest is therefore,



$$v = \frac{\text{Distance moved}}{\text{Corresponding time interval}} = \frac{\lambda}{T}$$

All parts of the wave pattern move with the same speed, so the speed of any one crest is just the speed of the wave. We can therefore, say that the speed v of the waves is

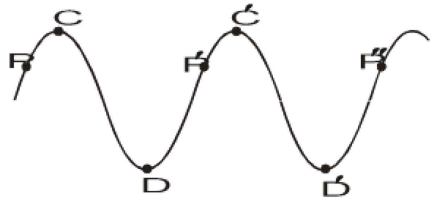
$$v = \frac{\lambda}{T} \qquad \ldots\ldots (1)$$

but $\frac{1}{T} = f$, where f is the frequency of the wave. It is the same as the frequency of the vibrator, generating the waves. Thus eq. (1) becomes

$$v = f\lambda \qquad \ldots\ldots (2)$$

Phase Relationship between Two Points on a Wave

The profile of periodic waves generated by a source executing SHM is represented by a sine curve. Figure shows the snapshot of a periodic wave passing through a medium. In this figure, set of points are shown which are moving in unison as the periodic wave passes. The points C and C′, as they move up and down, are always in the same state of vibration i.e., they always have identical displacements and velocities. Alternatively, we can say that as the wave passes, the points C and C′ move in phase. We may also say that C′ leads C by one time period of 2π radian. Any point at a distance x, C lags behind by phase angle.



$$\phi = \frac{2\pi x}{\lambda}$$

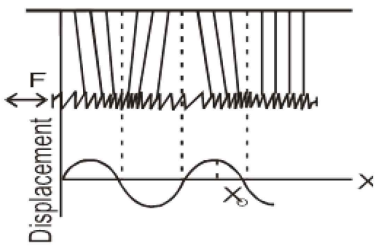
…… are all in phase with each other. These points can be anywhere along the wave and need not correspond with only the highest and lowest points. For example, points such as P, P′, P″, …… are all in phase. Each is separated from the next by a distance λ.

Some of the points are exactly out of step. For example, when point C reaches its maximum upward displacement, at the same time D reaches its maximum downward displacement. At the instant that C begins to go down, D begins to move up. Points such as these are called one half period out of phase. Any two points separated from one another by $\frac{\lambda}{2}, 3\frac{\lambda}{2}, 5\frac{\lambda}{2}, \ldots\ldots$ are out of phase.

Longitudinal Periodic Waves

In the previous section we have considered the generation of transverse periodic waves. Now we will see how the longitudinal periodic waves can be generated.

Consider a coil of spring as shown in figure. It is suspended by threads so that it can vibrate horizontally. Suppose an oscillating force F is applied to its end as indicated. The force will alternately stretch and compress the spring, thereby sending a series of stretched regions (called rarefaction) and compressions down the spring. We will see the oscillating force causes a longitudinal wave to move down the spring. This type of wave generated in springs is also called a compressional wave. Clearly in a compressional wave, the particles in the path of wave move back and forth along the line of propagation of the wave.



Notice in figure, the supporting threads would be exactly vertical if the spring were undisturbed. The disturbance passing down the spring causes displacements of the elements of the spring from their equilibrium positions. In figure, the displacements of the threads from the vertical are a direct measure of the displacements of the spring elements. It is, therefore, an easy way to graph the displacements of the spring elements from their equilibrium positions and this is done in the lower part of the figure.

Q.1 Define progressive waves with its types.

Ans. **PROGRESSIVE WAVES (TRAVELLING WAVE)**

A wave, which transfers energy in moving away from the source of disturbance, is called a progressive or travelling waves

There are two kinds of traveling waves

(i) Transverse waves.

(ii) Longitudinal waves.

(i) Transverse Waves

"Transverse waves are those in which particles of the medium are displaced in a direction perpendicular to the direction of propagation of waves."

e.g., water waves, light waves.

(ii) Longitudinal Waves (Compressional Waves)

Both types of waves can be setup in solids in liquids however, transverse waves die out very quickly and usually cannot be produced at all that is why sound waves in air one longitudinal in nature.

Periodic Waves

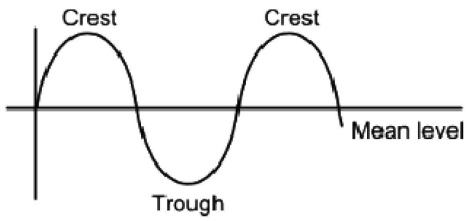
"Continuous, regular and rhythmic disturbances in a medium result from periodic vibrations of a source which cause periodic waves in that medium."

e.g., Oscillating mass–spring system.

Transverse Periodic Waves

Crest

"The portion of transverse wave above its mean position, is called crest."



Trough

"The potion of transverse wave below its mean position, is called trough."

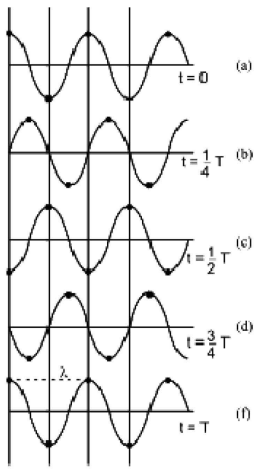
Wavelength

"The distance between any two consecutive crests or troughs, is called wave length."

It is denoted by a Greek letter Lambda (λ).

Q.2 Show that $V = \lambda f$.

Ans. The time that the crest takes to move a distance of one wave length is equal to the time required for a point in the medium to complete one oscillation i.e., crest moves one wave length 'λ' in one period of oscillation 'T', the speed 'V of the crest (wave) is



$$\text{As,} \quad V = \frac{\text{Distance moved}}{\text{Corresponding time interval}}$$

$$\therefore \quad V = \frac{\lambda}{T} \quad \left(\begin{matrix} S = V t \\ V = \frac{S}{t} \end{matrix} \right)$$

$$\text{Since,} \quad \frac{1}{T} = f$$

$$\therefore \quad V = \lambda f$$

Which is the relation between speed, frequency and wavelength.

Longitudinal Periodic Waves

"The portion of longitudinal wave where particles of medium are very close to each other is called compression."

Rarefaction

"The portion of longitudinal wave where particles of medium are far apart from each other is called rarefaction."

Q.3 Explain Newton's formula for the speed of sound in air.

Ans. SPEED OF SOUND IN AIR

(i) Newton's Formula for Speed of Sound in Air

When one particle of the medium is disturbed, the disturbance in the form of wave travel in all directions in the medium. The velocity of disturbance depends upon the density and the elasticity of the medium. The lighter the density of the medium, more quickly the disturbance moves from point to point and similarly greater the elasticity of the medium, more quickly disturbance will be propogated from point to point in the medium. Newton proposed the following formula for the velocity of sound through the materials which is as follows:

$$V = \sqrt{\frac{E}{\rho}} = \sqrt{\frac{\text{Elasticity}}{\text{Density}}}$$

Where $\in$ is the elasticity of the medium and ρ is the density.

Newton assumed that when a sound wave travels through air, the temperature of the air during compression remains constant and pressure changes from P to $(P + \Delta P)$ and therefore, the volume changes from V to $(V - \Delta V)$. According to Boyle's law

$$PV = (P + \Delta P)(V - \Delta V)$$

or $$PV = PV - P\Delta V + V\Delta P - \Delta P\Delta V$$

The product $\Delta P\Delta V$ is very small and can be neglected. So, the above equation becomes:

$$0 = -P\Delta V + V\Delta P$$

$$P = \frac{V\Delta P}{\Delta V}$$

$$P = \frac{\Delta P}{\frac{\Delta V}{V}}$$

Speed of sound in different media

Medium	Speed ms^{-1}
Solids at 20°C	
Lead	1320
Copper	3600
Aluminium	5100
Iron	5130
Glass	5500
Liquids at 20°C	
Methanol	1120
Water	1483
Gasses of S.T.P.	
Carbon dioxide	258
Oxygen	315
Air	332
Helium	972

$$\frac{\Delta V}{V} = \text{Volume strain}$$

$$P = \frac{\text{Stress}}{\text{Volume strain}} = \text{Elasticity}$$

The above equation becomes:

$$V = \sqrt{\frac{E}{\rho}} = \sqrt{\frac{P}{\rho}}$$

On substituting the values of atmospheric pressure and density of air at S.T.P. in above equation, we find that the speed of sound waves in air comes out to be 280 ms^{-1}, whereas its experimental value is 332 ms^{-1}.

Q.4 How laplace correct the speed of sound in air?

Ans. **LAPLACE CORRECTION FOR VELOCITY OF SOUND IN AIR**

The sound waves travel in the form of compressions and rarefactions. The compressions and rarefactions are so rapid, the temperature of air does not remain constant. The temperature increases due to compressions and the temperature decreases due to the rarefactions. Therefore during compression the air does not lose heat due to conduction and during rarefaction it does not gain heat. Thus the temperature throughout the medium does not remain constant. The relation between volume and pressure (PV = Constant) is not true but it is given as

$$PV^{\gamma} = \text{Constant}$$

Where γ is constant and its value depends upon the nature of the gas where

$$\gamma = \frac{\text{Molar specific heat at constant pressure}}{\text{Molar specific heat at constant volume}}$$

If 'P' be the pressure then the change in pressure is very small which is P + ΔP therefore volume decreases from V to V – ΔV then

$$PV^{\gamma} = (P + \Delta P)(V - \Delta V)^{\gamma}$$

$$PV^{\gamma} = (P + \Delta P)V^{\gamma}\left(1 - \frac{\Delta V}{V}\right)^{\gamma}$$

Applying Binomial theorem:

$$P = (P + \Delta P)\left(1 - \gamma\frac{\Delta V}{V}\right)$$

or $$P = P - \gamma P\frac{\Delta V}{V} + \Delta P - \gamma\Delta P\frac{\Delta V}{V}$$

Where $\left(\gamma\Delta P\frac{\Delta V}{V}\right)$ is negligible. Hence, we have

For Your Information	
Values of Constant	
Types of gas	**γ**
Monoatomic	1.67
Diatomic	1.40
Polyatomic	1.29

For Your Information	
Ranges of Hearing	
Organisms	**Frequencies (Hz)**

Cat	60 – 70,000
Dog	15 – 50,000
Human	20 – 20,000

or $$\frac{\frac{\Delta P}{\Delta V}}{V} = \gamma P = E$$

Therefore

$$V = \sqrt{\frac{E}{\rho}}$$

$$V = \sqrt{\frac{\gamma P}{\rho}}$$

On substituting the value of atmospheric pressure and γ then the speed of the sound is 333 m/s. This value of speed of sound is very close to the experimental value. Thus the laplace correction must therefore be correct.

Q.5 What is effect of variation of pressure on the speed of sound?

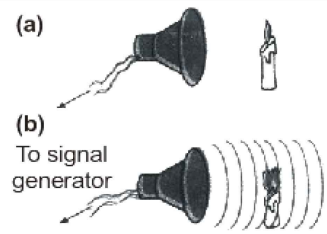
Ans. **EFFECT OF PRESSURE ON SPEED OF SOUND**

As, $$V = \sqrt{\frac{\gamma P}{\rho}}$$

$$\left(\begin{array}{l} \rho = \frac{m}{V} \\ P \rightarrow \text{increase} \\ V \rightarrow \text{decreases} \\ \rho \rightarrow \text{increase} \\ \because\ P \propto \rho \end{array}\right)$$

Since density is proportional to the pressure so the speed of sound is not affected by the variation in pressure of the gas.

Tidbits



Sound waves cause the candle flame to flicker.

Q.6 What is effect of density on the speed of sound?

Ans. **EFFECT OF DENSITY ON SPEED OF SOUND**

As, $$V = \sqrt{\frac{\gamma P}{\rho}}$$

At the same temperature and pressure for the gases having the same value of γ, the velocity is inversely proportional to the square root of their density.

i.e., $$V \propto \frac{1}{\sqrt{\rho}}$$

Note: *Speed of sound in hydrogen is four times its speed in oxygen as density of the oxygen is sixteen times that of the hydrogen.*

Q.7 What is the effect of temperature on the speed of sound in air?

Ans. **EFFECT OF TEMPERATURE ON SPEED OF SOUND**

When a gas is heated at constant pressure, its volume is increased and hence, its density is decreased.

Let, V_0 = Speed of sound at 0^oC , ρ_0 = Density of gas at 0^oC

V_t = Speed of sound at t^oC , ρ_t = Density of gas at t^oC

then, $$V_0 = \sqrt{\frac{\gamma P}{\rho_0}} \quad \ldots\ldots\ldots (1)$$

and $$V_t = \sqrt{\frac{\gamma P}{\rho_t}} \quad \ldots\ldots\ldots (2)$$

Dividing equation (2) by (1)

$$\frac{V_t}{V_0} = \sqrt{\frac{\gamma P/\rho_t}{\gamma P/\rho_0}}$$

$$\frac{V_t}{V_0} = \frac{\sqrt{\gamma P}}{\sqrt{\rho_t}} \times \frac{\sqrt{\rho_0}}{\sqrt{\gamma P}}$$

$$\frac{V_t}{V_0} = \frac{\sqrt{\rho_0}}{\sqrt{\rho_t}}$$

$$\frac{V_t}{V_0} = \frac{\sqrt{\rho_0}}{\sqrt{\rho_t}} \quad \ldots\ldots\ldots (3)$$

If V_0 is the volume of a gas at temperature 0^oC and V_t is volume at t^oC, then by using volume expansion.

$$V_t = V_0 (1 + \beta t)$$

Where β is the coefficient of volume expansion of the gas. For all gases, its value is about $\frac{1}{273}$.

Hence, $$V_t = V_0\left(1 + \frac{t}{273}\right)$$

As $$\rho = \frac{m}{V}$$

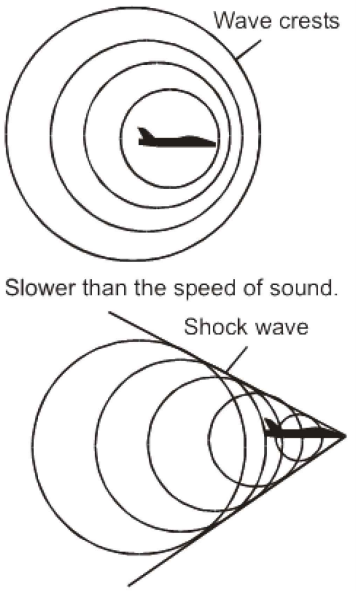
$$\text{Volume} = \frac{\text{Mass}}{\text{Density}}$$

$$V = \frac{m}{\rho}$$

$$\frac{m}{\rho_t} = \frac{m}{\rho_0}\left(1 + \frac{t}{273}\right)$$

$$\frac{1}{\rho_t} = \frac{1}{\rho_0}\left(1 + \frac{t}{273}\right)$$

Do You Know?



What happens when a jet plane like Concorde flies faster than the speed of sound?
A conical surface of concentrated sound energy sweeps over the ground as a supersonic plane passes overhead. It is known as sonic boom.

$$V_t - V_o \propto V, t$$

$$V_t - V_o = \beta V_o t$$

$$V_t = V_o + \beta V_o t$$

$$= V_o(1 + \beta t)$$

$$\frac{V_t}{V_0} = \sqrt{\frac{\rho_t\left(1+\frac{t}{273}\right)}{\rho_t}}$$

$$\frac{V_t}{V_0} = \sqrt{1+\frac{t}{273}} \qquad \ldots\ldots\ldots (4)$$

$$\frac{V_t}{V_0} = \sqrt{\frac{273+t}{273}}$$

$$\frac{V_t}{V_0} = \sqrt{\frac{T}{T_0}}$$

Where T and T_0 are the absolute temperature. Corresponding to 5°C and 0°C respectively. Thus the speed of sound is directly proportional to the square root of the absolute temperature.

Now, using Binomial theorem and neglecting high power, we have, eq. (4) as:

$$\frac{V_t}{V_0} = \left(1+\frac{t}{273}\right)^{1/2}$$

$$\frac{V_t}{V_0} = 1+\frac{1}{2}\left(\frac{t}{273}\right)$$

$$\frac{V_t}{V_0} = \left(1+\frac{t}{546}\right)$$

$$V_t = V_0+\frac{V_0\, t}{546}$$

As, $V_0 = 332$ m/s

Putting the value in the 2nd factor,

$$V_t = V_0+\frac{332}{546}t$$

$$V_t = V_0 + 0.61\ t$$

This shows that one degree Celsius rise in temperature produces approximately 0.61 m/s (61 cm/s) increase in the speed of sound.

Q.8 State the principle of superposition.

Ans. PRINCIPLE OF SUPERPOSITION

So far, we have considered single waves. What happens when two waves encounter each other in the same medium? Suppose two waves approach each other on a coil of spring, one travelling towards the right and the other travelling towards left. Figure shows that you would see happening on the spring. The waves pass through each other without being modified. After the encounter, each wave shape looks just as it did before and is travelling along just as it was before.

This phenomenon of passing through each other unchanged can be observed with all types of waves. You can easily see that it is true for surface ripples.

But what is going on during the time when the two waves overlap? Figure (c) shows that the displacements they produce just add up. At each instant, the spring's displacement at any point in the overlap region is just the sum of the displacements that would be caused by each of the two waves separately.

Thus, if a particle of a medium is simultaneously acted upon by n waves such that its displacement due to each of the individual n waves be y_1, y_2, ……, y_n, then the resultant displacement of the particle, under the simultaneous action of these n waves is the algebraic sum of all the displacements i.e.,

$$Y = y_1 + y_2 + \ldots\ldots + y_n$$

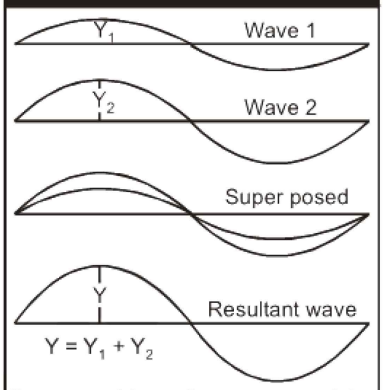
This is called principle of superposition.

Again, if two waves which cross each other have opposite phase, their resultant displacement will be

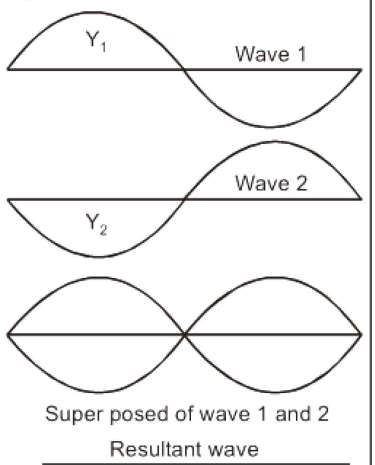
$$Y = y_1 - y_2$$

Particularly if $y_1 = y_2$ then result displacement $Y = 0$. Principle of superposition leads to many interesting phenomena with waves.

For Your Information



Superposition of two waves of the same frequency which are exactly in phase.



Superposition of two waves of the same frequency which are exactly out of phase.

(i) Two waves having same frequency and travelling in the same direction (Interference).

(ii) Two waves of slightly different frequencies and travelling in the same direction (Beats).

(iii) Two waves of equal frequency travelling in opposite direction (Stationary waves).

Q.9 State and explain the phenomenon of interference of sound.

Ans. INTERFERENCE

"Superposition of two waves having the same frequency and traveling in the same direction results in a phenomenon, called interference." There are two types:

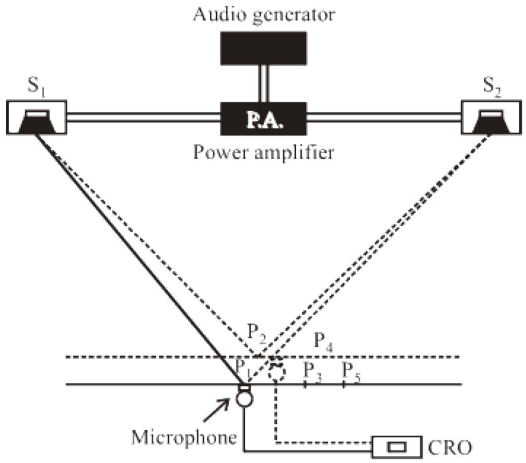


Fig. (a)

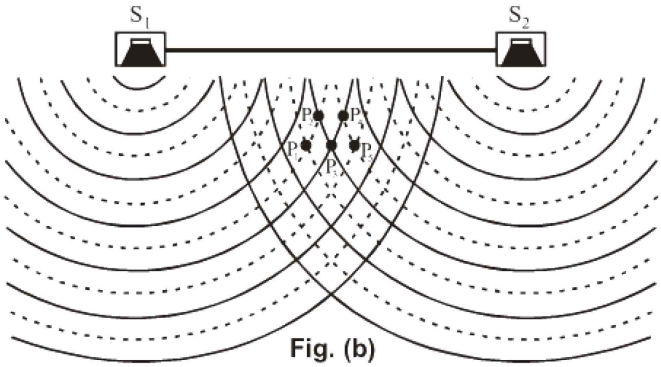


Fig. (b)

(i) Constructive Interference

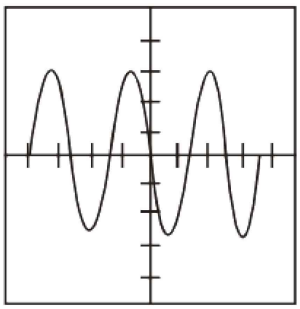
"If two waves arrive at a point in phase i.e., compression of one wave falls on compression on other wave and rarefaction of one wave falls on the rarefaction of other wave, then resultant sound is loudest."

or Whenever path difference is an integral multiple of wavelength the two waves are added up. This effect is called constructive interference.

∴ Condition for constructive interference can be written as

$$\Delta S = n\lambda$$

where $n = \pm 1, \pm 2, \pm 3, \ldots\ldots$


Fig. (c)
Constructive interference
Large displacement is displayed on the CRO screen

(ii) Destructive Interference

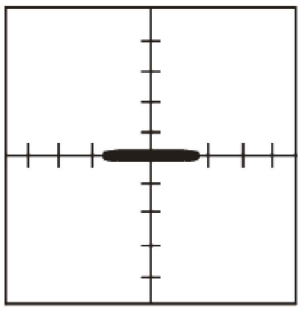
"If two waves reach a point out of phase i.e., compression of one wave falls on the rarefaction of other wave and rarefaction of one wave falls on the compression of other wave, then resultant sound will be minimum."

or At points where displacements of two waves cancel each other's effect, the path difference is an odd integral multiple of half the wavelength. This effect is called destructive interference.

Condition for destructive interference is

$$\Delta S = (2n + 1)\frac{\lambda}{2}$$

where $n = 0, \pm 1, \pm 2, \ldots\ldots$


Fig. (d)
Destructive interference
Zero displacement is displayed on the CRO screen

Explanation

An experimental set up to observe interference effect in sound waves as shown in figure.

Two loud speakers S_1 and S_2 act as two sources of harmonic sound waves of a fixed frequency

screen. The microphone is placed at various points, turn by turn, infront of the loud speakers as shown in the figure.

At points P_1, P_3 and P_5, we find that compressions met with compressions and rarefactions. So, the displacement of the two waves are added up at these points and large resultant displacement is produced. At points P_2 and P_4, compressions met with rarefactions so they cancel each other effect. The resultant displacement becomes zero. Now we have to find the path difference between the waves at point P_1 is

$$\Delta S = S_2P_1 - S_1P_1$$

$$\Delta S = 4\frac{1}{2}\lambda - 3\frac{1}{2}\lambda = \lambda$$

But $\Delta S = n\lambda$

For constructive interference.

Where n = 0, 1, 2, 3, ……

For destructive interference

$$\Delta S = S_2P_2 - S_1P_2$$

$$\Delta S = 4\lambda - 3\frac{1}{2}\lambda = \frac{1}{2}\lambda$$

So, $\Delta S = \left(n + \frac{1}{2}\right)\lambda$

Where n = 0, 1, 2, 3, ……

Q.10 What are beats? How they are produced? Show that the number of beats is equal to the difference between the frequencies of the tuning forks.

Ans. **BEATS**

Beat is the combined effect of two sound waves having frequencies slightly different from each other.

Consider two tuning forks each having frequency 32 cps. Slightly load (with wax or ring) one tuning fork so that frequency decreases a little. Let the frequency becomes 30 cps. The two tuning forks are sounded together and held at equal distance from the ear. Let at t = 0, the two forks are in phase. i.e., their right prongs moves towards right producing compressions at the same time and louder sound is heard by the listener.

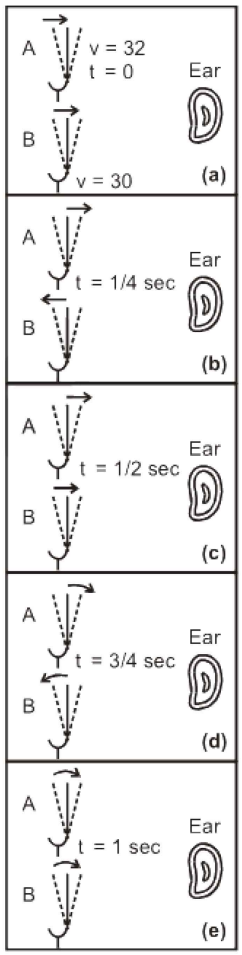
With passage of time, the tuning fork B (30 cps) begins to fall behind 'A'.

At $t = \frac{1}{4}$ sec, 'A' has completed 8 vib and 'B' has completed $7\frac{1}{2}$ vib. The prongs are now out of phase and no sound is heard due to destructive interference.

At $t = \frac{1}{2}$ sec, 'A' has completed 16 vib and 'B' completes 15 vib. The prongs of forks become in phase and louder sound is heard. At $t = \frac{3}{4}$ sec, 'A' has completed 24 vib while 'B' completes $22\frac{1}{2}$ vib. The prongs are now in opposite phase and once again no sound is heard.

At t = 1 sec, both forks have completed 32 vib and 30 vib. The prongs become in phase and max or louder sound is heard.

It is observed that in 1 sec, the sound falls in intensity twice. The sudden fall of sound in intensity is known as beat. Thus two beats are produced/sec which is equal to the difference in frequencies of two forks (32 – 30 = 2).



Definition of Beats

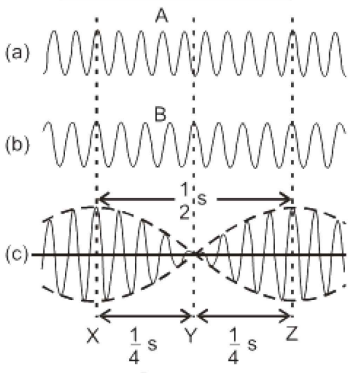
The periodic alteration of sound between maximum and minimum loudness as many times a second as the difference in frequencies is called phenomenon of beats.

$$\boxed{\text{No of beats/sec} = \text{Difference in frequencies}}$$

$$\pm n = f_A - f_B$$

Graphical Explanation of Beats

The displacements of the particles of the medium due to two waves are plotted separately as function of time. The resultant displacement of any particle will be the sum of the displacement due to each of the two waves. The resultant wave which is produced in shown in figure (c). It is seen that amplitude of resultant waves changes with time. The change in amplitude gives rise to production of beat.



Formation of Beats

Uses of Phenomenon of Beats

The phenomenon of beats is used to find out:

(i) Unknown frequency

(ii) To tune a musical instrument

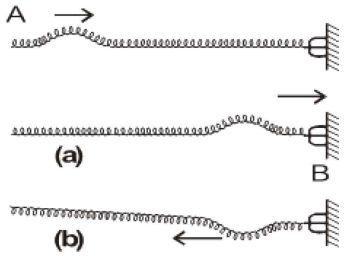
Q.11 Write a note on reflection of waves.

Ans. **REFLECTION OF WAVES**

In an extensivemedium, a wave travels in all direction from its source with a velocity depending upon the properties of the medium. However, when the wave comes across the boundary of two media, a part of it is reflected back. The reflected wave has the same wavelength and frequency but its phase may

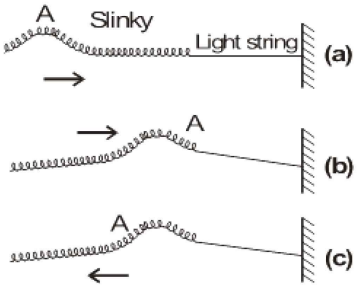
Now we will discuss two most common cases of reflection at the boundary. These cases will be explained with the help of waves travelling in slinky spring. (A slinky spring is a loose spring which has small initial length but a relatively large extended length).

One end of the slinky spring is tied to a rigid support on a smooth horizontal table. When a sharp jerk is given up to the free end of the slinky spring towards the side A, a displacement or a crest will travel from free end to the boundary (Figure a). It will exert a force on bound end towards the side A. Since this end is rigidly bound and acts as a denser medium, It will exert a reaction force on the spring in opposite direction. This force will produce displacement towards B and a trough will travel backwards along the spring (Figure b).



From the above discussion it can be concluded that whenever a transverse wave, travelling in a rarer medium, encounters a denser medium, it bounces back such that the direction of its displacement is reversed. An incident crest on reflection becomes a trough.

This experiment is repeated with a little variation by attaching one end of a light string to a slinky spring and the other end to the rigid support as shown in figure. If now the spring is given a sharp jerk towards A, a crest travels along the spring as shown in figure. When this crest reaches the spring-string boundary, it exert a force on the string towards the side it does not oppose the motion of the spring. The end of the spring, therefore, continues its displacement towards A. The spring behaves as if it has been plucked up. In other words a spring crest is again created at the boundary of the spring-string system, which travels backwards along the spring. From this it can be concluded that when a transverse wave travelling in a denser medium, is reflected from the **boundary of a rarer** medium, the direction of its displacement remains the same. An incident crest is reflected as a crest. We are already familiar with the fact that the direction of displacement is reversed when there is change of 180° in the phase of vibration. So, the above conclusion can be written as follows:



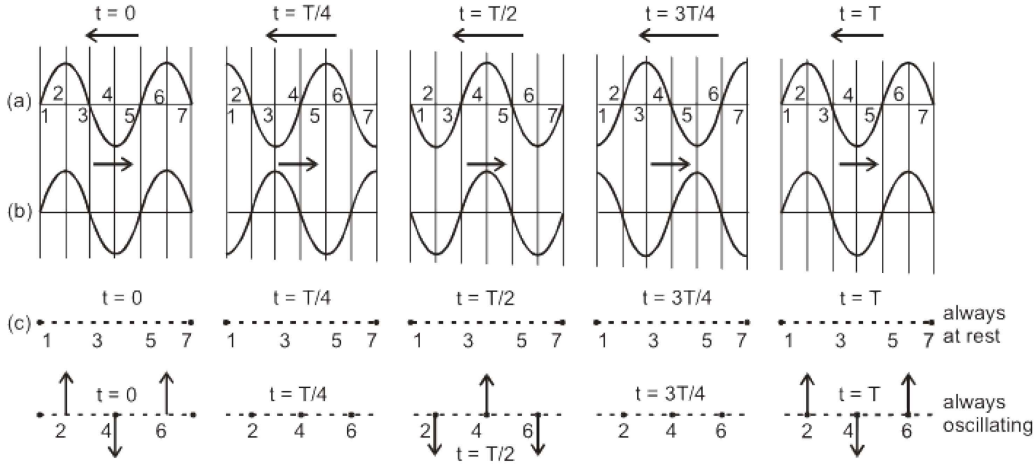
(i) If a transverse wave travelling in a rarer medium is incident on a denser medium, it is reflected such that it undergoes a phase change of 180°.

(ii) If a transverse wave travelling in a denser medium is incident on a rarer medium, it is reflected without any change in phase.

Q.12 What are stationary waves? How they one produced? Define node and anti-node.

Ans. **STATIONARY WAVES**

Now let us consider the superposition of two waves moving along a string in opposite directions. Figure (a, b) shows the profile of two such waves at instants = 0, T/4, 3/4 T and T, where T is the time period of the wave. We are interested in finding out the displacements of the points 1, 2, 3, 4, 5, 6 and 7 at these instants as the waves superpose. From the figure (a, b), it is obvious that the points 1, 2, 3, etc.,



are distant $\lambda/4$ apart, λ being the wavelength of the waves. We can determine the resultant displacement of these points by applying the principle of superposition. Figure (c) shows the resultant displacement of the points 1, 3, 5 and 7 at the instants t = 0, T/4, T/2, 3T/4 and T. It can be seen that the resultant displacement of these points is always zero. These points of the medium are known as nodes. Figure (c) shows that the distance between two consecutive nodes is $\lambda/2$. Figure (d) shows the resultant displacement of the points 2, 4 and 6 at the instant t = 0, T/4, T/2, 3T/4 and T. The figure shows that these points are moving with an amplitude which is the sum of the amplitudes of the component waves. These points are known as antinodes. They are situated midway between the nodes and are also $\lambda/2$ apart. The distance between a node and the next antinode is $\lambda/4$. Such a pattern of nodes and antinodes is known as a stationary or standing wave.

Energy in a wave moves because of the motion of the particles of the medium. The nodes always remain at rest, so energy cannot flow past these points. Hence energy remains "standing" in the medium between nodes, although it alternates between potential and kinetic forms. When the antinodes are all at their extreme displacements, the energy stored is wholly potential and when they are simultaneously passing through their equilibrium positions, the energy is wholly kinetic.

An easy way to generate a stationary wave is to superpose a wave travelling down a string with its reflection travelling in opposite direction as explained in the next section.

Q.13 Explain the stationary waves in a stretched string. Also calculate the frequencies.

Ans. **STATIONARY WAVES IN A STRETCHED STRING**

Consider a string of length '*l*' which is kept stretched by clamping its ends so that the tension in the string is F. If the string is plucked at its middle point, two transverse waves will originate from this point. One of them will move towards the left end of the string and the other towards the right end. When these waves reach the two clamped ends, they are reflected back, thus giving rise to stationary waves. The string will vibrate with such a frequency f_1, so that nodes are formed at two fixed ends (clamped ends) and anti-nodes between them. Thus the string vibrates in one loop as shown in Fig.

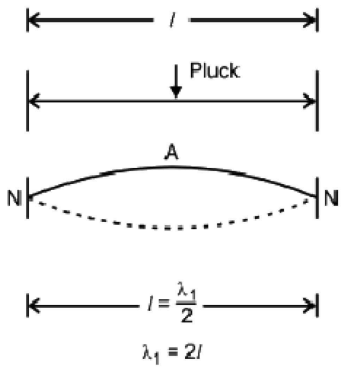
If λ_1 is the wavelength of this mode of vibration (1st mode of vibration) so,

As $l = \frac{\lambda_1}{2}$

$\lambda_1 = 2l$ ..... (i)

$V = \lambda f$

$f_1 = \frac{V}{\lambda_1}$



Putting value of λ_1.

$\therefore \quad f_1 = \frac{V}{2l}$ ..... (ii)

The speed 'V' of the waves in the string depends upon the tension F of the string and mass per unit length of the string. It is given by

$V = \sqrt{\frac{F}{m}}$

$\therefore \quad f_1 = \frac{\sqrt{F/m}}{2l}$

$f_1 = \frac{1}{2l}\sqrt{\frac{F}{m}}$ ..... (iii)

If the string is plucked from $\frac{1}{4}$ of its length, then again stationary waves will be set up, but now the string vibrate in two loops with f_2. If λ_2 is wave length in this case then,

As, $l = \frac{\lambda_2}{2} + \frac{\lambda_2}{2}$

$l = \frac{\lambda_2 + \lambda_2}{2}$

$l = \frac{2\lambda_2}{2}$

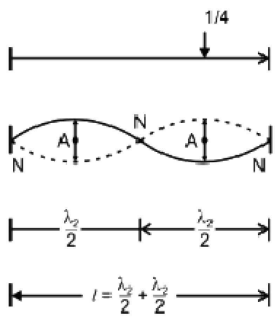
$l = \lambda_2$

$\therefore \quad f_2 = \frac{V}{\lambda_2}$

Putting value of λ_2

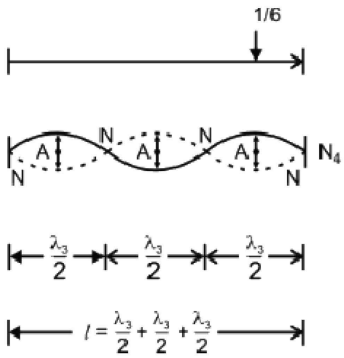
$\therefore \quad f_2 = 2\left(\frac{V}{2l}\right)$

$f_2 = 2f_1$



This shows that when string vibrates in two loops, its frequency is doubled and wave length becomes half than it vibrates in one loop.

Similarly if the string is plucked from $\frac{1}{6}$th of its length, it vibrates in three loops as shown in figure.



As $l = \frac{\lambda_3}{2} + \frac{\lambda_3}{2} + \frac{\lambda_3}{2}$

$l = 3\frac{\lambda_3}{2}$

$\lambda_3 = \frac{2l}{3}$

$\therefore \quad f_3 = \frac{V}{\lambda_3}$

Putting value of λ_3

$f_3 = \frac{V}{2l/3}$

$f_3 = 3\left(\frac{V}{2l}\right)$

$f_3 = 3f_1$

It means that when string vibrates in three loops, its frequency is three times the frequency when it vibrates in one loop.

Thus we can generalize that if the string is made to vibrate in 'n' loop, then

$f_n = nf_1$

and wave length is;

$\lambda_n = \frac{2l}{n}$

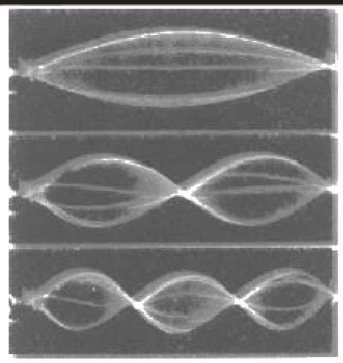
where n = 1, 2, 3, ……

It is clear that as the string vibrates in more and more loops, its frequency goes on increasing and the wave length gets shorter. However the product of frequency and wave length is always equal to V, (speed of the wave).

The above discussion clearly establishes that the stationary waves have a discrete set of frequencies f_1, $2f_1$, $3f_1$, ……, n f_1 which is known as harmonic series. The fundamental frequency 'f_1' is called first harmonic (over tone), 'f_2' is called second harmonic (over tone), and so on.

Note: *The frequency of a string on a musical instrument can be changed either by varying the tension or by changing the length. For example the tension in guitar and violin strings is*

Do You Know?



A standing-wave pattern is formed when the length of the string is an integral multiple of half wavelength; otherwise no standing wave is formed.

For Your Information



In an organ pipe, the primary driving mechanism is wavering,

Q.14 Describe the stationary waves in air column.

Ans. **STATIONARY WAVES IN AIR COLUMNS**

Stationary waves can be set in other media also, such as air column. A common example of vibrating air column is in the organ pipe. The relationship between the incident wave and the reflected wave depends on whether the reflecting end of the pipe is open or closed. If the reflecting end is open, the air molecules have complete freedom of motion and this behaves as an antinode. If the reflecting end is closed, then it behaves as a node because the movement of the molecules is restricted. The modes of vibration of an air column in a pipe open at both ends are shown in figure.

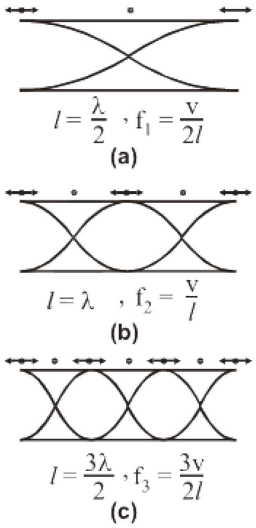


Fig. Stationary longitudinal waves in a pipe open at both ends.

In figure, the longitudinal waves set up in the pipe have been represented by transverse curved lines indicating the varying amplitude of vibration of the air particles at points along the axis of the pipe. However, it must be kept in mind that air vibrations are longitudinal along the length of the pipe. The wavelength 'λ_n' of nth harmonic and its frequency 'f_n' of any harmonic is given by

$$\lambda_n = \frac{2l}{n} \quad , \quad f_n = \frac{v}{\lambda_n} = \frac{nv}{2l} \quad \ldots\ldots (1)$$

$$n = 1, 2, 3, 4, \ldots\ldots$$

where 'v' is the speed of sound in air and 'l' is the length of the pipe. The equation (10 can also be written as

$$f_n = nf_1 \quad \ldots\ldots (2)$$

If a pipe is closed at one end and open at the other, the closed end is a node. The modes of vibration in this case are shown in figure.

In case of fundamental note, the distance between a node and antinode is one fourth of the wavelength,

Hence, $l = \frac{\lambda_1}{4}$ or $\lambda_1 = 4l$

Since $v = f\lambda$

Hence, $f_1 = \frac{v}{\lambda_1} = \frac{v}{4l}$

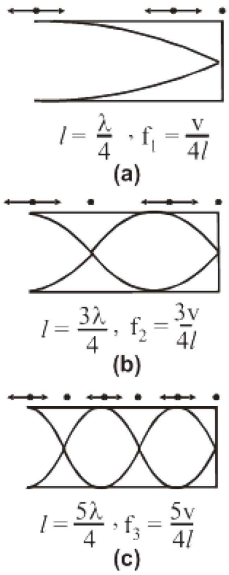


Fig. Stationary longitudinal waves in a pipe closed at one end. Only odd harmonics are present.

It can be proved that in a pipe closed at one end, only odd harmonics are generated, which are given by the equation.

$$f_n = \frac{nv}{4l} \quad \ldots\ldots (3)$$

where $n = 1, 3, 5, \ldots\ldots$

This shows that the pipe, which is open at both ends, is richer in harmonics.

In 1st mode

$$l = \frac{2\lambda_1}{4}$$

$$l = \frac{\lambda_1}{2}$$

$$\lambda_1 = 2l$$

As, $V = \lambda f$

$$f_1 = \frac{V}{\lambda_1}$$

Putting value of 'λ_1',

$$\therefore \quad f_1 = \frac{V}{2l}$$

In 2nd mode

$$l = \frac{\lambda_2 + 2\lambda_2 + \lambda_2}{4}$$

$$l = \frac{4\lambda_2}{4}$$

$$l = \lambda_2$$

$$\therefore \quad f_2 = \frac{V}{l}$$

Multiply and divided by (2).

$$f_2 = 2\left(\frac{V}{2l}\right)$$

In 3rd mode

$$l = \frac{\lambda_3 + 2\lambda_3 + 2\lambda_3 + \lambda_3}{4}$$

$$l = \frac{6\lambda_3}{4}$$

$$l = \frac{3\lambda_3}{2}$$

$$l = \frac{2l}{3}$$

As, $f_3 = \frac{V}{\lambda_3}$

Putting value of λ_3

$$\therefore \quad f_3 = \frac{V}{2l/3}$$

$$f_3 = 3\left(\frac{V}{2l}\right)$$

Case II

When pipe is open at one end and closed at other end.

In 1st mode

$$\lambda_1 = 4l$$

$$f_1 = \frac{V}{\lambda_1}$$

Putting value of λ_1

$$f_1 = \frac{V}{4l}$$

In 2nd mode

$$l = \frac{\lambda_2}{4} + \frac{\lambda_2}{2}$$

$$l = \frac{\lambda_2 + 2\lambda_2}{4}$$

$$l = \frac{3\lambda_2}{4}$$

$$\lambda_2 = \frac{4l}{3}$$

$$f = \frac{V}{\lambda_2}$$

Putting value of λ_2

$$f_3 = \frac{V}{4l/3}$$

$$f_3 = \frac{3V}{4l}$$

$$f_3 = 3(f_1)$$

We can generalize,

$$\therefore \quad f_n = \frac{n\,V}{4l}$$

where n = 1, 3, 5, ……

Interesting Information



Echolocation allows dolphins to detect small differences in the shape, size and thickness of objects.

Note: *The pipe which is open at both ends is richer in harmonics.*

Q.15 What is Doppler effect? Describe expression for apparently changed frequency when the observer is at rest while the source is in motion. (OR) What is Doppler effect? Describe the expression for apparently changed frequency when the observer is in motion while source is at rest.

Ans. DOPPLER EFFECT

Introduction

This effect was observed by Johann Doppler while he was observing the frequency of light emitted from distant stars. In some cases the frequency of light emitted from a star was found to be

Definition

"The apparent change in the pitch OR frequency of a source of sound, when there is a relative motion between the source of sound and the observer, is called Doppler effect."

For example, when an observer is standing on a railway platform, the pitch of the whistle of a approaching train is heard to be higher. But when the same train moves away, the pitch of the whistle becomes lower.

Explanation

Suppose 'V' is the velocity of the sound in a medium and a source emits a sound of frequency 'f' and wave length 'λ'. If both the source and the observer are stationary, then the waves received by the observer in one second are;

$$f = \frac{V}{\lambda}$$

Case-A

When observer 'O' is moving towards a stationary source 'S'

If an observer ('O') moves towards, a source 'S' with velocity U_0, the relative velocity of the waves and the observer is increased to $(V + U_0)$, then number of waves received in one second apparent frequency increases

$$f_A = \frac{V}{\lambda}$$

Putting the value

$$f_A = \frac{V + U_0}{V/f} \quad \left(\because \lambda = \frac{V}{f}\right)$$

$$f_A = \left(\frac{V + U_0}{V}\right) f$$

Hence, $\frac{V + U_0}{V} > 1$

$\therefore$ $f_A > f$

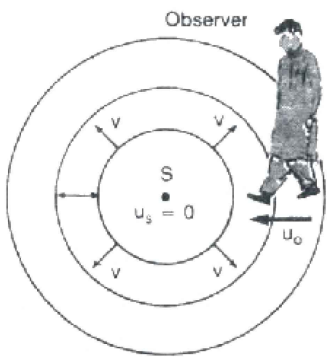


Fig. An observer moving with velocity u_o towards a stationary source hears a frequency f_A that is greater than the source frequency.

This means that when an observer 'O' is moving towards a stationary source S, the frequency of sound increases.

Case-B

When observer 'O' moves away from a stationary source S

When observer 'O' moves away from stationary source 'S' with velocity 'U_0,' then relative velocity of sound waves and the observer is, $(V - U_0)$, hence, number of waves received by the observer, per–second are reduced and is given by

$$f_B = \frac{V - U_0}{\lambda}$$

Putting value of

$$\lambda = \frac{V}{f}$$

$$\therefore \quad f_B = \frac{V - U_0}{V/f}$$

$$f_B = \left(\frac{V - U_0}{V}\right) f$$

As, $\quad \frac{V - U_0}{V} < 1$

$$\therefore \quad f_B < f$$

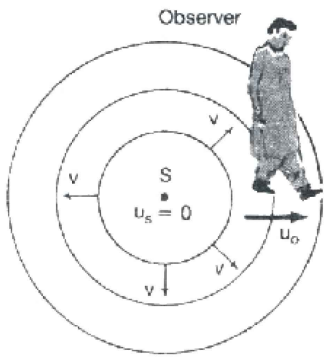


Fig. An observer moving with velocity u_o away from stationary source hears a frequency f_B that is smaller than the source frequency.

This means that when observer 'O' moves away from stationary source 'S,' the apparent frequency decreases.

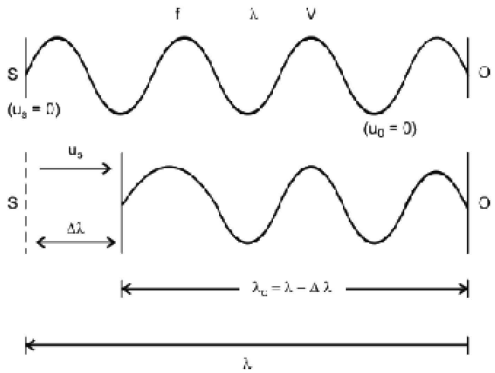
Case-C

When source 'S' is moving towards the stationary observer 'O'

If the source 'S' is moving towards the observer with velocity 'U_s' then in one second, the waves are compressed, (Wave length decreases), by an amount known as Doppler shift represented by $\Delta\lambda$.

As, $\quad V = f\lambda$

$$\Delta\lambda = \frac{U_s}{f}$$



The compression of waves is due to the fact that same number of waves are contained in a shorter space depending upon the velocity of the source.

The wave length for observer 'C' is then, $\lambda_c = \lambda - \Delta\lambda$.

Putting the values of λ and $\Delta\lambda$.

$$\therefore \quad \lambda_c = \frac{V}{f} - \frac{U_s}{f}$$

$$\lambda_c = \frac{V - U_s}{f}$$

The modified frequency for observer 'C' is

$$f_c = \frac{V}{\lambda_c}$$

Putting value of λ_c

$$\therefore \quad f_c = \frac{V}{\frac{V - U_s}{f}}$$

$$f_c = \left(\frac{V}{V - U_s}\right) f$$

As, $\quad \frac{V}{V - U_s} > 1$

$$\therefore \quad f_c > f$$

This means that the observed frequency increases when the source is moving towards the observer.

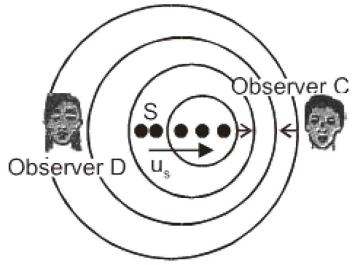


Fig. A source moving with velocity u_s towards a stationary observer C and away from stationary observer D. Observer C hears an increased and observer D hears a decreased frequency.

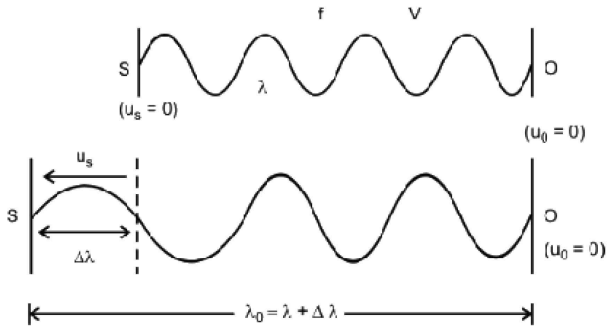
Case-D

When source 'S' is moving away from stationary observer 'O'

If the source is moving away from the observer 'O' with velocity 'U_s,' then in one second the waves are stretched (wave length increase) by an amount $\Delta\lambda$.

$$\Delta\lambda = \frac{U_s}{f}$$

The stretched of the waves is due to the fact that same number of wave are contained in larger (longer) space, depending upon the velocity of the source.



The wave length for observer 'D' is, $\lambda_D = \lambda + \Delta\lambda$.

Putting values of λ and $\Delta\lambda$.

$$\therefore \quad \lambda_D = \frac{V}{f} + \frac{U_s}{f}$$

$$\lambda_D = \frac{V + U_s}{f}$$

The modified frequency for observer 'D' will be

$$f_D = \frac{V}{\lambda_D}$$

Putting value of λ_D

$$\therefore \quad f_D = \frac{V}{\frac{V + U_s}{f}}$$

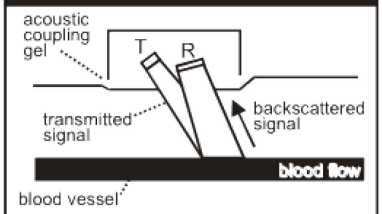
$$f_D = \left(\frac{V}{V + U_s}\right) f$$

As, $\quad \frac{V}{V + U_s} < 1$

$$\therefore \quad f_D < f$$

This means that the observed frequency decreases, when the source is moving away from the observer.

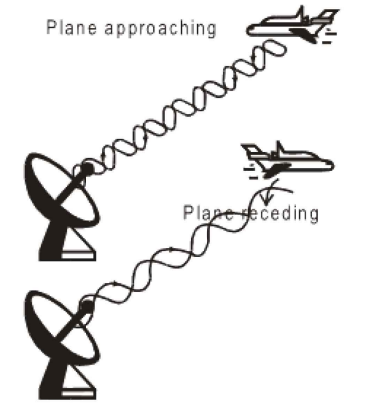
Do You Know?



The Doppler effect can be used to monitor blood flow through major arteries. Ultrasound waves of frequencies 5 MHz to 10 MHz are directed towards the artery and a receiver detects the back scattered signal. The apparent frequency depends on the velocity of flow of the blood.

Ans. APPLICATIONS OF DOPPLER EFFECT

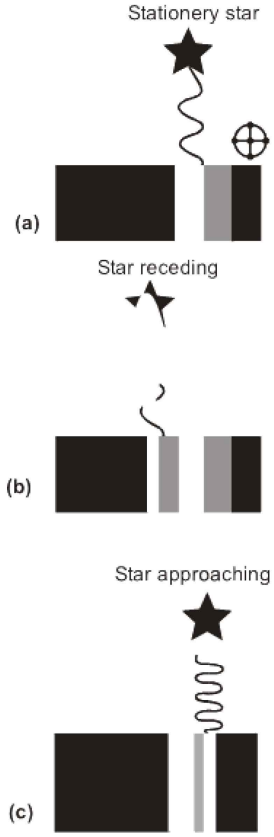
Doppler effect is applied in working of radar system. Radar uses radio waves to find the elevation and speed of an aeroplane. Radar is a device which transmits and receives radio waves. The radio waves transmitted from radar are reflected back from aeroplane and are received by radar. If the aeroplane is moving towards the radar then the wavelength of reflected wave is shorter. If the plane is moving away from the radar then the wavelength of reflected wave is longer as shown in figure.



A frequency shift is used in a radar to detect the motion of an aeroplane.

The difference of wavelength of transmitted and reflected waves is used to determine the speed of aeroplane. Term SONAR (is acronym) stands for sound navigation and ranging. Sonar is the name of the technique used for detecting the presence of objects under water by acoustical echo. In Sonar "Doppler detection" depends upon relative speed of the target and the detector. It employs. The Doppler effect in which an apparent change in frequency occurs when source and observer are in relative motion with respect to one another.

In military it is used for detection and location of submarine antisubmarine weapons and depth measurement of sea. Astronomers use Doppler effect to calculate the speeds of distant stars and galaxies. By comparing the line spectrum of light from the star with light from a laboratory source, the Doppler shift of stars light can be measured. Then speed of star can be calculated.



Doppler effect is used to determine whether a particular star or galaxy is approaching the earth or moving away from the earth. Light from the star is measured with the help of spectrometer. It has been found that stars moving towards the earth show a blue shift. Thus is because the emitted waves by the star have shorter wavelength than of the star had been at rest. So the spectrum is shifted towards shorter wavelength i.e., to the blue end of the spectrum.

It has been found that stars moving away from the earth show a red shift. This is because the emitted waves by the star have longer wavelength than of the star had been at rest. So the spectrum is shifted towards longer wavelength i.e., to the red end of the spectrum. Astronomers have discovered that all the distant galaxies are moving away from us. They have also measured their speed by measuring their red shift. Another important application of the Doppler shift using electromagnetic waves is radar speed trap. Microwaves are emitted from a transmitter in the form of short bursts. Each burst is reflected back by any moving car in the path of microwaves. The reflected microwaves are received back as Doppler's shift. By measuring Doppler shift the speed of the car can be calculated by computer programme.

Do You Know?



SOLVED EXAMPLES

EXAMPLE 8.1

Find the temperature at which the velocity of sound in air is two times its velocity at 10°C.

Data

Velocity of sound = V_t = $2\ V_{10}$

T_{10} = 10 + 273 = 283 K

To Find

Temperature = T = ?

SOLUTION

Using $\frac{V_t}{V_{10}} = \sqrt{\frac{T}{T_{10}}}$

Since $V_t = 2\ V_{10}$

$\therefore \quad \frac{2\ V_{10}}{V_{10}} = \sqrt{\frac{T}{283}}$

$\sqrt{\frac{T}{283}} = 2$

Square both sides

$\frac{T}{283} = 4$

$T = 4 \times 283$

$T = 1132$ K

or $T = 1132 - 273$

$T = 859^{o}C$

Result

Temperature = T = 859°C or 1132 K

EXAMPLE 8.2

A tuning fork A produces 4 beats per second with another tuning fork B. It is found that by loading B with some wax the beat frequency increases to 6 beats per second. If the frequency of A is 320 Hz, determine the frequency of B when loaded.

Data

Number of beats = n = 4

After loading B,

Number of beats = n' = 6

Frequency of tuning fork B = f_B = ? when loaded

SOLUTION

Using $f_A - f_B = \pm n$

$320 - f_B = \pm 4$

$f_B = 320 + 4$, $f_B = 320 - 4$

$f_B = 324$ Hz , $f_B = 316$ Hz

By loading B, its frequency will decrease. Thus if 324 Hz is original frequency the beat frequency will reduce. But in this case beat frequency increases.

$\therefore$ $f_B = 316$ Hz

After loading B,

$f_B = 316 - 2$

$f_B = 314$ Hz

Result

Frequency of fork B = 314 Hz

EXAMPLE 8.3

A steel wire hangs vertically from a fixed point, supporting a weight of 80 N at its lower end. The diameter of the wire is 0.50 mm and its length from the fixed point to the weight is 1.5 m. Calculate the fundamental frequency emitted by the wire when it is plucked?

Data

Weight of wire = W = 80 N

$\therefore$ Tension in wire = F = 80 N

Diameter of wire = d = 0.50 mm

$= 0.50 \times 10^{-3}$ m

Length of wire = l = 1.5 m

To Find

Fundamental frequency = f_1 = ?

SOLUTION

Using $f_1 = \frac{1}{2l}\sqrt{\frac{F}{m}}$

Where m = Mass per unit length

Since Volume = Area x Length

$\therefore \quad V = \pi r^2 l$

Put in (1)

$\therefore \quad m = \rho \pi r^2 l$

$$m = \rho \pi \left(\frac{d}{2}\right)^2 l$$

$\therefore$ Mass per unit length is

$$m = 7.8 \times 10^3 (3.14) \frac{(.50 \times 10^{-3})^2}{4} \times 1$$

$$= 1.53 \times 10^{-3} \text{ kg/m}$$

$$\therefore \quad f_1 = \frac{1}{2(1.5)} \sqrt{\frac{80}{1.53 \times 10^{-3}}}$$

$$f_1 = \frac{1}{3} \sqrt{\frac{80 \times 10^3}{1.53}}$$

$$f_1 = \frac{1}{3} \sqrt{\frac{80000}{1.53}}$$

$$f_1 = \frac{1}{3} \sqrt{52287.58}$$

$$f_1 = 76.22 \text{ Hz}$$

Result

Fundamental frequency = f_1 = 76.22 Hz

EXAMPLE 8.4

A pipe has a length of 1 m. determine the frequencies of the fundamental and the first two harmonics

(a) If the pipe is open at both ends.

(b) If the pipe is closed at one end.

(Speed of sound in air = 340 ms^{-1})

Data

$l = 1$ m

$V = 340 \text{ ms}^{-1}$

To Find

(a) When the pipe is open at both ends

Fundamental frequency = f_1 = ?

Next 1st harmonics = f_2 = ?

Fundamental frequency = f_1 = ?

Next 3rd harmonics = f_3 = ?

Next 5th harmonics = f_5 = ?

SOLUTION

(a) When pipe is open at both end,

Using $f_n = \frac{n\,V}{2l}$

$n = 1, 2, 3, 4, \ldots\ldots$

Here $f_1 = \frac{V}{2l}$

$f_1 = \frac{340}{2 \times 1}$

$f_1 = 170$ Hz

So, $f_2 = 2f_1$

$f_2 = 340$ Hz

$f_3 = 3f_1$

$f_3 = 510$ Hz

(b) When pipe is closed at one end and is open at the other

Using, $f_n = \frac{n\,V}{4l}$

$n = 1, 3, 5, 7, \ldots\ldots$

Here, $f_1 = \frac{V}{4l}$

$f_1 = \frac{340}{4 \times 1}$

$f_1 = 85$ Hz

and, $f_3 = 3f_1 = 3 \times 85$

$f_3 = 3f_1 = 255$ Hz

$f_5 = 5f_1 = 5 \times 85$

$f_5 = 5f_1 = 425$ Hz

Result

(a) When the pipe is open at both ends

Fundamental frequency = f_1 = 170 Hz

(b) When the pipe is closed at one end

Fundamental frequency = f_1 = 85 Hz

Next 3rd harmonics = f_3 = 255 Hz

Next 5th harmonics = f_5 = 425 Hz

EXAMPLE 8.5

A train is approaching a station at 90kmh^{-1} sounding a whistle of frequency 1000 Hz. What will be the apparent frequency of the whistle as heard by a listener sitting on the platform? What will be the apparent frequency heard by the same listener if the train moves away from the station with the same speed?

(Speed of sound = 340ms^{-1})

Data

Speed of train = U_s = 90 km/h

= 90 × 1000 m/3600s

= 25 m/s

Frequency of source = f_0 = 1000 Hz

Speed of sound = V = 340 m/s

To Find

Apparent frequency = f' = ?

Apparent frequency when train moves away from station with same speed f'' = ?

SOLUTION

When train is moving towards listener, then by using

$$f' = \left(\frac{V}{V - u_s}\right) f$$

Putting values.

$$f' = \left(\frac{340}{340 - 25}\right) \times 1000$$

$$= 1079.4 \text{ Hz.}$$

When train is moving away from listener then by using.

$$f'' = \left(\frac{V}{V - u_s}\right) f$$

Putting values.

$$f'' = \left(\frac{340}{340 + 25}\right) \times 1000$$

Result

Apparent frequency = f′ = 1079.4 Hz

Apparent frequency when train moves away from station with same speed

f″ = 931.5 Hz



WAVES

Each question has four possible answers, encircled the correct answer:

1. The mechanism in which energy is transferred from one place to another place is called:

(a) Wave motion **(b)** Wave

(c) Mechanical waves **(d)** Sound waves

2. The particle of the medium vibrates in longitudinal waves:

(a) Along the direction of wave motion **(b)** Do not vibrate at all

(c) Opposite the direction of wave motion **(d)** Perpendicular to the direction of wave motion

3. The waves which required certain medium for their propagation are called:

(a) Matter waves **(b)** Mechanical waves

(c) Water waves **(d)** Wave motion

4. The waves which do not required any medium for their propagation are called:

(a) Electromagnetic waves **(b)** Light waves

(c) X-rays **(d)** Radio waves

5. The waves associated with particles in motion are called:

(a) Light waves **(b)** Electronic waves

(c) Matter waves **(d)** Light waves

6. Electrons moving with high velocities behave like:

(a) Mechanical waves **(b)** Electronic waves

(c) Matter waves **(d)** Light waves

7. A mechanical wave is represented by:

(a) Light **(b)** Heat

(c) Compressional waves **(d)** None of the above

8. A wave which transfer energy in moving from the source of disturbance is called:

(a) Travelling waves **(b)** Matter waves

(c) Water waves **(d)** Radio waves

9. When the amplitude of the wave becomes double, its energy becomes:

(a) Four times **(b)** One half

(c) Double **(d)** Nine times

10. The speed of waves can be found indirectly from its:

(a) Frequency and time period **(b)** Frequency and wavelength

(c) Wavelength and time period **(d)** None of the above

11. Waves under ideal conditions may act as sources for transfer of:

(a) Matter only **(b)** Mass only

(c) Energy only **(d)** Transfer both mass and energy

12. The wavelength, frequency and speed of any progressive waves are written as:

(a) $f = \frac{\lambda}{v}$ **(b)** $f = \frac{v}{\lambda}$

(c) $f = v \times \lambda$ **(d)** $f = \lambda + v$

13. The distance between two successive crests or troughs is called:

(a) Area **(b)** Displacement

(c) Amplitude **(d)** Wavelength

14. The portion of the wave above the mean level is called:

(a) Trough **(b)** Crest

(c) Displacement **(d)** Amplitude

15. The portion of the wave below the mean level is called:

(a) Trough **(b)** Crest

(c) Wavelength **(d)** Amplitude

16. Crests and troughs are formed in:

(a) Chemical waves **(b)** Longitudinal waves

(c) Stationary waves **(d)** Transverse waves

17. All parts of the wave pattern move with:

(a) Same speed **(b)** Different speed

(c) Double speed **(d)** None of above

18. The expression $v = f\lambda$ is valid for all types of:

(a) Linear motion **(b)** Angular motion

(c) Wave motion **(d)** Circular motion

19. When a spring under tension is plucked one end at the wave formed as:

(a) Transverse waves **(b)** Square waves

(c) Longitudinal waves **(d)** Compressed waves

20. Waves in which particles of the medium vibrate parallel to the direction of propagation are called:

(a) Transverse waves **(b)** Stationary waves

(c) Longitudinal waves **(d)** Complex waves

21. Passage of waves from one medium into another is called:

(a) Reflection **(b)** Refraction

(c) Transmission **(d)** Diffraction

22. If 30 waves per second pass through a medium at a speed of 30 m/s, wavelength of these waves is:

(a) 30 m **(b)** 15 m

(c) 1 m **(d)** 280 m

23. Distance between two consecutive nodes is:

(a) λ **(b)** $\frac{\lambda}{2}$

(c) $\frac{\lambda}{4}$ **(d)** 2λ

24. The point at which the displacement of the wave is zero called:

(a) Node **(b)** Trough

(c) Anti-node **(d)** Crest

25. The point at which the displacement of the wave is maximum called the:

(a) Node **(b)** Trough

(c) Anti-node **(d)** Crest

26. When two identical waves are superposed, the velocity of the resultant wave:

(a) Becomes zero **(b)** Remains unchanged

(c) Increased **(d)** Decreased

27. When two similar waves moving along the same line in opposite direction are superposed, they give rise to:

(a) Stationary waves **(b)** Longitudinal waves

(c) Compressed waves **(d)** Travelling waves

28. The distance between two consecutive anti-node is:

(a) λ **(b)** 2λ

(c) $\frac{\lambda}{4}$ **(d)** $\frac{\lambda}{2}$

29. The stationary waves consists of:

(a) Crest and troughs **(b)** Nodes and anti-nodes

(c) Reflection & refraction **(d)** None of these

30. Water waves are:

(a) Stationary waves **(b)** Longitudinal waves

(c) Electromagnetic waves **(d)** Transverse waves

31. When a transverse wave is reflected on going from a denser to a rare medium, then:

(a) There is a 180° phase shift **(b)** There is no change in path

(c) A trough is converted into a crest **(d)** A crest is converted into a trough

32. When stationary waves are setup in a cord which is fixed at both ends, the points which always remain at rest is called:

(a) Nodes **(b)** Anti-nodes

(c) Both (a) & (b) **(d)** None of these

33. Expression for Newton's formula for speed of sound is:

(a) $v = \sqrt{\frac{E}{\rho}}$ **(b)** $v = \sqrt{\frac{\rho}{E}}$

(c) $v = \sqrt{\frac{E\gamma}{\rho}}$ **(d)** $v = \sqrt{\frac{\rho\gamma}{E}}$

34. The speed of sound waves is independent of:

(a) Pressure **(b)** Source of sound

(c) Medium **(d)** Temperature

35. The speed of sound in air proposed by Newton is:

(a) 280 m/s **(b)** 332 m/s

(c) 333 m/s **(d)** None of the above

36. Newton's formula for the speed of sound is corrected by:

(a) Graham Bell **(b)** Laplace

(c) Huygen **(d)** Weber-Fechner

37. If E is the modulus of elasticity and ρ is the density then the speed of sound is:

(a) $\sqrt{\frac{1}{E\rho}}$ **(b)** $\sqrt{\frac{E}{\rho}}$

(c) $\sqrt{E\rho}$ **(d)** $\sqrt{\frac{\rho}{E}}$

38. Laplace expression for the speed of sound in gas is:

(a) $v = \sqrt{\frac{\rho P}{\gamma}}$ **(b)** $v = \sqrt{\frac{\rho\gamma}{P}}$

(c) $v = \sqrt{\frac{P}{\gamma\rho}}$ **(d)** $v = \sqrt{\gamma P\rho}$

39. The velocity of sound in air at 0°C is:

(a) 332 m/s **(b)** 300 m/s

(c) 322 m/s **(d)** 280 m/s

40. Velocity of sound in vacuum is:

(a) Zero **(b)** 332 m/s

(c) 280 m/s **(d)** 325 m/s

41. The speed of sound waves in a medium depends upon:

(a) Density of medium **(b)** Amplitude of the particle

(c) Elasticity of medium **(d)** Both density and elasticity of medium

42. The velocity of sound is greatest in:

(a) Steel **(b)** Air

(c) Iron **(d)** Water

43. For all gases:

(a) $v_t = v_0\left(1 - \frac{t}{273}\right)$ **(b)** $v_t = v_0\left(1 + \frac{t}{273}\right)$

(c) $v_t = v_0\left(1 + \frac{273}{t}\right)$ **(d)** $v_t = v_0\,(1 + 273\,t)$

44. For temperature:

(a) $\frac{v_t}{v_0} = \sqrt{\frac{T}{T_0}}$ **(b)** $\frac{v_t}{v_0} = \sqrt{\frac{T_0}{T}}$

(c) $\frac{v_t}{v_0} = \frac{T}{T_0}$ **(d)** $\frac{v_t}{v_0} = TT_0$

45. For small temperature changes, velocity of sound can be determined by the relation:

(a) $v_t = v_0 + 0.61\,t$ **(b)** $v_t = v_0 + 61t$

(c) $v_t = v_0 + 2t$ **(d)** All of the above

46. Increase in velocity of sound in air for 1°C rise in temperature is:

(a) 0.61 m/s **(b)** 61.0 m/s

(c) 1.61 m/s **(d)** 2.00 m/s

47. The speed of sound is greater in solids than in gases due to their high:

(a) Temperature **(b)** Pressure

(c) Density **(d)** Elasticity

48. Which of the following properties for sound is affected by change in air temperature:

(a) Wavelength **(b)** Intensity

(c) Amplitude **(d)** Frequency

49. The superposition of a number of harmonic waves form:

(a) Standing waves **(b)** Complex waves

(c) Transverse waves **(d)** Matter waves

50. At the closed end of an air column, node occurs:

(a) Never **(b)** Always

(c) In certain case **(d)** None of these

51. Two waves having same frequency and traveling in the same direction is called:

(a) Beats **(b)** Interference

(c) Sound waves **(d)** None of these

52. Two waves of different frequency and traveling in the same direction is called:

(a) Interference **(b)** Beats

(c) Stationary waves **(d)** Sound waves

53. The interference in which the two waves are added up is called:

(a) Interaction **(b)** Constructive interference

(c) Destructive interference **(d)** None of these

54. The interference of sound waves in which two waves cancel each other is called:

(a) Interaction **(b)** Constructive interference

(c) Destructive interference **(d)** None of these

55. Two waves can interfere only if they have:

(a) Different frequency **(b)** Same velocity

(c) Propagation in opposite direction **(d)** Phase coherence

56. Periodic alternation of sound between maximum and minimum loudness are called:

(a) Diffraction **(b)** Interference

(c) Beats **(d)** None of these

57. Principle of superposition of waves is applied in:

(a) Formation of beats **(b)** Formation of stationary waves

(c) Interference of sound waves **(d)** All of the above

58. Beats cannot be heard if the difference of frequencies is more than about:

(a) 6 **(b)** 4

(c) 9 **(d)** 10

59. Laws of transverse vibrations of a stretched string are:

(a) $f \propto \sqrt{F}$ **(b)** $F \propto \frac{1}{l}$

(c) $f \propto \frac{1}{\sqrt{m}}$ **(d)** All of the above

60. A stretched string with both ends fixed corresponds to:

(a) A closed end pipe **(b)** An open-end organ pipe

(c) Both (a) & (b) **(d)** None of these

61. With the rise of temperature, the velocity of sound is:

(a) Increased **(b)** Decreased

(c) Remains constant **(d)** Becomes zero

62. The magnitude of auditory sensation produced by sound on the ear is known as:

(a) Loudness **(b)** Quality

(c) Intensity **(d)** Frequency

63. The loudness of sound L is proportional to the logarithm of intensity I_0 which is called:

(a) Newton formula for sound **(b)** Laplace formula for sound

(c) Weber-Fechner's law **(d)** None of these

64. The pitch of the sound is determined by its:

(a) Speed **(b)** Frequency

(c) Direction **(d)** Number of beats

65. The amplitude of sound waves determined by its:

(a) Speed **(b)** Frequency

(c) Direction **(d)** Number of beats

66. The amplitude of sound waves determines its:

(a) Pitch **(b)** Loudness

(c) Interference **(d)** None of the above

67. What is the approximate range of audible frequencies for a young person:

(a) 2 Hz to 2000 Hz **(b)** 20 Hz to 2000 Hz

(c) 20 Hz to 20,000 Hz **(d)** 200 Hz to 2 Hz

68. The unit of intensity level is:

(a) Watt **(b)** Joule

(c) Bel **(d)** None of these

69. Sound of frequencies lower than 20 Hz are called:

(a) Supersonics **(b)** Infrasonics

(c) Ultrasonics **(d)** Audible sound waves

70. Beats are the result of:

(a) Interference **(b)** Diffraction of sound waves

(c) Polarization **(d)** None of the above

71. Musical sound depends upon:

(a) Velocity **(b)** Frequency

(c) Amplitude **(d)** Periodicity and regularity

72. Quality of sound depends upon its:

(a) Amplitude **(b)** Frequency

(c) Harmonics **(d)** Intensity of sound

73. The pitch of sound depends upon:

(a) Loudness of sound **(b)** Wavelength of sound

(c) Intensity of sound **(d)** Frequency of sound

74. Loudness of sound depends upon:

(a) Frequency **(b)** Pitch

(c) Intensity of sound & ear **(d)** Ear alone

75. The number of beats produced per second is equal to:

(a) The difference of frequencies of two tuning forks

(b) The sum of the frequencies of two tuning forks

(c) The ratio of the frequencies of two tuning forks

(d) None of these

76. Two tuning forks of frequencies 260 Hz and 257 Hz are sounded together, the number of beats per second is:

(a) 3 **(b)** 4

(c) 2 **(d)** Zero

77. The apparent change in frequency as heard by an observer when there is relative motion between the source and observer is known as:

(a) Compton effect **(b)** Photo electric effect

(c) Doppler effect **(d)** None of these

78. Radar system is the application of:

(a) Photoelectric effect **(b)** Doppler effect

(c) Compton effect **(d)** None of these

79. Doppler's effect applies to:

(a) Light waves only **(b)** Sound waves only

(c) Both sound and light waves **(d)** None of these

80. When Doppler's effect is applied to electromagnetic waves source approaching the observer at rest represents:

(a) Identical situations **(b)** Different situations

(c) No change **(d)** None of these

81. When source of sound approaches the listener at rest, the frequency of sound received by him is:

(a) Less than the frequency of sound produced by source

(b) Greater than the frequency of sound produced by source

(c) Same as that produced by source

(d) Zero

82. When the source of sound moves away from a stationary listener, then there is:

(a) An apparent increase in frequency **(b)** An apparent decrease in frequency

(c) An apparent decrease in wavelength **(d)** No apparent change in frequency

83. When a listener is moving with velocity u_o towards the stationary source of sound of frequency f the speed of sound in air is v then changed frequency of the sound is given by:

(a) $f' = \frac{v}{v + u_o} f$ **(b)** $f' = \frac{v}{v - u_o} f$

(c) $f' = \frac{v - u_o}{v} f$ **(d)** $f' = \frac{v + u_o}{v} f$

84. When a listener is moving away with velocity u_o from the stationary source of sound of frequency f the speed of sound in air is v then the changed frequency of sound is given by:

(a) $f' = \frac{v + u_o}{v} f$ **(b)** $f' = \frac{v - u_o}{v} f$

(c) $f' = \frac{v}{v + u_o} f$ **(d)** $f' = \frac{v}{v - u_o} f$

85. A source of waves which gives out pure note means that it gives out:

(a) Mixture of frequency **(b)** Quantum frequencies

(c) Single frequency **(d)** None of these

86. When the difference between the frequencies of two sounds is more than about ————. Then it becomes difficult to recognize beats:

(a) 15 Hz **(b)** 10 Hz

(c) 5 Hz **(d)** 20 Hz

87. Dog hears sound which ranges:

(a) 150 – 150000 Hz **(b)** 100 – 12000 Hz

(c) 50 – 70000 Hz **(d)** 15 – 50000 Hz

88. Cat hears sound which ranges:

(a) 60 – 7000 Hz **(b)** 60 – 70000 Hz

(c) 15 – 50000 Hz **(d)** 150 – 150000 Hz

89. Speed of sound in hydrogen at 20°C at STP is:

(a) 332 m/s **(b)** 280 m/s

(c) 258 m/s **(d)** 333 m/s

90. Speed of sound in iron at 20°C is:

(a) 5130 m/s **(b)** 5230 m/s

(c) 5030 m/s **(d)** 3600 m/s

91. The distance between a node and antinode:

(a) λ **(b)** $\frac{\lambda}{2}$

(c) $\frac{\lambda}{4}$ **(d)** $\frac{3\lambda}{2}$

92. The speed of sound in air at 30°C is approximately equal to:

(a) 333 m/s **(b)** 350 m/s

(c) 340 m/s **(d)** 335 m/s

93. The speed of sound in air at S.T.P is 300 ms^{-1}. If the air pressure becomes double, the temperature remaining the same, the speed of sound would become:

(a) 1200 ms^{-1} **(b)** 600 ms^{-1}

(c) $300\sqrt{2}$ ms^{-1} **(d)** 300 ms^{-1}

94. If the number of loops of a stationary waves are increasing then:

(a) Wavelengths gets higher **(b)** Wavelengths gets shorter

(c) Wavelength becomes constant **(d)** None of these

95. Two pipes one is open and other is closed at one end are of same length then the ratio of their fundamental frequencies is:

(a) 1 : 2 **(b)** 2 : 1

(c) 1 : 1 **(d)** 1 : 4

96. The frequency of a stretched wire 1000 mm long is 256 Hz. When the wire is shortened to 400 mm at the same tension. What is the fundamental frequency?

(a) 102 Hz **(b)** 640 Hz

(c) 416 Hz **(d)** 162 Hz

97. The quantities which together determine the speed of sound in a liquid are:

(a) the bulk Modulus and the density **(b)** the bulk Modulus and the pressure

(c) the Young Modulus and the volume **(d)** the Young Modulus and the density

98. An organ pipe of effective length 0.68 m is closed at one end. Given that the speed of sound is 340 ms^{-1}. The two lowest Resonant frequencies are:

(a) 125 Hz and 250 Hz **(b)** 125 Hz and 375 Hz

(c) 250 Hz and 500 Hz **(d)** 250 Hz and 750 Hz

99. Two sources of sound have frequencies f_1 and f_2 respectively f_1 being slightly greater then f_2. What is the period of the beats heard when the sources operate simultaneously?

(a) $f_1 - f_2$ **(b)** $\frac{1}{f_1 - f_2}$

(c) $\frac{2}{f_1 - f_2}$ **(d)** $\frac{2\pi}{f_1 - f_2}$

100. When temperature increases, frequency of organ pipe:

(a) Decreases **(b)** Increases

(c) Unchanged **(d)** Becomes zero

101. The temperature at which the speed of sound in air becomes double its value at 0°C is:

(a) 1092°C **(b)** 819 K

(c) 819°C **(d)** 546°C

102. The distance between two consecutive antinodes is 0.50 m. The distance travelled by the wave in half the time period is:

(a) 2 m **(b)** 1 m

(c) 0.5 m **(d)** 0.25 m

103. It is possible to distinguish between transverse and longitudinal waves from the property of:

(a) Refraction **(b)** Interference

(c) Diffraction **(d)** Polarization

104. The wavelength of the fundamental mode of vibration of a closed end pipe is:

(a) $2l$ **(b)** l

(c) $4l$ **(d)** $l/2$

105. Stationary waves only of discrete set of frequencies are set up in a medium. This fact is called:

(a) Harmonics **(b)** Overtones

(c) Quantization of frequencies **(d)** Superposition of frequencies

106. Newton calculated the velocity of sound in air at S.T.P equal to:

(a) 280 ms^{-1} **(b)** 250 ms^{-1}

(c) 300 ms^{-1} **(d)** 322 ms^{-1}

107. Velocity of sound in vacuum at 0°C is:

(a) 332 ms^{-1} **(b)** 320 ms^{-1}

(c) Zero **(d)** 224 ms^{-1}

108. The magnitude of auditory sensation produced by sound on the ear is known as:

(a) Frequency **(b)** Intensity

(c) Quality **(d)** Loudness

109. If 20 waves pass through the medium in 1 second with speed of 20 ms^{-1} then the wavelength is:

(a) 20 m **(b)** 2 m

(c) 400 m **(d)** 1 m

110. The number of nodes between two consecutive antinodes is:

(a) Zero **(b)** 3

(c) 2 **(d)** 1

111. The system followed by Newton for the determination of speed of sound in air is:

(a) Adiabatic **(b)** Isothermal

(c) Isobaric **(d)** Isochoric

112. Stars moving towards the Earth show a:

(a) Red shift **(b)** Blue shift

(c) Yellow shift **(d)** Green shift

113. When two notes of frequencies f_1 and f_2 are sounded together, beats are formed if $f_1 > f_2$ then the frequency of beat is:

(a) $f_1 + f_2$ **(b)** $\frac{1}{2}(f_1 + f_2)$

(c) $f_1 - f_2$ **(d)** $\frac{1}{2}(f_1 - f_2)$

114. The speed of sound at 30° c is approximately equal to:

(a) 332 ms^{-1} **(b)** 335 ms^{-1}

(c) 340 ms^{-1} **(d)** 350 ms^{-1}

115. An air column in a pipe, which is closed at one end, will be in resonance with a vibrating tuning fork of frequency 250 Hz. The length of the column in cm is (Velocity of sound in air = 340 ms^{-1})

(a) 21.25 **(b)** 125

(c) 62.50 **(d)** 33.2

116. The minimum length of a closed pipe which can resound with a note of wavelength 1 m is:

(a) 0.25 m **(b)** 0.5 m

(c) 0.75 m **(d)** 1 m

117. A particle executes S.H.M. with a period of 6 s and amplitude of 3 cm. Its maximum speed in cm/s is:

(a) $\frac{\pi}{2}$ **(b)** π

(c) 2π **(d)** 3π

118. The end correction of a resonance column is 1 cm. If the shortest length resonating with a tunning fork is 15 cm, then the next resonating length is:

(a) 45 cm **(b)** 31 cm

(c) 46 cm **(d)** 47 cm

119. The ratio of the velocity of sound in air at 4 atmosphere and that at 1 atmosphere pressure would be:

(a) 1 : 1 **(b)** 4 : 1

(c) 1 : 4 **(d)** 3 : 1

120. A string of length l, fixed at both ends is vibrating in two segments. The wavelength of the corresponding wave is:

(a) $\frac{l}{4}$ **(b)** $\frac{l}{2}$

(c) l **(d)** $2l$

121. The frequency of waves produced to microwave oven is:

(a) 1435 MHz **(b)** 2450 MHz

(c) 1860 MHz **(d)** 2850 MHz

ANSWERS

1.	(a)	**2.**	(a)	**3.**	(b)	**4.**	(a)
5.	(c)	**6.**	(c)	**7.**	(c)	**8.**	(a)
9.	(a)	**10.**	(b)	**11.**	(d)	**12.**	(b)
13.	(d)	**14.**	(b)	**15.**	(a)	**16.**	(c)
17.	(a)	**18.**	(c)	**19.**	(a)	**20.**	(c)
21.	(c)	**22.**	(c)	**23.**	(b)	**24.**	(a)
25.	(c)	**26.**	(b)	**27.**	(a)	**28.**	(c)
29.	(b)	**30.**	(d)	**31.**	(c)	**32.**	(a)
33.	(a)	**34.**	(a)	**35.**	(a)	**36.**	(b)
37.	(b)	**38.**	(a)	**39.**	(a)	**40.**	(a)
41.	(d)	**42.**	(a)	**43.**	(a)	**44.**	(a)
45.	(a)	**46.**	(a)	**47.**	(d)	**48.**	(a)
49.	(a)	**50.**	(b)	**51.**	(b)	**52.**	(b)
53.	(b)	**54.**	(c)	**55.**	(d)	**56.**	(c)
57.	(d)	**58.**	(d)	**59.**	(d)	**60.**	(b)
61.	(a)	**62.**	(a)	**63.**	(c)	**64.**	(c)
65.	(c)	**66.**	(c)	**67.**	(c)	**68.**	(c)
69.	(b)	**70.**	(a)	**71.**	(d)	**72.**	(c)
73.	(d)	**74.**	(c)	**75.**	(a)	**76.**	(a)
77.	(c)	**78.**	(b)	**79.**	(c)	**80.**	(a)
81.	(b)	**82.**	(b)	**83.**	(d)	**84.**	(b)
85.	(c)	**86.**	(b)	**87.**	(d)	**88.**	(b)
89.	(c)	**90.**	(a)	**91.**	(c)	**92.**	(b)
93.	(d)	**94.**	(b)	**95.**	(b)	**96.**	(b)
97.	(a)	**98.**	(b)	**99.**	(b)	**100.**	(a)
101.	(c)	**102.**	(c)	**103.**	(d)	**104.**	(c)
105.	(c)	**106.**	(a)	**107.**	(c)	**108.**	(d)
109.	(d)	**110.**	(d)	**111.**	(d)	**112.**	(d)
113.	(b)	**114.**	(d)	**115.**	(d)	**116.**	(c)
117.	(c)	**118.**	(d)	**119.**	(a)	**120.**	(c)
121.	(b)						

SHORT QUESTIONS

8.1 What feature do longitudinal waves have in common with transverse waves?

Ans. The following features are common in transverse wave and longitudinal waves:

(i) Both are mechanical waves.

(ii) Both waves transfer energy from one point to another point but not matter.

(iii) Both produce disturbance in the medium through which they travel.

(iv) The relation $v = f\lambda$ holds for both the waves here v is speed of wave, "f", frequency and λ is wavelength.

8.2 The five possible waveforms obtained, when the output from a microphone is fed into the y-input of cathode ray oscilloscope, with the time base on, are shown in Fig. 8.23. These waveform are obtained under the same adjustment of the cathode ray oscilloscope controls, indicate the waveform:

(a) which trace represents the loudest note?

(b) which trace represents the highest frequency?

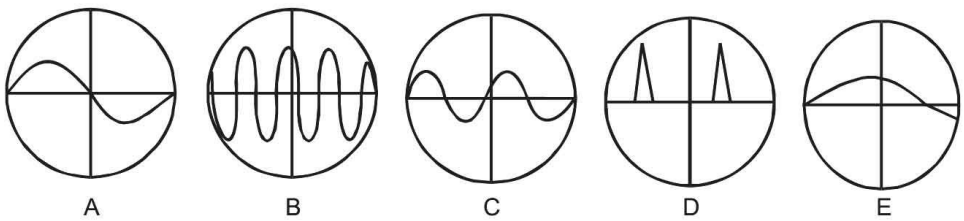


Fig. 8.23

Ans. (a) The trace (B) represents the loudest sound because the loudness of sound depends upon the amplitude of vibration.

(b) The trace (B) represents the highest frequency because the number of waves per second are maximum.

8.3 Is it possible for two identical waves traveling in the same direction along a string to give rise to a stationary wave?

Ans. No, the stationary waves are not produced when the two identical waves are travelling the same direction. Because in order to produce stationary waves, two identical waves should travel in opposite direction.

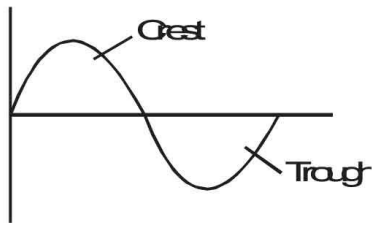
8.4 A wave is produced along a stretched string but some of its particle permanently shows zero displacement. What types of wave is it?

Ans. It will be a stationary wave because in stationary wave, some points will remain permanently at rest i.e., zero displacement called node.

8.5 Explain the terms crest, through, node, and anti-node.

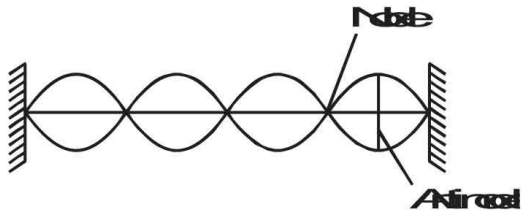
Ans. **Crest:** The upper portion of the transverse wave from the mean position is called crest.

Trough: The lower portion of the transverse wave from the mean position is called trough.



Node: The point at which the displacement of the stationary wave is zero is called node.

Anti-node: The point at which the displacement of the stationary wave is maximum is called anti-node.



8.6 Why does sound travel faster in solid than in gases?

Ans. As we know that the speed of sound is given by the expression

$$v = \sqrt{\frac{E}{\rho}}$$

From this equation we see that speed of sound is directly proportional to square root of modulus of elasticity. As the elasticity of medium is greater for solid as compared to gases and density is also greater for solids. So the effect of elasticity is greater than density thus the sound travels faster in solids than in gases.

8.7 How are beats useful in tuning musical instruments?

Ans. In musical instruments, various notes can be produced by changing the length of air column. To get a particular note, a standard instrument is taken and is sounded together with musical instrument which is to be tuned. The number of beats produced per second are recorded. The frequency of the instrument to be tuned is so adjusted that it gives no beat with standard instrument. So the musical instrument is tuned to a particular frequency with the help of phenomenon of beats.

8.8 When two notes of frequency f_1 and f_2 are sounded together, beats are formed. If $f_1 > f_2$, what will be frequency of beats?

(i) $f_1 + f_2$ **(ii)** $\frac{1}{2}(f_1 + f_2)$ **(iii)** $f_1 - f_2$ **(iv)** $\frac{1}{2}(f_2 - f_1)$

Ans. The number of beats produced in one second is equal to the difference in the frequencies of two notes. So:

Number of beats per second $= f_1 - f_2$

Hence the correct answer is (iii).

8.9 As a result of a distant explosion, an observer senses a ground tremor and then hears the explosion. Explain the time difference.

Ans. We know that sound waves travel faster through solid as compared to gases. So the time difference is due to that waves produced by explosions reach through solid ground much faster than the f sound waves travelling through air.

8.10 Explain why sound travels faster in warm air than in cold air.

Ans. We know that the expression for speed of sound in air is

$$v = \sqrt{\frac{rP}{\rho}}$$

From this equation we see that speed of sound is inversely proportional to $\sqrt{\rho}$. Which means that if density of air is greater, speed of sound will be small and vice versa. As warm air has smaller density than that of cold air therefore sound travel faster in warm air than in cold air.

8.11 How should a sound source move with respect to an observer so that frequency of its sound does not change?

Ans. If both sound waves and observer are moving in same direction with same velocity then their relative velocity is equal to zero. So the frequency of its sound does not change.

PROBLEMS WITH SOLUTIONS

PROBLEM 8.1

The wavelength of the signals from a radio transmitter is 1500 m and the frequency is 200 KHz. What is the wavelength for a transmitter operating at 1000 KHz and with what speed the radio waves travel?

Data

Wavelength of signals $= \lambda_1 = 1500$ m

Frequency of signals $= f_1 = 200$ KHz

$= 200 \times 1000$ Hz

$= 2 \times 10^5$ Hz

Frequency for transmitter $= f_2 = 1000$ KHz

$= 1000 \times 1000$ Hz

$= 10^6$ Hz

To Find

Wavelength for transmitter $= \lambda_2 = ?$

Speed of radio waves $= v = ?$

SOLUTION

By formula

$$v = f\lambda$$

For speed of radio waves

$$v = f_1\lambda_1$$

$$= 2 \times 10^5 \times 1500$$

$$= 3000 \times 10^5$$

$$= 3 \times 10^8 \text{ m/s}$$

And for wavelength

$$v = f_2\lambda_2$$

$$\lambda_2 = \frac{v}{f_2}$$

$$= \frac{3 \times 10^8}{10^6}$$

$$= 3 \times 10^{8-6}$$

$$= 3 \times 10^2$$

$$\lambda_2 = 300 \text{ m}$$

Result

Wavelength for transmitter = λ_2 = 300 m

Speed of radio waves = v = 3×10^8 m/s

PROBLEM 8.2

Two speakers are arranged as shown in Fig. 8.24. The distance between them is 3 m and they emit a constant tone of 344 Hz. A microphone P is moved along a line parallel to and 4.00 m from the line connecting the two speakers. It is found that tone of maximum loudness is heard and displayed on the CRO when microphone is on the centre of the line and directly opposite each speaker. Calculate the speed of sound.

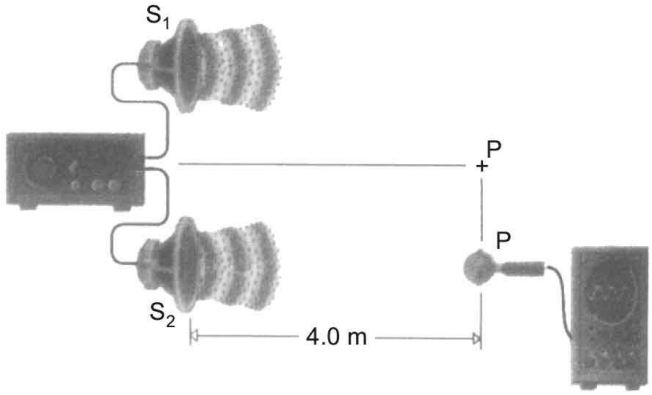


Fig. 8.24

Data

Distance between speakers = d = 3.0 m

Frequency of sound = f = 344 Hz

Distance between microphone and speakers = L = 4.0 m

To Find

Speed of sound = v = ?

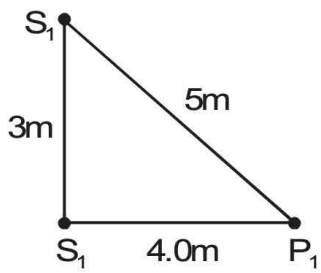
SOLUTION

By formula

$$\boxed{v = f\lambda}$$

Where λ = Path difference

= $S_1P_1 - S_2P_1$



Consider the $\Delta S_1P_1S_2$ is right angle triangle then

$$(S_1P_1)^2 = (S_1S_2)^2 + (S_2P_1)^2$$

$$= (3)^2 + (4)^2$$

$$(S_1P_1)^2 = 9 + 16$$

$$S_1P_1 = \sqrt{25}$$

$$= 5$$

So $\lambda = S_1P_1 - S_2P_1$

$= 5 - 4$

$\lambda = 1$ m

Then $v = f\lambda$

$= 1 \times 344$

$v = 344$ m/s

Result

Speed of sound = $v = 344$ m/s

PROBLEM 8.3

A stationary wave is established in a string which is 120 cm long and fixed at both ends. The string vibrates in four segments, at a frequency of 120 Hz. Determine its wavelength and the fundamental frequency?

Data

Length of string $= l = 120$ cm

$= 1.20$ m

Number of segments $= N = 4$

Frequency of four segments $= f_4 = 120$ Hz

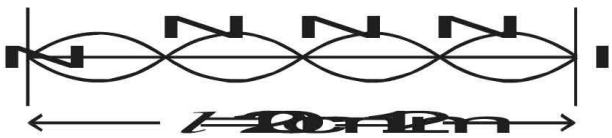
To Find

Fundamental frequency $= f_1 = ?$

Wavelength $= \lambda = ?$

SOLUTION

For the wavelength



$$l = 4 \times \frac{\lambda}{2}$$

$$\lambda = \frac{2l}{4} = \frac{2 \times 1.2}{4}$$

$\lambda = 0.6$ m

and for fundamental frequency

$f_4 = 4f_1$

$$\boxed{f_1 = \frac{f_4}{4}}$$

$$f_1 = \frac{120}{4}$$

$f_1 = 30$ Hz

Result

Fundamental frequency = f_1 = 30 Hz

Wavelength = λ = 0.6 m

PROBLEM 8.4

The frequency of the note emitted by a stretched string is 300 Hz. What will be the frequency of this note when

(a) the length of the wave is reduced by one-third without changing the tension.

(b) the tension is increased by one-third without changing the length of the wire.

Data

Frequency of the note = f = 300 Hz

To Find

(a) Frequency = f_1 = ? (When the length of the wave reduced by one-third)

(b) Frequency = f_2 = ? (When the tension is increased by one-third)

SOLUTION

(a) Suppose the length of wave = λ

One-third of that length = $\frac{1}{3}\lambda$

After reducing the length = $\lambda - \frac{1}{3}\lambda$

$$\lambda' = \frac{2}{3}\lambda$$

So according to relation

$$\lambda f = \frac{2}{3}\lambda f_1$$

$$\frac{2}{3} f_1 = f$$

$$f_1 = \frac{3}{2} f$$

$$f_1 = \frac{3}{2} \times 300$$

$$f_1 = 450 \text{ Hz}$$

(b) As we know that

$$f_2 = \frac{1}{2l}\sqrt{\frac{F}{m}}$$

Suppose the tension = F

One-third of that tension = $\frac{1}{3}$ F

After increasing the tension, the new tension becomes $= F' = F + \frac{1}{3}F$

$$= \frac{4}{3}F$$

Therefore the frequency at that tension is

$$f_2 = \frac{1}{2l}\sqrt{\frac{F'}{m}}$$

$$f_2 = \frac{1}{2l}\sqrt{\frac{\frac{4}{3}F}{m}}$$

$$f_2 = \frac{1}{2l}\sqrt{\frac{F}{m}} \times \sqrt{\frac{4}{3}}$$

Therefore; $f_2 = f \times \sqrt{\frac{4}{3}}$

$$f_2 = 300 \times 1.15$$

$$= 346.4 \text{ Hz}$$

Result

(a) Frequency when length of the wave is reduced $= f_1 = 450$ Hz

(b) Frequency when tension is increased $= f_2 = 346$ Hz

PROBLEM 8.5

An organ pipe has a length of 50 cm. Find the frequency of its fundamental note and the next harmonic when it is

(a) open at both ends.

(b) closed at one end.

(Speed of sound = 350 ms^{-1})

Data

Length of organ pipe $= l = 50$ cm

$= 0.5$ m

Speed of sound $= v = 350$ m/s

To Find

(a) Frequency $= f_1 = ?$

Frequency $= f_2 = ?$ (When open at both ends)

(b) Frequency $= f_1 = ?$

Frequency $= f_3 = ?$ (When closed at one end)

SOLUTION

(a) When pipe is opened at both ends

$$v = f\lambda$$

$$f_1 = \frac{v}{\lambda}$$

Since $l = \frac{\lambda}{2}$

$$\lambda = 2l$$

$$= 2 \times 0.5$$

$$= 1.0$$

So $f_1 = \frac{350}{1.0} = 350 \text{ Hz}$

Next harmonic frequency $= f_2 = 2f_1$

$$= 2 \times 350$$

$$= 700 \text{ Hz}$$

(b) When pipe is closed at one-end

$$f_1 = \frac{v}{\lambda} \qquad \text{But} \quad l = \frac{\lambda}{4}$$

$$\lambda = 4l$$

$$= 4 \times 0.5$$

$$= 2.0$$

So $f_1 = \frac{350}{2.0} = 175 \text{ Hz}$

For next harmonic $= f_3 = 175 \times 3$

$$= 525 \text{ Hz}$$

Result

(a) Frequency $= f_1 = 350$ Hz

Next harmonic frequency $= f_2 = 700$ Hz (When pipe is opened at both ends)

(b) Frequency $= f_2 = 175$ Hz

Next harmonic frequency $= f_3 = 525$ Hz (When pipe is closed at one end)

PROBLEM 8.6

A church organ consists of pipes, each open at one end of different lengths. The minimum length is 30 mm and the longest is 4m. Calculate the frequency range of the fundamental notes.

(Speed of sound = 340 ms^{-1})

Data

Minimum length of pipe $= l_1 = 30$ mm

$= 30 \times 10^{-3}$ m

$= 0.03$ m

Maximum length of pipe $= l_2 = 4$ m

Speed of sound $= v = 340$ m/s

To Find

Frequency for minimum length $= f_1 = ?$

Frequency for maximum length $= f_2 = ?$

SOLUTION

By formula

$$f_1 = \frac{v}{4l_1}$$ (When the pipes are opened at one-end)

For minimum length Since $\lambda = 4l_1$

$$f_1 = \frac{340}{4(0.03)}$$

$$= \frac{340}{0.12}$$

$$f_1 = 2833 \text{ Hz}$$

For maximum length

$$f_2 = \frac{v}{4l_2}$$

$$= \frac{340}{4 \times 4} = \frac{340}{16} = 21.2 \text{ Hz}$$

Result

Frequency for minimum length $= f_1 = 2833$ Hz

Frequency for maximum length $= f_2 = 21$ Hz

PROBLEM 8.7

Two tuning forks exhibit beats at a beat frequency of 3 Hz. The frequency of one fork is 256 Hz. Its frequency is then lowered slightly by adding a bit of wax to one of its prong. The two forks then exhibit a beat frequency of 1 Hz. Determine the frequency of the second tuning fork.

Data

Number of beats per second before loadings $= n = 3$

Number of beats after loading $= n = 1$

Frequency of 1st tuning fork $= f_A = 256$ Hz

To Find

Frequency of 2nd tuning fork $= f_B = ?$

SOLUTION

By formula

$$f_A - f_B = \pm n$$

$$f_B = f_A \pm n$$

$$= 256 \pm 3$$

$$f_A = 256 + 3 \quad \text{or} \quad f_B = 256 - 3$$

$$f_B = 259 \text{ Hz} \quad \text{or} \quad f_B = 253 \text{ Hz}$$

As after loading number of beats reduces so.

Result

Frequency of 2nd tuning fork $= f_B = 253$ Hz

PROBLEM 8.8

Two cars P and Q are traveling along a motorway in the same direction. The leading car P travels at a steady speed of 12 ms^{-1}; the other car Q, traveling at a steady speed of 20 ms^{-1}, sound its horn to emit a steady note which P's driver estimates, has a frequency of 830 Hz. What frequency does Q's own driver hear?

(Speed of sound = 340 ms^{-1})

Data

Speed of car P = 12 m/s

Speed of car Q = 20 m/s

Relative speed $= u_s = 20 - 12$

$= 8$ m/s

Speed of sound $= v = 340$ m/s

Apparent frequency $= f_A = 830$ Hz

To Find

Frequency heard by Q's driver $= f = ?$

SOLUTION

By using formula, when the source moves towards the observer

$$f_A = \left(\frac{v}{v - u_s}\right) f$$

$$\boxed{f = \frac{(v - u_s)\, f_A}{v}}$$

$$= \frac{340 - 8}{340} \times 830$$

$$= \frac{332 \times 830}{340}$$

$$f = 810 \text{ Hz}$$

Result

Frequency heard by Q's driver = f = 810 Hz

PROBLEM 8.9

A train sounds its horn before it sets off from the station and an observer waiting on the plateform estimates its frequency at 1200 Hz. The train then moves off and accelerates steadily. Fifty seconds after departure, the driver sounds the horn again and the plateform observer estimates the frequency at 1140 Hz. Calculate the train speed 50 s after departure. How far from the station is the train after 50 s?

(Speed of sound = 340 ms^{-1})

Data

Fundamental frequency = f = 1200 Hz

Apparent frequency = f_A = 1140 Hz

Speed of sound = v = 340 m/s

Time taken = t = 50 sec.

To Find

Speed of train = u_s = ?

Distance covered by train = S = ?

SOLUTION

By formula, when the source moves away from the observer

$$f_A = \frac{v}{v + u_s} f$$

$$v + u_s = \frac{v}{f_A} f$$

$$\boxed{u_s = \frac{vf}{f_A} - v}$$

$$u_s = \frac{340 \times 1200}{1140} - 340$$

$$= 357.894 - 340$$

$$u_s = 17.894 \text{ m/s}$$

For the distance covered by the train

$$S = u_{ave} \times t$$

$$u_{ave} = \frac{0 + 17.9}{2} = \frac{17.9}{2} = 8.95 \text{ m/s}$$

So, $S = 8.95 \times 50$

$= 448$ m

Result

Speed of train $= u_s = 17.89$ m/s

Distance covered by train $= S = 448$ m

PROBLEM 8.10

The absorption spectrum of faint galaxy is measured and the wavelength of one of the lines identified as the Calcium α line is found to be 478 nm. The same line has a wavelength of 397 nm when measured in a laboratory.

(a) Is the galaxy moving towards or away from the Earth?

(b) Calculated the speed of the galaxy relative to Earth.

(Speed of light = 3.0×10^8 ms^{-1})

Data

Apparent wavelength $= \lambda_A = 478$ nm

$= 478 \times 10^{-9}$ m

Fundamental wavelength $= \lambda = 397$ nm

$= 397 \times 10^{-9}$ m

Speed of light $= C = 3 \times 10^8$ m/s

To Find

(a) Is the galaxy moving towards or away from the earth?

(b) Speed of galaxy relative to earth $= u_s = ?$

SOLUTION

(a) As we know that

$$f = \frac{C}{\lambda}$$

For apparent wavelength

$$f_A = \frac{C}{\lambda_A}$$

$$= \frac{3 \times 10^8}{478 \times 10^{-9}}$$

$$= 6.27 \times 10^{8+9-3}$$

$$= 6.27 \times 10^{14} \text{ Hz}$$

For fundamental wavelength

$$f = \frac{C}{\lambda}$$

$$= \frac{3 \times 10^8}{397 \times 10^{-9}}$$

$$= 7.55 \times 10^{14} \text{ Hz}$$

So $f_A < f$

The galaxy is moving away from the earth.

(b) For the speed of galaxy, when the galaxy is moving away from the earth

$$f_A = \frac{v}{v + u_s} f$$

$$v + u_s = \frac{v_f}{f_A}$$

$$\boxed{u_s = \frac{v_f}{f_A} - v}$$

$$= \frac{3 \times 10^8 \times 7.55 \times 10^{14}}{6.27 \times 10^{14}} - 3 \times 10^8$$

$$u_s = 3.612 \times 10^8 - 3 \times 10^8$$

$$= 0.612 \times 10^8$$

$$= 6.12 \times 10^7 \text{ m/s}$$

Result

(a) Galaxy is moving away from the earth.

(b) Speed of galaxy $= u_s = 6.12 \times 10^7$ m/s