

SOUND WAVES

KEY CONCEPTS

Sound is a mechanical three dimensional and longitudinal wave that is created by a vibrating source such as a guitar string, the human vocal cords, the prongs of a tuning fork or the diaphragm of a loudspeaker.

Sound waves are the most common example of longitudinal waves. They travel through any material waves. They travel through any material medium with a speed that depends on the properties of the medium. As the waves travel through air, the elements of air vibrate to produce changes in density and pressure along the direction of motion of the wave. If the source of the sound waves vibrates sinusoidally, the pressure variations are also sinusoidal. The mathematical description of sinusoidally, the pressure variations are also sinusoidal sound waves is very similar to that of sinusoidal string waves.

EQUATION OF SOUND WAVES

As the piston oscillates sinusoidally, regions of compression and rarefaction are continuously set up. The distance between two successive compressions (or two successive rarefactions) equals the wavelength λ . As these regions travel through the tube, any small element of the medium moves with simple harmonic motion parallel to the direction of the wave. If $s(x, t)$ is the position of a small element relative to its equilibrium position, We can express this harmonic position function as

$$s(x, t) = s_{\max} \cos(kx - \omega t)$$

Where $s_{\max}$ is the maximum position of the element relative to equilibrium. This is often called the displacement amplitude of the wave. The parameter k is the wave number and ω is the angular frequency of the piston. Note that the displacement of the element is along s , in the direction of propagation of the sound wave, which means we are describing a longitudinal wave.

Consider a thin disk-shaped element of gas whose circular cross section is parallel to the piston in figure. This element will undergo changes in position, pressure, and density as a sound wave propagates through the gas. From the definition of bulk modulus, the pressure variation in the gas is

$$\Delta P = -B \frac{\Delta V}{V_i}$$

The element has a thickness Δx in the horizontal direction and a cross-sectional area A , so its volume is $V_i = A\Delta x$. The change in volume ΔV accompanying the pressure change is equal to $A\Delta s$, where Δs is the difference between the value of s at $x + \Delta x$ and the value of s at x . Hence, we can express ΔP as

$$\Delta P = -B \frac{\Delta V}{V_i} = -B \frac{A\Delta s}{A\Delta x} = -B \frac{\Delta s}{\Delta x}$$

As Δx approaches zero, the ratio $\Delta s/\Delta x$ becomes $\partial s/\partial x$ (The partial derivative indicates that we are interested in the variation of s with position at a fixed time.) Therefore,

$$\Delta P = -B \frac{\partial s}{\partial x}$$

If the position function is the simple sinusoidal function given by Equation , we find that

$$\Delta P = -B \frac{\partial}{\partial x} [s_{\max} \cos(kx - \omega t)] = Bs_{\max} k \sin(kx - \omega t)$$

$$\Delta P = \Delta P_{\max} \sin(kx - \omega t)$$

Thus we can describe sound waves either in terms of excess pressure (equation 1.1) or in terms of the longitudinal displacement suffered by the particles of the medium.

If $s = s_0 \sin \omega(t - x/v)$ represents a sound wave where s = displacement of medium particle from its mean position at x , then it can be proved that

$$P = P_0 \sin \{ \omega(t - x/v) + \pi/2 \} \quad \dots (3.2)$$

represents that same sound wave where, P is excess pressure at position x , over and above the average atmospheric pressure and the pressure amplitude P_0 is given by

$$P_0 = \frac{B\omega s_0}{v} = BKs_0 \quad \dots (3.3)$$

(B = Bulk modulus of the medium, K = angular wave number)

Note from equation (3.1) and (3.2) that the displacement of a medium particle and excess pressure

at any position are out of phase by $\frac{\pi}{2}$. Hence a displacement maxima corresponds to a pressure minima and vice-versa.

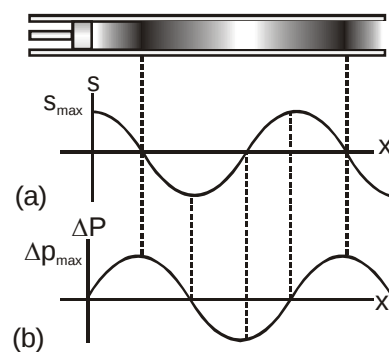


Figure : (a) Displacement amplitude and (b) pressure amplitude versus position for a sinusoidal longitudinal wave

Ex. The equation of a sound wave in air is given by $P = 0.2 \sin [3000 t - 9x]$, where all variables are in S.I. units.

(a) Find the frequency, wavelength and the speed of sound wave in air.

(b) If the equilibrium pressure of air is $1.0 \times 10^5 \text{ N/m}^2$, what are the maximum and minimum pressures at a point as the wave passes through that point?

Sol. (a) Comparing with the standard form of a travelling wave

$$P = P_0 \sin [\omega(t - x/v)]$$

we see that $\omega = 3000 \text{ s}^{-1}$. The frequency is

$$f = \frac{\omega}{2\pi} = \frac{3000}{2\pi} \text{ Hz}$$

Also from the same comparison, $\omega/v = 9.0 \text{ m}^{-1}$.

$$\text{or, } v = \frac{\omega}{9.0 \text{ m}^{-1}} = \frac{3000 \text{ s}^{-1}}{9.0 \text{ m}^{-1}} = \frac{1000}{3} \text{ m/s}^{-1}$$

$$\text{The wavelength is } \lambda = \frac{v}{f} = \frac{1000/3 \text{ m/s}}{3000/2\pi \text{ Hz}} = \frac{2\pi}{9} \text{ m}$$

(b) The pressure amplitude is $P_0 = 0.02 \text{ N/m}^2$. Hence, the maximum and minimum pressures at a point in the wave motion will be $(1.01 \times 10^5 \pm 0.02) \text{ N/m}^2$.

Ex. A sound wave of wavelength 40cm travels in air. If the difference between the maximum and minimum pressure at a given point is $4.0 \times 10^{-3} \text{ N/m}^2$, find the amplitude of vibration of the particles of the medium. The bulk modulus of air is $1.4 \times 10^5 \text{ N/m}^2$.

Sol. The pressure amplitude is

$$p_0 = \frac{4.0 \times 10^{-3} \text{ N/m}^2}{2} = 2 \times 10^{-3} \text{ N/m}^2$$

The displacement amplitude s_0 is given by

$$p_0 = Bks_0$$

or
$$s_0 = \frac{p_0}{Bk} = \frac{p_0 \lambda}{2\pi B}$$

$$= \frac{2 \times 10^{-3} \text{ N/m}^2 \times (40 \times 10^{-2} \text{ m})}{2 \times \pi \times 1.4 \times 10^5 \text{ N/m}^2} = \frac{200}{7\pi} \text{ A}$$

$$= 13.2 \text{ A}$$

SPEED OF SOUND WAVES :

Velocity of sound waves in a linear solid medium is given by

$$v = \sqrt{\frac{Y}{\rho}} \quad (4.1)$$

where Y = young's modulus of elasticity and ρ = density

Velocity of sound wave in a fluid medium (liquid or gas) is given by

$$v = \sqrt{\frac{B}{\rho}} \quad (4.2)$$

where, ρ = density of the medium and B = Bulk modulus of the medium given by,

$$B = -V \frac{dP}{dV} \quad (4.3)$$

Newton's formula : Newton assumed propagation of sound through a gaseous medium to be an isothermal process.

$$PV = \text{constant}$$

$$\Rightarrow \frac{dP}{dV} = \frac{-P}{V} \quad \text{and} \quad \text{hence } B = P$$

and thus he obtained for velocity of sound in a gas.

$$v = \sqrt{\frac{P}{\rho}} = \sqrt{\frac{RT}{M}} \quad \text{where } M = \text{molar mass}$$

Laplace's correction : Later Laplace established that propagation of sound in a gas is not an isothermal but an adiabatic process and hence $PV^\gamma = \text{constant}$

$$\Rightarrow \frac{dP}{dV} = -\gamma \frac{P}{V}$$

where, $B = -V \frac{dP}{dV} = \gamma P$

and hence speed of sound in a gas,

$$v = \sqrt{\frac{\gamma P}{\rho}} = \sqrt{\frac{\gamma RT}{M}} \quad (4.4)$$

FACTORS AFFECTING SPEED OF SOUND IN ATMOSPHERE

(a) Effect of temperature : as temperature (T) increases velocity (v) increases. For small change in temperature above room temperature v increases linearly by 0.6 m/s for every 1°C rise in temp.

(b) Effect of humidity : With increase in humidity density decreases. This is because the molar mass of water vapour is less than the molar mass of air.

(c) Effect of pressure :

The speed of sound in a gas is given by $v = \sqrt{\frac{\gamma P}{\rho}} = \sqrt{\frac{\gamma RT}{M}}$

So at constant temperature, if P changes then ρ also changes in such a way that P/ρ remains constant. Hence pressure does not have any effect on velocity of sound as long as temperature is constant.

Ex. The constant γ for oxygen as well as for hydrogen is 1.40. If the speed of sound in oxygen is 450 m/s, what will be the speed of hydrogen at the same temperature and pressure?

Sol. $v = \sqrt{\frac{\gamma RT}{M}}$

since temperature, T is constant

$$\therefore \frac{v_{(H_2)}}{v_{(O_2)}} = \sqrt{\frac{M_{O_2}}{M_{H_2}}} = \sqrt{\frac{32}{2}} = 4 \Rightarrow v_{(H_2)} = 4 \times 450 = 1800 \text{ m/s}$$

Aliter : The speed of sound in a gas is given by $u = \sqrt{\frac{\gamma P}{\rho}}$. At STP, 22.4 litres of oxygen has a mass of 32g whereas the same volume of hydrogen has a mass of 2g. Thus, the density of oxygen is 16times the density of hydrogen at the same temperature and pressure. As γ is same for both the gases.

$$\frac{f_{(\text{hydrogen})}}{f_{(\text{oxygen})}} = \sqrt{\frac{\rho_{(\text{oxygen})}}{\rho_{(\text{hydrogen})}}}$$

or $f_{(\text{hydrogen})} = 4f_{(\text{oxygen})} = 4 \times 450 \text{ m/s} = 1800 \text{ m/s}$

INTENSITY OF PERIODIC SOUND WAVES

Like any other progressive wave, sound waves also carry energy from one point of space to the other. This energy can be used to work, for example, forcing the eardrums to vibrate or in the extreme case of a sonic boom created by supersonic jet, can even cause glass panes of windows to crack.

The amount of energy carried per unit by a wave is called its power and power per unit area held perpendicular a sound wave travelling along positive x-axis described by the equation.

We define the intensity I of a wave, or the power per unit area, to be the rate at which the energy being transported by the wave transfers through a unit area A perpendicular to the direction of travel of the wave :

$$I = \frac{P}{A}$$

In the present case, therefore, the intensity is

$$I = \frac{P}{A} = \frac{1}{2} \rho A v (\omega s_{\max})^2$$

Thus, we see that the intensity of a periodic sound wave is proportional to the square of the displacement amplitude and to the square of the angular frequency (as in the case of a periodic string wave). this can also be written in terms of the pressure amplitude $\Delta P_{\max}$; in this case, we use Equation to obtain

$$I = \frac{\Delta P_{\max}^2}{2\rho v}$$

Ex. The pressure amplitude in a sound wave from a radio receiver is $4.0 \times 10^{-3} \text{ N/m}^2$ and the intensity at a point is 10^{-6} W/m^2 . If by turning the “Volume” knob the pressure amplitude is increased to $6 \times 10^{-3} \text{ N/m}^2$, evaluate the intensity.

Sol. The intensity is proportional to the square of the pressure amplitude.

Thus,
$$\frac{I'}{I} = \left(\frac{P'_0}{P_0} \right)^2$$

or
$$I' = \left(\frac{P'_0}{P_0} \right)^2 I = \left(\frac{6}{4} \right)^2 \times 10^{-6} \text{ W/m}^2 = 2.25 \times 10^{-6} \text{ W/m}^2.$$

APPEARANCE OF SOUND TO HUMAN EAR

Pitch and Frequency

Frequency as we have discussed till now is an objective property measured its units of Hz and which can be assigned a unique value. However a person's perception of frequency is subjective. The brain interprets frequency primarily in terms of a subjective quality called Pitch. A pure note of high frequency is interpreted as high-pitched sound and a pure note of low frequency as low-pitched sound.

Pitch of a sound is that sensation by which we differentiate a buffalo voice, a male voice is of low pitch, a male voice has higher pitch and a female voice has (generally) still higher pitch. This sensation primarily depends on the dominant frequency present in the sound. Higher the frequency, higher will be the pitch and vice versa. The dominant frequency of a buffalo voice is smaller than that of a male voice which in turn is smaller than that of a female voice.

Loudness and Intensity

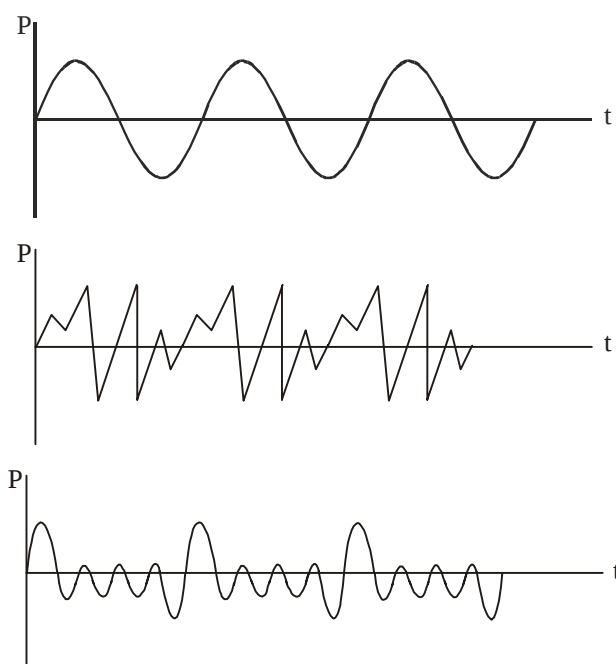
The loudness that we sense is related to the intensity of sound through it is not directly proportional to it. Our perception of loudness is better correlated with the sound level measured in decibels (abbreviated and dB) and defined as follows.

$$\beta = 10 \log_{10} \left(\frac{I}{I_0} \right),$$

where I is the intensity of the sound and I_0 is a constant reference intensity 10^{-12} W/m^2 . The reference intensity represents roughly the minimum intensity that is just audible at intermediate frequencies. For $I = I_0$, the sound level $\beta = 0$. Table shows the approximate sound levels of some of the sounds commonly encountered.

Quality and Waveform

A sound generated by a source may contain a number of frequency components in it. Different frequency components have different amplitudes and superposition of them results in the actual waveform. The appearance of sound depends on this waveform apart from the dominant frequency and intensity. Figure shows waveforms for a tuning fork, a clarinet and a corset playing the same note (fundamental frequency = 440 Hz) with equal loudness.



We differentiate between the sound from a table and that from a mridang by saying that they have different quality. A musical sound has certain well-defined frequencies which have considerable amplitude. These frequencies are generally harmonics of a fundamental frequency. Such a sound is particularly pleasant to the ear. On the other hand, a noise has frequencies that do not bear well-defined relationship among themselves.

Ex. A bird is singing on a tree. A person approaches the tree and perceives that the intensity has increased by 10 dB. Find the ratio of initial and final separation between the man and the bird.

Sol. $\beta_1 = 10 \log \frac{I_1}{I_0}$

$$\beta_2 = 10 \log \frac{I_2}{I_0} \Rightarrow \beta_2 - \beta_1 = 10 \log \frac{I_2}{I_1} \quad \text{or } 10 = 10 \log_{10} \left(\frac{I_2}{I_1} \right)$$

$$\Rightarrow \frac{I_2}{I_1} = 10^1 = 10$$

for point source $I \propto \frac{1}{r^2}$

$$\Rightarrow \frac{r_1}{r_2} = \sqrt{\frac{I_2}{I_1}} = \sqrt{10}$$

INTERFERENCE OF SOUND WAVES :

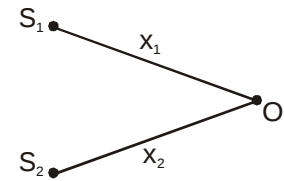
If $p_1 = p_{m1} \sin(\omega t - kx_1 + \theta_1)$

and $p_2 = p_{m2} \sin(\omega t - kx_2 + \theta_1)$

resultant excess pressure at point O is

$$p = p_1 + p_2$$

$$\Rightarrow p = p_0 \sin(\omega t - kx + \theta)$$



where, $p_0 = \sqrt{p_{m1}^2 + p_{m2}^2 + 2p_{m1}p_{m2} \cos \phi}$, $\phi = |k(x_1 - x_2) + (\theta_1 - \theta_2)| \dots$ (6.1)

(i) for constructive interference

$$\phi = 2n\pi \Rightarrow p_0 = p_{m1} + p_{m2}$$

(ii) for destructive interference

$$\phi = (2n + 1)\pi \Rightarrow p_0 = |p_{m1} - p_{m2}|$$

If ϕ is only due to path difference, then $\phi = \frac{2\pi}{\lambda} \Delta x$, and

Condition for constructive interference : $\Delta x = n\lambda$, $n = 0, \pm 1, \pm 2$

Condition for destructive interference : $\Delta x = (2n + 1) \frac{\lambda}{2}$, $n = 0, \pm 1, \pm 2$

from equation (6.1)

$$P_0^2 = P_{m1}^2 + P_{m2}^2 + 2P_{m1}P_{m2} \cos \phi$$

Since intensity, $I \propto (\text{Pressure amplitude})^2$,

we have, for resultant intensity, $I = I_1 + I_2 + 2\sqrt{I_1 I_2} \cos \phi \dots$ (6.2)

$$\text{If } I_1 = I_2 = I_0$$

$$I = 2I_0 (1 + \cos \phi)$$

$$\Rightarrow I = 4I_0 \cos^2 \frac{\phi}{2} \quad \dots (6.3)$$

Hence in this case,

for constructive interference : $\phi = 0, 2\pi, 4\pi, \dots$ and

and for destructive interference : $\phi = \pi, 3\pi, \dots$ and

$$I_{\max} = 4I_0$$

$$I_{\min} = 0$$

Coherence : Two sources are said to be coherent if the phase difference between them does not change with time. In this case their resultant intensity at any point in space remains constant with time. Two independent sources of sound are generally incoherent in nature, i.e. phase difference between them changes with time and hence the resultant intensity due to them at any point in space changes with time.

- Ex.** Figure shows a tube structure in which a sound signal is sent from one end and is received at the other end. The semicircular part has a radius of 10.0 cm. The frequency of the sound source can be varied from 1 to 10 kHz. Find the frequencies at which the ear perceives maximum intensity. The speed of sound in air = 342 m/s.



- Sol.** The sound wave bifurcates at the junction of the straight and the semicircular parts. The wave through the straight part travels a distance $s_1 = 2 \times 10$ cm and the wave through the curved part travels a distance $s_2 = \pi \times 10$ cm = 31.4 cm before they meet again and travel to the receiver. The path difference between the two waves received is, therefore,

$$\Delta s = s_2 - s_1 = 31.4 \text{ cm} - 20 \text{ cm} = 11.4 \text{ cm}$$

The wavelength of either wave is $\frac{v}{\nu} = \frac{330 \text{ m/s}}{\nu}$. For constructive interference, $\Delta p = n\lambda$, where n is an integer.

$$\text{or, } \Delta p = n \cdot \frac{v}{\nu} \Rightarrow \nu = \frac{n \cdot v}{\Delta p} \Rightarrow \frac{n \cdot 342}{(0.114)} = 3000 n$$

Thus, the frequencies within the specified range which cause maximum of intensity are

3000×1	3000×2	and	$3000 \times 3 \text{ Hz}$
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LONGITUDINAL STANDING WAVES :

Two longitudinal waves of same frequency and amplitude travelling in opposite directions interfere to produce a standing wave.

If the two interfering wave are given by

$$p_1 = p_0 \sin (\omega t - kx)$$

$$\text{and } p_2 = p_0 \sin (\omega t + kx + \phi)$$

then the equation of the resultant standing wave would be given by

$$p + p_1 + p_2 = 2p_0 \cos \left(kx + \frac{\phi}{2}\right) \sin \left(\omega t + \frac{\phi}{2}\right)$$

$$\Rightarrow p = p_0' \sin \left(\omega t + \frac{\phi}{2}\right) \quad \dots (8.1)$$

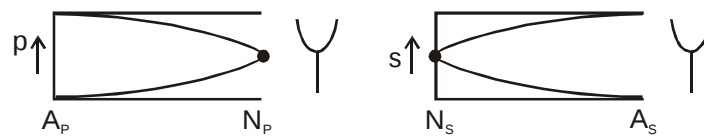
VIBRATION OF AIR COLUMNS

Standing waves can be set up in air-columns trapped inside cylindrical tubes if frequency of the tuning fork sounding the air column matches one of the natural frequency of air columns. In such a case the sound of the tuning fork becomes markedly louder, and we say there is resonance between the tuning fork and air column. To determine the natural frequency of the air column, notice that there is a displacement node (pressure antinode) at each closed end of the tube as air molecules there are not free to move, and a displacement antinode (pressure-node) at each open end of the air-column.

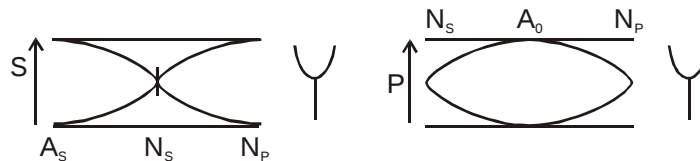
In reality antinodes do not occur exactly at the open end but a little distance outside. However if diameter of tube is small compared to its length, this end correction can be neglected.

Closed organ pipe

(In the diagram, A_p = Pressure antinode, A_s = displacement antinode, N_p = pressure node, N_s = displacement node.)

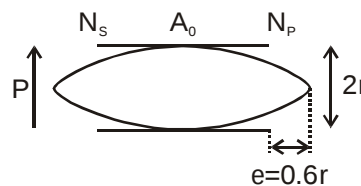


Open organ pipe :



End correction : As mentioned earlier the displacement antinode at an open end of an organ pipe lies slightly outside the open end. The distance of the antinode from the open end is called end correction and its value is given by

$$e = 0.6 r$$



where r = radius of the organ pipe.

with end correction, the fundamental frequency of a closed pipe (f_c) and an open organ pipe (f_0) will be given by

$$f_c = \frac{v}{4(\ell + 0.6r)} \text{ and}$$

$$f_0 = \frac{v}{2(\ell + 1.2r)} \quad \dots\dots\dots (9.5)$$

Ex. A tuning fork is vibrating at frequency 200 Hz. When another tuning fork is sounded simultaneously, 6 beats per second are heard. When some mass is added to the tuning fork of 200 Hz, beat frequency decreases. Find the frequency of the other tuning fork.

Sol. $|f - 200| = 6$

$\Rightarrow f = 194 \text{ or } 206$

when 1st tuning fork is loaded its frequency decreases and so does beat frequency

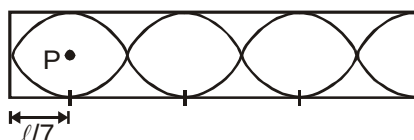
$\Rightarrow 200 > f$

$\Rightarrow f = 194 \text{ Hz}$

Ex. A closed organ pipe has length ' ℓ '. The air in it is vibrating in 3rd overtone with maximum amplitude ' a '. Find the amplitude at a distance of $\ell/7$ from closed end of the pipe.

Sol. The figure shows variation of displacement of particles in a closed organ pipe for 3rd overtone.

For third overtone $\ell = \frac{7\lambda}{4}$ or $\lambda = \frac{4\ell}{7}$ or $\frac{\lambda}{4} = \frac{\ell}{7}$



Hence the amplitude at P at a distance $\frac{\ell}{7}$ from closed end is ' a ' because there is an antinode at that point.

BEATS

When two sound waves of same amplitude and different frequency superimpose, then intensity at any point in space varies periodically with time. This effect is called beats.

If the equation of the two interfering sound waves emitted by s_1 and s_2 at point O are,

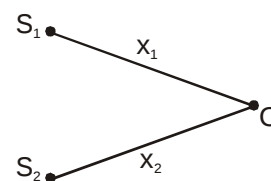
$$p_1 = p_0 \sin(2\pi f_1 t - kx_1 + \theta_1)$$

$$p_2 = p_0 \sin(2\pi f_2 t - kx_2 + \theta_2)$$

By principle of superposition

$$p = p_1 + p_2$$

$$= 2p_0 \cos \left\{ \pi(f_1 - f_2)t + \frac{\theta_1 + \theta_2}{2} \right\} \sin \left\{ \pi(f_1 + f_2)t + \frac{\theta_1 + \theta_2}{2} \right\}$$



i.e., the resultant sound at point O has frequency $\left(\frac{f_1 + f_2}{2} \right)$ while pressure amplitude $p'_0(t)$ varies with time as

$$p_0(t) = 2p_0 \cos \left\{ \pi(f_1 - f_2)t + \frac{\phi_1 + \phi_2}{2} \right\}$$

Hence pressure amplitude at point O varies with time with a frequency of $\left(\frac{f_1 - f_2}{2} \right)$.

Hence sound intensity will vary with a frequency $f_1 - f_2$.

This frequency is called beat frequency (f_B) and the time interval between two successive intensity maxima (or minima) is called beat time period (T_B)

$$f_B = f_1 - f_2$$

$$T_B = \frac{1}{f_1 - f_2}$$

IMPORTANT POINTS :

- (i) The frequency $|f_1 - f_2|$ should be less than 16 Hz, for it to be audible.
- (ii) Beat phenomenon can be used for determining an unknown frequency by sounding it together with a sound of known frequency.

Ex. Two strings X and Y of a sitar produces a beat of frequency 4Hz. When the tension of string Y is slightly increased, the beat frequency is found to be 2Hz. If the frequency of X is 300 Hz, then the original frequency of Y was.

Ans. 296 Hz

DOPPLER EFFECT

We can express the general relationship for the observed frequency when a source is moving and an observer is at rest as equation , with the same sign convention applied to v_s as was applied to v_0 : a positive value is substituted for v_s when the source moves toward the observer and a negative value is substituted when the source moves away from the observer.

Finally, we find the following general relationship for the observed frequency :

$$f' = \left(\frac{v + v_0}{v - v_s} \right) f$$

In this expression, the signs for the values substituted for v_0 and v_s depend on the direction of the velocity. A positive value is used for motion of the observer or the source toward the other, and a negative sign for motion of one away from the other.

A convenient rule concerning signs for you to remember when working with all Doppler effect problems is as follows :

The word toward is associated with an increase in observed frequency. The words away from are associated with a decrease in observed frequency.

Ex. A submarine (sub A) travels through water at a speed of 8.00 m/s, emitting a sonar wave at a frequency of 1400 Hz. The speed of sound in the water is 1533 m/s. A second submarine (sub B) is located such that both submarines are traveling directly toward one another. The second submarine is moving at 9.00 m/s.

- (A) What frequency is detected by an observer riding on sub B as the subs approach each other?
- (B) The subs barely miss each other and pass. What frequency is detected by an observer riding on sub B as the subs recede from each other?

Sol. (A) We use equation to find the Doppler - shifted frequency. As the two submarines approach each other, the observer in sub B hears the frequency

$$f' = \left(\frac{v + v_0}{v - v_s} \right) f = \left(\frac{1533 \text{ m/s} + (+9.00 \text{ m/s})}{1533 \text{ m/s} - (+8.00 \text{ m/s})} \right) (1400 \text{ Hz}) = 1416 \text{ Hz}$$

(B) As the two submarines recede from each other, the observer in sub B hears the frequency

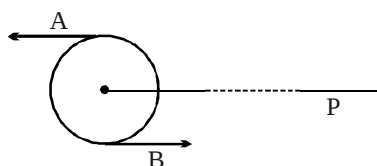
$$f' = \left(\frac{v + v_0}{v - v_s} \right) f$$

$$= \left(\frac{1533 \text{ m/s} + (-9.00 \text{ m/s})}{1533 \text{ m/s} - (-8.00 \text{ m/s})} \right) (1400 \text{ Hz}) = 1385 \text{ Hz}$$

Ex. A whistle of frequency 540 Hz is moving in a circle of radius 2m at a constant angular speed of 15rad/s. What are the lowest and height frequencies heard by a listener standing at rest, a long distance away from the centre of the circle ? (velocity of sound in air is 330 m/s ft/sec.)

Sol. The whistle is moving along a circular path with constant angular velocity ω . The linear velocity of the whistle is given by

$$v_s = \omega R$$



where, R is radius of the circle

At points A and B, the velocity v_s of whistle is parallel to line OP, i.e. with respect to observer at P, whistle has maximum velocity v_s away from P at point A, and towards P at point B. (Since distance OP is large compared to radius R , whistle may be assumed to be moving along line OP) Observer, therefore, listens maximum frequency when source is at B moving towards observer.

$$f_{\max} = f \frac{v}{v - v_s} = 540 \times \frac{330}{330 - 30} = 540 \times \frac{330}{300} = 594 \text{ Hz}$$

where, v is speed of sound in air. Similarly, observer listens minimum frequency when source is at A, moving away from observer.

$$f_{\min} = \frac{f v}{v + v_s} = 540 \times \frac{330}{360} = 495 \text{ Hz}$$

1. Vibrating air columns :

(i) In a pipe of length L closed at one end, the fundamental note has a frequency $f_1 = \frac{v}{4L}$, where v is the velocity of sound in air.

(ii) The first overtone $f_2 = \frac{v}{L} = 2f_1$

2. Propagation of sound in solids :

(i) The velocity of propagation of a longitudinal wave in a rod of Young's modulus Y and

$$\text{density } \rho \text{ is given by } v = \sqrt{\frac{Y}{\rho}}$$

(ii) In a sonometer wire of length L and mass per unit length m under tension T vibrating in n

$$\text{loops } f_n = \frac{n}{2L} \sqrt{\frac{T}{m}}$$

(iii) Propagation of sound in gases

Laplace formula $v = \sqrt{\frac{\gamma P}{\rho}}$ where γ is the ratio of specific heats, P is the pressure and ρ is the

density. $\frac{v_t}{v_0} = \sqrt{\frac{T}{T_0}} = \sqrt{\frac{273+t}{273}}$

3. Doppler Effect :

- (i) When a source of sound moves with a velocity v_s in a certain direction, the wavelength decreases in front of the source and increases behind the source.

$$\lambda' \text{ (in front)} = \frac{v - v_s}{f_s}; f' = \frac{v}{\lambda'} = \frac{v}{v - v_s} f_s$$

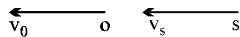
$$\lambda'' \text{ (behind)} = \frac{v + v_s}{f_s}; f'' = \frac{v}{\lambda''} = \frac{v}{v + v_s} f_s$$

Here v is the velocity of sound in air.

- (ii) The apparent frequency = $\frac{v - v_0}{v} f_s$

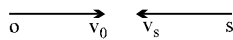
- (a) When the source is moving towards the observer and the observer is moving away from the source, the apparent frequency

$$f_a = \frac{v - v_0}{v - v_s} f_s$$



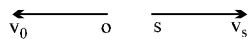
- (b) When the source and the observer are moving towards each other.

$$f_a = \frac{v + v_0}{v - v_s} f_s$$



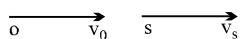
- (c) When the source and observer are moving away from each other,

$$f_a = \frac{v - v_0}{v + v_s} f_s$$



- (d) When the source is moving away from the observer and the observer is moving towards the source

$$f_a = \frac{v + v_0}{v + v_s} f_s$$



Here all velocities are relation to the medium.

4. Loudness of sound :

The loudness level B of sound is expressed in decibels, $B = 10 \log \frac{I}{I_0}$ where I is the intensity, I_0 is a reference intensity.

5. Beats :

When two tuning forks of close but different frequencies f_1 and f_2 are vibrating simultaneously at nearby places, a listener observes a fluctuation in the intensity of sound, called beats. The number of beats heard per second is $f_1 - f_2$.

WORKED OUT EXAMPLES

Ex.1 It is found that an increase in pressure of 100 kPa causes a certain volume of water to decrease by 5×10^{-3} percent of its original volume. Then the speed of sound in the water is about (density of water 10^3 kg/m^3)

- (A) 330 m/s (B) 1414 m/s (C) 1732 m/s (D) 2500 m/s

Ans. (B)

Sol. Bulk modulus $\beta = -\frac{\Delta P}{\frac{\Delta V}{V}} = \frac{100 \times 10^3}{\frac{5 \times 10^{-3}}{100}} = 2 \times 10^9$

$$\text{speed } v = \sqrt{\frac{\beta}{\rho}} = \sqrt{\frac{2 \times 10^9}{10^3}} \approx 1414 \text{ m/s}$$

Ex.2 A sound wave is travelling in a uniform pipe with gas of adiabatic exponent γ . If u is the particle velocity at any point in medium and c is the wave velocity, then relative change in pressure $\frac{dP}{P}$ while wave passes through this point is :-

- (A) $\frac{u}{\gamma c}$ (B) $\gamma \sqrt{\frac{u}{c}}$ (C) $\gamma \frac{u}{c}$ (D) $\frac{u^2}{\gamma c^2}$

Ans. (C)

Sol. $\Delta P = -B \left(\frac{dv}{v} \right)$

$$\Delta P = -B \left(\frac{\delta y}{\delta x} \right)$$

$$\Delta P = -\gamma P \frac{\delta y}{\delta x}$$

$$\frac{\Delta P}{P} = \gamma \left(\frac{u}{c} \right)$$

Ex.3 A point source emits sound equally in all directions in a non-absorbing medium. Two points P and Q are at a distance of 9 meters and 25 meters respectively from the source. The ratio of the amplitudes of the waves at P and Q is :-

- (A) 5 : 3 (B) 3 : 5 (C) 25 : 9 (D) 625 : 81

Ans. (C)

Sol. $I \propto A^2$, $I \propto \frac{1}{r^2}$, $\frac{A_1}{A_2} = \frac{r_2}{r_1}$

Ex.4 In a resonance tube experiment, an 80 cm air column is in resonance with a tuning fork in first overtone. Which equation can represent correct pressure variation in the air column ($x = 0$ is the top point of the tube, neglect end correction, speed of sound = 320 m/sec) :-

- (A) $A \sin \frac{15\pi}{8} x \cos 600\pi t$ (B) $A \cos \frac{15\pi}{8} x \sin 600 \pi t$
 (C) $A \cos \frac{15\pi}{8} x \sin 300 \pi t$ (D) $A \sin \frac{15\pi}{8} x \sin 300 \pi t$

Ans. (A)

Sol. $\frac{\omega}{k} = 320$

Ex.5 The displacement of the medium in a sound wave is given by the equation ; $y_1 = A \cos (ax + bt)$ where A, a & b are positive constants. The wave is reflected by an obstacle situated at $x = 0$. The intensity of the reflected wave is 0.64 times that of the incident wave.

- (a) what are the wavelength & frequency of the incident wave.
 (b) write the equation for the reflected wave.
 (c) in the resultant wave formed after reflection, find the maximum & minimum values of the particle speeds in the medium.

Ans. (a) $2\pi/a$, $b/2\pi$, (b) $y_2 = \pm 0.8 A \cos (ax - bt)$, (c) max. = $1.8 b A$, min. = 0,

Sol. (a) $\omega = b$ & $k = a$

$$f = \frac{2\pi}{\omega} \text{ \& \; } \lambda = \frac{2\pi}{k}$$

(b) $I \propto A^2$

So $A_r = 0.8 A$

(c) $(A_{\text{net}})_{\text{max}} = A + 0.8 A = 1.8 A$

Ex.6 An observer moves towards a stationary source of sound, with a velocity one-fifth of the velocity of sound. what is the percentage increase in the apparent frequency ?[AIEEE - 2005]

- (1) zero (2) 0.5% (3) 5% (4) 20%

Ans. (4)

Sol. $\frac{f_{\text{app}}}{f} = \left(\frac{v + \frac{v}{5}}{v} \right) = \frac{6}{5}$

Ex.7 The equation of a longitudinal standing wave due to superposition of the progressive waves produced by two sources of sound is $s = -20 \sin 10 \pi x \sin 100 \pi t$ where s is the displacement from mean position measured in mm ; x is in meters and t in seconds. The specific gravity of the medium is 10^{-3} . Find

- (a) wavelength, frequency and velocity of the progressive waves.
 (b) Bulk modulus of the medium and the pressure amplitude of the progressive waves.
 (c) minimum distance between pressure antinode and the displacement antinode.

Ans. (a) $1/5$ m, 50 Hz, 10 m/s; (b) 100 Pa, 10π Pa, (c) $1/20$ m

Sol. $k = 10\pi$

$$\omega = 100 \pi$$

$$\therefore \lambda = \frac{1}{5} \text{ \& } f = 50 \text{ Hz}$$

$$v = \lambda f = 10 \text{ m/s}$$

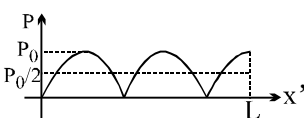
$$B = \rho v^2$$

$$P_0 = BKs$$

$$\text{Minimum distance between pressure antinode and displacement antinode} = \frac{\lambda}{4}$$

Ex.8 The air column in a pipe closed at one end and open to atmosphere at the other end is made to vibrate in its fifth harmonic by a tuning fork of frequency 470 Hz. The length of air column is $\frac{15}{16}$ m. Neglect end correction. Let p_0 denote the maximum gauge pressure at the closed end

- (a) Find the speed of sound in air.
 (b) Draw the graph of pressure amplitude vs distance from the open end of the tube.
 (c) Find the points where the maximum gauge pressure is $\frac{p_0}{2}$.

Ans. (a) 352.5 m/s, (b) , (c) $\frac{l}{15}, \frac{5l}{15}, \frac{7l}{15}, \frac{11l}{15}, \frac{13l}{15}$

Sol. $\frac{5\lambda}{4} = \frac{15}{16}$

$$\lambda = 0.75 \text{ m}$$

$$f = 470$$

$$v = \lambda f = 352.5 \text{ m/s}$$

$$P = P_0 \sin\left(\frac{2\pi}{\lambda} x\right)$$

$$\text{where } \lambda = \frac{4\ell}{5}$$

$$P = P_0 \sin\left(\frac{5\pi}{2\ell} x\right)$$

Ex.9 A metal rod of length $l = 100$ cm is clamped at two points. Distance of each clamp from nearer end is $a = 30$ cm. If density and Young's modulus of elasticity of rod material are $\rho = 9000 \text{ kg m}^{-3}$ and $Y = 144 \text{ GPa}$ respectively, calculate minimum and next higher frequency of natural longitudinal oscillations of the rod.

Ans. 10kHz, 30kHz

Sol. $v = \sqrt{\frac{Y}{\rho}} = 4 \times 10^3 \text{ m/s}$

$$\lambda = 0.4 \text{ m}$$

$$f_0 = \frac{v}{\lambda} = 10 \text{ kHz}$$

Ex.10 When two tuning forks (fork 1 and fork 2) are sounded simultaneously, 4 beats per second are heard. Now, some tape is attached on the prong of the fork 2. When the tuning forks are sounded again, 6 beats per second are heard. If the frequency of fork 1 is 200 Hz, then what was the original frequency of fork 2 ?

[AIEEE - 2005]

- (1) 200 Hz (2) 202 Hz (3) 196 Hz (4) 204 Hz

Ans. (3)

Sol. $f_1 - f_2 = 4$ or $f_2 - f_1 = 4$
But according to question
 $f_1 - f_2 = 4$
So $f_2 = 196$

Ex.11 A whistling train approaches a junction. An observer standing at junction observes the frequency to be 2.2 KHz and 1.8 KHz of the approaching and the receding train. Find the speed of the train (speed of sound = 300 m/s).

[JEE 2005]

Ans. $V_s = 30 \text{ m/s}$

Sol. $\left(\frac{v}{v - v_s} \right) f_0 = 2.2 \times 10^3$

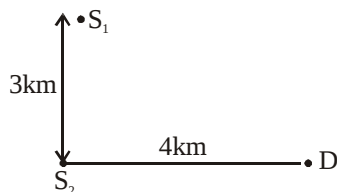
$$\left(\frac{v}{v + v_s} \right) f_0 = 1.8 \times 10^3$$

Dividing both we get

$$\frac{v + v_s}{v - v_s} = \frac{11}{9}$$

$$v_s = 30$$

Ex.12 Two point sound source S_1 and S_2 are both have the same power and send out sound waves in the same phase. The wavelength of both the waves is $\frac{48}{5}$ m. The intensity due to S_2 alone at D is 25 W/m^2 . The resultant intensity at D is :



- (A) 59 W/m^2 (B) 61 W/m^2 (C) 65 W/m^2 (D) None of these

Ans. (B)

Sol. $I \propto \frac{1}{r^2}$

Intensity due to S_1 alone at D = 16 W/m^2

$$\text{Phase difference} = \frac{2\pi}{\left(\frac{48}{5}\right)} \times 1000 = \frac{625}{3} \pi$$

$$I_{\text{res}} = I_1 + I_2 + 2\sqrt{I_1}\sqrt{I_2} \cos\phi$$

$$= 25 + 16 + 2(5)(4) \left(\frac{1}{2}\right)$$

Ex.13 Spherical sound waves are emitted uniformly in all directions from a point source. The variation in sound level SL as a function of distance $r(> 0)$ from the source can be written as :- (where a and b are positive constant)

- (A) $SL = -b \log r^a$ (B) $SL = a - b \log r$ (C) $SL = a - b(\log r)^2$ (D) $SL = a - \frac{b}{r^2}$

Ans. (B)

Sol. $I \propto \frac{1}{r^2}$

$$SL = 20 \log_{10} \frac{I}{I_0}$$

EXERCISE (S-1)**Sound basics**

1. Find the intensity of sound wave whose frequency is 250 Hz. The displacement amplitude of particles of the medium at this position is 1×10^{-8} m. The density of the medium is 1 kg/m^3 , bulk modulus of elasticity of the medium is 400 N/m^2 .

SW0001

2. In a mixture of gases, the average number of degrees of freedom per molecule is 6. The rms speed of the molecules of the gas is c . Find the velocity of sound in the gas.

SW0002

3. The loudness level at a distance R from a long linear source of sound is found to be 40dB. At this point, the amplitude of oscillations of air molecules is 0.01 cm. Then find the loudness level & amplitude at a point located at a distance '10R' from the source.

SW0003**Superposition of sound**

4. The first overtone of a pipe closed at one end resonates with the third harmonic of a string fixed at its ends. The ratio of the speed of sound to the speed of transverse wave travelling on the string is 2 : 1. Find the ratio of the length of pipe to the length of string.

SW0004

5. In a resonance-column experiment, a long tube, open at the top, is clamped vertically. By a separate device, water level inside the tube can be moved up or down. The section of the tube from the open end to the water level act as a closed organ pipe. A vibrating tuning fork is held above the open end, first and the second resonances occur when the water level is 24.1 cm and 74.1 cm respectively below the open end. Find the diameter of the tube.

SW0005

6. A tuning fork of frequency 480 Hz resonates with a tube closed at one end of length, 16 cm and diameter 5 cm in fundamental mode. Calculate velocity of sound in air.

SW0006

7. An open organ pipe filled with air has a fundamental frequency 500Hz. The first harmonic of another organ pipe closed at one end and filled with carbon dioxide has the same frequency as that of the first harmonic of the open organ pipe. Calculate the length of each pipe. Assume that the velocity of sound in air and in carbondioxide to be 330 and 264 m/s respectively.

SW0007

8. A steel rod having a length of 1 m is fastened at its middle. Assuming young's modulus to be $2 \times 10^{11} \text{ Pa}$, and density to be 8 gm/cm^3 find the fundamental frequency of the longitudinal vibration and frequency of first overtone.

SW0008

9. Two narrow cylindrical pipes A and B have the same length. Pipe A is open at both ends and is filled with a monoatomic gas of molar mass M_A . Pipe B is open at one end and closed at the other end, and is filled with a diatomic gas of molar mass M_B . Both gases are at the same temperature.

[JEE 2002]

SW0009

- (a) If the frequency of the second harmonic of the fundamental mode in pipe A is equal to the frequency of the third harmonic of the fundamental mode in pipe B, determine the value of M_A/M_B .
(b) Now the open end of pipe B is also closed (so that the pipe is closed at both ends). Find the ratio of the fundamental frequency in pipe A to that in pipe B.
10. A tube of a certain diameter and of length 48 cm is open at both ends. Its fundamental frequency of resonance is found to be 320 Hz. The velocity of sound in air is 320 m/sec. Estimate the diameter of the tube.

[IIT-1980]

SW0010

Beats

11. A stretched uniform wire of a sonometer between two fixed knife edges, when vibrates in its second harmonic gives 1 beat per second with a vibrating tuning fork of frequency 200 Hz. Find the percentage change in the tension of the wire to be in unison with the tuning fork.
12. A, B and C are three tuning forks. Frequency of A is 350 Hz. Beats produced by A and B are 5 per second and by B and C are 4 per second. When a wax is put on A beat frequency between A and B is 2 Hz and between A and C is 6 Hz. Then, find the frequency of B and C respectively.
13. A source of sound of frequency 256 Hz is moving rapidly towards wall with a velocity of 5 m/sec. How many beats per second will be heard if sound travels at a speed of 330 m/sec?
14. Two tuning forks with natural frequencies of 340 Hz each move relative to a stationary observer. One fork moves away from the observer, while the other moves towards him at the same speed. The observer hears beats of frequency 3 Hz. Find the speed of the tuning fork (assume $v_{\text{sound}} = 340$ m/s)

SW0011

SW0012

[IIT-1981]

SW0013

[IIT-1986]

SW0014

Doppler effect

15. Two tuning forks A and B lying on opposite sides of observer 'O' and of natural frequency 85 Hz move with velocity 10 m/s relative to stationary observer O. Fork A moves away from the observer while the fork B moves towards him. A wind with a speed 10 m/s is blowing in the direction of motion of fork A. Find the beat frequency measured by the observer in Hz. [Take speed of sound in air as 340 m/s]
16. A car is moving towards a huge wall with a speed $= c/10$, where c = speed of sound in still air. A wind is also blowing parallel to the velocity of the car in the same direction and with the same speed. If the car sounds a horn of frequency f , then what is the frequency of the reflected sound of the horn heard by driver of the car?

SW0015

SW0016

17. A plane sound wave of frequency f_0 and wavelength λ_0 travels horizontally toward the right. It strikes and is reflected from a large, rigid, vertical plane surface, perpendicular to the direction of propagation of the wave and moving towards the left with a speed v .
- (a) How many positive wave crests strike the surface in a time interval t ?
 - (b) At the end of this time interval, how far to the left of the surface is the wave that was reflected at the beginning of the time interval ?
 - (c) What is the wavelength of the reflected waves, in terms of λ_0 ?
 - (d) What is the frequency, in terms of f_0 ?
 - (e) A listener is at rest at the left of the moving surface. Describe the sensation of sound that he hears as a result of the combined effect of the incident and reflected wave trains.

SW0017

18. A bus is moving towards a huge wall with a velocity of 5 ms^{-1} . The driver sounds a horn of frequency 200 Hz. The frequency of the beats heard by a passenger of the bus will be..... Hz (speed of sound in air = 342 ms^{-1})

[IIT-1994]

SW0018

EXERCISE (S-2)

1. A boat is travelling in a river with a speed of 10 m/s along the stream flowing with a speed 2 m/s. From this boat, a sound transmitter is lowered into the river through a rigid support. The wavelength of the sound emitted from the transmitter inside the water is 14.45 mm. Assume that attenuation of sound in water and air is negligible. [JEE 2001]

- (a) What will be the frequency detected by a receiver kept inside the river downstream ?
 (b) The transmitter and the receiver are now pulled up into air. The air is blowing with a speed 5 m/sec in the direction opposite the river stream. Determine the frequency of the sound detected by the receiver.

(Temperature of the air and water = 20°C ; Density of river water = 10^3 Kg/m^3 ; Bulk modulus of the water = $2.088 \times 10^9 \text{ Pa}$; Gas constant $R = 8.31 \text{ J/mol-K}$; Mean molecular mass of air = $28.8 \times 10^{-3} \text{ kg/mol}$; C_p/C_v for air = 1.4)

SW0019

Note: Boat velocity is with respect to ground & receiver is stationary w.r.t. ground

2. The air column in a pipe closed at one end is made to vibrate in its second overtone by a tuning fork of frequency 440 Hz . The speed of sound in air is 330 ms^{-1} . End corrections may be neglected. Let P_0 denote the mean pressure at any point in the pipe & ΔP_0 the maximum amplitude of pressure variation. [JEE '98]

- (i) Find the length L of the air column.
 (ii) What is the amplitude of pressure variation at the middle of the column ?
 (iii) What are the maximum & minimum pressures at the open end of the pipe .
 (iv) What are the maximum & minimum pressures at the closed end of the pipe?

SW0020

3. A train of length l is moving with a constant speed v along a circular track of radius R , The engine of the train emits a whistle of frequency f . Find the frequency heard by a guard at the rear end of the train. Make suitable assumption.

SW0021

4. A string 25 cm long and having a mass of 2.5 gm is under tension. A pipe closed at one end is 40 cm long. When the string is set vibrating in its first overtone and the air in the pipe in its fundamental frequency, 8 beats per second are heard. It is observed that decreasing the tension in the string decreases beat frequency. If the speed of sound in air is 320 m/s, find the tension in the string.

[IIT-1982]

SW0022

5. A train approaching a hill at speed of 40 km/hr sound a whistle of frequency 580 Hz when it is at a distance of 1 km from a hill. A wind a speed of 40 km/hr blowing the direction of motion of the train. Find

(i) the frequency of the whistle as heard by an observer on the hill.
 (ii) the distance from the hill at which the echo from the hill is heard by the driver and its frequency.
 (Velocity of sound in air = 1,200 km/hr)

[IIT-1988]

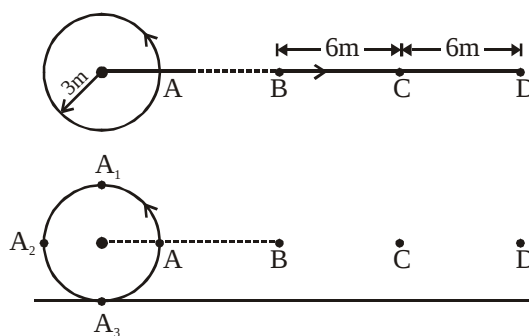
SW0023

6. A source of sound is moving along a circular orbit of radius 3 metres with an angular velocity of 10 rad/s. A sound detector located far away from the source is executing linear simple harmonic motion along the line BD with an amplitude $BC = CD = 6$ metres. The frequency of oscillation of the

detector is $\frac{5}{\pi}$ per second. The source is at the point A when the detector is at the point B. If the source

is at the point A when the detector is at the point B. If the source emits a continuous sound wave of frequency 340 Hz, find the maximum and the minimum frequencies recorded by the detector.

[IIT-1990]



SW0024

7. Two radio stations broadcast their programmes at the same amplitude A and at slight different frequencies ω_1 and ω_2 respectively, where $\omega_1 - \omega_2 = 10^3$ Hz. A detector receives the signals from the two stations simultaneously. It can only detect signals of intensity $\geq 2A^2$.

(i) Find the time interval between successive maxima of the intensity of the signal received by the detector.
 (ii) Find the time for which the detector remains idle in each cycle of the intensity of the signal.

[IIT-1993]

SW0025

8. A sonometer wire under tension of 64 Newtons vibrating in its fundamental mode is in resonance with a vibrating tuning fork. The vibrating portion of the sonometer wire has a length of 10 cm and a mass of 1 gm. The vibrating tuning fork is now moved away of 1 gm. The vibrating wire with a constant speed and an observer standing near the sonometer hears one beat per second. Calculate the speed with which the tuning fork is moved if the speed of sound in air is 300 m/s.

[IIT-1983]

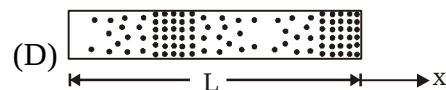
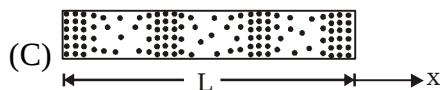
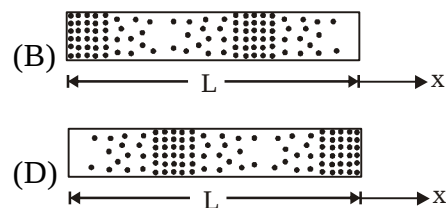
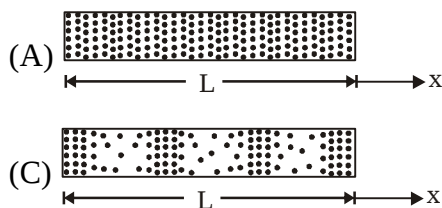
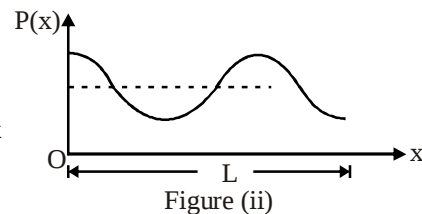
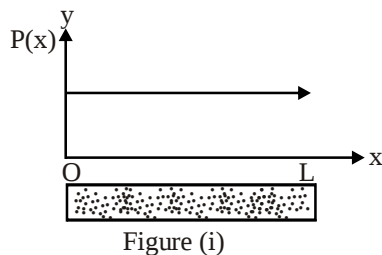
SW0026

9. The displacement of the medium in a sound wave is given by the equation $y_1 = A \cos(ax + bt)$ where A , a and b are positive constants. The wave is reflected by an obstacle situated at $x = 0$. The intensity of the reflected wave is 0.64 times that of the incident wave. **[IIT-1991]**
- (a) What are the wavelength and frequency of incident wave?
 - (b) Write the equation for the reflected wave.
 - (c) In the resultant wave formed after reflection, find the maximum and minimum values of the particle speeds in the medium.
 - (d) Express the resultant wave as a superpositions of standing wave and a travelling wave. What are the positions of the antinodes of the standing wave? What is the directions of propagation of travelling wave?
- SW0027**
10. The air column in a pipe closed at one end is made to vibrate in its second overtone by a tuning fork of frequency 440 Hz. The speed of sound in air is 330 ms^{-1} . End corrections may be neglected. Let P_0 denote the mean pressure at any point in the pipe, and ΔP_0 the maximum amplitude of pressure variation.
- (a) Find the length L of the air column.
 - (b) What is the amplitude of pressure variation at the middle of the column?
 - (c) What are the maximum and minimum pressure at the open end of the pipe?
 - (d) What are the maximum and minimum pressure at the closed end of the pipe? **[IIT-1998]**
- SW0028**
11. A 3.6m long vertical pipe resonates with a source of frequency 212.5 Hz when water level is at certain height in the pipe. Find the height of water level (from the bottom of the pipe) at which resonance occurs. Neglect end correction. Now, the pipe is filled to a height H ($\approx 3.6 \text{ m}$). A small hole is drilled very close to its bottom and water is allowed to leak. Obtain an expression for the rate of fall of water level in the pipe as a function of H . If the radii of the pipe and the hole are $2 \times 10^{-2} \text{ m}$ and $1 \times 10^{-3} \text{ m}$ respectively calculate the time interval between the occurrence of first two resonances. Speed of sound in air is 340 m/s and $g = 10 \text{ m/s}^2$. **[IIT-2000]**
- SW0029**

EXERCISE (O-1)

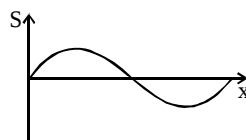
Sound basics

- A sound wave has a wavelength of 3.0 m. The distance from a compression center to the adjacent rarefaction center is :-
 (A) 0.75 m (B) 1.5 m (C) 3.0 m (D) need to know wave speed
SW0030
- You are listening to an "A" note played on a violin string. Let the subscript "s" refer to the violin string and "a" refer to the air. Then :-
 (A) $f_s = f_a$ but $\lambda_s \neq \lambda_a$ (B) $f_s = f_a$ and $\lambda_s = \lambda_a$ (C) $\lambda_s = \lambda_a$ but $f_s \neq f_a$ (D) $\lambda_s \neq \lambda_a$ and $f_s \neq f_a$
SW0031
- The fig.(i) shows the graphical representation of the air molecules in a tube of air (length = L) at atmospheric pressure on the absolute pressure $P(x)$ graph. Which one of the following pictures corresponds to the absolute pressure $P(x)$ graph of fig. (ii).

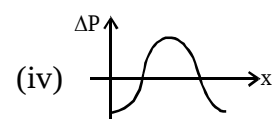
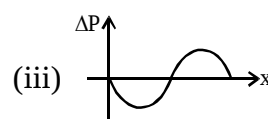
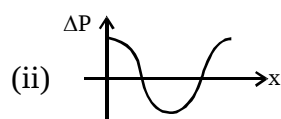
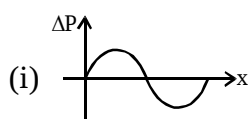


SW0032

- If a sound wave is travelling and snap shot at $t = 0$ is as shown in figure.



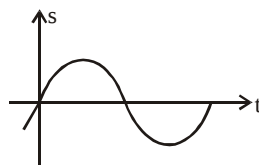
Choose snapshot of pressure variation.



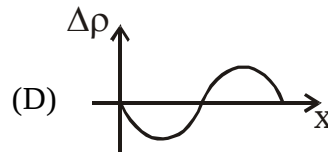
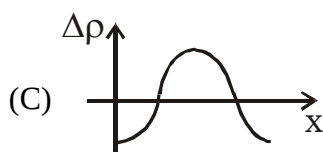
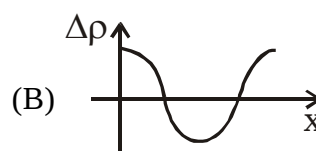
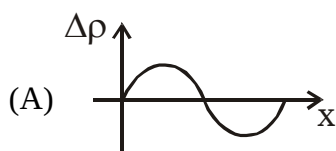
- (A) For wave travelling towards right or left (i) is correct.
 (B) For wave travelling towards right graph (iv) and for wave travelling towards left graph (iv) is correct.
 (C) For wave travelling towards right graph (i) and for wave travelling towards left graph (iii) is correct
 (D) For wave travelling towards right or left (ii) is correct.

SW0033

5. A sound waves is travelling towards right and its s-t graph is as shown for $x = 0$.



What will be the variation in density vs x graph at $t = T/4$:-



SW0034

6. A point source of sound is located somewhere along the x -axis. Experiments show that the same wave front simultaneously reaches listeners at $x = -8$ m and $x = +2.0$ m. A third listener is positioned along the positive y -axis. What is her y -coordinate (in m) if the same wave front reaches her at the same instant as it does the first two listeners ?
 (A) 4 (B) 3 (C) 2 (D) 5

SW0035

7. Two monatomic ideal gases 1 and 2 of molecular masses m_1 and m_2 respectively are enclosed in separate container kept at the same temperature. The ratio of the speed of sound in gas 1 to that in gas 2 is given by [JEE 2000 (Scr)]

(A) $\sqrt{\frac{m_1}{m_2}}$

(B) $\sqrt{\frac{m_2}{m_1}}$

(C) $\frac{m_1}{m_2}$

(D) $\frac{m_2}{m_1}$

SW0036

8. A firecracker exploding on the surface of a lake is heard as two sounds a time interval t apart by a man on a boat close to water surface. Sound travels with a speed u in water and a speed v in air. The distance from the exploding firecracker to the boat is

(A) $\frac{uvt}{u+v}$

(B) $\frac{t(u+v)}{uv}$

(C) $\frac{t(u-v)}{uv}$

(D) $\frac{uvt}{u-v}$

SW0037

9. The speed of longitudinal wave is 100 times the speed of transverse wave in a taut brass wire. If the Young's modulus of brass is $1.0 \times 10^{11} \text{ N/m}^2$, the stress in wire is :-
 (A) $1.0 \times 10^7 \text{ N/m}^2$ (B) $1.0 \times 10^6 \text{ N/m}^2$ (C) $1.0 \times 10^5 \text{ N/m}^2$ (D) $1.0 \times 10^8 \text{ N/m}^2$

SW0038

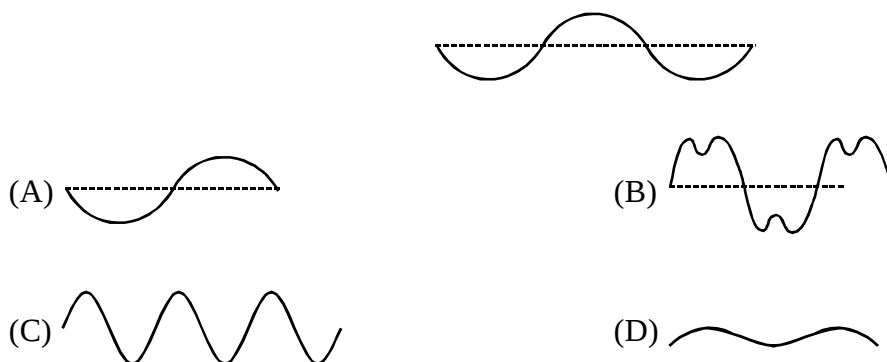
10. The equations of S.H.M. of medium particle due to sound waves propagating in a medium are given by $s_1 = 2 \sin(200\pi t)$ and $s_2 = 5 \sin(150\pi t)$. The ratio of average intensities of sound at these points is:
 (A) 4 : 25 (B) 9 : 100 (C) 8 : 15 (D) 64 : 225

SW0039

11. A is singing a note and at the same time B is also singing a note with $1/8$ th the frequency of A. The energies of the two sounds are equal. The displacement amplitude of the note of B is:
 (A) same as that of A (B) twice that of A
 (C) four times that of A (D) eight times that of A

SW0040

12. A microphone is connected to an oscilloscope. The diagram shows the trace on the screen when the microphone receives a pure note. Which trace can be obtained when a musical instrument produces a note of the same pitch but of a different quality ?



SW0041

13. Choose **correct** statement?
 (A) Two different acoustic musical instruments can not have same loudness
 (B) Two different acoustic musical instruments can not have same pitch
 (C) Two different acoustic musical instruments can not have same quality
 (D) Two different acoustic musical instruments can have more than two characteristics same

SW0042

14. A plane transverse wave is propagating in a direction making an angle of 30° with positive x-axis in the x-y plane. Find phase difference between points (0, 0, 0) and (1, 1, 1). Wavelength of the wave is 1m :-

- (A) $2\pi \text{ rad}$ (B) $(\sqrt{3} + 1)\pi \text{ rad}$ (C) $(\sqrt{2} + 1)\pi \text{ rad}$ (D) None

SW0043

15. Which of the following is the equation of a spherical wave :-

(A) $S = S_0 \sin(Kx - \omega t)$ (B) $S = S_0 \cos(Kx - \omega t)$
 (C) $S = (S_0/x) \sin(\omega t - Kx)$ (D) $S = (S_0/x^2) \sin(\omega t - Kx)$

SW0044

16. A note is produced when you blow air across the top of a test tube. Two students were asked about the effect of blowing harder.

Student-A : The pitch of sound would increase.

Student-B : The intensity of sound would increase

(A) A is correct, B is wrong (B) B is correct, A is wrong
 (C) both are correct (D) both are wrong

SW0045

17. A sound absorber attenuates the sound level by 20 dB. The intensity decreases by a factor of-

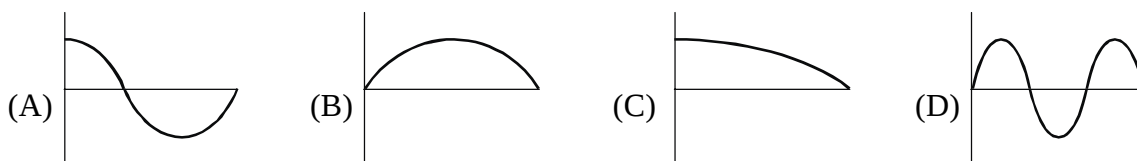
[AIEEE - 2007]

(A) 1000 (B) 10000 (C) 10 (D) 100

SW0046

Standing waves

18. Which of the figures, shows the pressure difference from regular atmospheric pressure for an organ pipe of length L closed at one end, corresponds to the 1st overtone for the pipe?



SW0047

19. In an organ pipe whose one end is at $x = 0$, the pressure is expressed by

$$p = p_0 \cos \frac{3\pi x}{2} \sin 300\pi t \quad \text{where } x \text{ is in meter and } t \text{ in sec. The organ pipe can be}$$

(A) closed at one end, open at another with length = 0.5m
 (B) open at both ends, length = 1m
 (C) closed at both ends, length = 2m
 (D) closed at one end, open at another with length = $\frac{2}{3}$ m

SW0048

20. If l_1 and l_2 are the lengths of air column for the first and second resonance when a tuning fork of frequency n is sounded on a resonance tube, then the distance of the displacement antinode from the top end of the resonance tube is:

(A) $2(l_2 - l_1)$ (B) $\frac{1}{2}(2l_1 - l_2)$ (C) $\frac{l_2 - 3l_1}{2}$ (D) $\frac{l_2 - l_1}{2}$

SW0049

21. A student is experimenting with resonance tube apparatus in Physics lab to find the speed of sound at room temperature. He got resonating lengths of air column as 17 cm and 51 cm, using tuning fork of frequency 512 Hz. Find speed of sound at room temperature and specify, whether the side water reservoir was moved upward or downward to obtain the second resonance (51 cm)?
- (A) 348 m/s, downwards (B) 348 m/s, upwards
(C) 332 m/s, downwards (D) 332 m/s, upwards

SW0050

Interference

22. The ratio of maximum to minimum intensity due to superposition of two waves is $\frac{49}{9}$. Then the ratio of the intensity of component waves is :-

- (A) $\frac{25}{4}$ (B) $\frac{16}{25}$ (C) $\frac{4}{49}$ (D) $\frac{9}{49}$

SW0051

23. Two waves of sound having intensities I and $4I$ interfere to produce interference pattern. The phase difference between the waves is $\pi/2$ at point A and π at point B. Then the difference between the resultant intensities at A and B is
- (A) $2I$ (B) $4I$ (C) $5I$ (D) $7I$

SW0052

24. Three coherent waves of equal frequencies having amplitude $10\ \mu\text{m}$, $4\ \mu\text{m}$ and $7\ \mu\text{m}$ respectively, arrive at a given point with successive phase difference of $\pi/2$. The amplitude of the resulting wave in μm is given by
- (A) 5 (B) 6 (C) 3 (D) 4

SW0053

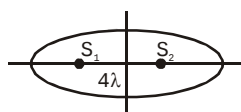
25. The ratio of intensities between two coherent sound sources is $4 : 1$. The difference of loudness in dB between maximum and minimum intensities when they interfere in space is:
- (A) $10 \log 2$ (B) $20 \log 3$ (C) $10 \log 3$ (D) $20 \log 2$

SW0054

26. In Quincke's tube a detector detects minimum intensity. Now one of the tube is displaced by 5 cm. During displacement detector detects maximum intensity 10 times, then finally a minimum intensity (when displacement is complete). The wavelength of sound is:
- (A) $10/9\ \text{cm}$ (B) $1\ \text{cm}$ (C) $1/2\ \text{cm}$ (D) $5/9\ \text{cm}$

SW0055

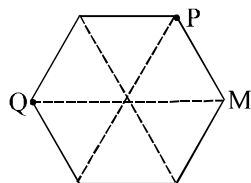
27. S_1, S_2 are two coherent sources of sound located along x-axis separated by 4λ where λ is wavelength of sound emitted by them. Number of maxima located on the elliptical boundary around it will be :



- (A) 16 (B) 12 (C) 8 (D) 4

SW0056

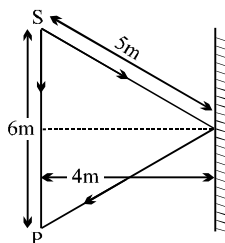
28. Two sound source emitting sound of wavelength 1 m are located at points P and Q as shown in figure. All sides of the polygon are equal and of length 1m. The intensity of sound at M due to both the individual sources is I_0 . What will be the intensity of sound at point M when both the sources are on.



- (A) $4I_0$ (B) $2I_0$ (C) I_0 (D) $(1/2)I_0$

SW0057

29. A person standing at a distance of 6 m from a source of sound receives sound wave in two ways, one directly from the source and other after reflection from a rigid boundary as shown in the figure. The maximum wavelength for which, the person will receive maximum sound intensity, is



- (A) 4 m (B) $\frac{16}{3}$ m (C) 2 m (D) $\frac{8}{3}$ m

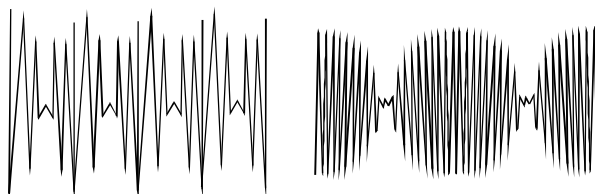
SW0058

Beats

30. Beats are heard when the A strings of two violins are played. The beat frequency decreases as the tension in the A string of violin 1 is slowly increased. Which of the following statement is correct ?
- (A) the fundamental frequency of the A string in violin 1 is less than that for violin 2
- (B) the fundamental frequency of the A string in violin 1 is greater than that for violin 2
- (C) the fundamental frequency of the A string in violin 1 may be greater or less than that for violin 2 depending on the linear mass densities of the two strings.
- (D) None of these

SW0059

31. Two waves with similar frequencies are added. The resulting waveform oscillates with the average frequency and with an oscillating amplitude that changes with a frequency equal to the difference between the original frequencies. These oscillations in the amplitude are known as beats. The traces show the resulting waveforms that occur when two different pairs of waves are added. Graph is for the same time interval in both cases, which of the following statements is TRUE?



- (A) On average, the waves on the left had higher frequencies, but the difference between frequencies less
 (B) On average, the waves on the right had higher frequencies, but the difference between frequencies less
 (C) On average, the waves on the left had higher frequencies, but the difference between frequencies more
 (D) On average, the waves on the right had higher frequencies, but the difference between frequencies more

SW0060

Doppler effect

32. A source when at rest in a medium produces waves with a velocity v and a wavelength of λ . If the source is set in motion with a velocity v_s what would be the wavelengths produced directly in front of the source?

(A) $\lambda \left(1 - \frac{v_s}{v}\right)$ (B) $\lambda \left(1 + \frac{v_s}{v}\right)$ (C) $\lambda \left(1 + \frac{v}{v_s}\right)$ (D) $\frac{\lambda v}{v + v_s}$

SW0061

33. A source of sound S having frequency f . Wind is blowing from source to observer O with velocity u . If speed of sound with respect to air is C , the wavelength of sound detected by O is:

(A) $\frac{C + u}{f}$ (B) $\frac{C - u}{f}$ (C) $\frac{C(C + u)}{(C - u)f}$ (D) $\frac{C}{f}$

SW0062

34. A train moving towards a hill at a speed of 72 km / hr sounds a whistle of frequency 500 Hz. A wind is blowing from the hill at a speed of 36 km / hr. If the speed of sound in air is 340 m / s, the frequency heard by a man on the hill is

(A) 532.25 Hz. (B) 565.0 Hz. (C) 516.1 Hz. (D) none of the above.

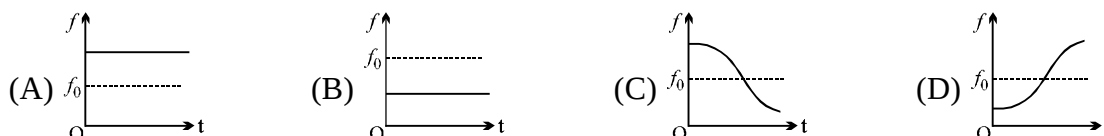
SW0063

35. A source is moving with constant speed $v_s = 20$ m/sec towards a stationary observer due east of source. Wind is blowing at the speed of 20 m/sec due to 60° north of east. The source is generating of frequency 500 Hz. Then frequency registered by observer is: [Speed of sound in still air = 330 m/sec.]

(A) 500 Hz (B) 532 Hz (C) 531 Hz (D) 530 Hz

SW0064

36. Source and observer both start moving simultaneously from origin, one along x-axis and the other along y-axis with speed of source = twice the speed of observer. The graph between the apparent frequency observed by observer f and time t would approximately be :



SW0065

37. A siren placed at a railway platform is emitting sound of frequency 5 kHz. A passenger sitting in a moving train A records a frequency of 5.5 kHz while the train approaches the siren. During his return journey in a different train B he records a frequency of 6.0 kHz while approaching the same siren. The ratio of the velocity of train B to that of train A is :-

(A) 242/252 (B) 2 (C) 5/6 (D) 11/6

SW0066

38. A police van moving with velocity 22 m/s and emitting sound of frequency 176 Hz, follows a motor cycle in turn is moving towards a stationary car and away from the police van. The stationary car is emitting frequency 165 Hz. If motorcyclist does not hear any beats then his velocity is ($v_s = 330$ m/s)

[JEE 2003 (Scr)]

(A) 22 m/s (B) 24 m/s (C) 20 m/s (D) 18 m/s

SW0067

EXERCISE (O-2)

1. Two tuning forks of frequency 250 Hz and 256 Hz produce beats. If a maximum of intensity is observed just now, after how much time the minimum is observed at the same place ?

(A) $\frac{1}{18}$ sec (B) $\frac{1}{4}$ sec. (C) $\frac{1}{3}$ sec. (D) $\frac{1}{12}$ sec.

SW0068

2. The particle displacement of a travelling longitudinal wave is represented by $S = S(x, t)$. The midpoints of a compression zone and an adjacent rarefaction zone are represented by the letter 'C' and 'R'. Which of the following is true?

(A) $|\partial S / \partial x|_C = |\partial S / \partial x|_R$
 (B) $|\partial S / \partial t|_C = |\partial S / \partial t|_R = 0$
 (C) $(\text{pressure})_C - (\text{pressure})_R = 2 |\partial S / \partial x|_C \times \text{Bulk modulus of air.}$
 (D) Particles of air are stationary mid-way between 'C' and 'R'.

SW0069

3. Which of the following statements are wrong about the velocity of sound in air:
 (A) decreases with increases in temperature (B) increases with decrease in temperature
 (C) decreases as humidity increases (D) independent of density of air.

SW0070

4. A car moves towards a hill with speed v_c . It blows a horn of frequency f which is heard by an observer following the car with speed v_o . The speed of sound in air is v .

(A) the wavelength of sound reaching the hill is $\frac{v}{f}$

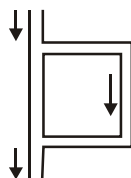
(B) the wavelength of sound reaching the hill is $\frac{v - v_c}{f}$

(C) the beat frequency observed by the observer is $\left(\frac{v + v_o}{v - v_c} \right) f$

(D) the beat frequency observed by the observer is $\frac{2v_c(v + v_o)f}{v^2 - v_c^2}$

SW0071

5. Three coherent source kept along the same line produce intensity I_0 each at point P on this line. When S_1 & S_2 are switched on simultaneously, intensity at point P is $2I_0$. When S_2 and S_3 are switched on simultaneously, intensity at point P is $2I_0$. Then
- (A) When S_1 and S_3 are switched on simultaneously, intensity at point P can be $2I_0$
 (B) When S_1 and S_3 are switched on simultaneously, intensity at point P can be 0
 (C) When all 3 sources are switched on simultaneously, intensity at point P can be I_0
 (D) When all 3 sources are switched on simultaneously, intensity at point P can be $3I_0$
6. A sound consists of four frequencies $\rightarrow$ 300 Hz, 900 Hz, 2400 Hz and 4500 Hz. A sound 'filter' is made by passing this sound through a bifurcated pipe as shown. The sound waves have to travel a distance of 50 cm more in the right branch-pipe than in the straight pipe. The speed of sound in air is 300 m/s. Then, which of the following frequencies will be almost completely muffled or "silenced" at the outlet ?



- (A) 300 Hz (B) 900 Hz (C) 2400 Hz (D) 4500 Hz

SW0073

Paragraph for Question No. 7 to 9

A metallic rod of length 1m has one end free and other end rigidly clamped. Longitudinal stationary waves are set up in the rod in such a way that there are total six antinodes present along the rod. The amplitude of an antinode is 4×10^{-6} m. Young's modulus and density of the rod are 6.4×10^{10} N/m² and 4×10^3 Kg/m³ respectively. Consider the free end to be at origin and at $t=0$ particles at free end are at positive extreme.

7. The equation describing displacements of particles about their mean positions is

- (A) $s = 4 \times 10^{-6} \cos\left(\frac{11\pi}{2}x\right) \cos(22\pi \times 10^3 t)$ (B) $s = 4 \times 10^{-6} \cos\left(\frac{11\pi}{2}x\right) \sin(22\pi \times 10^3 t)$
 (C) $s = 4 \times 10^{-6} \cos(5\pi x) \cos(20\pi \times 10^3 t)$ (D) $s = 4 \times 10^{-6} \cos(5\pi x) \sin(20\pi \times 10^3 t)$

SW0074

8. The equation describing stress developed in the rod is

(A) $140.8\pi \times 10^4 \cos\left(\frac{11}{2}\pi x + \pi\right) \cos(22\pi \times 10^3 t)$

(B) $140.8\pi \times 10^4 \sin\left(\frac{11}{2}\pi x + \pi\right) \cos(22\pi \times 10^3 t)$

(C) $128\pi \times 10^4 \cos(5\pi x + \pi) \cos(20\pi \times 10^3 t)$

(D) $128\pi \times 10^4 \sin(5\pi x + \pi) \cos(20\pi \times 10^3 t)$

SW0074

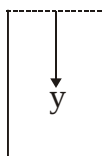
9. The magnitude of strain at midpoint of the rod at $t = 1$ sec is

(A) $11\sqrt{3}\pi \times 10^{-6}$ (B) $11\sqrt{2}\pi \times 10^{-6}$ (C) $10\sqrt{3}\pi \times 10^{-6}$ (D) $10\sqrt{2}\pi \times 10^{-6}$

SW0074

Paragraph for Question No. 10 to 12

In an organ pipe (may be closed or open) of length 1m standing wave is setup, whose equation for longitudinal displacement is given by $\xi = (0.1 \text{ mm}) \cos \frac{2\pi}{0.8}(y) \cos(400)t$ where y is measured from the top of the tube in meters and t in second.



10. The upper end and the lower ends of the tube are respectively:

(A) open – closed (B) closed – open (C) open – open (D) closed – closed

SW0075

11. The air column is vibrating in

(A) First overtone (B) Second overtone (C) Third harmonic (D) Fundamental mode

SW0075

12. Equation of the standing wave in terms of excess pressure is (Bulk modulus of air $B = 5 \times 10^5 \text{ N/m}^2$)

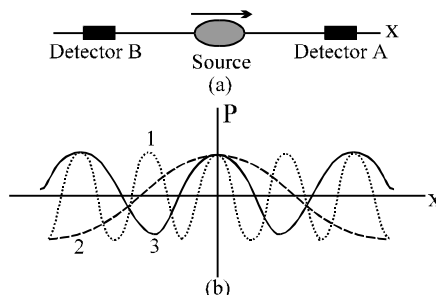
(A) $P_{\text{ex}} = (125 \pi \text{ N/m}^2) \sin \frac{2\pi}{0.8}(y) \cos(400t)$ (B) $P_{\text{ex}} = (125 \pi \text{ N/m}^2) \cos \frac{2\pi}{0.8}(y) \sin(400t)$

(C) $P_{\text{ex}} = (225 \pi \text{ N/m}^2) \sin \frac{2\pi}{0.8}(y) \cos(200t)$ (D) $P_{\text{ex}} = (225 \pi \text{ N/m}^2) \cos \frac{2\pi}{0.8}(y) \sin(200t)$

SW0075

Paragraph for Question No. 13 to 16

A source emitting a sound wave at a certain frequency moves with constant speed along an x-axis figure (a). The source moves directly towards a stationary detector A and directly away from another stationary detector B. The superimposed three plots of figure (b) indicate the pressure function $P(x)$ of the sound wave as measured by detector A, by detector B, and by someone (c) in the rest frame of the source.



13. Which of the following plot corresponds to the measurement done by detector A?
 (A) 1 (B) 2 (C) 3 (D) These plots are not possible
14. The plot corresponding to the measurement done by detector B is
 (A) 1 (B) 2 (C) 3 (D) These plots are not possible
15. The plot corresponding to the measurement done by the detector C is
 (A) 1 (B) 2 (C) 3 (D) These plots are not possible
16. Now the source stops and begins to move along y-axis with same speed, the plot which corresponds to the measurement of B now is
 (A) 1 (B) 2 (C) 3 (D) none of these

SW0076

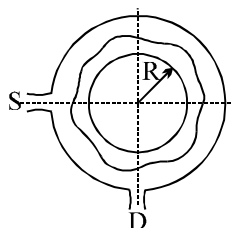
SW0076

SW0076

SW0076

Paragraph for Question No. 17 to 21

A narrow tube is bent in the form of a circle of radius R , as shown in the figure. Two small holes S and D are made in the tube at the positions right angle to each other. A source placed at S generated a wave of intensity I_0 which is equally divided into two parts : One part travels along the longer path, while the other travels along the shorter path. Both the part waves meet at the point D where a detector is placed



17. If a maxima is formed at the detector then, the magnitude of wavelength λ of the wave produced is given by :-

(A) πR (B) $\frac{\pi R}{2}$ (C) $\frac{\pi R}{4}$ (D) $\frac{2\pi R}{3}$

SW0077

18. If the minima is formed at the detector then, the magnitude of wavelength λ of the wave produced is given by :-

(A) $2\pi R$ (B) $\frac{3\pi R}{2}$ (C) $\frac{2\pi R}{3}$ (D) $\frac{2\pi R}{5}$

SW0077

19. The maximum intensity produced at D is given by :-

(A) $4I_0$ (B) $2I_0$ (C) I_0 (D) $3I_0$

SW0077

20. The maximum value of λ to produce a maxima at D is given by :-

(A) πR (B) $2\pi R$ (C) $\frac{\pi R}{2}$ (D) $\frac{3\pi R}{2}$

SW0077

21. The maximum value of λ to produce a minima at D is given by :-

(A) πR (B) $2\pi R$ (C) $\frac{\pi R}{2}$ (D) $\frac{3\pi R}{2}$

SW0077

Paragraph for Question Nos. 22 to 24

Two waves $y_1 = A \cos (0.5 \pi x - 100 \pi t)$ and $y_2 = A \cos (0.46 \pi x - 92 \pi t)$ are travelling in a pipe placed along x-axis.

[JEE 2006]

22. Find the number of times intensity is maximum in time interval of 1 sec.

(A) 4 (B) 6 (C) 8 (D) 10

SW0078

23. Find wave velocity of louder sound

(A) 100 m/s (B) 192 m/s (C) 200 m/s (D) 96 m/s

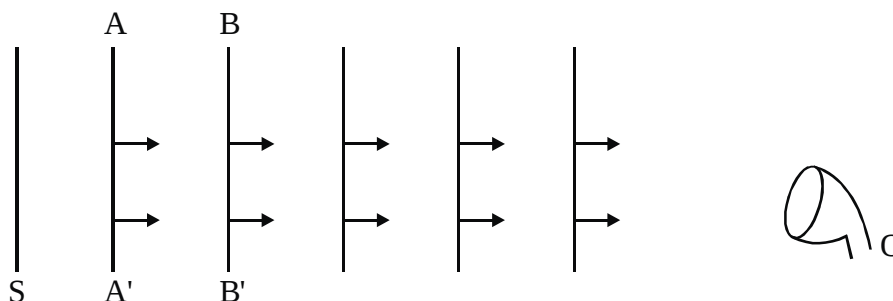
SW0078

24. At $x = 0$ how many times the value of $y_1 + y_2$ is zero in one second?

(A) 100 (B) 46 (C) 192 (D) 96

SW0078

25. Consider a large plane diaphragm 'S' emitting sound and a detector 'O'. The diagram shows plane wavefronts for the sound wave travelling in air towards right when source, observer and medium are at rest. AA' and BB' are fixed imaginary planes. Column-I describes about the motion of source, observer or medium and column-II describes various effects. Match them correctly.

**Column-I**

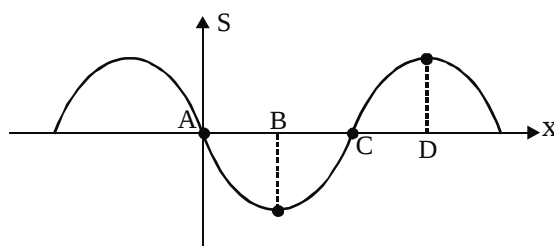
- (A) Source starts moving towards right
(B) Air starts moving towards right
(C) Observer and source both move towards left with same speed.
(D) Source and medium (air) both move towards right with same speed.

Column-II

- (P) Distance between any two wavefronts will increase.
(Q) Distance between any two wavefronts will decrease.
(R) The time needed by sound to move from plane AA' to BB' will increase.
(S) The time needed by sound to move from plane AA' to BB' will decrease.
(T) Frequency received by observer increases.

SW0079

26. Figure shows a graph of particle displacement function of x at $t = 0$ for a longitudinal wave travelling in positive x -direction in a gas. A, B, C, D denote position of particles in space.

**Column-I**

- (A) point A
(B) point B
(C) point C
(D) point D

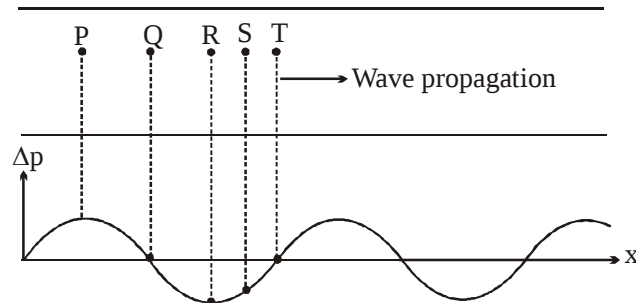
Column II

- (P) Particle velocity is in direction of wave propagation
(Q) Maximum magnitude of strain
(R) Excess pressure is zero
(S) Maximum density
(T) Maximum magnitude of excess pressure

SW0080

27. Sound is travelling in a long tube towards right and the graph of excess pressure variation versus position (at some instant) is given below.

Match velocities in column-I with column-II. P,Q,R,S,T are medium particles inside the tube.



Column-I

- (A) velocity is towards right
- (B) velocity is towards left
- (C) velocity is zero
- (D) Speed is maximum

Column-II

- (P) P
- (Q) Q
- (R) R
- (S) S
- (T) T

SW0081

EXERCISE - JM

1. **Statement-1:** Two longitudinal waves given by equations : $y_1(x, t) = 2a \sin(\omega t - kx)$ and $y_2(x, t) = a \sin(2\omega t - 2kx)$ will have equal intensity.

Statement-1: Intensity of waves of given frequency in same medium is proportional to square of amplitude only. [AIEEE - 2011]

- (1) Statement-1 is false, statement-2 is true
 (2) Statement-1 is true, statement-2 is false
 (3) Statement-1 is true, statement-2 true; statement-2 is the correct explanation of statement-1
 (4) Statement-1 is true, statement-2 is true; statement-2 is not correct explanation of statement-1.

SW0082

2. A pipe of length 85 cm is closed from one end. Find the number of possible natural oscillations of air column in the pipe whose frequencies lie below 1250 Hz. The velocity of sound in air is 340 m/s. [JEE Main - 2014]

- (1) 6 (2) 4 (3) 12 (4) 8

SW0083

3. A train is moving on a straight track with speed 20 ms^{-1} . It is blowing its whistle at the frequency of 1000 Hz. The percentage change in the frequency heard by a person standing near the track as the train passes him is (speed of sound = 320 ms^{-1}) close to :- [JEE Main - 2015]

- (1) 18% (2) 24% (3) 6% (4) 12%

SW0084

4. A pipe open at both ends has a fundamental frequency f in air. The pipe is dipped vertically in water so that half of it is in water. The fundamental frequency of the air column is now :-

[JEE-Main-2016]

- (1) f (2) $\frac{f}{2}$ (3) $\frac{3f}{4}$ (4) $2f$

SW0085

5. An observer is moving with half the speed of light towards a stationary microwave source emitting waves at frequency 10 GHz. What is the frequency of the microwave measured by the observer?

(speed of light = $3 \times 10^8 \text{ ms}^{-1}$)

[JEE Main - 2017]

- (1) 17.3 GHz (2) 15.3 GHz (3) 10.1 GHz (4) 12.1 GHz

SW0086

EXERCISE (JA)

1. When two progressive waves $y_1 = 4 \sin(2x - 6t)$ and $y_2 = 3 \sin\left(2x - 6t - \frac{\pi}{2}\right)$ are superimposed, the

amplitude of the resultant wave is

[IIT-JEE 2010]

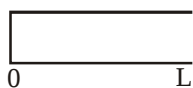
SW0087

2. **Column I** shows four systems, each of the same length L , for producing standing waves. The lowest possible natural frequency of a system is called its fundamental frequency, whose wavelength is denoted as λ_f . Match each system with statements given in **Column II** describing the nature and wavelength of the standing waves.

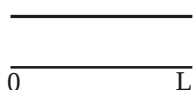
[IIT-JEE 2011]

Column I

- (A) Pipe closed at one end



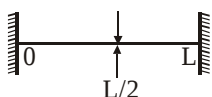
- (B) Pipe open at both ends



- (C) Stretched wire clamped at both ends



- (D) Stretched wire clamped at both ends and at mid-point



Column II

- (p) Longitudinal waves

- (q) Transverse Waves

- (r) $\lambda_f = L$

- (s) $\lambda_f = 2L$

- (t) $\lambda_f = 4L$

SW0088

3. A police car with a siren of frequency 8 kHz is moving with uniform velocity 36 km/hr towards a tall building which reflects the sound waves. The speed of sound in air is 320 m/s. The frequency of the siren heard by the car driver is [JEE 2011]

(A) 8.50 kHz (B) 8.25 kHz (C) 7.75 kHz (D) 7.50 kHz

SW0089

4. A person blows into open-end of a long pipe. As a result, a high-pressure pulse of air travels down the pipe. When this pulse reaches the other end of the pipe. [JEE 2012]

(A) a high-pressure pulse starts travelling up the pipe, if the other end of the pipe is open
 (B) a low -pressure pulse starts travelling up the pipe, if the other end of the pipe is open
 (C) a low pressure pulse starts travelling up the pipe, if the other end of the pipe is closed
 (D) a high-pressure pulse starts travelling up the pipe, if the other end of the pipe is closed

SW0090

5. A student is performing the experiment of Resonance Column. The diameter of the column tube is 4cm. The frequency of the tuning fork is 512 Hz. The air temperature is 38°C in which the speed of sound is 336 m/s. The zero of the meter scale coincides with the top end of the Resonance column tube. When the first resonance occurs, the reading of the water level in the column is :-

[JEE 2012]

(A) 14.0 cm (B) 15.2 cm (C) 16.4 cm (D) 17.6 cm

SW0091

6. A student is performing an experiment using a resonance column and a tuning fork of frequency 244 s^{-1} . He is told that the air in the tube has been replaced by another gas (assume that the column remains filled with the gas). If the minimum height at which resonance occurs is $(0.350 \pm 0.005) \text{ m}$, the gas in the tube is

(Useful information : $\sqrt{167RT} = 640 \text{ J}^{1/2} \text{ mole}^{-1/2}$; $\sqrt{140RT} = 590 \text{ J}^{1/2} \text{ mole}^{-1/2}$. The molar masses

M in grams are given in the options. Take the values of $\sqrt{\frac{10}{M}}$ for each gas as given there.)

[JEE Advanced-2014]

(A) Neon $\left(M = 20, \sqrt{\frac{10}{20}} = \frac{7}{10} \right)$

(B) Nitrogen $\left(M = 28, \sqrt{\frac{10}{28}} = \frac{3}{5} \right)$

(C) Oxygen $\left(M = 32, \sqrt{\frac{10}{32}} = \frac{9}{16} \right)$

(D) Argon $\left(M = 36, \sqrt{\frac{10}{36}} = \frac{17}{32} \right)$

SW0092

7. Four harmonic waves of equal frequencies and equal intensities I_0 have phase angles $0, \pi/3, 2\pi/3$ and π . When they are superposed, the intensity of the resulting wave is nI_0 . The value of n is.

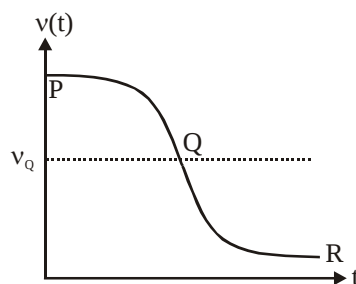
[JEE-Advance-2015]

SW0093

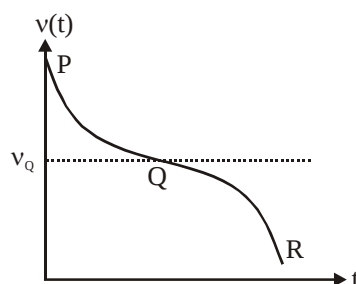
8. Two loudspeakers M and N are located 20m apart and emit sound at frequencies 118 Hz and 121 Hz, respectively. A car is initially at a point P, 1800 m away from the midpoint Q of the line MN and moves towards Q constantly at 60 km/hr along the perpendicular bisector of MN. It crosses Q and eventually reaches a point R, 1800 m away from Q. Let $v(t)$ represent the beat frequency measured by a person sitting in the car at time t . Let v_P, v_Q and v_R be the beat frequencies measured at locations P, Q and R, respectively. The speed of sound in air is 330 ms^{-1} . Which of the following statement(s) is(are) true regarding the sound heard by the person ?

[JEE Advanced 2016]

- (A) The plot below represents schematically the variation of beat frequency with time



- (B) The plot below represents schematically the variations of beat frequency with time



- (C) The rate of change in beat frequency is maximum when the car passes through Q

(D) $v_P + v_R = 2v_Q$

SW0094

9. A stationary source emits sound of frequency $f_0 = 492 \text{ Hz}$. The sound is reflected by a large car approaching the source with a speed of 2 ms^{-1} . The reflected signal is received by the source and superposed with the original. What will be the beat frequency of the resulting signal in Hz ? (Given that the speed of sound in air is 330 ms^{-1} and the car reflects the sound at the frequency it has received).

[JEE Advanced 2017]

SW0095

10. Two men are walking along a horizontal straight line in the same direction. The man in front walks at a speed 1.0 ms^{-1} and the man behind walks at a speed 2.0 ms^{-1} . A third man is standing at a height 12 m above the same horizontal line such that all three men are in a vertical plane. The two walking men are blowing identical whistles which emit a sound of frequency 1430 Hz . The speed of sound in air is 330 ms^{-1} . At the instant, when the moving men are 10 m apart, the stationary man is equidistant from them. The frequency of beats in Hz , heard by the stationary man at this instant, is _____

[JEE Advanced 2018]

SW0096

11. In an experiment to measure the speed of sound by a resonating air column, a tuning fork of frequency 500 Hz is used. The length of the air column is varied by changing the level of water in the resonance tube. Two successive resonances are heard at air columns of length 50.7 cm and 83.9 cm . Which of the following statements is (are) true ?

[JEE Advanced 2018]

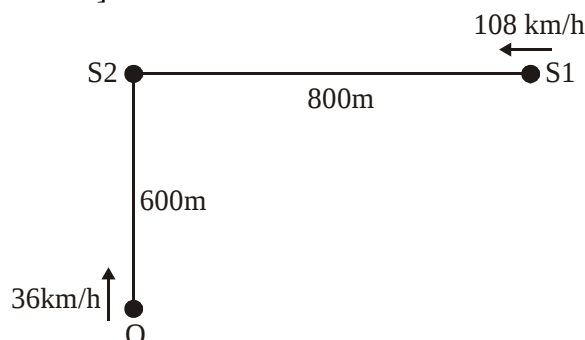
- (A) The speed of sound determined from this experiment is 332 ms^{-1}
 (B) The end correction in this experiment is 0.9 cm
 (C) The wavelength of the sound wave is 66.4 cm
 (D) The resonance at 50.7 cm corresponds to the fundamental harmonic

SW0097

12. A train S_1 , moving with a uniform velocity of 108 km/h , approaches another train S_2 standing on a platform. An observer O moves with a uniform velocity of 36 km/h towards S_2 , as shown in figure. Both the trains are blowing whistles of same frequency 120 Hz . When O is 600 m away from S_2 and distance between S_1 and S_2 is 800 m , the number of beats heard by O is _____.

[Speed of the sound = 330 m/s]

[JEE Advanced 2019]



SW0098

ANSWER KEY

EXERCISE (S-1)

1. **Ans.** $\frac{\pi^2 \times 10^{-9}}{4} \text{ W/m}^2$ 2. **Ans.** $2c/3$ 3. **Ans.** 30 dB, $10\sqrt{10} \text{ } \mu\text{m}$
 4. **Ans.** 1 : 1 5. **Ans.** 3 cm 6. **Ans.** 336 m/s
 7. **Ans.** 33 cm and 13.2 cm 8. **Ans.** 2.5 kHz, 7.5 kHz 9. **Ans.** (a) 2.116, (b) $\frac{3}{4}$
 10. **Ans.** 3.33 cm, 163 Hz 11. **Ans.** 1% 12. **Ans.** 345, 341 or 349 Hz
 13. **Ans.** 8 14. **Ans.** 1.5 m/s 15. **Ans.** 5
 16. **Ans.** $11f/9$
 17. **Ans.** (a) $\left(\frac{v + \lambda_0 f_0}{\lambda_0}\right)t$ (b) $(\lambda_0 f_0 - v)t$ (c) $\lambda_0 \left(\frac{\lambda_0 f_0 - v}{\lambda_0 f_0 + v}\right)$ (d) $f_0 \left(\frac{\lambda_0 f_0 + v}{\lambda_0 f_0 - v}\right)$ (e) $\frac{2vf_0}{\lambda_0 f_0 - v}$
 18. **Ans.** 6 Hz

EXERCISE (S-2)

1. **Ans.** (a) 100696 Hz (b) 103038 Hz
 2. **Ans.** (i) $L = \frac{15}{16} \text{ m}$, (ii) $\frac{\Delta P_0}{\sqrt{2}}$, (iii) $P_{\max} = P_{\min} = P_0$ (iv) $P_{\max} = P_0 + \Delta P_0$, $P_{\min} = P_0 - \Delta P_0$
 3. **Ans.** f 4. **Ans.** 27.04 N 5. **Ans.** (i) 599 Hz, (ii) 0.935 km, 620 Hz
 6. **Ans.** 438.7 Hz, 257.3 Hz 7. **Ans.** (i) 10^{-3} sec , (ii) $2 \times 10^{-3} \text{ sec}$
 8. **Ans.** 0.75 m/s
 9. **Ans.** (a) $\frac{2\pi}{a}, \frac{b}{2\pi}$, (b) $y = -0.8 A \cos(ax - bt)$ **OR** $y = 0.8 A \cos(ax - bt)$, (c) 1.8 Ab, 0
 (d) $y = -1.6 A \sin ax \sin bt + 0.2 A \cos(ax + bt)$, $\left[n + \frac{(-1)^2}{2}\right] \frac{\pi}{a}$, -X direction **OR**
 $y = 0.2 A \cos(ax + bt) + 1.6 A \cos ax \cos bt$, $x = \frac{n\pi}{a}$, -X direction
 10. **Ans.** (a) $\frac{15}{16} \text{ m}$ (b) $\frac{\Delta P_0}{\sqrt{2}}$ (c) equal to mean pressure (d) $P_0 + \Delta P_0$, $P_0 - \Delta P_0$
 11. **Ans.** $\frac{-dH}{dt} = (1.11 \times 10^{-2})\sqrt{H}$, 43 sec.

EXERCISE (O-1)

- | | | | | | |
|--------------|--------------|--------------|--------------|--------------|--------------|
| 1. Ans. (B) | 2. Ans. (A) | 3. Ans. (B) | 4. Ans. (B) | 5. Ans. (A) | 6. Ans. (A) |
| 7. Ans. (B) | 8. Ans. (D) | 9. Ans. (A) | 10. Ans. (D) | 11. Ans. (D) | 12. Ans. (B) |
| 13. Ans. (C) | 14. Ans. (B) | 15. Ans. (C) | 16. Ans. (B) | 17. Ans. (D) | 18. Ans. (A) |
| 19. Ans. (C) | 20. Ans. (C) | 21. Ans. (A) | 22. Ans. (A) | 23. Ans. (B) | 24. Ans. (A) |
| 25. Ans. (B) | 26. Ans. (B) | 27. Ans. (A) | 28. Ans. (A) | 29. Ans. (A) | 30. Ans. (A) |
| 31. Ans. (B) | 32. Ans. (A) | 33. Ans. (A) | 34. Ans. (A) | 35. Ans. (C) | 36. Ans. (B) |
| 37. Ans. (B) | 38. Ans. (A) | | | | |

EXERCISE (O-2)

- | | | | |
|---|-------------------|-------------------|---------------|
| 1. Ans. (B,D) | 2. Ans. (A,C,D) | 3. Ans. (A,B,C,D) | 4. Ans. (B,D) |
| 5. Ans. (B, C) | 6. Ans. (A, B, D) | 7. Ans. (A) | 8. Ans. (B) |
| 9. Ans. (B) | 10. Ans. (A) | 11. Ans. (B) | 12. Ans. (A) |
| 13. Ans. (A) | 14. Ans. (B) | 15. Ans. (C) | 16. Ans. (D) |
| 17. Ans. (A,B,C) | 18. Ans. (A,C,D) | 19. Ans. (B) | 20. Ans. (A) |
| 21. Ans. (B) | 22. Ans. (A) | 23. Ans. (C) | 24. Ans. (A) |
| 25. Ans. (A) (Q,T) ; (B) (P,S) ; (C) (P) (D) (S,T) | | | |
| 26. Ans. (A) (P,Q,S,T); (B) (R); (C) (Q,T); (D) (R) | | | |
| 27. Ans. (A) (P); (B) (R,S); (C) (Q,T); (D) (P,R) | | | |

EXERCISE (JM)

- | | | | | |
|-------------|-------------|-------------|-------------|-------------|
| 1. Ans. (4) | 2. Ans. (1) | 3. Ans. (4) | 4. Ans. (1) | 5. Ans. (1) |
|-------------|-------------|-------------|-------------|-------------|

EXERCISE (JA)

- | | | |
|-------------------------|---|-------------------------|
| 1. Ans. 5 | 2. Ans. (A) p,t (B) p,s (C) q,s (D) q,r | 3. Ans. (A) |
| 4. Ans. (B,D) | 5. Ans. (B) | 6. Ans. (D) |
| 8. Ans. (A, C, D) | 9. Ans. 6 | 10. Ans. 5 [4.99, 5.01] |
| 12. Ans. (8.12 to 8.13) | | 11. Ans. (A,B,C) |