WAVES

Q # 1. Define the term wave.

Ans. Wave is the disturbance produced in a medium which is used to transport energy from one point to another without transporting matter.

Q # 2. Differentiate among mechanical and electromagnetic waves.

Ans. There are two main types of waves

1. Mechanical Waves
2. Electromagnetic Waves

Mechanical Waves

The waves which require any medium for their propagation by the oscillation of material particles are called mechanical waves e.g., sound waves, water waves etc.

Electromagnetic Waves

The waves don't require any medium for their propagation are called electromagnetic waves. These waves propagate out in space due to oscillations of electric and magnetic fields. Some examples of electromagnetic waves are visible light, radio waves, television signals, and x-rays.

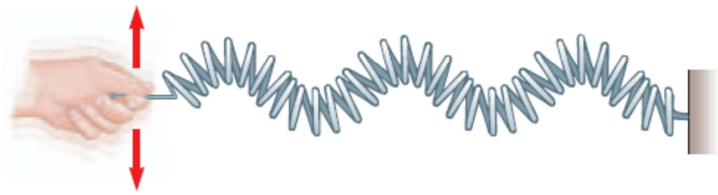
Q # 3. What do you know about Progressive or travelling waves? Also describe its types.

Ans. A wave, which transfers energy by moving away from the source of disturbance, is called a progressive or travelling wave. There are two types of progressive waves:

1. Transverse Waves
2. Longitudinal Waves

Transverse Waves

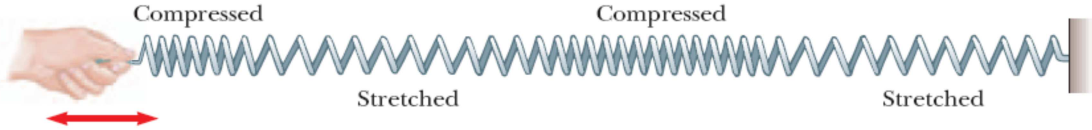
A traveling wave that causes the elements of the disturbed medium to move perpendicular to the direction of propagation is called a transverse wave.



(a) Transverse wave

Longitudinal Waves

A traveling wave that causes the elements of the medium to move parallel to the direction of propagation is called a longitudinal wave.



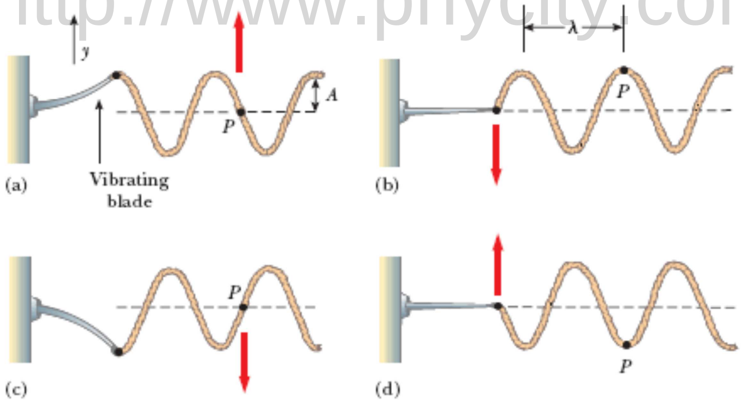
(b) Longitudinal wave

Q # 4. What do you know about periodic waves.

Ans. Continuous, regular and rhythmic disturbance in a medium result from periodic vibrations of the source causes the periodic waves in the medium.

Q # 5. Describe the different properties of transverse periodic waves.

Ans. Consider a string whose left end is connected to a blade that is set vibrating. The wave travels towards right as the crest and trough in turn, replace each other. Every part of the string, such as point *P*, oscillates vertically with simple harmonic motion.



Crest

The crest is a pattern in which the rope is displaced above its equilibrium position.

Trough

The portion of the rope which has displacement below its equilibrium position is called trough.

Amplitude

The maximum displacement of an element of the medium from equilibrium position is called the amplitude of the wave.

Wavelength

The distance between two consecutive crest and trough of a wave is called wavelength and is denoted by the symbol λ.

Time Period

The period *T* of a wave is the time interval required for the wave to travel one wavelength.

Frequency

The frequency of a periodic wave is the number of crests (or troughs) that pass a given point in a unit time interval. The frequency f of a wave is related to the period T by the expression:

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

Q # 6. Derive the expression for the Speed of Wave through a medium.

Ans. Consider a crest of wave moves one wavelength λ in one period of oscillation T. The speed of the crest is therefore:

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

$$v = \frac{\lambda}{\mathrm{T}} \quad \text{----------} \quad (1)$$

But $f = \dfrac{1}{T}$

Thus the equation (1) becomes:

$$v = f\lambda$$

Q # 7. How the longitudinal periodic waves are represented by waveform.

Ans. Consider a coil of spring capable of vibrating horizontally. Suppose an oscillating force F is applied to its ends horizontally. The force will alternately stretch and compress the spring, thereby sending a series of stretched regions (rarefactions) and compressions down the spring. Such types of waves are also called the compressional waves. Theses compressions and rarefactions are represented by corresponding crests and troughs as shown in the figure:

Q # 8. Describe the formula for the speed of sound in term of modulus of elasticity of the medium.

Ans. The speed of sound waves depends on the compressibility and inertia of the medium through which they are travelling. If the medium has elastic modulus E and density ρ then, speed v is given by:

$$v = \sqrt{\frac{E}{\rho}} \quad \text{------------} \quad (1)$$

Q # 9. How Newton derived the Formula for Speed of Sound.

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

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

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

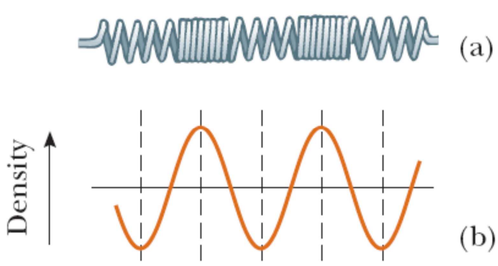
$$\Rightarrow -P\Delta V + V\Delta P - \Delta P\Delta V = 0$$

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

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

$$\Rightarrow P\Delta V = V\Delta P$$

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



The expression $\left(\frac{\Delta P}{\Delta V/V}\right)$ is the elastic constant E at constant temperature. Therefore:

$$P = E$$

So, substituting P for E in equation (1) gives us the Newton's formula for speed of sound in air. Hence

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

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

Q # 10. Describe the Laplace's correction in the Newton's Formula for Speed of Sound.

Ans. Laplace pointed out that the compression and rarefactions occur so rapidly that heat of compressions remains confined to the regions where it is generated and does not have time to flow to the neighboring cooler regions which have undergone an expansion. Hence the temperature of the medium does not remain constant. In such case, Boyle's law takes the form:

$$PV^{\gamma} = const. \quad \text{-----------} \quad (1)$$

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

If the pressure of the gas changes from P to $(P+\Delta P)$ and volume changes from V to $(V-\Delta V)$, then equation (1) will become:

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

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

$$\Rightarrow P = (P+\Delta P)\left(1-\frac{\Delta V}{V}\right)^{\gamma} \quad \text{-----------} \quad (4)$$

By binomial theorem: $\left(1-\frac{\Delta V}{V}\right)^{\gamma} = 1-\gamma\frac{\Delta V}{V} + negligible\,terms$

Putting values in equation (4), we get:

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

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

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

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

Where the term $\gamma\Delta P\frac{\Delta V}{V}$ is negligible, we have:

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

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

$$\Rightarrow \gamma P = \frac{\Delta P}{\Delta V / V} = E$$

Hence by substituting the value of elastic modulus in equation (2), we get the Laplace's expression for speed of sound in air.

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

For air $\gamma = 1.4$. So at S.T.P, the speed of sound in air will be:

$$v = 333\ ms^{-1}$$

This value is very close to the experimental value.

Q # 11. Describe the effect of Variation of Pressure, Density and Temperature on Speed of Sound in a Gas.

Ans.

Effect of Variation of Pressure on Speed of Sound in a Gas

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

Effect of Variation of Density on Speed of Sound in a Gas

At same temperature and pressure for the gases having the same value of γ, the speed is inversely proportional to the square root of their densities. Thus the speed of sound in hydrogen is four time its speed in oxygen as the density of oxygen is 16 times that of hydrogen.

Effect of Variation of Temperature on Speed of Sound in a Gas

When the gas is heated at constant pressure, its volume is increased and hence its density as:

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

So, the speed of sound increased with increase in temperature.

Q # 11. Show that one degree Celsius rise in temperature produces approximately 0.61 ms^{-1} increases the speed of sound.

Ans. Let

$$v_0 = Speed\ of\ sound\ at\ 0^0 C$$
$$v_t = Speed\ of\ sound\ at\ t^0 C$$
$$\rho_0 = Density\ of\ gas\ at\ 0^0 C$$
$$\rho_t = Density\ of\ gas\ at\ t^0 C$$

Then $v_0 = \sqrt{\frac{\gamma P}{\rho_0}}$ ---------- (1)

And $v_t = \sqrt{\frac{\gamma P}{\rho_t}}$ ---------- (2)

Dividing equation (1) & (2), we get:

$$\frac{v_t}{v_0} = \sqrt{\frac{\rho_0}{\rho_t}} \quad \text{----------} \quad (3)$$

If V_0 is the volume of the gas at $0°C$ and V_t is the volume at $t°C$, then by Charles Law:

$$V_t = V_0\left(1+\frac{t}{273}\right) \quad \text{----------} \quad (4)$$

Since

Volume = $\frac{\text{mass}}{\text{density}}$, so the equation (4) becomes:

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

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

Putting values in equation (3), we get:

$$\frac{v_t}{v_0} = \sqrt{1+\frac{t}{273}}$$

$$\frac{v_t}{v_0} = \left(1+\frac{t}{273}\right)^{1/2}$$

Expending using Binomial Theorem and neglecting higher powers, we have:

$$\frac{v_t}{v_0} = 1+\frac{t}{576}$$

$$\Rightarrow v_t = v_0\left(1+\frac{t}{576}\right) = v_0 + \frac{v_0 t}{576}$$

As $v_0 = 332\, ms^{-1}$, therefore:

$$v_t = v_0 + \frac{332}{576}t$$

$$v_t = v_0 + 0.61t$$

This shows that one degree Celsius rise in temperature produces approximately 0.61 ms^{-1} increases the speed of sound.

Q # 12. State the Principal of Superposition of waves. Also describe its significance.

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

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

Application of Superposition Principle

Principle of superposition leads to many interesting phenomenon with waves:

1. Superposition of two waves having same frequency and travelling in the same direction will result in a phenomenon called interference
2. Superposition of two waves having slightly different frequencies and travelling in the same direction will produce beats phenomenon
3. Superposition of two waves having same frequency and travelling in the opposite direction will produce the stationary waves

Q # 13. What do you know about the Interference of waves? Also describe different types of interference phenomenon.

Ans. Superposition of two waves having same frequency and travelling in the same direction will result in a phenomenon called interference.

Types of Interference

There are two types of interference:

1. Constructive Interference
2. Destructive Interference

Constructive Interference

Whenever the path difference between the two waves is an integral multiple of wavelength, then the both waves reinforce each other. This effect is called constructive interference.

If ΔS is the path difference between two waves having wavelength λ, then condition of constructive interference can be describe as:

$$\Delta S = n\lambda$$

Where $n = 0, \pm 1, \pm 2, \pm 3, \ldots\ldots$

Destructive Interference

Whenever the path difference between the two waves is an odd integral multiple of half of wavelength, then the both waves cancel each other's effect. This effect is called constructive interference.

If ΔS is the path difference between two waves having wavelength λ, then condition of constructive interference can be describe as:

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

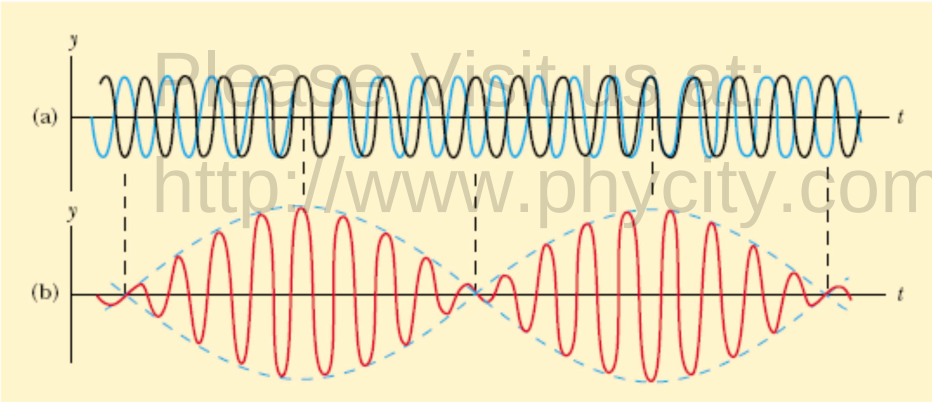
Where $n = 0, \pm 1, \pm 2, \pm 3, \ldots\ldots$

Q # 14. What do you know about the Beats phenomenon? Also describe its applications.

Ans. The periodic rise and fall in the amplitude of resultant wave due to superposition of two waves having slightly different frequencies but moving in the same direction.

Important Note:

Number of beats per second is equal to the difference between the frequencies of the tuning forks. When the difference between the frequencies of the two sounds is more than 10 Hz, then it becomes difficult to recognize the beats.



Uses of Beats

- Beats are used to determine unknown frequency.
- Beats are used in tuning the musical instruments such as piano or violin.
- Beats are also used to produce the variety in music.

Q # 15. Describe the two conditions of reflection of waves.

- If a transverse wave travelling in the rare medium is incident on a denser medium, it is reflected such that it undergoes a phase change of 180^0.
- If a transverse wave travelling in the denser medium is incident on a rare medium, it is reflected without any change in phase.

Q # 16. What are the stationary waves? Describe the main characteristics of stationary waves.

The stationary waves are produced by the superposition of two waves having same frequency and travelling in the opposite direction.

Characteristics of Stationary Waves

- The points of zero displacement in the stationary waves are called nodes.
- The points of maximum displacement in the stationary waves are called anti-nodes.
- No energy is transferred from particle to particle in stationary waves.
- Particles, except nodes, perform SHM with the same period as the component waves.
- Distance between the two consecutive nodes or anti-nodes is equal to $\frac{\lambda}{2}$.
- Distance between node and its neighboring anti-nodes is equal to $\frac{\lambda}{4}$.

Q # 17. How the stationary waves are produced in stretched string?

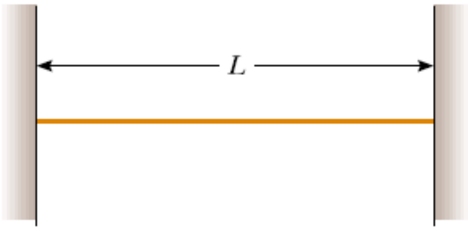
- When the string is plucked at its middle point, two transverse waves will originate from this point. One of waves will moves towards the left end of the string and the other towards the right end. When these waves reach the two clamped ends, they are reflected back thus giving rise to stationary waves and the string vibrate in one loop.

- When the string is plucked from one quarter of its length, the stationary waves will be setup and the string vibrates in two loops.
- When the string is plucked from one-sixth of its length, the stationary waves will be setup and the string vibrates in three loops.
- Similarly, by plucking the string properly, it can be made to vibrate in 4, 5, 6,…..,n loops and the frequency of these modes of vibration will be $4f_1$, $5f_1$, $6f_1$,…., nf_1 , respectively.

Q # 18. Describe the expression of frequency of stationary waves produced in a stretched string. Or Show that the frequencies of stationary waves in stretched string are quantized.

Ans. Consider a string of length L which is kept stretched by clamping its ends so that the tension in the string is F. The speed v of the waves in the string depends upon the tension F of the string and m, mass per unit length of string. The speed of the stationary waves is given by the expression:

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



(a)

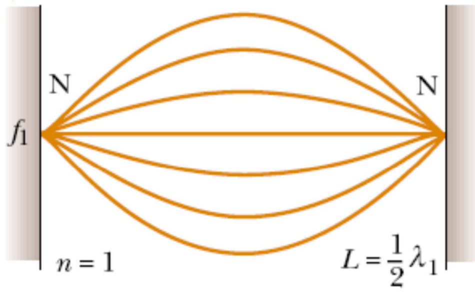
When the string is plucked at its Middle Point

When the string is plucked at its middle point, the stationary waves will be setup and the string vibrates in one loop.

If f_1 and λ_1 be the frequency and the wavelength of the stationary wave, then from figure (b):

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

$$\lambda_1 = 2L$$



(b)

The frequency corresponding to one loop in stretched string is denoted by f_1 and is called fundamental frequency. If v is the speed of the wave, then

$$v = f_1\lambda_1 = f_1(2L)$$

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

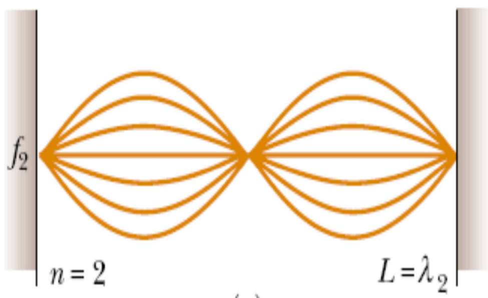
When the string is plucked One Quarter of its Length

When the string is plucked from one quarter of its length, the stationary waves will be setup and the string vibrates in two loops.

If f_2 and λ_2 be the frequency and the wavelength of the stationary wave, then from figure (c):

$$L = 2\left(\frac{\lambda_2}{2}\right)$$

$$\lambda_2 = L$$



(c)

The frequency corresponding to two loops in stretched string is denoted by f_2. If v is the speed of the wave, then

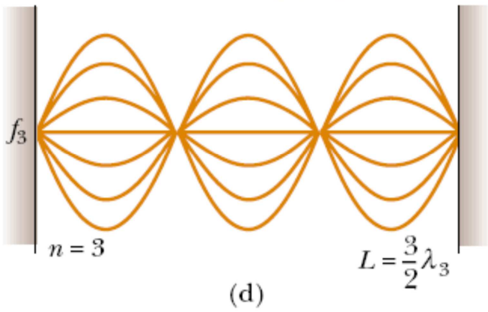
$$v = f_2\lambda_2 = f_2(L)$$

$$f_2 = \frac{v}{L} = 2\left(\frac{v}{2L}\right) = 2f_1$$

Hence f_2 is double of fundamental frequency.

When the string is plucked One Sixth of its Length

When the string is plucked from one-sixth of its length, the stationary waves will be setup and the string vibrates in three loops. If f_3 and λ_3 be the frequency and the wavelength of the stationary wave, then from figure (c):



(d)

$$L = 3\left(\frac{\lambda_3}{2}\right)$$

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

The frequency corresponding to two loops in stretched string is denoted by f_3. If v is the speed of the wave, then

$$v = f_3\lambda_3 = f_3\left(\frac{2L}{3}\right)$$

$$f_3 = \frac{v}{\left(\frac{2L}{3}\right)} = 3\left(\frac{v}{2L}\right) = 3f_1$$

Hence f_3 is thrice the fundamental frequency.

Generalization

Similarly, by plucking the string properly, it can be made to vibrate in 4, 5, 6,….. loops and the frequency of these modes of vibration will be $4f_1$, $5f_1$, $6f_1$,…. respectively.

Thus we can generalize that if the string is made to vibrate in n loops, then its frequency f_n is described by the relation:

$$f_n = nf_1 ,$$

This proves that the frequencies of stationary waves in stretched string are quantized.

Q # 19. What is an organ pipe? Describe its different types.

Ans. An organ pipe is a wind instrument. It consist of a long tube in which air is forced from one end and sound is produced by means of a vibrating air column.

When air is forced in the pipe, the air inside is set into vibrations and stationary waves are produced in the pipe.

Types of Organ Pipe

There are two types of organ pipes:

(i) Closed Pipe (ii) Open Pipe

Closed Pipe

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

Open Pipe

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

Q # 20. Describe the phenomenon of stationary waves in air column.

Ans. Stationary waves can be set in air column, such as in case of organ pipe. The relationship between the incident wave and the reflected wave depends on whether the reflecting end is open or close.

- If the reflecting end is open, as in case of open organ pipe, the air molecule has complete freedom of motion and this behaves as an anti-node.
- If the reflecting end is closed, as in case of close organ pipe, the motion of the air molecules is restricted and it behaves as a node.

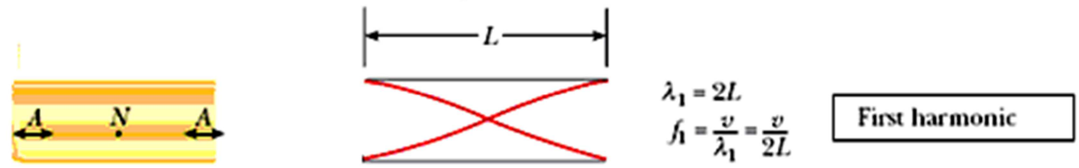
Q # 21. Describe the expression of frequency of stationary waves produce in the air column produced in the air column of Open Organ Pipe.

Ans. Modes of vibrations in an Open Air Column

Let a vibrating tuning fork be held at the mouth of an open pipe of length L. If the pipe is open at both ends, then its ends behaves as anti-nodes.

First Harmonic

If f_1 and λ_1 be the frequency and the wavelength of the stationary wave for the case of first harmonic, then from figure:



$$L = \frac{\lambda_1}{2} \Rightarrow \lambda_1 = 2L$$

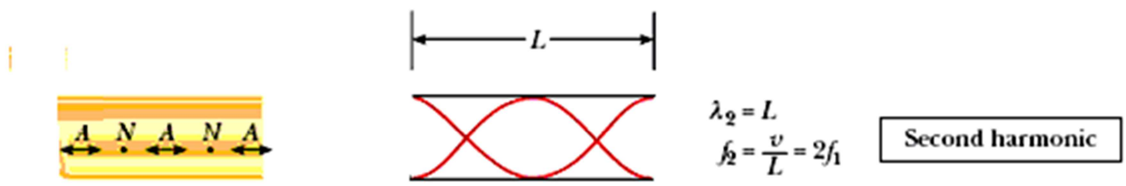
If v is the speed of the wave, then

$$v = f_1\lambda_1 = f_1(2L)$$

$$\Rightarrow f_1 = \frac{v}{2L}$$

Second Harmonic

If f_2 and λ_2 be the frequency and the wavelength of the stationary wave for the case of second harmonic, then from figure:



$$L = 2\left(\frac{\lambda_2}{2}\right) \Rightarrow \lambda_2 = L$$

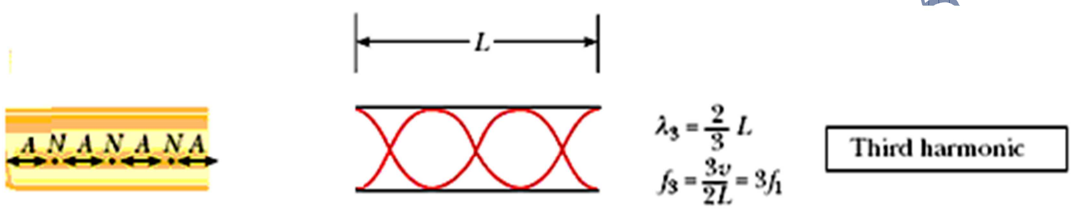
If v is the speed of the wave, then

$$v = f_2\lambda_2 = f_2(L)$$

$$\Rightarrow f_2 = \frac{v}{L} = 2\left(\frac{v}{2L}\right) = 2f_1$$

Third Harmonic

If f_3 and λ_3 be the frequency and the wavelength of the stationary wave for the case of third harmonic, then from figure:



$$L = 3\left(\frac{\lambda_3}{2}\right) \Rightarrow \lambda_3 = \frac{2L}{3}$$

If v is the speed of the wave, then

$$v = f_3\lambda_3 = f_3\left(\frac{2L}{3}\right)$$

$$\Rightarrow f_3 = 3\left(\frac{v}{2L}\right) = 3f_1$$

Generalization

Similarly for the nth harmonic,

$$f_n = nf_1$$

Where $n = 1, 2, 3, ...$

Hence, it is proved that all harmonics are present in an open organ pipe.

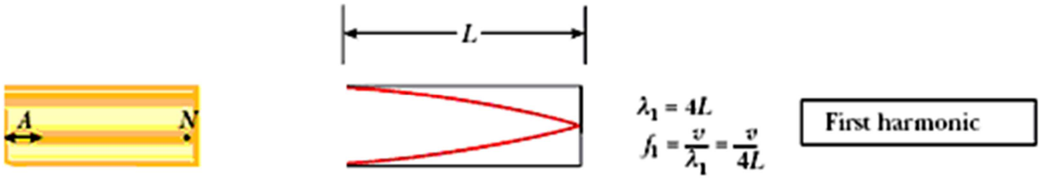
Q # 22. Describe the expression of frequency of stationary waves produce in the air column produced in the air column of Close Organ Pipe

Ans. Modes of vibrations in a Close Air Column

Let a vibrating tuning fork be held at the mouth of an open pipe of length L. If the pipe is close at one end and open at the other, the close end acts as node while the open end behaves as anti-nodes.

First Harmonic

If f_1 and λ_1 be the frequency and the wavelength of the stationary wave for the case of first harmonic, then from figure:



$$L = \frac{\lambda_1}{4} \Rightarrow \lambda_1 = 4L$$

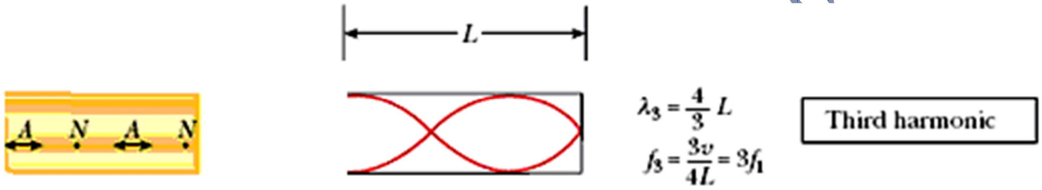
If v is the speed of the wave, then

$$v = f_1\lambda_1 = f_1(4L)$$

$$\Rightarrow f_1 = \frac{v}{4L}$$

Second Harmonic

If f_2 and λ_2 be the frequency and the wavelength of the stationary wave for the case of second harmonic, then from figure:



$$L = 3\left(\frac{\lambda_2}{4}\right) \Rightarrow \lambda_2 = \frac{4L}{3}$$

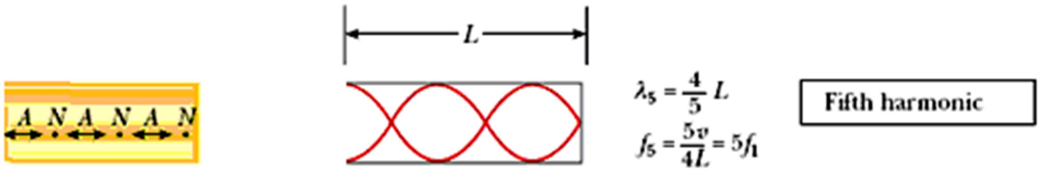
If v is the speed of the wave, then

$$v = f_2\lambda_2 = f_2\left(\frac{4L}{3}\right)$$

$$\Rightarrow f_2 = 3\left(\frac{v}{4L}\right) = 3f_1$$

Third Harmonic

If f_3 and λ_3 be the frequency and the wavelength of the stationary wave for the case of third harmonic, then from figure:



$$L = 5\left(\frac{\lambda_3}{2}\right) \Rightarrow \lambda_3 = \frac{2L}{5}$$

If v is the speed of the wave, then

$$v = f_3\lambda_3 = f_3\left(\frac{2L}{5}\right)$$

$$\Rightarrow f_3 = 5\left(\frac{v}{2L}\right) = 5f_1$$

Generalization

Similarly for the nth harmonic,

$$f_n = nf_1$$

Where $n = 1, 3, 5, ...$

Hence, it is proved that only the odd harmonics are present in a close organ pipe.

Q # 23. What is the Doppler Effect? Find out the expression of apparently changed frequency for the following cases:

- **(i) When the observer moves towards the stationary source**
- **(ii) When the observer moves away from stationary source**
- **(iii) When the source moves towards the stationary observer**
- **(iv) When the source moves away from stationary observer**

Ans. Doppler's Effect

The apparent change in the frequency of sound due to relative motion between the observer and source of sound is called Doppler Effect.

Suppose a source of sound emits a sound of frequency f and wavelength λ. Let the velocity of the sound in the medium is v. If both the source and observer are stationary, the number of waves observed by the observer in one second are:

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

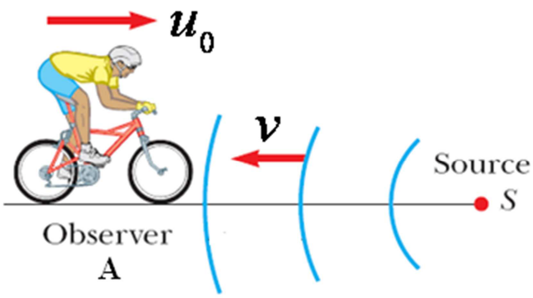
We want to find out the expression of apparent change in the frequency of sound due to the relative motion between source and observer.

Case 1. When the observer moves towards the stationary source

If the observer A moves towards the stationary source with velocity u_0, then the relative velocity of the waves and the observer is increased to $(v+u_0)$. Then the frequency of sound received by the observer A is :

$$f_A = \frac{v+u_0}{\lambda} = \frac{v+u_0}{\left(v/f\right)}$$

$$f_A = \left(\frac{v+u_0}{v}\right)f$$



Since $\frac{v+u_0}{v} > 1$, therefore $f_A > f$

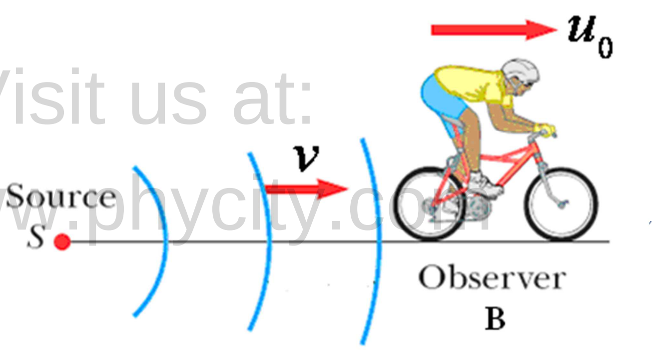
Result: The apparent frequency of the sound increases, when the observer moves towards the stationary source of sound.

Case 2. When the observer moves away from stationary source

Let the observer moves away from the stationary source with velocity u_0, then the relative velocity of the waves and the observer is $(v-u_0)$. Then the frequency of sound received by the observer B is :

$$f_B = \frac{v-u_0}{\lambda} = \frac{v-u_0}{\left(v/f\right)}$$

$$f_B = \left(\frac{v-u_0}{v}\right) f$$



Since $\frac{v-u_0}{v} < 1$, therefore $f_B < f$

Result: The apparent frequency of the sound decreases, when the observer moves away from the stationary source of sound.

Case 3. When the source moves towards the stationary observer

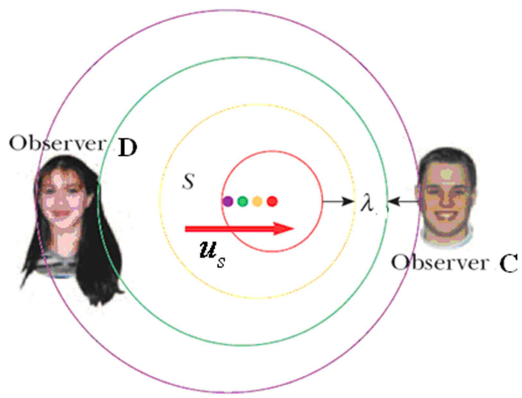
If the source is moving away towards the observer C with speed u_s, then the waves are compressed per second by an amount $\Delta\lambda$, known as Doppler Shift:

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

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 source.

The wavelength for observer C is

$$\lambda_c = \lambda - \Delta\lambda = \frac{v}{f} - \frac{u_s}{f} = \frac{v-u_s}{f}$$



The modified frequency for observer C is

$$f_c = \frac{v}{\lambda_c} = \frac{v}{\left(\frac{v-u_s}{f}\right)} = \left(\frac{v}{v-u_s}\right) f$$

Since $\frac{v}{v-u_s} > 1$, therefore $f_c > f$

Result: The apparent frequency of the sound increases, when the source moves towards the stationary observer.

Case 4. When the source moves away from the stationary observer

If the source is moving away towards the observer D with speed u_s, the wavelength of increases by an amount $\Delta\lambda$, known as Doppler Shift:

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

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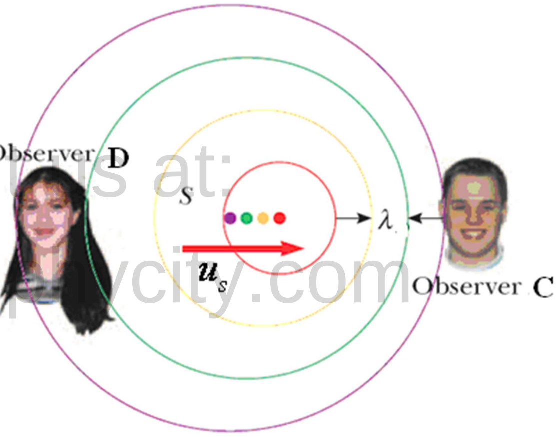
The expansion of wavelength is due to the fact that same number of waves are contained in a larger space depending upon the velocity of source.

The wavelength for observer D is

$$\lambda_D = \lambda + \Delta\lambda = \frac{v}{f} + \frac{u_s}{f} = \frac{v+u_s}{f}$$



The modified frequency for observer D is

$$f_D = \frac{v}{\lambda_D} = \frac{v}{\left(\frac{v+u_s}{f}\right)} = \left(\frac{v}{v+u_s}\right) f$$

Since $\frac{v}{v+u_s} < 1$, therefore $f_D < f$

Result: The apparent frequency of the sound decrease, when the source moves away from the stationary observer.

Q # 24. Describe the application of Doppler effect.

Radar System

In radar systems, the Doppler effect is used to determine the elevation and speed of aeroplane. Radar is a device, which transmits and receives the radio waves.

- If the aeroplane approaches towards the radar, then the wavelength of the wave reflected from the aeroplane would be shorter.
- If the aeroplane moves away from radar, then the wavelength of the wave reflected from the aeroplane would be larger.

The speed of satellites moving around the earth can also be determined from the same principal.

SONARS

In SONAR, the "Doppler detection" relies upon the relative speed of the target and the detector to provide and indication of the target speed. Its known military application include:

- The detection and location of submarines
- Control of anti-submarine weapons
- Mine Hunting
- Depth measurement of sea

Applications in Astronomy

Astronomers use the Doppler Effect to calculate the speed of distant star and galaxies.

Star moving towards the Earth show a blue shift, while stars moving away from the Earth show a red shift. By comparing the line spectrum of light from the star with light from a laboratory source, the Doppler shift of the star's light can be measured. Then the speed of star can be calculated.

Radar Speed Trap System

In radar speed tramp system, the microwaves are emitted from a transmitter in short bursts. Each burst is reflected off by any car in the path of microwaves. The transmitter is open to detect the reflected microwaves. If the election is caused by a moving obstacle, the reflected microwaves are Doppler shifted. By measuring the Doppler shift, the speed at which the car moves is calculated by the computer program.

EXERCISE SHORT QUESTIONS

Q # 1. What features do longitudinal waves have in common with transverse waves?

Ans. Following features are common in transverse and longitudinal waves:

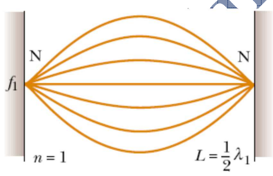
- Both are mechanical waves.
- Particles oscillate about their mean position in both types of waves.
- Both transport energy from one place to another.
- Both satisfy the equation: $v = f\lambda$

Q # 2. Is it possible for two identical waves travelling in the same direction along a string to give rise to stationary waves?

Ans. No, it is not possible for two identical waves travelling in the same direction along a string to give rise to stationary waves. For stationary waves, two identical waves must travel in opposite direction.

Q # 3. A wave is produced along a stretched string but some of its particles permanently show zero displacement. What type of wave is it?

Ans. It is a stationary wave and the pints are called Nodes.



(b)

Q # 4. Explain the terms crest, trough, node and anti-node.

Ans.

Crest. The portion of the wave above the mean level is called crest.

Trough. The portion of the wave below the mean level is called trough.

Node. The points of zero displacement in stationary waves are called Nodes

Anti-node. The points of maximum displacement in stationary waves are called anti-nodes.

Q # 5. Why should sound travel faster in solids than in gases?

Ans. The formula for speed of sound is:

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

Where

E = Modulus of Elasticity
ρ = Density

Although the density of solids is greater than the density of gases but the modulus of elasticity for solids is much greater than gases. Hence, sound travel faster in solids than in gases.

Q # 6. How are the beats useful in tuning musical instruments?

Ans. We know that the number of beats produced per second is equal to the difference of frequencies of the two bodies. To tune a musical instrument to the required frequency, it is sounded together with an instrument of known frequency. Now the number of beats produce will tell the difference of their frequency.

The frequency of the untuned instrument is adjusted till the number of beats become zero. At this stage, the two instruments will have the same frequencies. Thus the musical instrument is said to be tuned.

Q # 7. 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 the 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 correct answer is **(iii)** $f_1 - f_2$

Q # 8. As a result of a distant explosion, an observer senses a ground tremor and then hears the explosion. Explain the time difference.

Ans. The waves produced by the explosion reach the observer quickly through the ground as compared to the sound waves reaching through the air. This is due to the reason that sound travels faster in solid than gases.

Q # 9. Explain why sound travels faster in warm air than in cold air.

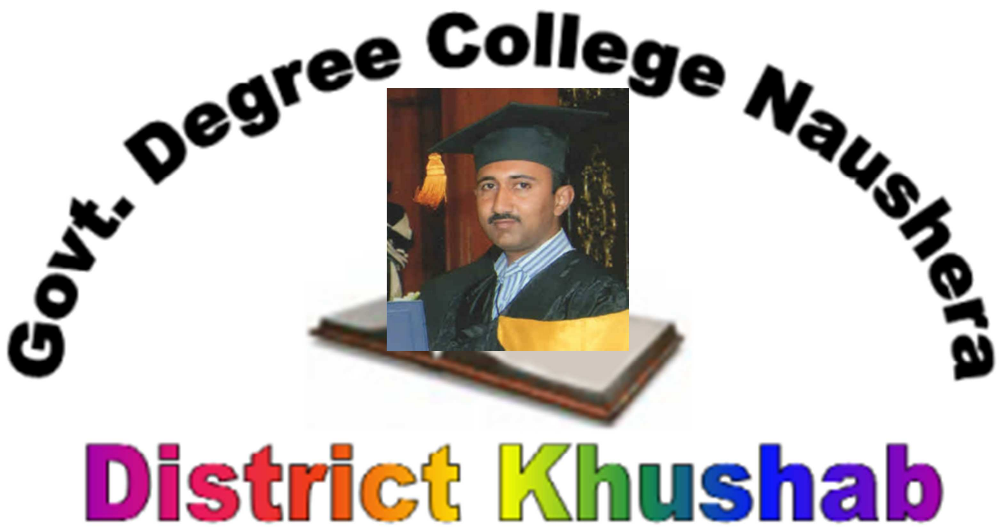
Ans. The speed of sound varies directly as the square root of absolute temperature, i.e.,

$$v \ \alpha \ \sqrt{T}$$

It means that greater the temperature of air, more will be the speed of sound in it. That's why sound travel faster in warm air than in cold air.

Q # 10. How should a sound source move with respect to an observer so that the frequency of its sound does not change?

Ans. If the relative velocity between the source and the observer is zero, then there will be no change in frequency of the source and the apparent frequency will be zero.



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