Fsc Part 1 Chapter 8

WAVES

Wave

A disturbance created in a medium is called a wave. Waves can transport energy only and can not transport matter.

Wave Motion

A mechanism by which energy can be transferred from one place to another place is called as wave motion.

Types Of Waves

There are three types of waves given as

1. Mechanical Waves

The waves which require a material medium for their propogation are called mechanical waves.

For Example

a. Sound waves

b. Water waves

c. Waves produced in a string

2. Electromagnetic Waves

The waves which do not require any material medium for their propogation are called electro-magnetic waves.

For Example

a. Light waves

b. Heat waves

c. Radio waves

d. X-rays.

3. Matter Waves

The waves which are associated with moving particles are called matter waves.

For Example

Electrons moving with very high velocities behave like matter waves.

Progressive or Travelling Waves

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

For example, when a pebble is drop into the water, then ripples will be produced and spread out across the water. These ripples produced are called progressive or travelling waves because they carry energy across the water surface.

TYPES OF PROGRESSIVE WAVES

There are two types of progressive waves
a. Transverse waves.
b. Longitudenal or Compressional waves.

TRANSVERSE WAVES

Those waves in which particles of the medium are displaced in a direction perpendicular to the direction of propogation of waves are called as transverse waves.

FOR EXAMPLE

a. Light waves.
b. Waves produced in a rope or a string.
c. Waves produced on the surface of water.

LONGITUDENAL OR COMPRESSIONAL WAVES

Those waves in which particles of the medium are displaced in a direction parallel to the direction of propogation of waves are called as longitudenal or compressional waves.

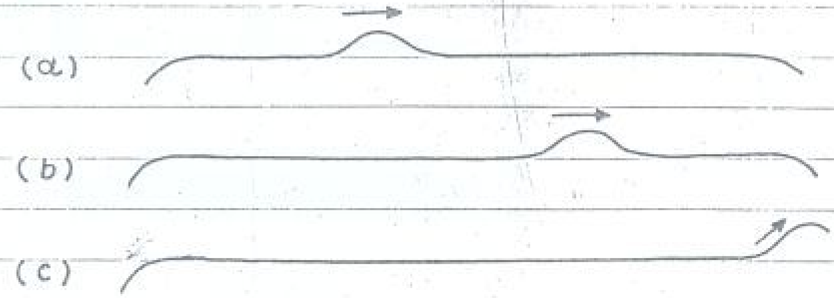
FOR EXAMPLE

Sound waves.

Both type of waves can be set up in solids. In fluids, transverse waves die out very quickly and usually cannot be produced. Waves produced in fluids are longitudenal in nature.

EXPLANATION

Consider two persons holding a rope from opposite ends. Suddenly, one person gives a jerk to the rope up and down. This disturb the rope and creates a hump in it which travels along the rope towards the other person as shown in figure (a) and (b). When this hump reaches the other person, it causes his hand to move up as shown in figure (c). Hence, the energy and momentum delivered by the first person to the end of the rope has reached the other end of the rope. So a wave has been set up on the rope in the form of a moving hump, called a pulse.

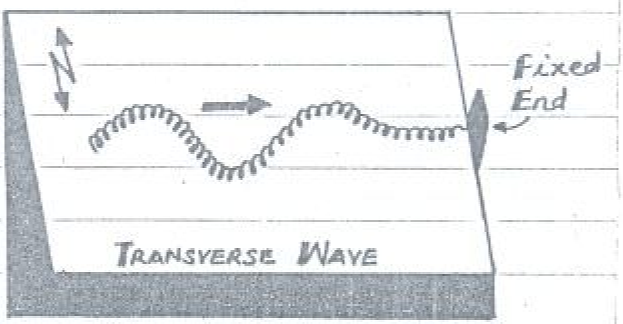


The forward motion of the pulse from one end of the rope to the other end is an example of progressive or travelling wave. Here, the hand jerk at one end of the rope is the source of the wave while the rope is the medium in which the wave moves.

Example For Transverse Waves

Consider a long and loose spring coil, called slinky spring is lying on a smooth table with its one end fixed with a rigid support so that spring does not sag under gravity. If the free end of the spring is moved from side to side, a pulse of wave is produced as shown in figure.

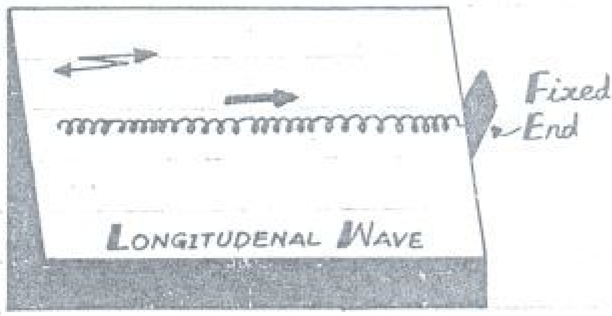
Such waves in which displacement of the spring is perpendicular to the direction of motion of waves are called transverse waves.



Example For Longitudenal Waves

Consider a slinky spring is lying on a smooth table with its one end fixed with a rigid support so that the spring does not sag under gravity as shown in the figure.

If the free end of the spring is moved back and forth along the direction of the spring itself, then a wave with back and forth displacement is produced which move along the spring as shown in figure.



Such waves in which displacement of the spring is in the direction of motion of waves are called longitudenal or compressional waves.

Periodic Waves

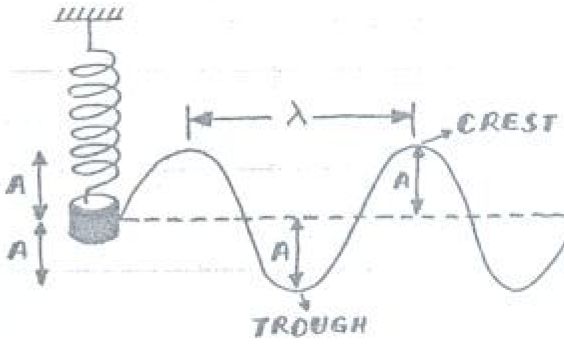
The periodic vibrations of a source produces continuous, regular and rhythmic disturbances in the medium which causes periodic waves in that medium.

An oscillating mass-spring system is a good example of a periodic vibrator which produces the periodic waves.

Transverse Periodic Waves

To understand transverse periodic waves, we perform an experiment

Consider a mass attached with a vertically suspended spring which form a mass-spring system as shown.



A rope is also attached to the mass. When mass-spring system vibrates up and down, then a transverse periodic wave travels along the length of the rope consists of crests and troughs as shown in figure.

As the source executes harmonic motion with amplitude 'A' and frequency 'f', then each particle of the rope along the length of the rope executes SHM with same amplitude and frequency. The wave travels towards right as crests and troughs in turn replace one another but the positions of particles of the rope remains same.

The terms involved in transverse periodic waves are defined as under

CREST

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

TROUGH

The portion of the transverse wave below its mean position is called trough.

FREQUENCY

The number of wave pulses passing through a certain point in one second is called frequency.

- It is denoted by f.
- Its SI-unit is hertz (Hz).
- Its dimension is $[T^{-1}]$ or $[M^0L^0T^{-1}]$.

TIME PERIOD

The time taken by a wave pulse in passing through a certain point is called time period.

- It is denoted by T.
- Its SI-unit is second (s).
- Its dimension is $[T]$ or $[M^0L^0T]$.

AMPLITUDE

The maximum value of displacement in a crest or trough from mean position is called amplitude.

- It is denoted by A or x_0.
- Its SI-unit is meter (m).
- Its dimension is $[L]$ or $[M^0LT^0]$.

WAVELENGTH

The distance between any two consecutive crests or troughs is called wavelength.

- It is denoted by λ (Greek letter Lambda).
- Its unit and dimension same as amplitude.

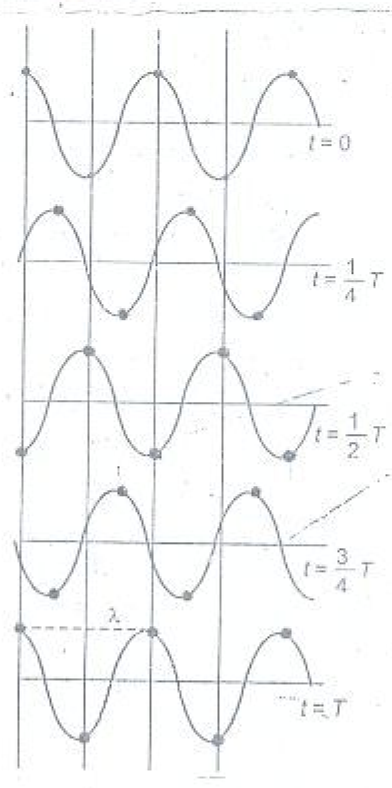
WAVE SPEED

The speed of a wave can be calculated by dividing the distance covered by a wave pulse with time taken to cover this distance.

$$\text{WAVE SPEED} = V = \frac{\text{DISTANCE COVERED}}{\text{TIME TAKEN}}$$

RELATION BETWEEN SPEED, WAVELENGTH AND FREQUENCY OF A WAVE OR PROVE THAT $V = \lambda/T$ or $V = f\lambda$.

When a wave propogates, then each point in the medium vibrates periodically with the same frequency and time period as that of the source. Figure shows a periodic wave is moving towards right from the source. In figure, the crest started from 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 move through one vibration i-e; the crest moves one wavelength λ in one period of vibration T. Hence the speed V of the crest is

$$V = \frac{\text{Distance Moved}}{\text{Corresponding Time Interval}}$$

or $$\boxed{V = \frac{\lambda}{T}}$$

As

$$\frac{1}{T} = f = \text{Frequency of the wave}$$

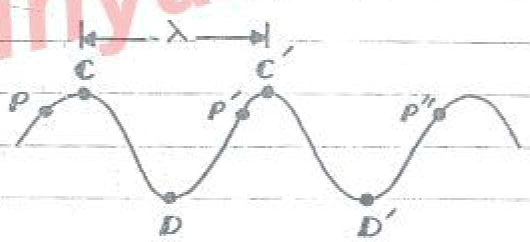
$$\therefore \quad \boxed{V = f\lambda}$$

So, the speed of propogation is equal to the product of frequency and wavelength.

Phase Points In Waves

Those points on a periodic wave which have similar displacements are said to be in phase.

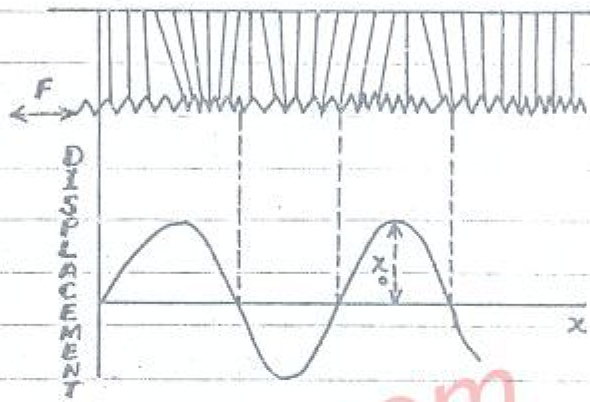
All the points or particles which are in phase have same displacements and velocities. The distance between any two consecutive points in phase is equal to the wavelength λ. So, the distance between any two points in phase may be separated by any one of $\lambda, 2\lambda, 3\lambda,$ ---------------. For example, points P, P', P'' are all in phase as shown.



Some of the points are exactly out of phase from one another. For example, when point C reaches its maximum upward displacement, then at the same time D reaches its maximum downward displacement. Such points like C and D are said to be out of phase or opposite phase. The distance between any two consecutive points which are out of phase is equal to $\lambda/2$. Hence, any two points separated from one another by $\lambda/2, 3\lambda/2, 5\lambda/2,$ ------- are out of phase.

Longitudenal Periodic Waves

Consider a coil spring suspended by threads so that it can vibrate horizontally as shown in figure. Consider an oscillating force F is applied at one end of the spring. This force produces compressions and rarefactions on the spring. Hence, the longitudenal waves are produced on the spring. This wave has constant value of time period which is equal to the time period of the oscillating force. This type of wave generated in springs is called longitudenal or compressional periodic wave.



When longitudenal periodic wave passes through the spring, then suspension threads starts vibrations. The displacement of the suspension threads measures the displacement of particular parts of the spring due to longitudenal periodic waves. A graph can be plotted between different values of displacement and corresponding values of position of the spring as shown in figure.

Compression

The portion in a longitudenal wave where the crowding of the particles of the medium is maximum, called compression.

Rarefaction

The portion in a longitudenal wave where the crowding of the particles of the medium is minimum, called rarefaction.

Wavelength ⟹ The distance between two consecutive compressions or rarefactions is called wavelength.

NEWTON'S FORMULA FOR SPEED OF SOUND IN AIR

In fact, the speed of all mechanical waves can be expressed in a general form given as

$$V = \sqrt{\text{Elastic Property}/\text{Inertial Property}}$$

Sound waves travel through any medium with a speed which is the chracteristic of that medium. The speed of sound depends on the elasticity and density of the medium. Newton was the first who derived the formula for speed of sound in air given as

$$V = \sqrt{E/\rho} \longrightarrow (1)$$

Where

E = Elasticity of medium or Bulk modulus.
= Stress / Volumetric strain.
ρ = Density of the medium.

Sound waves travel in gases in the form of compressions and rarefactions. Newton assumed that when a sound wave travels through air, the temperature of the air during compression and rarefaction remains constant. Such a process is called an isothermal process.

Let V be the volume of a gas at pressure P, then Boyle's law for isothermal process is

$$PV = \text{Constant} \longrightarrow (2)$$

If pressure increases from P to $(P+\Delta P)$ at constant temperature, then its volume decreases from V to $(V-\Delta V)$. Now, according to Boyle's law

$$(P+\Delta P)(V-\Delta V) = \text{Constant} \longrightarrow (3)$$

Comparing equation (2) and (3)

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

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

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

As $\Delta P << 1 \implies \Delta V << 1$, so

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

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

or $$P\Delta V = V\Delta P$$

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

or $$P = \frac{\Delta P}{\Delta V / V} = \frac{\text{Stress}}{\text{Volumetric Strain}}$$

or $$P = E$$

Put this value in equation ①, so Newton's formula for speed of sound is

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

Where atmospheric pressure P is given as

$$P = h\rho' g$$

So

$$v = \sqrt{\frac{h\rho' g}{\rho}}$$

Putting the values of atmospheric pressure and density of air at S.T.P. in above equation

$$P = h\rho' g = 1.013 \times 10^5 \ N/m^2$$

$$\rho = 1.293 \ Kg/m^3$$

$$\therefore \quad v = \sqrt{\frac{1.013 \times 10^5}{1.293}} = 280 \ m/s$$

As, the experimental value of speed of sound in air is 332 m/s and theoretical value comes out to be 280 m/s. Hence, theoretical value is about 16% less than the experimental value. This shows that Newton's formula was not correct.

LAPLACE'S CORRECTION

Newton's formula for speed of sound in air gave an incorrect result. Later on it was corrected by 'LAPLACE'.

Laplace pointed out that during the propogation of sound waves in air, the temperature of air does not remain constant. In sound waves, the compressions and rarefactions occurs so rapidly that heat produced in compressed regions does not have time to flow to the neighbouring rarefactions. This means that during compression, temperature rises and during rarefaction, temperature falls. Hence, temperature of air does not remain constant but total amount of heat remain constant. Hence, the process is no more isothermal but adiabatic one.

Now, Boyle's law for adiabatic process is

$$PV^{\gamma} = \text{Constant} \longrightarrow (1)$$

Where $\gamma = \dfrac{\text{Molar specific heat of gas at constant pressure}}{\text{Molar specific heat of gas at constant volume}}$

or $\gamma = C_P / C_V$

If pressure of a given mass of a gas is changed from P to $(P+\Delta P)$ and volume changes from V to $(V-\Delta V)$, then

$$(P+\Delta P)(V-\Delta V)^{\gamma} = \text{Constant} \longrightarrow (2)$$

Comparing equation (1) and (2)

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

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

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

or $$P = (P+\Delta P)\left(1-\frac{\Delta V}{V}\right)^{\gamma} \longrightarrow (3)$$

Applying Binomial theorem

$$(1+x)^n = 1 + nx + \frac{n(n-1)}{2\times 1}x^2 + \text{--------}$$

$$\Rightarrow \left(1-\frac{\Delta V}{V}\right)^{\gamma} = 1 + \gamma\left(-\frac{\Delta V}{V}\right) + \text{neglecting terms} \quad (\because \Delta V << V)$$

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

Put this value in equation ③

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

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

or $$0 = -\frac{\gamma P \Delta V}{V} + \Delta P - \frac{\gamma \Delta P \Delta V}{V}$$

As, $\Delta V << V$, so $\gamma \Delta V \Delta P / V$ can be neglected.

$\therefore$ $$0 = -\frac{\gamma P \Delta V}{V} + \Delta P$$

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

or $$\gamma P = \frac{\Delta P}{\Delta V / V} = \frac{\text{STRESS}}{\text{VOLUMETRIC STRAIN}}$$

or $$\gamma P = E$$

Hence, Laplace's formula for speed of sound in a gas is

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

Putting values of atmospheric pressure P, density ρ and γ as

$$P = h\rho' g = 1.013 \times 10^5 \, N/m^2 \quad \text{at S.T.P.}$$

For air, $\rho = 1.293 \, Kg/m^3$

$\gamma = 1.4$

$\therefore$ $$v = \sqrt{\frac{1.4 \times 1.013 \times 10^5}{1.293}}$$

$\Rightarrow$ $$v = 333 \, m/s$$

This value of speed of sound is very close to the experimental value. Hence, Laplace's formula for speed of sound is correct.

Effects Of Variations Of Pressure, Density And Temperature On The Speed Of Sound In A Gas

1. Effect Of Pressure

As we know that the speed of sound in a gas is

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

Since, the density of a gas is directly proportional to its pressure, so the ratio P/ρ remains constant for any change of pressure. Hence, the speed of sound is not affected by a change in the pressure of the gas.

2. Effect Of Density

We know that the speed of sound in a gas is

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

As, pressure is not affected the speed sound and γ is constant for a gas, so

$$v = \frac{\text{Constant}}{\sqrt{\rho}} \Rightarrow \boxed{v \propto 1/\sqrt{\rho}}$$

Hence, at the same temperature and pressure for the gases having the same value of γ, the speed of sound is inversely proportional to the square root of their densities.

For example, the speed of sound in hydrogen is four times its speed in oxygen as density of oxygen is 16 times that of hydrogen.

3. Effect Of Temperature

OR Prove That $v_t = v_0 + 0.61t$

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

As, speed of sound in gases is given as

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

So, the speed of sound is increased with rise in temperature as density is decreased.

Let

v_0 = Speed of sound at $0°C$; ρ_0 = Density of gas at $0°C$

v_t = Speed of sound at $t°C$; ρ_t = Density of gas at $t°C$

Now speed of sound at $0°C$ and $t°C$ are given as

$$v_0 = \sqrt{\frac{\gamma P}{\rho_0}} \quad \text{and} \quad v_t = \sqrt{\frac{\gamma P}{\rho_t}}$$

On dividing

$$\frac{v_t}{v_0} = \frac{\sqrt{\gamma P/\rho_t}}{\sqrt{\gamma P/\rho_0}} = \sqrt{\frac{\gamma P}{\rho_t} \times \frac{\rho_0}{\gamma P}}$$

or

$$\frac{v_t}{v_0} = \sqrt{\frac{\rho_0}{\rho_t}} \longrightarrow (1)$$

If V_0 is the volume of a gas at temperature $0°C$ and V_t is the volume at $t°C$, then for volume expansion of a gas, we have

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

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

$$V_t = V_0(1 + t/273) \longrightarrow (2)$$

As

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

So, volume of gas at $0°C$ and $t°C$ are given as

$$V_t = \frac{m}{\rho_t} \quad \text{and} \quad V_0 = \frac{m}{\rho_0}$$

Put these values in equation (2)

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

or

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

Put value of ρ_o in equation ①

$$\frac{v_t}{v_o} = \sqrt{\frac{\rho_t(1+t/273)}{\rho_t}}$$

$$\frac{v_t}{v_o} = \sqrt{1+\frac{t}{273}} \longrightarrow ③$$

$$\frac{v_t}{v_o} = \sqrt{\frac{273+t}{273}}$$

Where

$$273+t = T = \text{Absolute temperature at } t^\circ C$$

$$273 = T_o = \text{Absolute temperature at } 0^\circ C$$

$$\therefore \quad \frac{v_t}{v_o} = \sqrt{\frac{T}{T_o}} \Rightarrow \boxed{v \propto \sqrt{T}}$$

Hence, the speed of sound varies directly as the square root of absolute temperature.

From equation ③, we have

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

Using Binomial theorem and neglecting higher powers, we have.

$$\frac{v_t}{v_o} = \left[1+\frac{1}{2}\left(\frac{t}{273}\right)\right]$$

or $$\frac{v_t}{v_o} = 1+\frac{t}{546}$$

or $$v_t = v_o\left(1+t/546\right) = v_o + v_o t/546$$

As $$v_o = 332\ m/s$$

$$\therefore \quad v_t = v_o + \frac{332t}{546}$$

or $$\boxed{v_t = v_o + 0.61t}$$

This shows that one degree centigrade rise in temperature increases the speed of sound approximately 0.61 m/s.

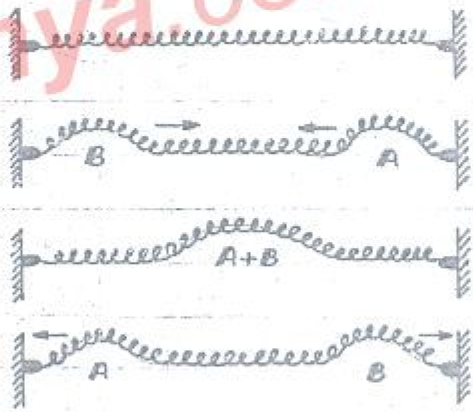
Principle Of Superposition

Statement: The principle of superposition states that
"When a particle of the medium is acted upon by a number of waves simultaneously, then its resultant displacement is equal to the vector sum of their individual displacements at that instant."

OR "If two or more waves are travelling in the same region, then the resultant displacement at any point is equal to the vector sum of their individual displacements at that point."

Explanation

Consider a coil spring which is held horizontally under tension. If the spring is plucked at the two ends, two waves are produced in it as shown. The wave A moves towards left and wave B moves towards right. When two waves cross each other at a point, the resultant wave displacement of the spring (medium) is equal to the sum of the displacements due to two waves. After crossing each other, they again assume their original shapes and continued to move along the spring in their respective directions.



Thus, if a particle of a medium is acted upon by n-waves simultaneously such that its displacements due to each of the individual n-waves is $y_1, y_2, y_3, \ldots\ldots, y_n$, then the resultant displacement Y of the particle under the simultaneous action of n-waves is given by

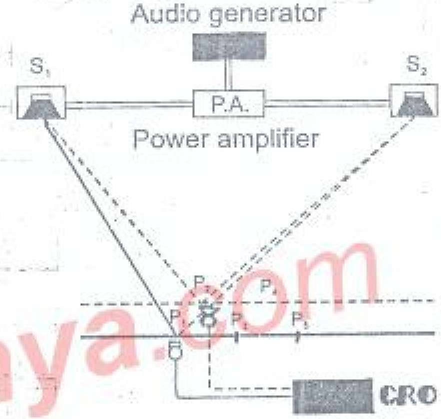
$$Y = y_1 + y_2 + y_3 + \cdots\cdots + y_n$$

INTERFERENCE

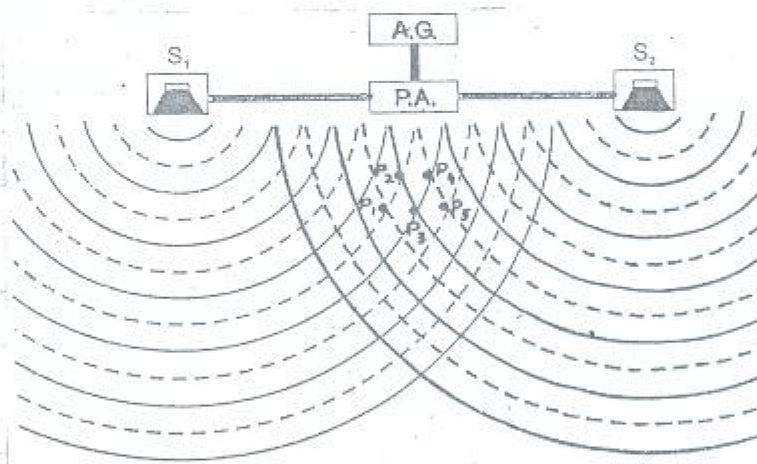
The phenomenon of superposition of two waves having the same frequency and travelling in the same direction is called interference.

EXPLANATION

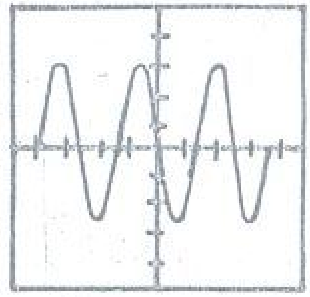
In order to observe interference effect in sound waves, we consider an experimental arrangement as shown in the figure.



Consider two loud speakers S_1 and S_2 act as two sound sources of a fixed frequency produced by an audio generator. A microphone attached to a sensitive cathode ray oscilloscope (CRO) act as a detector of sound waves. The CRO is a device to display the input signal into waveform on its screen. The microphone is placed at different points, turn by turn, infront of loudspeakers.



At points P_1, P_3, P_5 a large signal is seen on the CRO, whereas at points P_2, P_4 no signal is seen on CRO screen. Both speakers emitted compressions and rarefactions alternately. In figure, continuous lines shown compression and dotted lines show rarefaction. At points P_1, P_3 and P_5, compression meets with a compression and rarefaction meets with a rarefaction. So, the displacement of two waves added up at these points and a large resultant displacement is produced which is seen on the CRO screen as shown in figure.



At points P_2 and P_4, compression meets with a rarefaction, so they cancel each other's effect and the resultant displacement becomes zero as shown in figure.

Types Of Interference

There are two types of interference

(i) Constructive Interference

(ii) Destructive Interference

Constructive Interference

When sound waves superpose each other in such a way that compression of one wave falls on the compression of the other and rarefaction of one falls on the rarefaction of the other, then resultant sound is loud and the interference is called constructive interference.

Condition For Constructive Interference

The path difference ΔS between the waves at the point P_1 is

$$\Delta S = S_2P_1 - S_1P_1$$

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

or $$\Delta S = \lambda$$

Similarly, at points P_3 and P_5, the path difference is zero and $-\lambda$ respectively. Therefore, the condition for constructive interference may be written as

$$\boxed{\text{PATH DIFFERENCE} = \Delta S = n\lambda}$$

Where $n = 0, \pm 1, \pm 2, \pm 3, \text{------------}$

Hence whenever path difference is an integral multiple of wavelength displacements, the two waves are added up. This effect is called constructive interf.

DESTRUCTIVE INTERFERENCE

When sound waves superpose each other in such a way that compression of one wave falls on the rarefaction of the other wave and rarefaction of one wave falls on the compression of the other wave, then resultant sound is low and the interference is called destructive interference.

CONDITION FOR DESTRUCTIVE INTERFERENCE

The path difference ΔS between the waves at point P_2 is

$$\Delta S = S_2P_2 - S_1P_2$$

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

or $\Delta S = \tfrac{1}{2}\lambda$

Similarly, the path difference at point P_4 is $-\tfrac{1}{2}\lambda$.

Therefore, the condition for destructive interference may be written as

$$\boxed{\text{PATH DIFFERENCE} = (2n+1)\frac{\lambda}{2}}$$

Where $n = 0, \pm 1, \pm 2, \pm 3, \text{------------}$

Hence at points where the 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.

BEATS

The periodic variations of sound between the maximum and minimum loudness are called beats.

EXPLANATION

When two bodies of slightly different frequencies are sounded at a time, then the loudness of resultant sound rises and falls. If sound waves due to two bodies are in phase, then loudness of resultant sound rises and if sound waves are in opposite phase, then loudness falls. One rise and one fall, make one beat.

Consider two tuning forks A and B of same frequencies say 256 Hz. As tuning forks give out pure notes. If they are sounded simultaneously, it will be difficult to recognize the notes of both tuning forks. If tuning fork B is loaded with some wax or plasticene, its frequency will be lowered slightly. So

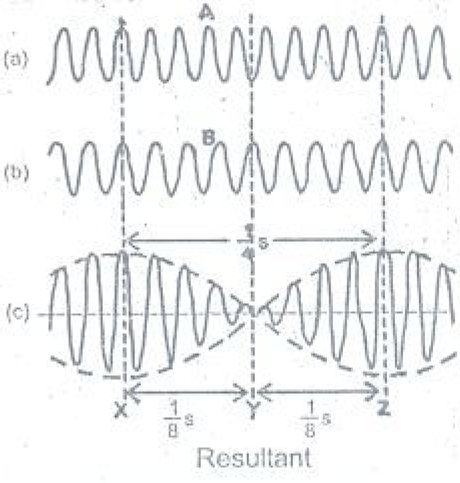
Frequency of tuning fork $A = f_A = 256\ Hz$

and Frequency of tuning fork $B = f_B = 252\ Hz$

Now if both tuning forks are sounded together, a note of alternately increasing and decreasing intensity will be heard. This note is called beat note or a beat which is due to interference between the sound waves from tuning forks A and B.

WAVEFORM OF BEATS OR DISPLACEMENT CURVE

When we draw displacement curves of sound waves produced by the tuning forks, then the resultant displacement is equal to the sum of two waves. It is seen that resultant displacement varies with time. The variations of displacements give rise to variations of



loudness which we call "BEATS".

Figure (a) shows the waveform of the note emitted from tuning fork A and figure (b) shows the waveform of the note emitted by tuning fork B. When both the tuning forks are sounded together, the resultant waveform is shown in figure (c).

At some instant X, the displacement of the two waves is in the same direction and resultant displacement is large due to which loud sound is heard. After $1/8$ s, the displacement of the wave due to one tuning fork is opposite to the displacement of the wave due to the other tuning fork resulting in a minimum displacement Y, hence low sound or no sound is heard. After another $1/8$ s, displacements are again in the same direction and a loud sound is heard at Z as shown in figure.

This means that a loud sound is heard four times in each second. As difference of frequency of the two tuning forks is also 4 Hz, so we find that

Number of beats per second is equal to the difference between the frequencies of the tuning forks. i.e;

$$\boxed{f_A - f_B = n \text{ (No. of beats/second)}}$$

When the difference of frequencies of the two sounds is more than about 10 Hz, then it is difficult to recognize the beats.

APPLICATIONS OR USES OF BEATS

(i) Beats are used in tuning the musical instruments.

(ii) Beats are used to determine unknown frequency.

(iii) Beats are used to produce variety in music.

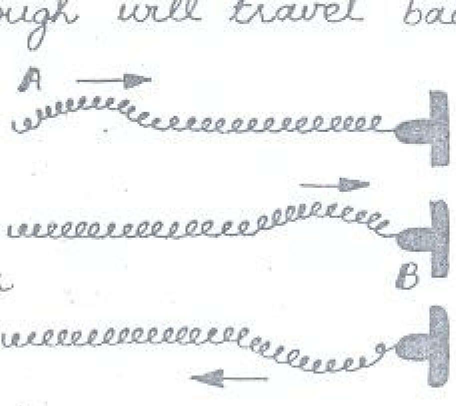
Reflection Of Waves

When a wave is travelling in one medium comes across the boundary of another medium, then a part of it is reflected back in the same medium. This bouncing back of the wave from the boundary of another medium is called "Reflection of waves".

When the wave comes across the boundary of two different media, a part of it is reflected back. The reflected wave has the same wavelength and frequency but its phase may change depending upon the nature of the boundary.

Reflection Of Wave From The Boundary Of A Denser Medium

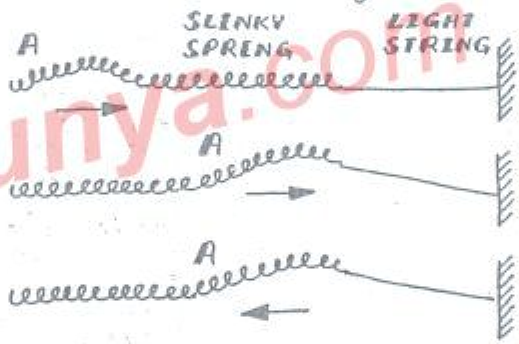
Consider a slinky spring attached with a rigid support from one end on a smooth horizontal table. When a jerk is given to the free end of the slinky spring towards the side A, a crest will travel from free end to the boundary. It will exert a force on fixed end towards the side A. Since, this end is rigidly bound and acts as a denser medium, it will exert a reaction force force on the spring in opposite direction. This force will produce displacements towards B and a trough will travel backwards along the spring.



Hence, it can be concluded that if a transverse wave travelling in a rarer medium is incident on a denser medium, then wave bounces back such that the direction of its displacement is reversed i-e; it undergoes a phase change of 180°. An incident crest on reflection becomes a trough.

Reflection Of Wave From The Boundary Of A Rarer Medium

Consider one end of a light string is attached to a slinky spring and other end of string attached to a rigid support. The spring is given a sharp jerk towards A and then a crest travels along the spring. When this crest reaches the string boundary which act as a rarer medium, it exerts a force on the string towards the side A. Since the string has a small mass as compared to spring, it does not oppose the motion of the spring. The end of the spring continues its displacement towards A. So a crest is again produced at the boundary of the spring - string system which travels backward along the spring.



Hence it can be concluded that if a transverse wave travelling in a denser medium is incident on a rarer medium, the direction of its displacement remains the same i-e; it reflected without any change in phase. So an incident crest is reflected as a crest.

Conclusion

(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.

Transmission Of Waves

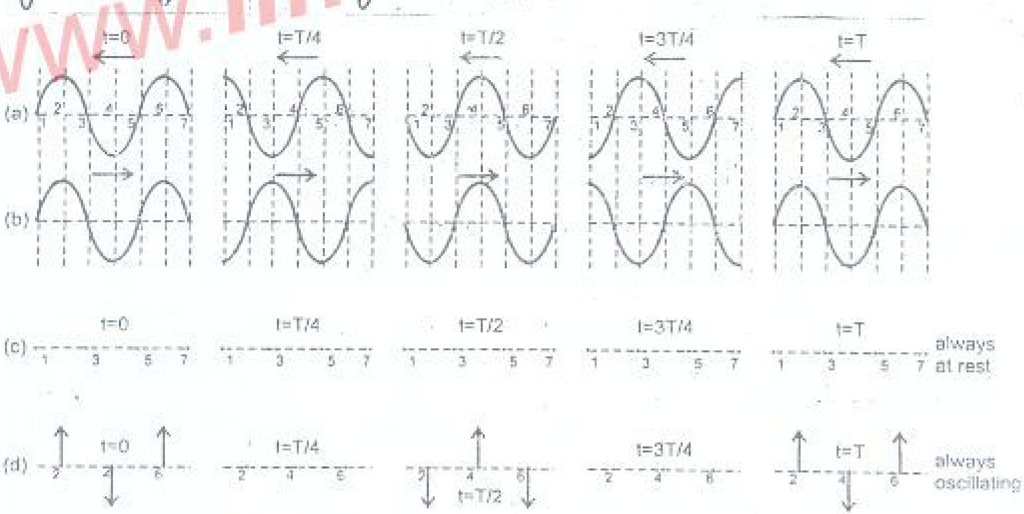
When a wave is moving across a certain medium and comes across another medium, only a portion of it is reflected and the remaining portion passes into the other medium. This passage of the wave from one medium into the other medium is called transmission of waves.

Stationary Waves or Standing Waves

When two similar waves having the same frequency, wavelength and amplitude move along the same line but in opposite directions, superpose each other according to the principle of superposition, then special kind of waves are produced, called stationary waves or standing waves.

Explanation

Consider the superposition of two waves moving along a string in opposite directions as shown.



Let us find the displacements of the points 1, 2, 3, 4, 5, 6, 7 at the instants $t = T/4, T/2, 3T/4$ and T as the waves superpose. The points 1, 2, 3, 4, 5, 6, 7 are $\lambda/4$ distant apart as shown in figure (a) and (b).

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 is clear that the resultant displacement of these points is always zero. These points of the medium are known as nodes.

Similarly, figure (d) shows the resultant displacement of the points 2, 4 and 6 at the instants $t=0, T/4, T/2, 3T/4$ and T. These points are known as antinodes. These points are moving with an amplitude which is the sum of the amplitudes of the component waves.

The distance between two consecutive nodes or antinodes is $\lambda/2$ and the distance between a node and the next antinode is $\lambda/4$. Such a pattern of nodes and antinodes is known as stationary waves or standing waves.

ENERGY OF STATIONARY WAVES

Energy in a wave moves because of the motion of the particles of the medium. As in case of stationary waves, the nodes always remain at rest, so energy can not flow past these points. Hence energy remains "standing" in the medium between nodes but energy changes between potential and kinetic forms. When the antinodes are all at their extreme positions, the energy stored is wholly potential and when they are passing through their mean positions, the energy is wholly kinetic.

Hence, there is no net flow of energy in case of stationary waves.

NODE ⇒ A point in stationary wave where the displacement is zero and strain is maximum, known as a node.

ANTINODE ⇒ A point in a stationary wave where the displacement is maximum and strain is minimum, known as antinode.

Characteristics Of Stationary Waves

(i) The displacement of the particles is zero at nodes and maximum at antinodes.

(ii) The particles at nodes remain at rest and vibrate with maximum displacement at antinodes.

(iii) The velocity of the particles of the medium at node is zero and changes harmonically at other points.

(iv) Strain is maximum at nodes and minimum at antinodes.

(v) There is a node between two consecutive antinodes and there is a antinode between two consecutive nodes.

(vi) Distance between two consecutive nodes or anti-nodes is $\lambda/2$.

(vii) The distance between a node and the next anti-node is $\lambda/4$.

(viii) The waveform between two consecutive nodes is called a loop.

(ix) A loop contains two nodes and only one antinode

Types Of Stationary Waves

There are two types of stationary waves

Transverse Stationary Waves

Transverse stationary waves are formed in a string whose one end is fixed by sending properly timed impulses along a string. In this case, the waves produced are transverse stationary waves.

Longitudenal Stationary Waves

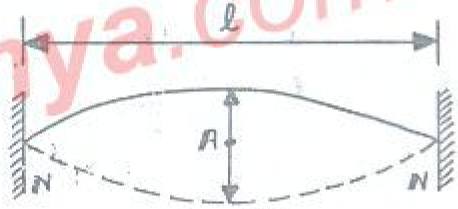
The waves set up in a vibrating air column are called longitudenal stationary waves. In case of organ pipe, the waves produced are longitude-nal stationary waves.

Stationary Waves In A Stretched String

Consider a stretched string of length 'l' fixed at both ends with supports so that the tension in the string is 'F'. Transverse stationary waves are produced in the string having different frequencies by plucking it at different places.

First Mode Of Vibration

If we pluck the string at its middle point, two transverse waves will produce from that point. These waves move along the string in opposite directions. When these waves reach the two fixed ends, they are reflected back and superpose to form stationary waves. Thus, the string vibrates in one loop as shown in figure. As two ends of the string are fixed, so no motion will take place there. Hence nodes will be formed at the two ends and an antinode is formed in between nodes.



$l = \lambda/2$

Let

Frequency of waves $= f_1$

Wavelength of waves $= \lambda_1$

Speed of waves $= v$

As, distance between two consecutive nodes is $\lambda/2$, so in this mode of vibration, the length 'l' of the string is

$$l = \lambda/2$$

or $$\lambda_1 = 2l \longrightarrow (1)$$

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

$$V = \sqrt{F/m} \longrightarrow ②$$

Also

$$V = f_1 \lambda_1$$

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

From equation ①, $\lambda_1 = 2l$

$$\therefore \boxed{f_1 = \frac{V}{2l}} \longrightarrow ③$$

Put value of V from equation ②, so

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

This frequency is called fundamental frequency.

SECOND MODE OF VIBRATION

Now let the same string is plucked from one fourth of its length. Again stationary waves will set up with nodes and antinodes as shown in figure. Now string vibrate in two loops with another frequency f_2. If λ_2 is the wave-length of waves in this case, then length of string is

$l = \lambda_2 = 2 \times \lambda_2/2$

$$l = 2 \times \lambda_2/2 = \lambda_2$$

or $$\boxed{\lambda_2 = l}$$

As speed of waves depends upon the tension F and mass per unit length of the string 'm' and it is independent of the point from where the string plucked to produce waves. So, speed of waves remain same.

If f_2 is the frequency of second mode of vibration of the string, then speed of waves is

$$V = f_2 \lambda_2$$

or $$V = f_2 l \qquad (\because \lambda_2 = l)$$

or $$f_2 = \frac{v}{l}$$

or $$f_2 = 2 \cdot \frac{v}{2l}$$

From equation ③, we have

$$f_1 = \frac{v}{2l}$$

So

$$\boxed{f_2 = 2f_1}$$

Hence, when string vibrates in two loops, its frequency is doubled as when it vibrates in one loop.

Similarly, if string is plucked from one sixth of its length, then it vibrate in three loops with nodes and antinodes as shown in figure. If f_3 and λ_3 be the frequency and wavelength of third mode of vibration of the string, then

$l = 3\lambda_3/2$

$$f_3 = 3f_1$$

and

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

Similarly, if the string is made to vibrate in 'n' loops, the frequency of stationary waves in a stretched string will be given as

$$\boxed{f_n = nf_1}$$

And the wavelength is given as

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

As, the string vibrates in more and more loops, its frequency goes on increasing and corresponding wavelength decreases. However, the product of the frequency and wavelength is always equal to the speed of waves V i-e;

$$\boxed{V = f_n \lambda_n}$$

Hence, stationary waves have a discrete set of frequencies $f_1, 2f_1, 3f_1, \ldots\ldots, nf_1$ known as harmonic series. The fundamental frequency f_1 is called as first harmonic and frequency $f_2 = 2f_1$ is called as second harmonic and so on.

Fundamental Frequency

The lowest frequency (f_1) with which a transverse wave is produced in a string is called fundamental frequency.

Harmonics or Overtones

The frequencies other than the fundamental frequency are called harmonics or overtones. i-e;

$$f_n = nf_1 \qquad \text{where } n = 2, 3, 4, \ldots\ldots$$

Frequency Variations In Musical Instruments

The frequency of a string on a musical device can be changed either by varying the tension or by changing the length of the string.

For example, the tension in guitar and violin strings is changed by tightening or loosing the pegs on the neck of the instrument. When the instrument is adjusted, then the musicians change the frequency by moving their fingers along the neck of musical instrument.

Organ Pipe

An organ pipe is an air instrument. It consists of a long tube in which air is forced from one end. Sound is produced by means of vibrating air column which produces stationary waves in the pipe. Sound is produced in organ pipe, due to resonance between the forced air and stationary waves.

There are two types of organ pipes

Closed Organ Pipe

If one end of an organ pipe is closed, it is called closed organ pipe.

Open Organ Pipe

If both ends of an organ pipe are open, it is called open organ pipe.

Stationary Waves In Air Column

Stationary waves can be set up in an air column. For example, stationary waves can be set up in organ pipe due to vibrating air column. The modes of vibration of an air column in a closed pipe and open pipe are discussed as

Modes Of Vibration In An Open Pipe

Consider a vibrating tuning fork held at the mouth of an open pipe of length 'l'. If the pipe is open at both ends, then its ends behave as antinodes. The modes of vibration in this are shown in figure. In figure, the longitudenal waves are set up in the pipe represented by transverse curved lines indicating the changing amplitude of vibration of air particles.

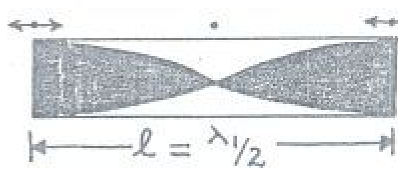
Fundamental Mode Of Vibration

Let

Frequency of longitudenal wave $= f_1$

Wavelength of longitudenal wave $= \lambda_1$

In case of fundamental mode of vibration, the distance between two open ends of the pipe is equal to the half the wavelength, so



$$l = \lambda_1/2$$

or $\lambda_1 = 2l$

Now, speed of waves is given as

$$v = f_1 \lambda_1$$

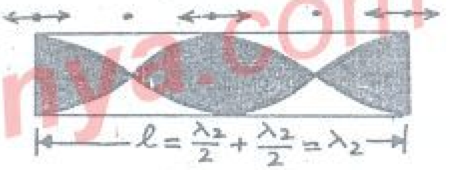
or $f_1 = \frac{v}{\lambda_1}$

or $\boxed{f_1 = \frac{v}{2l}}$

Second Mode Of Vibration

In case of second mode of vibration, let
Frequency of longitudenal wave $= f_2$
Wavelength of longitudenal wave $= \lambda_2$
Now the distance between two open ends is

$$l = \lambda_2/2 + \lambda_2/2 = \lambda_2$$



or $\lambda_2 = l$

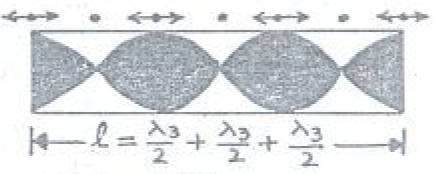
The speed of waves is

$$v = f_2 \lambda_2$$

or $f_2 = \frac{v}{\lambda_2} = \frac{v}{l} = 2\left(\frac{v}{2l}\right)$

or $\boxed{f_2 = 2f_1}$ $\left(\because \frac{v}{2l} = f_1\right)$

Similarly, the frequency of third mode of vibration is



$\Rightarrow l = 3\lambda_3/2$

$$f_3 = 3f_1$$
$$f_4 = 4f_1$$
$$\vdots \quad \vdots$$

$\boxed{f_n = nf_1}$ or $\boxed{f_n = \frac{nv}{2l}}$

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

Hence, all harmonics are present in an open pipe as proved in above relation i-e; $f_n = nf_1$.

Modes Of Vibration In A Closed Pipe

Consider a pipe of length 'l' which is closed at one end. Let a vibrating tuning fork is held at the open end of the pipe. Here node is produced at the closed end and an antinode is always formed at the open end of the pipe.

The modes of vibration in this case are

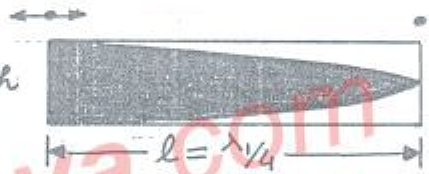
Fundamental Mode Of Vibration

In case of fundamental mode of vibration, let

Frequency of longitudenal wave $= f_1$

Wavelength of longitudenal wave $= \lambda_1$

Here the distance between a node and antinode is one fourth of the wavelength given as



$$l = \lambda_1/4$$

or $$\lambda_1 = 4l$$

Now the speed of waves is

$$v = f_1 \lambda_1$$

or $$f_1 = \frac{v}{\lambda_1}$$

or $$\boxed{f_1 = \frac{v}{4l}}$$

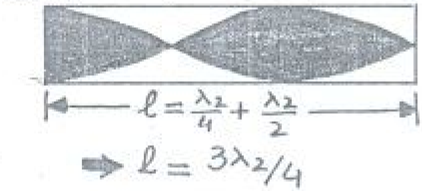
Second Mode Of Vibration

In case of second mode of vibration, let

Frequency of longitudenal wave $= f_2$

Wavelength of longitudenal wave $= \lambda_2$

Here the distance between a node and antinode is three fourth of wavelength, so



$$l = 3\lambda_2/4$$

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

The speed of waves is

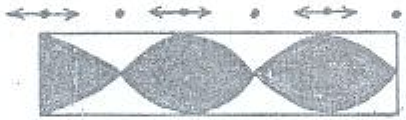
$$v = f_2 \lambda_2$$

or $$f_2 = \frac{v}{\lambda_2} = \frac{v}{4l/3}$$

or $$f_2 = 3\left(\frac{v}{4l}\right) \qquad \left(\because \frac{v}{4l} = f_1\right)$$

or $$\boxed{f_2 = 3 f_1}$$

Similarly, the frequency of third mode of vibration is



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

$$\Rightarrow l = \frac{5\lambda_3}{4}$$

$$f_3 = 5 f_1$$

$$f_4 = 7 f_1$$

$$\vdots \qquad \vdots$$

$$\boxed{f_n = n f_1} \quad \text{or} \quad \boxed{f_n = \frac{nv}{4l}}$$

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

Above relation shows that only odd harmonics are present in a closed pipe.

Doppler's Effect

Statement: The apparent change in the pitch of sound due to the relative motion between the observer and the source of sound is called Doppler's Effect.

This effect was observed by Johann Doppler while observing the frequency of light emitted from distant stars.

Explanation

Consider an observer is standing on a railway plateform. The apparent pitch of the whistle of the train increases, when the train moving towards the observer. But the apparent pitch of the whistle of the train decreases, when the train is moving away from the observer.

This change in frequency (pitch) can be calculated easily whenever the source of sound and the observer are moving with respect to each other along a straight line joining them.

Consider that 'V' be the velocity of sound in the medium and source emits a sound of frequency f and wavelength λ. If both the source and the observer are stationary, then the number of waves recieved by the observer in one second (frequency) are

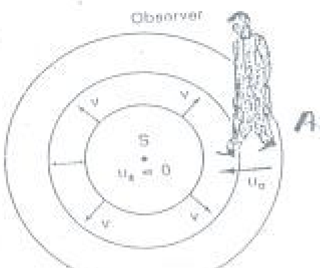
$$f = \frac{V}{\lambda} \qquad (\because V = f\lambda)$$

Now, we discuss different cases

Case (i) When Observer Moves Towards The Stationary Source

Consider an observer A moves towards the stationary source with velocity 'u_o' as shown in figure. Now the relative velocity of the waves and observer is increased to $(V + u_o)$. Hence number of waves recieved by the observer in one second or new frequency f_A is

$$f_A = \frac{V + u_o}{\lambda} \longrightarrow (1)$$



As $\quad V = f\lambda$

or $\quad \lambda = V/f$

Put in equation (1)

$$\therefore \quad f_A = \frac{V + u_o}{V/f}$$

or

$$\boxed{f_A = \left(\frac{V + u_o}{V}\right) f} \longrightarrow (2)$$

As $(V + u_o) > V$ or $\frac{V+u_o}{V} > 1$

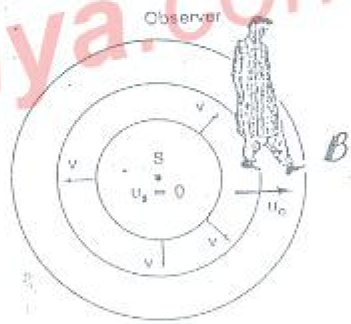
$\Rightarrow f_A > f$

Hence the frequency of sound increases. So, pitch of sound also increases when observer moves towards the stationary source of sound.

Case (ii) When Observer Moves Away From The Stationary Source

Consider an observer B moves away from the stationary source with velocity 'u_o' as shown in figure. Now the relative velocity of the waves and the observer is decreased to $(V - u_o)$. So, the observer receives less number of waves. Hence, the number of waves received by the observer in one second or new frequency f_B is

$$f_B = \frac{V - u_o}{\lambda} \longrightarrow ③$$



As $V = f\lambda$

or $\lambda = V/f$

Put in equation ③

$$f_B = \frac{V - u_o}{V/f}$$

or
$$\boxed{f_B = \left(\frac{V - u_o}{V}\right) f} \longrightarrow ④$$

As $(V - u_o) < V$ or $\frac{V - u_o}{V} < 1$

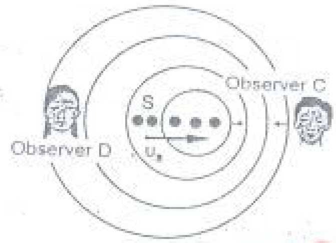
$\Rightarrow f_B < f$

Hence the frequency of sound decreases. So apparent pitch of sound also decreases when observer moves away from the stationary source of sound.

Case (iii) When Source Moves Towards The Stationary Observer

Now consider that the source is moving towards the stationary observer with velocity 'u_s' as shown in figure. As source emitting sound waves 'f' in one second. But when source moves towards the stationary observer C, then in one second, the same number of waves are compressed in a shorter distance depending on the velocity of the source. This is known as Doppler shift represented by $\Delta\lambda$. The Doppler shift $\Delta\lambda$ is given as

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



Now wavelength λ_c for observer C is

$$\lambda_c = \lambda - \Delta\lambda \longrightarrow ⑤$$

As $\quad V = f\lambda$

or $\quad \lambda = V/f$

Put values in equation ⑤

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

The new frequency f_c for observer C is

$$V = f_c\lambda_c$$

or $$f_c = \frac{V}{\lambda_c} = \frac{V}{(V-u_s)/f} \qquad \left(\because \lambda_c = \frac{V-u_s}{V}\right)$$

or $$\boxed{f_c = \left(\frac{V}{V-u_s}\right)f} \longrightarrow ⑥$$

As $\quad V > (V-u_s) \quad$ or $\quad \frac{V}{V-u_s} > 1$

$$\Rightarrow \boxed{f_c > f}$$

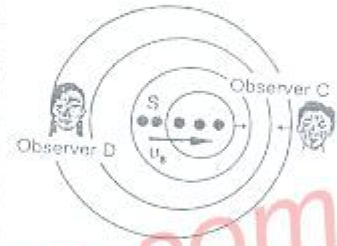
Hence frequency of sound increases. So apparent pitch of sound also increases when source moves towards the stationary observer.

Case (iv) When Source Moves Away From The Stationary Observer

Now consider that the source is moving away from the stationary observer with velocity 'u_s'

as shown in figure. As source emitting sound waves 'f' in one second. But when source moves away from the stationary observer D, then in one second, the same number of waves are contained in a greater distance depending on the velocity of the source. This is known as Doppler's shift represented by $\Delta\lambda$. The Doppler shift $\Delta\lambda$ is given as

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



Now, wavelength λ_D for observer D is

$$\lambda_D = \lambda + \Delta\lambda \longrightarrow (6)$$

As $\quad V = f\lambda$

or $\quad \lambda = V/f$

Put values in equation (6)

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

The new frequency f_D for observer D is

$$V = f_D \lambda_D$$

or $\quad f_D = \dfrac{V}{\lambda_D} = \dfrac{V}{(V+u_s)/f} \qquad \left(\because \lambda_D = \dfrac{V+u_s}{f}\right)$

or $\quad \boxed{f_D = \left(\dfrac{V}{V+u_s}\right) f}$

As $\quad V < (V+u_s) \quad$ or $\quad \dfrac{V}{V+u_s} < 1$

$\Rightarrow \quad \boxed{f_D < f}$

Hence frequency of sound decreases. So apparent pitch of sound also decreases when source moves away from the stationary observer.

APPLICATION OF DOPPLER'S EFFECT

RADAR SYSTEM

The important application of Doppler effect is the radar system, which uses radio waves to determine the elevation and speed of an aeroplane. Radar is a device, which transmits and receives radio waves If an aeroplane moves towards the radar, then the frequency of the reflected waves increases and if it moves away, then the frequency of reflected waves decreases. Similarly, speed of satellites moving around the earth can also be determined by the same principle.

SONAR

Sonar is derived from "Sound navigation and ranging". Sonar is the name of a technique for detecting the presence of underwater objects by acoustical echo.

Sonar relies upon the relative speed of the target and the detector to provide an indication of the target speed. It uses Doppler effect in which apparent change in frequency occurs when the source and the observer are in relative motion to one another. Its known military applications include the detection and location of the submarines, control of anti-submarine weapons, mine hunting and depth measurement of sea.

FOR ASTRONOMERS

Astronomers uses the Doppler effect to calculate the speeds of distant stars and glaxies. It can be done by comparing the line spectrum of light from the star with light from a labortory source. So Doppler shift of the star's light can be measured and hence speed of the star can be calculated.

Fsc Part 1 Chapter 8

Stars

When stars moving towards the earth, then it show a blue shift because the wavelength of the light emitted by the star are shorter as compared to stationary star. So the spectrum is shifted towards shorter wavelength i-e; to the blue end of the spectrum.

Stars moving away from the earth show a red shift. Now the emitted light waves have a longer wave-length as compared to stationary star. So the spectrum is shifted towards longer wavelength i-e; towards the red end of the spectrum. Astronomers have discovered that all the distant glaxies are moving away from us and by measuring their red shifts, they have estimated their speeds.

Microwaves

Microwaves are emitted from a transmitter in short bursts. The transmitter is open to detect the reflected microwaves. If the reflection is caused by a moving obstacle, the reflected microwaves are Doppler shifted. By measuring the Doppler shift, the speed at which the obstacle moves is calculated by computer programme.

Fsc Part 1 Chapter 8

SHORT QUESTIONS & ANSWERS

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

Longitudinal and transverse waves have the following common features.

Ans. (i) Both types of waves produce disturbances in the medium through which they travel.

(ii) Both transport energy from one place to another but not matter.

(iii) Both have a frequency 'f' wavelength 'λ' and their speed is the product '$f\lambda$'.

8.2 The five possible waveforms obtained, when the output from a microphone is fed into Y-input of cathode ray oscilloscope, with the time base on, are shown in Fig. 8.31. These waveforms 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. 8.31

Ans. (a) As loudness depends on amplitude and hence, trace B represents the loudest sound.

(b) Trace B represents the highest frequency.

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, two waves traveling in the same direction cannot give rise to a stationary wave. Stationary wave is a result of superposition of two identical waves traveling in opposite directions in the same medium.

8.4 A wave is produced along a stretched string but some of its particles permanently show zero displacement? What type of wave is it?

Ans. This is a stationary wave as some of the points of the medium remain permanently stationary. These particles are called as nodes.

8.5 Explain the terms crest, trough, node and antinode.

Ans. (i) Crest is the portion of the disturbance above the equilibrium position in case of a transverse wave.

(ii) Trough is the portion of disturbance below the equilibrium position in case of a transverse wave.

(iii) Node is the point of zero displacement in the case of a stationary wave.

(iv) Antinode is the point of maximum displacement in the case of a stationary wave.

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

Ans. The speed of sound is given by the expression

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

where 'E' is the elastic modulus and 'ρ' is the density of the medium through which sound wave travels. Although density of solids is greater than gases but the value of elastic modulus for solids is much greater as compared to gases. Hence, elastic effect wins over the density effect and sound travels faster in solids than the gases.

8.7 How are the beats useful in tuning musical instruments?

Ans. A faulty musical instrument and a standard musical instrument are sounded together to play the same note. Beats are produced if the string frequencies of faulty instrument are not the same as that off the standard instrument. The strings can then be adjusted to the desired frequency by tightening or loosening them until no beats are heard.

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

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

Ans. The number of beats produced in one second equals the difference in the frequencies of two notes. Hence, correct answer is (iii) $f_1 - f_2$

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. The time difference is due to the fact that waves produced by the explosion reaches through the solid ground much faster than the sound waves traveling through air as explained in question 8.6.

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

Ans. As speed of sound in air is given by

$$v = \sqrt{\frac{\gamma p}{\rho}}$$

In warm air, gas molecules have a greater mobility and can easily transport energy of the propagating sound waves.

The air density of warm air is less than cold air. Hence, speed of sound is faster in warm air than in cold air.

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

Ans. Doppler's effect, states that the apparent frequency of the sound heard by the listener changes, is produced only due to relative motion of the source and the observer.

If both source of sound and observer are in motion then there relative velocity is zero. Hence the apparent frequency of the sound will not be changed.