- Live Webinars (online lectures) with recordings.
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- Career Counseling

Wave Motion

Important definations

1. Wave : Wave is a mode of energy transfer through material elastic medium in the form of disturbance propagation through the medium due to periodic, vibrational motion of particle about their mean position.
2. Amplitude (a) : The maximum displacement of particle of medium from its mean position is called the amplitude (a) of the wave.
   (unit is m or cm)
3. Wavelength (λ) : The distance between two nearest particles of medium which are in the same phase is called the wavelength (λ) of wave. (unit is m or cm or A^0)

   OR

The distance travelled by the wave in one periodic time (T) is called wavelength of wave.

4. Period (T) : The time taken by the particle to complete one vibration is called the periodic time (T) or period of the wave (unit is second)

5. Frequency (n) : The number of vibrations completed in one second / unit time is called frequency of wave.

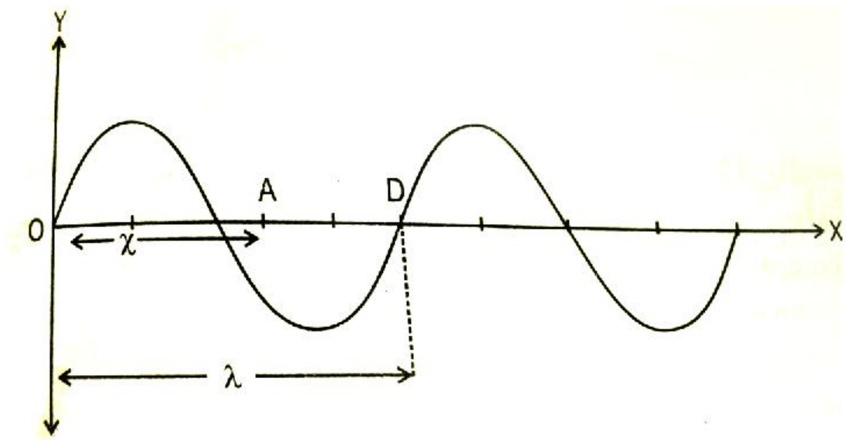
$$\therefore\ v = n\lambda$$

Simple harmonic progressive wave.

Definition: A wave which travel continuously on particular direction with the particle of medium performing simple harmonic (periodic) vibration is called simple harmonic wave.

Progressive waves are doubly periodic. i.e. periodic in time and space. When a progressive wave travels through the medium, it can be observed that the particle of the medium repeats the motion after fixed time interval time to time. That means progressive wave is periodic in time. Also it can be observed that at any instant the shape of the wave repeats at equal distances. That means progressive wave is periodic in space.

Equation of simple harmonic progressive wave.



$$y = a \sin(\omega t - \delta)$$

For the particle at distance λ from origin log by angle 2π.

The particle at distance 'X' from origin will log behind by angle $\delta = 2\dfrac{\pi x}{\lambda}$

{For λ = 2π for x = δ = ? $\delta = 2\pi \dfrac{x}{\lambda}$}

Different forms of equation of S.H. Progressive wave :

i. $y = a \sin\left(\omega t - 2\pi \dfrac{x}{\lambda}\right)$

ii. we know that $\omega = \dfrac{2\pi}{T}$

$\therefore\ y = a \sin\left(2\pi \dfrac{t}{T} - 2\pi \dfrac{x}{\lambda}\right)$

$\therefore\ y = a \sin 2\pi\left(\dfrac{t}{T} - \dfrac{x}{\lambda}\right)$

iii. Also $n = \dfrac{1}{T}$

$\therefore\ y = a \sin 2\pi\left(nt - \dfrac{x}{\lambda}\right)$

iv. As $y = a \sin 2\pi n\left(t - \dfrac{x}{v}\right)$

$\therefore$ Now, $2\pi n = \omega$ & $v = n\lambda$

$\therefore\ y = a \sin \omega\left(t - \dfrac{x}{n\lambda}\right)$

Q.32 The equation of a transverse wave is given by where x and y are in m and t is in sec. The frequency of the wave is

(a.32) 1 Hz (b.32) 2 Hz (c.32) 3 Hz (d.32) 4 Hz

Q.34 A wave equation is given by , where x and y are in metres and t is the time in seconds. Which one of the following is a wrong statement?

(a.34) Of amplitude 10^{-4}m traveling in the negative x direction (b.34) Of wavelength π meter

(c.34) Of frequency hertz (d.34) Traveling with a velocity of 30 m/s, in the positive x direction

Q.35 The equation of a transverses wave traveling along a string is given by y=5 cos π (100t−x) cm. Its wavelength is

(a.35) 10 cm (b.35) 5 cm (c.35) 3 cm (d.35) 2 cm

Q.1 Sound waves having their frequencies below 20 Hz (the audible range) are known as

(a.1) Ultrasonic waves (b.1) Infrasonic waves (c.1) Audible waves (d.1) Supersonic waves

Superposition of waves

Ans.

When two or more waves arrive at a point travelling through the medium simultaneously each wave produces its own displacement independently at that point as if other waves are absent. Hence the resultant displacement at that point is the vector sum of all the displacements, produced by the waves.

Interference of waves.

constructive interference:-amplitude is maximum

As intensity of the wave is directly proportional to the square of its amplitude, the intensity is also maximum (loudness of sound). It is called **waxing.**

Destructive interference:- resultant displacement is minimum and hence the intensity is also minimum. It is called **waning.**

Beats : When two sound waves of very nearly equal frequency (differing by a few vibrations) and of equal or comparable amplitude travel through the same region simultaneously, the resultant intensity changes with time. It alternates between maximum of sound (waxing) and minimum of sound (waning). This phenomenon of alternate waxing and waning is called beat formation.

For beats :

Period : The time interval between two successive waxings or wanings is called period of the beat.

Frequency : The number of beats completed per second is called the frequency of the beat.

.

Conditions for audible beats :

1. The amplitudes of two sound waves producing beats must be nearly equal or comparable.
2. The frequency of two sound waves must be nearly equal or differ only by few vibrations.

   The audible beats are produced only if frequency difference is not more than 7/second (seven per second)
3. The two waves sound pass through the same region simultaneously.

   For the superposition of two waves the resultant displacement is given by

Frequency of the beat

The two sound waves of equal amplitude ‘a’ and slightly different frequencies ‘n_1’, and ‘n_2’ are represented as

$y_1 = a \sin 2\pi n_1 t$ and $y_2 = a \sin 2\pi n_2 t$

These two waves interfere to produce beats. Thus the resultant displacement ‘y’ is given by,

$y = y_1 + y_2$

$\therefore\ y = a\sin 2\pi n_1 t + a\sin 2\pi n_2 t$

$\therefore\ y = a\{\sin(2\pi n_1 t) + \sin(2\pi n_2 t)$

We know,

$$\sin C + \sin D = 2\sin\left(\frac{C+D}{2}\right)\cos\left(\frac{C+D}{2}\right)$$

$\sin(2\pi n_1 t) + \sin(2\pi n_2 t)$

$$= 2\left[\sin\left(\frac{2\pi n_1 t + 2\pi n_2 t}{2}\right)\cos\left(\frac{2\pi n_1 t - 2\pi n_2 t}{2}\right)\right]$$

$$\therefore y = 2a \sin 2\pi \left(\frac{n_1 + n_2}{2}\right) t \cos 2\pi \left(\frac{n_1 - n_2}{2}\right) t$$

$$y = 2a \cos 2\pi \left(\frac{n_1 - n_2}{2}\right) t \sin 2\pi \left(\frac{n_1 - n_2}{2}\right) t$$

Let $2a \cos \pi \left(\frac{n_1 - n_2}{2}\right) t = A$

$\therefore y = A \sin \pi \left(\frac{n_1 + n_2}{2}\right) t$ Where A is resultant amplitude.

For waxing

For A = ±2 a intensity is maximum i.e. waxing

$$\cos 2\pi \left(\frac{n_1 - n_2}{2}\right) t = \pm 1$$

$$2\pi \left(\frac{n_1 - n_2}{2}\right) t = 0\ ,\ \pi, 2\pi, 3\pi..........$$

i.e. $t = O, \frac{1}{n_1 - n_2}, \frac{2}{n_1 - n_2}, \frac{3}{n_1 - n_2}$

Thus the period of beats is

$$\frac{1}{n_1 - n_2} - 0 = \frac{2}{n_1 - n_2} - \frac{1}{n_1 - n_2} = \frac{1}{n_1 - n_2}$$

$\therefore$.Period of beats = $\frac{1}{n_1 - n_2}$

Now,

frequency of beats = $\frac{1}{\text{Period of beats}}$

$$= \frac{1}{\frac{1}{(n_1 - n_2)}}$$

$\therefore$. Frequency of beats = $(n_1 - n_2)$

Thus, frequency of beats is equal to the difference between frequencies of two waves.

Also, period of beat is the reciprocal of difference of two frequencies.

Application of Beats

1. The phenomenon of beats is used to determine an unknown frequency. The sound note of unknown frequency is sounded simultaneously with a note of known frequency which can be changed. The known frequency is so adjusted that beats are heard. The further adjustment is made till the beats reduce to zero i.e. the frequency of the two notes become equal.

2. Musical instrument can be tuned by noting the beats produced when two different instruments are sounded together. By adjusting the frequency of sound of one of the instruments, the number of beats is reduced to zero.

When this is done, both the instruments are emitting sound of the same frequency. The instruments are then in unison with each other.

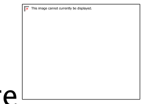
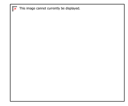
3. The phenomenon of beats can be used to produce low frequency notes used in Jazz orchestra or western music.

4. Beats are used to detect the presence of dangerous gases in mines. Air from a reservoir is blown through a pipe or flute. Air from the mine is blown through another similar pipe or flute. Speed of sound is different in different gases. Hence reservoir with different concentrations than air will sound slightly different frequencies.

If no dangerous gases are present in air from the mine, the two flutes will produce notes of the same frequency and beats will not be heard.

However if the air from the mine is polluted with presence of dangerous gases, the two flutes will produce notes of slightly different frequencies, giving rise to beats, which serves as an early warning system for safety.

5. In modern days incoming frequency of radio receiver is superposed with a locally produced frequency to produce intermediate frequency which is always constant. This makes tuning of the receiver very simple. This is used in superheterodyne oscillators.

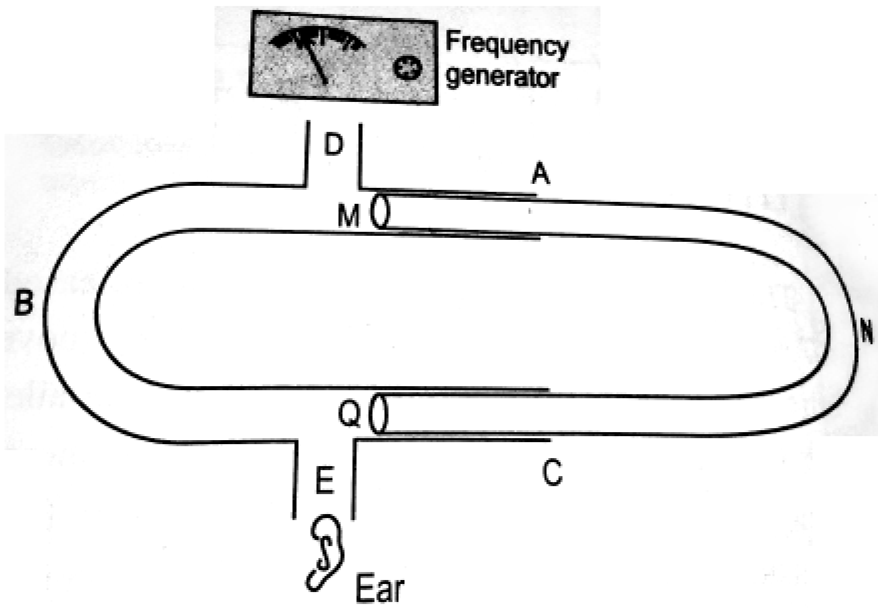
Q.51 Wavelengths of two sound notes in air are  and  respectively. Each note produces 4 beats/sec, with a third note of a fixed frequency. What is the velocity of sound in air?

(a.51) 300 m/s (b.51) 320 m/s (c.51) 310 m/s (d.51) 350 m/s

Q.52 A tuning fork A produces 4 beats/second with another tuning fork of frequency 246 Hz. When the prongs of A are filed a little, the number of beats heard is 6 per second. What is the original frequency of the fork A?

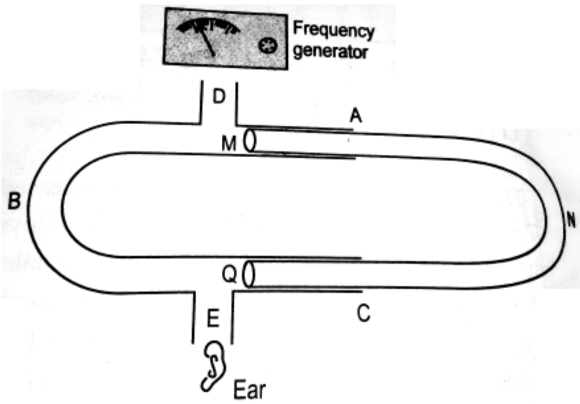
(a.52) 242 Hz (b.52) 240 Hz (c.52) 250 Hz (d.52) 252 Hz

Quincke's Tube Experiment:



Quincke's Tube Experiment

The apparatus consists of a U – tube ABC, about 2 cm in diameter which has two side openings at D and E. A second U – tube, MNQ closely fits into ABC and can be pushed into or pulled out of ABC (Fig. 7.7). Thus the effective length of the right branch DNE can be altered and frequency generator is held at the opening D. The sound waves travel along the two branches DBE and DNE and meet at E.

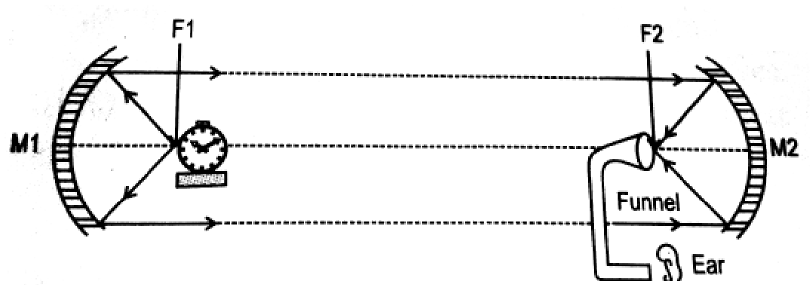


Quincke's Tube Experiment

The ear of a listener is situated at E. Initially, the tube MNQ, is so adjusted, that the paths DBE and DNE are of equal lengths or the path difference between the waves travelling along DBE and DNE is zero. Then the intensity of sound heard by the listener at E is maximum. The moving tube MNQ is then slowly pulled out of ABC.

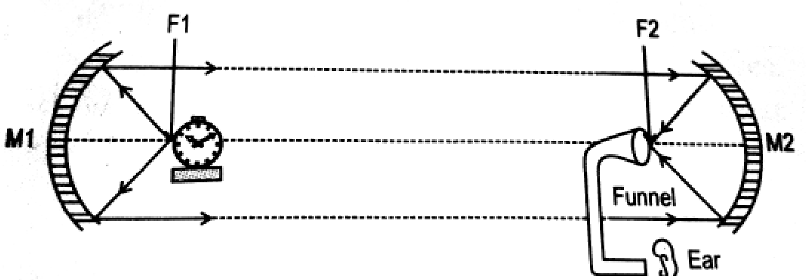
It is found that the intensity of sound heard by the listener becomes zero when the path difference between the waves travelling along the two branches becomes λ / 2. On further pulling out the tube MNQ, the sound intensity is again found to becomes maximum when the path difference between the waves travelling along the two branches becomes λ. In general whenever the path difference becomes 0, λ, 2λ etc. or nλ where n = 0, 1, 2 ……., the intensity of sound at E becomes maximum and whenever the path difference becomes $\frac{\lambda}{2}, \frac{3\lambda}{2}, \frac{5\lambda}{2}$ or $\left(n + \frac{1}{2}\right)\lambda$, where n = 0, 1, 2, 3 ……..; the intensity of sound at E becomes minimum (zero).

Reflection of transverse and longitudinal waves



Reflection of sound by curved surfaces.

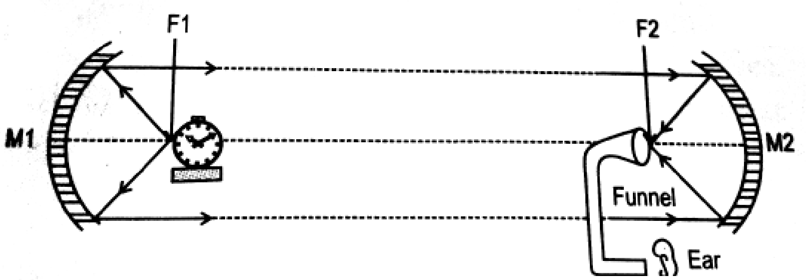
When energy travelling in a homogeneous medium meets a boundary of some other medium, it has a tendency to travel in the opposite direction. This is called reflection of energy or a wave. Reflection of light energy from mirrors of different shapes is a common phenomenon. Similarly, sound energy can also be reflected from large plane surfaces or curved surfaces like walls of buildings or hilly areas. The wavelength of light waves (order of A^{o}) is very small compared to wavelength of sound waves (order of mm).



Reflection of sound by curved surfaces.

Hence, a small surface is enough for reflection of light waves, a large surface is required for reflection of sound waves. However, sound waves obey the same laws as are obeyed by light waves for reflection. A popular example of reflection of sound is an echo.

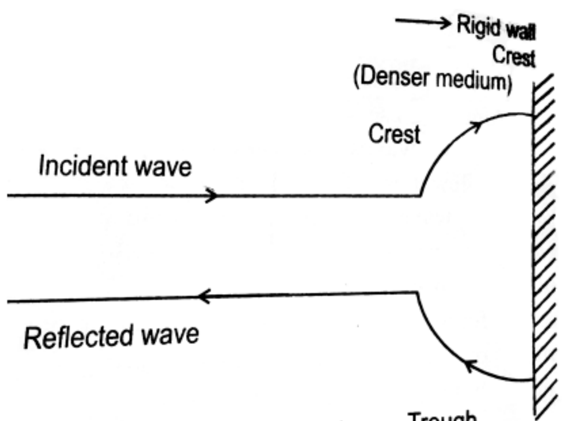
Reflection of sound waves from a curved surface can be demonstrated by the arrangement shown in fig (7.2) M_1 and M_2 are two large concave spherical mirrors having foci F_1 and F_2 respectively are arrange co – axially facing each other. A watch is placed at F_1 and a funnel is kept on the common axis, facing M_2.



Reflection of sound by curved surfaces.

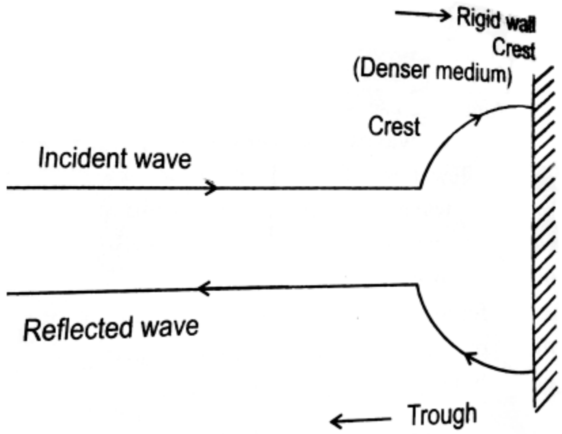
A rubber tube is connected to the funnel and a listener can hear the ticking of the clock by keeping the ear close to the free end of the rubber tube. On moving the funnel away from and towards M_2, along the common axis, it is found, that the ticking is heard most distinctly when the funnel is at F_2. Sound waves starting from the watch at F_1, get reflected from M_1. The reflected waves travel parallel to the axis and fall on M_2 which focuses them at F_2.

Reflection of Waves:-When a wave is progressing, it has a certain velocity of propagation called 'wave velocity.' The particles of the medium are in S.H.M. So their velocity is constantly changing. It is called 'particle velocity'. Reflection of wave depends on how these two velocities are getting affected due to reflection.



Reflection of Transverse wave

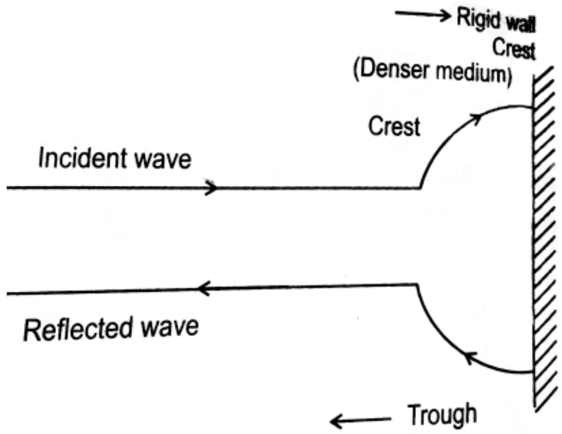
i. When a transverse wave strikes a rigid surface (like a wall), the wave velocity is reversed, i.e. the wave will start travelling in the opposite direction.



Reflection of Transverse wave

The particle velocity is also reversed because the particles of the rigid surface receiving the wave (or the wave energy) are not free to move. So, they reflect the particle velocity in such a way that their own resultant velocity remains zero. This is possible only when the particle velocity after reflection is equal and opposite to the particle velocity of the incident wave.

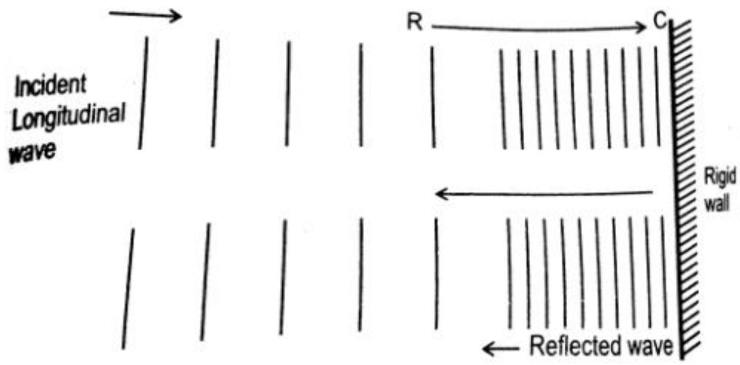
Thus, both wave velocity and the particle velocity are reversed. This creates a phase difference of π^c between both the velocities.



Reflection of Transverse wave

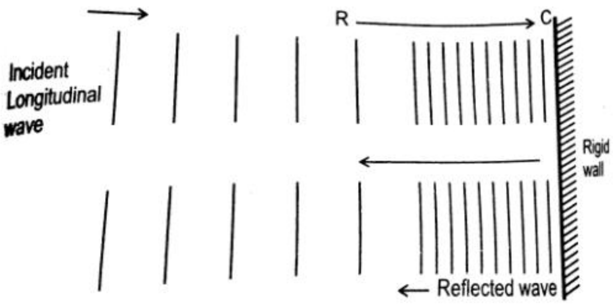
We know that there is phase difference of π^c between successive crest and trough. Thus, a crest is reflected as trough and the trough as a crest.

ii. When a transverse wave strikes a rare medium, the wave velocity is reversed. But as the particles of the medium receiving the wave are free to move, the particle velocity is not reversed. So, a crest is reflected as a crest and a trough is reflected as trough. (fig 8 lines)



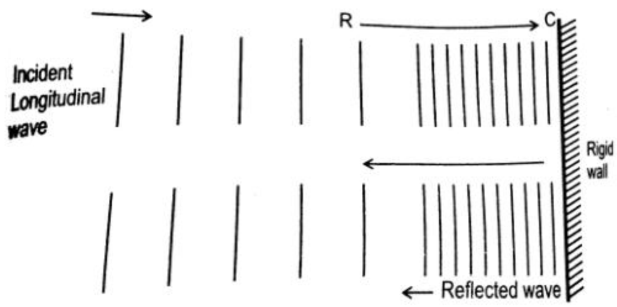
Reflection of longitudinal wave

iii. When a longitudinal wave strikes a rigid surface, both wave and particle velocities are reversed just as in the case of transverse waves. But if a compression strikes the surface, the wave velocity and particle velocity of the incident wave are in the same direction (towards the surface). When the wave is reflected, both these velocities are reversed and once again become same (away from the surface). Thus a compression is reflected as a compression. (fig 8 lines)



Reflection of longitudinal wave

If a rarefaction strikes the surface, the wave velocity is directed towards the surface and the particle velocity is directed away from the surface. Due to reflection, both these velocities are reversed. So, the wave starts moving away from the surface and particle velocity is directed towards the surface. Hence, the velocities remain opposite after the reflection also. Thus a rarefaction is reflected as a rarefaction.



Reflection of longitudinal wave

iv. When a longitudinal wave strikes a rare medium, as the particles of the medium are free to move, the wave velocity is reversed but the particle velocity remains as it is. Thus, when a compression strikes a rare medium, wave velocity and particle velocity are directed oppositely. Thus, it is reflected as a rarefaction. On the other hand, when a rarefaction is reflected, both wave velocity and particle velocity are directed in the same direction. Thus, the rarefaction is reflected as a compression. (fig 8 lines)

9. What is Doppler effect ? Explain it.

Ans:

Doppler effect : It is our common experience that the frequency of sound waves heard changes if there is relative motion between observer and source of the sound. That means the frequency of sound heard is different than the actual frequency.

Definition : The phenomenon of apparent change in frequency of sound waves due to relative motion between the observer and source of the sound is called ‘Doppler effect.’

The general formula for apparent frequency is

$$nA = n\left(\frac{V \pm V_0}{V \pm V_s}\right)$$

Where,

n = actual frequency

v = velocity of the sound

v_0 = velocity of observer.

v_s = velocity of source

Case (I) :

When observer is at rest and the source is moving towards it, then frequency of sound wave increases.

O V_s S

$n_A = n$

Case (II) :

When source is stationary and observer is moving towards the source.

O → S

V_O

$V_s = 0$

$$n_A = n\left(\frac{V + V_0}{V}\right)$$

Case (III) :

When source is stationary and observer is moving away from the source.

O ← S

V_0

$V_s = 0$

$$n_A = n\left(\frac{V - V_0}{V}\right)$$

Case (IV) :

When observer is stationary and source is moving away from observer.

$V_0 = 0$ $\quad\quad$ $S \rightarrow O$

V_s

$$n_A = n\left(\frac{V}{V + V_s}\right)$$

Case (V) :

Both observer and sound source are moving then

$$n_A = n\left(\frac{V \pm V_0}{V \pm V_S}\right)$$

i, When observer and source are moving towards each ohter, then

$$\xrightarrow[v_0]{+ve} O \quad S \xleftarrow[v_S]{-ve}$$

$V_0 = +ve$, $V_s = -ve$

ii. When observer and source are moving away from each other, then

$$O \xleftarrow[V_0]{\quad\quad} \quad \xrightarrow[V_s]{\quad\quad} S$$

$V_0 = -ve$, $V_s = +ve$

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