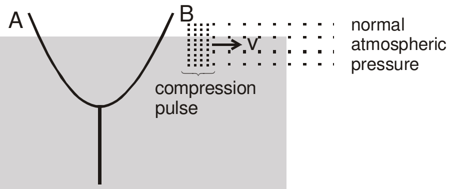
SOUND WAVES

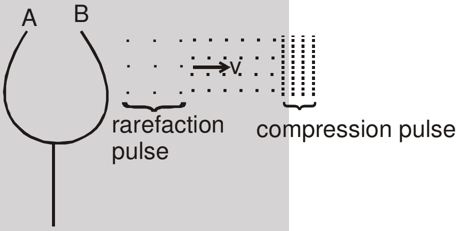
1. PROPAGATION OF SOUND WAVES :

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. Being a mechanical wave, sound needs a medium having properties of inertia and elasticity for its propagation. Sound waves propagate in any medium through a series of periodic compressions and rarefactions of pressure, which is produced by the vibrating source.
Consider a tuning fork producing sound waves.

When Prong B moves outward towards right it compresses the air in front of it, causing the pressure to rise slightly. The region of increased pressure is called a compression pulse and it travels away from the prong with the speed of sound.



After producing the compression pulse, the prong B reverses its motion and moves inward. This drags away some air from the region in front of it, causing the pressure to dip slightly below the normal pressure. This region of decreased pressure is called a rarefaction pulse. Following immediately behind the compression pulse, the rarefaction pulse also travels away from the prong with the speed of sound.



If the prongs vibrate in SHM, the pressure variations in the layer close to the prong also varies simple harmonically and hence increase in pressure above normal value can be written as

$$\delta P = \delta P_0 \sin \omega t$$

where δP_0 is the maximum increase in pressure above normal value.
As this disturbance travel towards right with wave velocity v, the excess pressure at any position x at time t will be given by

$$\delta P = \delta P_0 \sin \omega(t - x/v) \qquad (1.1)$$

Using $p = \delta P$, $p_0 = \delta P_0$, the above equation of sound wave can b written as :

$$p = p_0 \sin \omega(t - x/v) \qquad (1.2)$$

Solved Example

Example 1. Find the following for given wave equation.
P = 0.02 sin [(3000 t – 9 x] (all quantities are in S.I. units.)
(a) Frequency (b) Wavelength (c) Speed of sound wave
(d) If the equilibrium pressure of air is in 10^5 Pa then find maximum and minimum pressure.

Solution : (a) Comparing with the standard form of a travelling wave

$$p = p_0 \sin [\omega (t - x/v)]$$

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

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

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

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

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

(b) The pressure amplitude is $p_0 = 0.02\ N/m^2$. Hence, the maximum and minimum pressures at a point in the wave motion will be $(1.0 \times 10^5 \pm 0.02)\ N/m^2$.

2. FREQUENCY AND PITCH OF SOUND WAVES

FREQUENCY :

Each cycle of a sound wave includes one compression and one rarefaction, and frequency is the number of cycles per second that passes by a given location. This is normally equal to the frequency of vibration of the (tuning fork) source producing sound. If the source, vibrates in SHM of a single frequency, sound produced has a single frequency and it is called a pure tone.

However a sound source may not always vibrate in SHM (this is the case with most of the common sound sources e.g. guitar string, human vocal card, surface of drum etc.) and hence the pulse generated by it may not have the shape of a sine wave. But even such a pulse may be considered to be obtained by superposition of a large number of sine waves of different frequency and amplitudes. We say that the pulse contain all these frequencies.

AUDIBLE FREQUENCY RANGE FOR HUMAN :

A normal person hears all frequencies between 20 & 20 KHz. This is a subjective range (obtained experimentally) which may vary slightly from person to person. The ability to hear the high frequencies decreases with age and a middle-age person can hear only upto 12 to 14 KHz.

INFRASONIC SOUND :

Sound can be generated with frequency below 20 Hz called **infrasonic sound.**

ULTRASONIC SOUND :

Sound can be generated with frequency above 20 kHz called **ultrasonic sound.**

Even through humans cannot hear these frequencies, other animals may. For instance Rhinos communicate through infrasonic frequencies as low as 5Hz, and bats use ultrasonic frequencies as high as 100 KHz for navigating.

PITCH :

Frequency as we have discussed till now is an objective property measured its units is 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

Solved Example

Example 2. A wave of wavelength 4 mm is produced in air and it travels at a speed of 300 m/s. Will it be audible ?

Solution : From the relation v = $\nu\lambda$, the frequency of the wave is

$$\nu = \frac{v}{\lambda} = \frac{300\ \text{m/s}}{4\times10^{-3}\text{m}} = 75000\ \text{Hz}.$$

This is much above the audible range. It is an ultrasonic wave and will not be audible to humans, but it will be audible to bats.

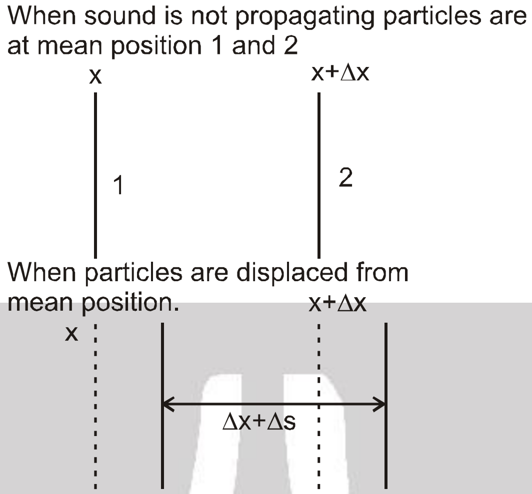
3. PRESSURE WAVE AND DISPLACEMENT WAVE :

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 w.r.t. mean position.

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,

$s = s_0 \sin (\omega t - kx)$ .....(3.1)



Change in volume = $\Delta V = (\Delta x + \Delta s)A - \Delta xA = \Delta sA$

$$\frac{\Delta V}{V} = \frac{\Delta sA}{\Delta xA} = \frac{\Delta s}{\Delta x}$$

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

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

$$dp = -\frac{Bds}{dx}$$

$dp = -B\,(-k\,s_0)\cos(\omega t - kx)$

$dp = Bks_0 \cos(\omega t - kx)$

$dp = (dp)_{max} \cos(\omega t - kx)$

$p = p_0 \sin(\omega t - kx + \pi/2)$ .....(3.2)

where $p = dp$ = variation in pressure at position x and

$p_0 = Bks_0$ = maximum pressure variation

Equation 3.2 represents that same sound wave where, P is excess pressure at position x, over and above the average atmospheric pressure

and pressure amplitude p_0 is given by $p_0 = BKs_0$ .....(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.

Solved Examples

Example 3. A sound wave of wavelength 40 cm travels in air. If the difference between the maximum and minimum pressures at a given point is 2.0×10^{-3} N/m^2, find the amplitude of vibration of the particles of the medium. The bulk modulus of air is 1.4×10^5 N/m^2.

Solution : The pressure amplitude is $p_0 = \frac{2.0 \times 10^{-3} N/m^2}{2} = 10^{-3}$ N/m^2.

The displacement amplitude s_0 is given by $p_0 = B\,k\,s_0$

or, $s_0 = \frac{p_0}{B\ k} = \frac{p_0 \lambda}{2\ \pi\ B} = \frac{10^{-3} N/m^2 \times (40 \times 10^{-2} m)}{2 \times \pi \times 14 \times 10^4 N/m^2} = \frac{100}{7\pi}$ Å = 4.54 Å

4. SPEED OF SOUND WAVES

4.1 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.

4.2. Velocity of sound waves 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 = constant

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

and hence B = P using equ. ...(4.3)

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

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

the density of air at 0º and pressure 76 cm of Hg column is ρ = 1.293 kg/m^3. This temperature and pressure is called standard temperature and pressure at STP. Speed of sound in air is 280 m/s. This value is some what less than measured speed of sound in air 332 m/s then Laplace suggested the correction.

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

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

4.3 Factors affecting speed of sound in atmosphere.

(a) Effect of temperature : as temperature (T) increases velocity (v) increases.

$$v \propto \sqrt{T}$$

For small change in temperature above room temperature v increases linearly by 0.6 m/s for every 1°C rise in temp.

$$v = \sqrt{\frac{\gamma R}{M}} \times T^{1/2} \;;\quad \frac{\Delta v}{v} = \frac{1}{2}\frac{\Delta T}{T} \;;\quad \Delta v = \left(\frac{1}{2}\frac{v}{T}\right)\Delta T$$

$$\Delta v = (0.6)\Delta T$$

(b) 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.

(c) 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.

Solved Example

Example 4. Find the speed of sound in H_2 at temperature T, if the speed of sound in O_2 is 450 m/s at this temperature.

Solution : $v = \sqrt{\frac{\gamma RT}{M}}$

Since temperature, T is constant,

$$\frac{v_{(H_2)}}{v_{(O_2)}} = \sqrt{\frac{M_{O_2}}{M_{H_2}}} = \sqrt{\frac{32}{2}} = 4$$

v (H_2) = 4 × 450 = 1800 m/s **Ans.**

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

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

or, $v_{(hydrogen)} = 4v_{(oxygen)} = 4 \times 450$ m/s = 1800 m/s. **Ans.**

5. INTENSITY OF 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 do work, for example, forcing the eardrums to vibrate or in the extreme case of a sonic boom created by a supersonic jet, can even cause glass panes of windows to crack.

The amount of energy carried per unit time by a wave is called its power and power per unit area held perpendicular to the direction of energy flow is called intensity.

For a sound wave travelling along positive x-axis described by the equation.

$$s = s_0 \sin(\omega t - kx + \phi)$$

$$p = p_0 \cos(\omega t - kx + \phi)$$

$$\frac{\delta s}{\delta t} = \omega s_0 \cos(\omega t - kx + \phi)$$

Instantaneous power $P = F.v = pA\frac{\delta s}{\delta t}$

$$P = p_0 \cos(\omega t - kx + \phi)\, A\omega s_0 \cos(\omega t - kx + \phi)$$

$$P_{average} = \langle P\rangle = p_0 A\omega s_0 \langle \cos^2(\omega t - kx + \phi)\rangle = \frac{p_0 \omega s_0 A}{2} \Rightarrow v = \sqrt{\frac{B}{\rho}}$$

$$B = \rho v^2 \Rightarrow p_0 = Bks_0 = \rho v^2 ks_0$$

$$P_{average} = \frac{1}{2}\omega p_0 A\left(\frac{p_0}{\rho v^2 k}\right) = \frac{p_0^2 A}{2\rho v} = \frac{pAv\omega^2 s_0^2}{2}$$

maximum power = $P_{max} = \frac{p_0^2 A}{\rho v}$ = (pA) v $v^2_{p,\,max}$ = pAv$\omega^2 s_0^2$

Total energy transfer = $P_{av} \times t = \frac{\rho A v \omega^2 s_0^2}{2} \times t$

Average intensity = average power / area

the average intensity at position x is given by

$$< I > = \frac{1}{2}\ \frac{\omega^2 s_0^2 B}{v} = \frac{P_0^2 v}{2B} \qquad .....(5.1)$$

Substituting B = ρv^2, intensity can also be expressed as

$$I = \frac{P_0^2}{2\rho v} \qquad .....(5.2)$$

Note :

☞ If the source is a point source then $I \propto \frac{1}{r^2}$ and $s_0 \propto \frac{1}{r}$ and $s = \frac{a}{r}\sin(\omega t - kr + \theta)$

☞ If a sound source is a line source then $I \propto \frac{1}{r}$ and $s_0 \propto \frac{1}{\sqrt{r}}$ and

$$s = \frac{a}{\sqrt{r}}\sin(\omega t - kr + \theta)$$

Solved Example

Example 5. The pressure amplitude in a sound wave from a radio receiver is 2.0 × 10^{-3} 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 3 × 10^{-3} N/m^2, evaluate the intensity.

Solution : The intensity is proportional to the square of the pressure amplitude.

Thus, $\frac{I'}{I} = \left(\frac{p'_0}{p_0}\right)^2$

or $I' = \left(\frac{p'_0}{p_0}\right)^2 I = \left(\frac{3}{2.0}\right)^2 \times 10^{-6}$ W/m^2 = 2.25 × 10^{-6} W/m^2.

Example 6. A circular plate of area 0.4 cm^2 is kept at distance of 2m from source of power π W. Find the amount of energy received by plate in 5 secs.

Solution : The energy emitted by the speaker in one second is π J. Let us consider a sphere of radius 2.0 m centered at the speaker. The energy π J falls normally on the total surface of this sphere in one second. The energy falling on the area 0.4 cm^2 of the microphone in one second

$$= \frac{0.4 \times 10^{-4}}{4\ \pi\ 2^2} \times \pi = 2.5 \times 10^{-6}\ \text{J}$$

The energy falling on the microphone in 5.0 sec is 2.5 × 10^{-6} J × 5 = 12.5 μJ.

Example 7. Find the displacement amplitude of particles of air of density 1.2 kg/m^3, if intensity, frequency and speed of sound are 8 × 10^{-6} w/m^2, 5000 Hz and 330 m/s respectively.

Solution : The relation between the intensity of sound and the displacement amplitude is

$$I = \frac{P_0^2}{2\rho v}, \quad P_0 = \sqrt{2\rho v I}$$

$$s_0 = \frac{P_0}{Bk} = \frac{\sqrt{2\rho v I}}{\rho v^2 2\pi f}\ v = \sqrt{\frac{I}{\rho v 2}}\ \frac{1}{\pi f}$$

or, s_0 = 6.4 nm.

6. LOUDNESS :

Audible intensity range for humans :

The ability of human to perceive intensity at different frequency is different. The perception of intensity is maximum at 1000 Hz and perception of intensity decreases as the frequency decreases or increases from 1000 Hz.

- For a 1000 Hz tone, the smallest sound intensity that a human ear can detect is 10^{-12} watt./m^2. On the other hand, continuous exposure to intensities above 1W/m^2 can result in permanent hearing loss.
- The overall perception of intensity of sound to human ear is called **loudness**.
- Human ear do not perceives loudness on a linear intensity scale rather it perceives loudness on logarithmic intensity scale.
  For example ;
  If intensity is increased 10 times human ear does not perceive 10 times increase in loudness. It roughly perceived that loudness is doubled where intensity increased by 10 times. Hence it is prudent to define a logarithmic scale for intensity.

DECIBEL SCALE :

The logarithmic scale which is used for comparing two sound intensity is called **decibel scale**.

The intensity level β described in terms of decibels is defined as $\beta = 10 \log \left(\frac{I}{I_0}\right)$ (dB)

Here I_0 is the threshold intensity of hearing for human ear

i.e. $I = 10^{-12}$ watt/m^2.

- In terms of decibel threshold of human hearing is 1 dB
- Note that intensity level β is a dimensionless quantity and is not same as intensity expressed in W/m^2.

Solved Example

Example 8. If the intensity is increased by a factor of 20, by how many decibels is the intensity level increased.

Solution : Let the initial intensity be I and the intensity level be β_1 and when the intensity is increased by 20 times, the intensity level increases to β_2.

Then $\beta_1 = 10 \log (I / I_0)$

and $\beta_2 = 10 \log (20I / I_0)$

Thus, $\beta_2 - \beta_1 = 10 \log (20I / I)$

$= 10 \log 20 = 13$ dB.

Example 9. How many times the pressure amplitude is increased, if sound level is increased by 40 dB.

Solution : The sound level in dB is $\beta = 10 \log_{10} \left(\frac{I}{I_0}\right)$.

If β_1 and β_2 are the sound levels and I_1 and I_2 are the intensities in the two cases,

$$\beta_2 - \beta_1 = 10 \left[\log_{10}\left(\frac{I_2}{I_0}\right) - \log_{10}\left(\frac{I_1}{I_0}\right)\right]$$

or, $40 = 10 \log_{10} \left(\frac{I_2}{I_1}\right)$ or, $\frac{I_2}{I_1} = 10^4$.

As the intensity is proportional to the square of the pressure amplitude,

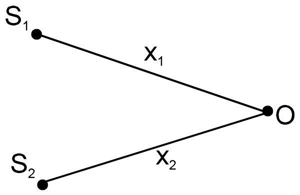
we have $\frac{p_{02}}{p_{01}} = \sqrt{\frac{I_2}{I_1}} = \sqrt{10000} = 100$.

7. INTERFERENCE OF SOUND WAVES :

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

and $p_2 = p_{m2} \sin(\omega t - kx_2 + \theta_2)$

resultant excess pressure at point O is



$p = p_1 + p_2$

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

where, $p_0 = \sqrt{p_{m_1}^2 + p_{m_2}^2 + 2p_{m_1}p_{m_2}\cos\phi}$, $\phi = \left| k(x_1 - x_2) + (\theta_2 - \theta_1) \right|$ ...(7.1)

(i) For constructive interference

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

(ii) For destructive interference

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

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)

$$P_0^2 = P_{m_1}^2 + P_{m_2}^2 + 2P_{m_1}P_{m_2}\cos\phi$$

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

we have, for resultant intensity, $I = I_1 + I_2 + 2\sqrt{I_1 I_2}\cos\phi$ ....(7.2)

If $I_1 = I_2 = I_0$

$I = 2I_0(1 + \cos\phi) \Rightarrow I = 4I_0\cos^2\frac{\phi}{2}$ ....(7.3)

Hence in this case,

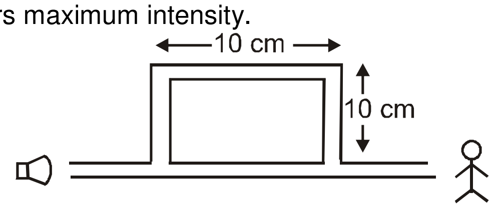
for constructive interference : $\phi = 0, 2\pi, 4\pi....$ and $I_{max} = 4I_0$

and for destructive interference : $\phi = \pi, 3\pi...$ and $I_{min} = 0$

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.

Solved Example

Example 10. Figure shows a tube having sound source at one end and observer at other end. Source produces frequencies upto 10000 Hz. Speed of sound is 400 m/s. Find the frequencies at which person hears maximum intensity.



Solution : The sound wave bifurcates at the junction of the straight and the rectangular parts. The wave through the straight part travels a distance p_1 = 10 cm and the wave through the rectangular part travels a distance $p_2 = 3 \times 10$ cm = 30 cm before they meet again and travel to the receiver. The path difference between the two waves received is, therefore.

$\Delta p = p_2 - p_1$ = 30 cm – 10 cm = 20 cm

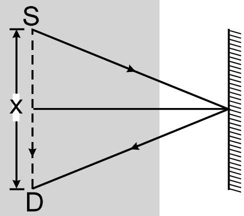
The wavelength of either wave is $\frac{v}{\upsilon} = \frac{400\,m/s}{\upsilon}$. For constructive interference, $\Delta p = n\lambda$, where n is an integer.

or, $\Delta p = n.\frac{v}{\nu} \Rightarrow \nu = \frac{n.v}{\Delta p} \Rightarrow \nu = \frac{400}{0.1} = 4000\, n$

Thus, the frequencies within the specified range which cause maximum of intensity are
4000 × 1 Hz, 4000 × 2 Hz

Example 11. A source emitting sound of frequency 165 Hz is placed in front of a wall at a distance of 2 m from it. A detector is also placed in front of the wall at the same distance from it. Find the distance between the source and the detector for which the detector detects phase difference of 2π between the direct and reflected wave. Speed of sound in air = 330 m/s.

Solution : The situation is shown in figure. Suppose the detector is placed at a distance of x meter from the source. The direct wave received from the source travels a distance of x meter. The wave reaching the detector after reflection from the wall has travelled a distance of $2[(2)^2 + x^2/4]^{1/2}$ meter. The path difference between the two waves is



$$\Delta = \left\{2\left[(2)^2 + \frac{x^2}{4}\right]^{1/2} - x\right\} \text{ meter.}$$

$\Delta = \lambda$ for $\Delta\phi = 2\pi$ ....(i)

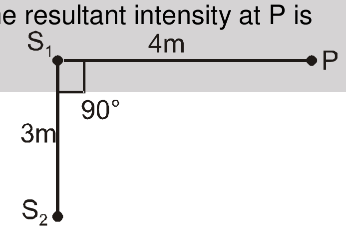
The wavelength is $\lambda = \frac{\upsilon}{v} = \frac{330\,m/s}{165\,s^{-1}} = 2$ m.

Thus, by (i) $2\left[(2)^2 + \frac{x^2}{4}\right]^{1/2} - x = 2$

or, $\left[4 + \frac{x^2}{4}\right]^{1/2} = 1 + \frac{x}{2}$ or, $4 + \frac{x^2}{4} = 1 + \frac{x^2}{4} + x$ or, $x = 3$

Thus, the detector should be placed at a distance of 3 m from the source. Note that there is no abrupt phase change.

Example 12. S_1 and S_2 are two coherent sources of sound of frequency 110Hz each. They have no initial phase difference. The intensity at a point P due to S_1 is I_0 and due to S_2 is $4I_0$. If the velocity of sound is 330 m/s then the resultant intensity at P is



(A) I_0 (B) $9I_0$ (C*) $3I_0$ (D) $8I_0$

Answer : **(C)**

Solution : The wavelength of sound source = $\frac{330}{110}$ = 3 metre.

The phase difference betwen interfering waves at P is

$= \Delta\phi = \frac{2\pi}{\lambda}(S_2P - S_1P) = \frac{2\pi}{3}(5-4) = \frac{2\pi}{3}$

$\therefore$ Resultant intensity at P = $I_0 + 4I_0 + 2\sqrt{I_0}\sqrt{4I_0}\cos\frac{2\pi}{3} = 3I_0$

8. REFLECTION OF SOUND WAVES :

Reflection of sound waves for displacement from a rigid boundary (e.g. closed end of an organ pipe) is analogous to reflection of a string wave from rigid boundary; reflection accompanied by an inversion i.e. an abrupt phase change of π. This is consistent with the requirement of displacement amplitude to remain zero at the rigid end, since a medium particle at the rigid end can not vibrate. As the excess pressure and displacement corresponding to the same sound wave vary by $\pi/2$ in term of phase, a displacement minima at the rigid end will be a point of pressure maxima. This implies that the reflected pressure wave from the rigid boundary will have same phase as the incident wave, i.e., a compression pulse is reflected as a compression pulse and a rarefaction pulse is reflected as a rarefaction pulse.

On the other hand, reflection of sound wave for displacement from a low pressure region (like open end of an organ pipe) is analogous to reflection of string wave from a free end. This point corresponds to a displacement maxima, so that the incident & reflected displacement wave at this point must be in phase. This would imply that this point would be a minima for pressure wave (i.e. pressure at this point remains at its average value), and hence the reflected pressure wave would be out of phase by π with respect to the incident wave. i.e. a compression pulse is reflected as a rarefaction pulse and vice-versa.

9. 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 waves are given by

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

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

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

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

$$\Rightarrow \quad p = p'_0 \sin\left(\omega t + \frac{\phi}{2}\right) \qquad .....(9.1)$$

This is equation of SHM* in which the amplitude p'_0 depends on position as

$$p'_0 = 2p_0 \cos\left(kx + \frac{\phi}{2}\right) \qquad .....(9.2)$$

Points where pressure remains permanently at its average value; i.e. pressure amplitude is zero is called a pressure node, and the condition for a pressure node would be given by

$$p'_0 = 0$$

i.e. $\cos\left(kx + \frac{\phi}{2}\right) = 0$

i.e. $kx + \frac{\phi}{2} = 2n\pi \pm \frac{\pi}{2}$, $n = 0, 1, 2, ...$ .....(9.3)

Similarly points where pressure amplitude is maximum is called a pressure antinode and condition for a pressure antinode would be given by

$$p'_0 = \pm 2p_0$$

i.e. $\cos\left(kx + \frac{\phi}{2}\right) = \pm 1$

or $\left(kx + \frac{\phi}{2}\right) = n\pi$, $n = 0, 1, 2, ...$ ....(9.4)

∗ Note that a pressure node in a standing wave would correspond to a displacement antinode; and a pressure anti-node would correspond to a displacement node.

∗ (when we label eqn (9.1) as SHM, what we mean is that excess pressure at any point varies simple-harmonically. If the sound waves were represented in terms of displacement waves, then the equation of standing wave corresponding to (9.1) would be

$$s = s'_0 \cos(\omega t + \frac{\phi}{2}) \text{ where } s'_0 = 2s_0 \sin(kx + \frac{\phi}{2})$$

This can be easily observed to be an equation of SHM. It represents the medium particles moving simple harmonically about their mean position at x.)

10. VIBRATION OF AIR COLUMNS :

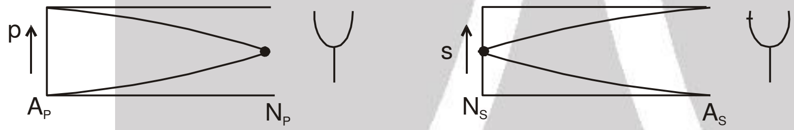
Standing waves can be set up in air-columns trapped inside cylindrical tubes if frequency of the tuning fork sounding the air column matches one of the natural frequency of air columns. In such a case the sound of the tuning fork becomes markedly louder, and we say there is resonance between the tuning 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 occurs 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.

10.1 Closed organ pipe

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

Fundamental mode :



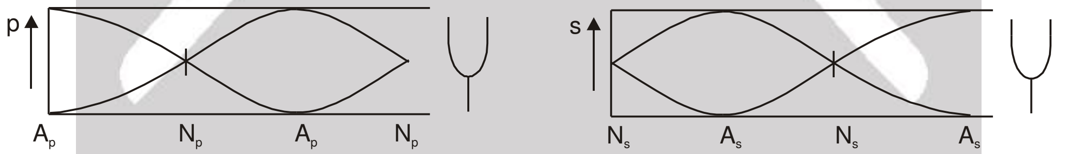
The smallest frequency (largest wavelength) that satisfies the boundary condition for resonance (i.e. displacement node at left end and antinode at right end is $\lambda_0 = 4\ell$, where ℓ = length of closed pipe the corresponding frequency.

$$\frac{\lambda}{4} = \ell \Rightarrow \lambda = 4\ell$$

$$\nu_0 = \frac{v}{\lambda} = \frac{v}{4L} \text{ is called the fundamental frequency.} \qquad .....(10.1)$$

First Overtone : Here there is one node and one antinode apart from the nodes and antinodes at the ends.

$$\frac{3\lambda}{4} = \ell \Rightarrow \lambda = \frac{4\ell}{3}$$



$$\lambda_1 = \frac{4\ell}{3} = \frac{\lambda_0}{3}$$

and corresponding frequency,

$$\nu_1 = \frac{v}{\lambda_1} = 3\nu_0$$

This frequency is 3 times the fundamental frequency and hence is called the 3rd harmonic.

nth overtone :

In general, the nth overtone will have n nodes and n antinodes between the two ends. The corresponding wavelength is

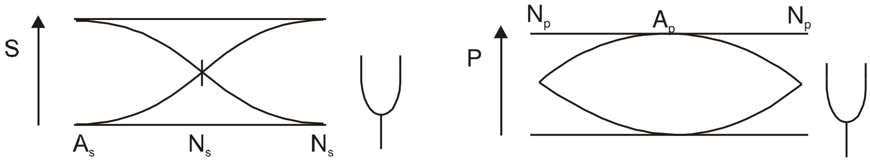
$$(2n + 1)\frac{\lambda}{4} = \ell$$

$$\lambda_n = \frac{4\ell}{2n+1} = \frac{\lambda_0}{2n+1} \text{ and } n_n = (2n + 1)\nu_0 \qquad ....(10.2)$$

This corresponds to the $(2n + 1)^{th}$ harmonic. Clearly only odd harmonic are allowed in a closed pipe.

10.2 Open organ pipe :

Fundamental mode :



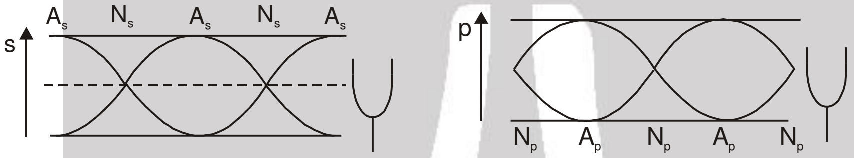
The smallest frequency (largest wave length) that satisfies the boundary condition for resonance (i.e. displacement antinodes at both ends) is,

$\lambda_0 = 2\ell$

corresponding frequency, is called the fundamental frequency

$$\nu_0 = \frac{v}{2\ell} \qquad ....(10.3)$$

1st Overtone : Here there is one displacement antinode between the two antinodes at the ends.



$$\lambda_1 = \frac{2\ell}{2} \qquad \Rightarrow \lambda_1 = \frac{\lambda_0}{2}$$

and, corresponding frequency

$$\nu_1 = \frac{v}{\lambda_1} = 2\nu_0$$

This frequency is 2 times the fundamental frequency and is called the 2nd harmonic.

nth overtone : The nth overtone has n displacement antinodes between the two antinode at the ends.

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

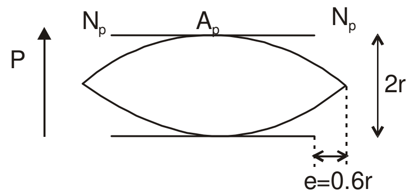
$$\lambda_n = \frac{2\ell}{n+1} = \frac{\lambda_0}{n+1} \qquad \text{and} \qquad \nu_n = (n + 1)\, \nu_0 \qquad ....(10.4)$$

This correspond to $(n + 1)^{th}$ harmonic: clearly both even and odd harmonics are allowed in an open pipe.

10.3 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.



Effective length of closed organ pipe is $\ell' = \ell + e$

and effective length of open organ pipe is $\ell' = \ell + 2e$

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

$$f_c = \frac{v}{4(\ell + 0.6r)} \text{ and } f_0 = \frac{v}{2(\ell + 1.2r)} \qquad ....(10.5)$$

Solved Example

Example 13. Fundamental frequency of a organ pipe filled with N_2 is 1000 Hz. Find the fundamental frequency if N_2 is replaced by H_2.

Solution : Suppose the speed of sound in hydrogen is v_H and that in nitrogen is v_N. The fundamental frequency of an organ pipe is proportional to the speed of sound in the gas contained in it. If the fundamental frequency with hydrogen in the tube is ν, we have

$$\frac{n}{1000\text{Hz}} = \frac{v_H}{v_N} = \sqrt{\frac{M_N}{M_H}} \quad \text{(Since both } N_2 \text{ and } H_2 \text{ are diatomic, } \gamma \text{ is same for both)}$$

or, $\frac{n}{1\text{kHz}} = \sqrt{\frac{28}{2}} \Rightarrow n = 1000\sqrt{14}$ Hz. **Ans.**

Example 14. A tube open at only one end is cut into two tubes of non equal lengths. The piece open at both ends has of fundamental frequency of 450 Hz and other has fundamental frequency of 675 Hz. What is the 1st overtone frequency of the original tube.

Solution : $450 = \frac{v}{2\ell_1} \quad 675 = \frac{v}{4\ell_2}$

length of original tube = $(\ell_1 + \ell_2)$

its first obtained frequency, $n_1 = \frac{v}{4(\ell_1+\ell_2)} = \frac{v}{4\left(\frac{v}{900}+\frac{v}{675\times 4}\right)} = \frac{(2700\times 900)}{4(2700+900)} = 168.75$

Ist overtone = $3n_1$ = 506.25

Example 15. The range of audible frequency for humans is 20 Hz to 20,000 Hz. If speed of sound in air is 336 m/s. What can be the maximum and minimum length of a musical instrument, based on resonance pipe.

Solution : For an open pipe, $f = \frac{v}{2\ell}\, n$

$\Rightarrow \ell = \frac{v}{2f}.n$

Similarly for a closed pipe, $\ell = \frac{v}{4f}$ s (2n + 1)

$\ell_{min} = \frac{v}{4f_{max}} (2n+1)_{min} = \frac{336}{4\times 20000} = 4.2$ mm

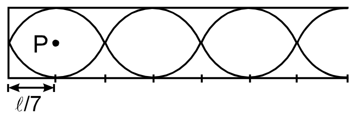
$\ell_{max} = \frac{v}{2f_{min}} n_{max} = \frac{v}{2\times 20} n_{max} = 8.4\ (m) \times n_{max}$

Clearly there is no upper limit on the length of such an musical instrument.

Example 16. 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.

Solution : 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

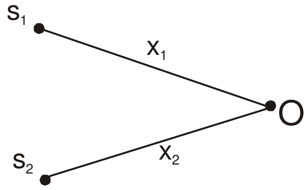
11. INTERFERENCE IN TIME : BEATS

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,

$p_1 = p_0 \sin (2\pi f_1 t - k_1x_1 + \theta_1)$

$p_2 = p_0 \sin (2\pi f_2 t - k_2x_2 + \theta_2)$



Let $-k_1x_1 + \theta_1 = \phi_1$ and $- k_2x_2 + \theta_2 = \phi_2$

By principle of superposition

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

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)

$f_B = f_1 - f_2$

$$T_B = \frac{1}{f_1 - f_2} \qquad .....(11.1)$$

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 source of known frequency.

(iii) If the arm of a tuning fork is waxed or loaded, then its frequency decreases.

(iv) If arm of tuning fork is filed, then its frequency increases.

Solved Example

Example 17. A tuning fork is vibrating at frequency 100 Hz. When another tuning fork is sounded simultaneously, 4 beats per second are heard. When some mass is added to the tuning fork of 100 Hz, beat frequency decreases. Find the frequency of the other tuning fork.

Solution : $|f - 100| = 4 \quad \Rightarrow \quad f = 96$ or 104

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

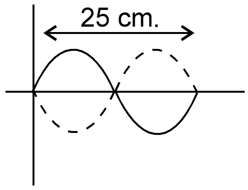
$\Rightarrow \quad 100 > f \quad \Rightarrow \quad f = 96$ Hz.

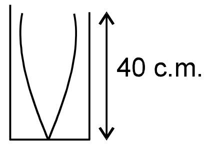
Example 18. Two strings X and Y of a sitar produces a beat of frequency 4Hz. When the tension of string Y is slightly increased, the beat frequency is found to be 2Hz. If the frequency of X is 300Hz, then the original frequency of Y was.

(A) 296 Hz (B) 298 Hz (C) 302 Hz (D) 304 Hz.

Answer : **(A)**

Example 19. A string 25 cm long fixed at both ends and having a mass of 2.5 g is under tension. A pipe closed from 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 the beat frequency. If the speed of sound in air is 320 m/s. Find tension in the string.





Solution : $\mu = \frac{2.5}{25} = 0.1 \text{ g / cm} = 10^{-2} \text{ Kg/m}$

Ist overtone

$\lambda_s = 25 \text{ cm} = 0.25 \text{ m} \quad \Rightarrow \quad f_s = \frac{1}{\lambda_s}\sqrt{\frac{T}{\mu}}$

pipe in fundamental freq

$\lambda_p = 160 \text{ cm} = 1.6 \text{ m} \quad \Rightarrow \quad f_p = \frac{V}{\lambda_p}$

$\because$ by decreasing the tension, beat freq is decreased

$\therefore\ f_s > f_p \Rightarrow f_s - f_p = 8 \Rightarrow \frac{1}{0.25}\sqrt{\frac{T}{10^{-2}}} - \frac{320}{1.6} = 8 \Rightarrow T = 27.04 \text{ N}$

Solved Examples

Example 20. The wavelength of two sound waves are 49cm and 50 cm respectively. If the room temperature is 30°C then the number of beats produced by them is approximately (velocity of sound in air at 0°C = 332 m/s).

(A) 6 (B) 10 (C) 14 (D) 18

Answer : **(C)**

Solution : $v = 332\sqrt{\frac{303}{273}} \quad \Rightarrow$ Beat frequency $= f_1 - f_2 = v\left(\frac{1}{\lambda_1} - \frac{1}{\lambda_2}\right)$

$= 332\sqrt{\frac{303}{273}}\left(\frac{1}{49} - \frac{1}{50}\right) \times 100 \cong 14$ **Ans.**

12. DOPPLER'S EFFECT

When there is relative motion between the source of a sound/light wave & an observer along the line joining them, the actual frequency observed is different from the frequency of the source. This phenomenon is called Doppler's Effect. If the observer and source are moving towards each other, the observed frequency is greater than the frequency of the source. If the observer and source move away from each other, the observed frequency is less than the frequency of source.

(v = velocity of sound wrt. ground. , c = velocity of sound with respect to medium, v_m = velocity of medium, v_O = velocity of observer, v_s = velocity of source.)

(a) Sound source is moving and observer is stationary :

If the source emitting a sound of frequency f is travelling with velocity v_s along the line joining the source and observer,

observed frequency, $f' = \left(\frac{v}{v - v_s}\right)f$ ...(12.1)

and Apparent wavelength $\lambda' = \lambda\left(\frac{v - v_s}{v}\right)$ ...(12.2)

$*$ In the above expression, the positive direction is taken along the velocity of sound, i.e. from source to observer. Hence v_s is positive if source is moving towards the observer, and negative if source is moving away from the observer.

(b) Sound source is stationary and observer is moving with velocity v_0 along the line joining them :

The source (at rest) is emitting a sound of frequency 'f' travelling with velocity 'v' so that wavelength is $\lambda = v/f$, i.e. there is no change in wavelength. How ever since the observer is moving with a velocity v_0 along the line joining the source and observer, the observed frequency is

$f' = f\left(\frac{v - v_0}{v}\right)$ ...(12.3)

$*$ In the above expression, the positive direction is taken along the velocity of sound, i.e. from source to observer. Hence v_O is positive if observer is moving away from the source, and negative if observer is moving towards the source.

(c) The source and observer both are moving with velocities v_s and v_0 along the line joining them :

The observed frequency, $f' = f$ ...(12.4)

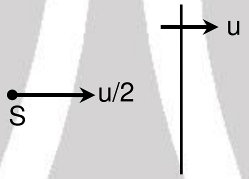
and Apparent wavelength $\lambda' = \lambda$ ...(12.5)

- $*$ In the above expression also, the positive direction is taken along the velocity of sound, i.e. from source to observer.
- $*$ In all of the above expression from equation 11.1 to 11.5, v stands for velocity of sound with respect to ground.

If velocity of sound with respect to medium is c and the medium is moving in the direction of sound from source to observer with speed v_m, $v = c + v_m$, and if the medium is moving opposite to the direction of sound from observer to source with speed v_m, $v = c - v_m$

Solved Examples

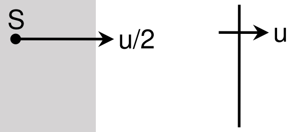
Example 21. A wall is moving with velocity u and a source of sound moves with velocity u/2 in the same direction as shown in figure. Assuming that the sound travels with velocity 10u. The ratio of incident sound wavelength on the wall to the reflected sound wavelength by the wall, is equal to (assume observer for reflected sound is at rest) :



(A) 9 : 11 (B) 11 : 19 (C) 4 : 5 (D) 5 : 4

Answer : **(A)**

Solution : $F^1{}_{\text{wall (received)}} = \dfrac{10u - u}{10u - u/2} f = \dfrac{9u}{9.5u} f \Rightarrow \lambda_1 = \dfrac{9.5u}{f}$

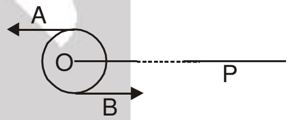


$F^{11}{}_{\text{wall (received)}} = \dfrac{10.u}{10u + u} f^1 = \dfrac{10u}{11u} \times \dfrac{9u}{9.5u} f \Rightarrow \lambda_2 = \dfrac{11u \times 9.5}{9f}$

$= \dfrac{\lambda_1}{\lambda_2} = \dfrac{9.5}{11 \times 9.5} \times 9 = \dfrac{9}{11}$

Example 22. A whistle of frequency 540 Hz is moving in a circle of radius 2 ft at a constant angular speed of 15 rad/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 1100 ft/sec.)

Solution : 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:

$$f_{max} = f \left(\frac{v - v_0}{v - v_s} \right)$$

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

$$f_{min} = f \left(\frac{v - v_s}{v} \right)$$

For f = 540 Hz, v_s = 2 ft × 15 rad/s = 30 ft/s, and v = 1100 ft/s,

we get (approx.) f_{max} = 555 Hz and, f_{min} = 525 Hz.

Example 23. A train approaching a hill at a speed of 40 km/hr sounds a whistle of frequency 600 Hz when it is at a distance of 1 km from a hill. A wind with a speed of 40 km/hr is blowing in the direction of motion of the train. Find,

(a) the frequency of the whistle as heard by an observer on the hill.

(b) 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 = 1200 km/hr.)

Solution : A train is moving towards a hill with speed v_s with respect to the ground. The speed of sound in air, i.e. the speed of sound with respect to medium (air) is c, while air itself is blowing towards hill with velocity v_m (as observed from ground). For an observer standing on the ground, which is the inertial frame, the speed of sound towards hill is given by

$v = c + v_m$

(a) The observer on the hill is stationary while source is approaching him. Hence, frequency of whistle heard by him is

$$f' = f\frac{v}{v - v_s}$$

for f = 600 Hz, v_s = 40 km/hr, and V = (1200 + 40) km/hr, we get

$$f' = 600\ .\ \frac{1240}{1240 - 40} = 620 \text{ Hz.}$$

(b) The train sounds the whistle when it is at distance x from the hill. Sound moving with velocity v with respect to ground, takes time t to reach the hill, such that,

$$t = \frac{x}{v} = \frac{x}{c + v_m} \qquad \text{....(i)}$$

After reflection from hill, sound waves move backwards, towards the train. The sound is now moving opposite to the wind direction. Hence, its velocity with respect to the ground is

$v' = c - v_m$

Suppose when this reflected sound (or echo) reaches the train, it is at distance x' from hill. The time taken by echo to travel distance x' is given by

$$t' = \frac{x'}{v} = \frac{x'}{c - v_m} \qquad \text{....(ii)}$$

Thus, total time (t + t′) elapses between sounding the whistle and echo reaching back. In the same time, the train moves a distance (x – x') with constant speed v_s, as observed from ground. That is,

$x - x' = (t + t')\, v_s$.

Substituting from (i) and (ii), for t and t′, we find

$$x - x' = \frac{v_s}{c + v_m}x + \frac{v_s}{c - v_m}x' \qquad \text{or,} \qquad \frac{c + v_m - v_s}{c + v_m}\ x = \frac{v_s + c - v_m}{c - v_m}\ x'$$

For x = 1 km, c = 1200 km/hr, v_s = 40 km/hr, and v_m = 40 km/hr, we get

$$\frac{1200 + 40 - 40}{1200 + 40} \times 1 = \frac{40 + 1200 - 40}{1200 - 40}\ x'$$

or, $$x' = \frac{1160}{1240} = 0.935 \text{ km.}$$

Thus, the echo is heard when train is 935 m from the hill.

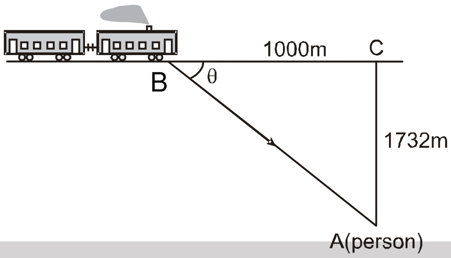
Now, for the observer moving along with train, echo is a sound produced by a stationary source, i.e., the hill. Hence as observed from ground, source is stationary and observer is moving towards source with speed 40 km/hr. Hence v_O = – 40 km/hr. On the other hand, reflected sound travels opposite to wind velocity. That is, velocity of echo with respect to ground is v′. Further, the source (hill) is emitting sound of frequency f′ which is the frequency observed by the hill.

Thus, frequency of echo as heard by observer on train, is given by

$$f'' = f'\ \frac{v' + v_O}{v'} \quad \Rightarrow \quad f'' = \frac{(1160 - (-40))}{1160} \times 620 = 641 \text{ Hz}$$

Example 24. A train producing frequency of 640 Hz is moving towards point c with speed 72 km/hr. A person is sitting 1732 m from point c as shown. Find the frequency heard by person when sound generated at B reaches to the person, if speed of sound is 330 m/s.

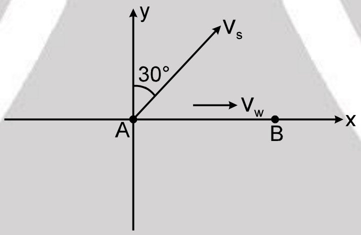
Solution : The observer A is at rest with respect to the air and the source is travelling at a velocity of 72 km/h i.e.,



20 m/s. As is clear from the figure, the person receives the sound of the whistle in a direction BA making an angle θ with the track where $\tan\theta = \frac{1732}{1000} = \sqrt{3}$, i.e. $\theta = 60^{\circ}$. The component of the velocity of the source (i.e., of the train) along this direction is $20\cos\theta = 10$ m/s. As the source is approaching the person with this component, the frequency heard by the observer is

$$\upsilon' = \frac{v}{v - u\cos\theta}\,\upsilon = \frac{330}{330-10} \times 640 \text{ Hz} = 660 \text{ Hz}.$$

Example 25. In the figure shown a source of sound of frequency 510 Hz moves with constant velocity v_s = 20 m/s in the direction shown. The wind is blowing at a constant velocity v_w = 20 m/s towards an observer who is at rest at point B. The frequency detected by the observer corresponding to the sound emitted by the source at initial position A, will be (speed of sound relative to air = 330 m/s)



(A) 485 Hz (B) 500 Hz (C) 512 Hz (D) 525 Hz

Answer : **(D)**

Solution : Apparent frequency

$$n' = n\,\frac{(u + v_w)}{(u + v_w - v_s\cos 60^{\circ})} = \frac{510\ \ (330+20)}{330+20-20\ \ \cos 60^{\circ}} = 510 \times \frac{350}{340} = 525 \text{ Hz } \textbf{Ans.}$$

Example 26. An observer is moving with half the speed of light towards stationary microwave source emitting waves at frequency 10GHz. What is the frequency of the microwave measured by the observer? (speed of light = 3×10^{8}ms^{-1}) **[JEE Main 2017 ; 4/120, –1]**

(A) 15.3 GHz (B) 10.1 GHz (C) 12.1 GHz (D) 17.3 GHz

Answer : **(D)**

Solution :
$$\nu' = \nu\sqrt{\frac{1+\frac{v}{c}}{1-\frac{v}{c}}}$$

$$\nu' = \nu\sqrt{\frac{1+\frac{1}{2}}{1-\frac{1}{2}}} = \sqrt{3}\nu$$

ν' = 10 × 1.73 = 17.3 GHz

Exercise-1

✍ **Marked Questions can be used as Revision Questions.**

PART - I : SUBJECTIVE QUESTIONS

Section (A) : Equation of sound wave, wavelength, frequency, Pressure and Displacement amplitude

A 1. The audible frequency for a normal human being is 20 Hz to 20 kHz. Find the corresponding wavelengths if the speed of sound in air 320 m/s

A 2. A sound wave of frequency 80 Hz is traveling with speed 320 m/s.
(a) Find the change in phase at a given position in 400 ms interval.
(b) Find the phase difference between two positions separated by 20 cm at a particular instant

A 3. A traveling sound wave is described by the equation $y = 2 \sin (4t - 5x)$ where y is measured in centimeter, t in seconds and x in meters.
(a) Find the ratio of amplitude and wavelength of wave.
(b) Find the ratio of maximum velocity of particle to wave velocity.

A 4. The pressure at a point varies from 99980 Pa to 100020 Pa due to a simple harmonic sound wave. The amplitude and wavelength of the wave are 5×10^{-6} m and 40 cm respectively. Find the bulk modulus of air

A 5.✍ Find the minimum and maximum wavelengths of sound in water that is in the audible range (20 - 20000 Hz) for an average human ear. Speed of sound in water = 1500 m/s.

Section (B) : Speed of sound

B 1. A man stands before a large wall at a distance of 100.0 m and claps his hands at regular intervals In such way that echo of a clap merges with the next clap. If he claps 5 times during every 3 seconds, find the velocity of sound in air.

B-2. ✍ Earthquake generate sound waves inside the earth. Unlike a gas, the earth can experience both transverse(S) and longitudinal (P) sound waves. Typically the speed of 'S' wave is about 4 km/s and that of P wave is 8 km/s. A seismograph records P and S waves from an earthquake. The first P wave arrives 4 min. before the first S wave. Assuming the waves travel in straight line, the epicentre of earthquake is at 120 η (in km). Find η .

B 3. (a) Find the speed of sound in a mixture of 1 mol of helium and 2 mol of oxygen at 27°C.
(b) If now temp. is raised by 1K from 300 K. Find the percentage change in the speed of sound in the gaseous mixture. [Note : This can be done after studying heat.] **[JEE - 1995]**

B 4. A gas mixture has 24 % of Argon, 32 % of oxygen, and 44 % of CO_2 by mass. Find the velocity of sound in the gas mixture at 27 °C. Given R = 8.4 S.I. units. Molecular weight of Ar = 40, O_2 = 32, CO_2 = 44. $\gamma_{Ar} = 5/3$, $\gamma_{O2} = 7/5$, $\gamma_{CO2} = 4/3$. [Note : This can be done after studying heat.]

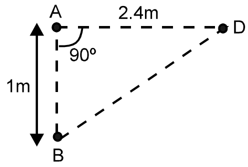
Section (C) : Intensity of sound, Decibel scale

C 1. Two sound waves one in air and the other in fresh water are equal in intensity.
(a) Find the ratio of pressure amplitudes of the wave in water to that of the wave in air.
(b) If the pressure amplitudes of the waves are equal then what will be the ratio of the intensities of the waves. [V_{sound} = 340 m/s in air & density of air = 1.25 kg/m^3, V_{sound} = 1530 m/s in water, density of water = 1000 kg/m^3]

C 2.✍ A point A is located at a distance r = 1.5 m from a point source of sound of frequency n = 600 Hz. The power of the source P = 0.80 W. Neglecting the damping of the wave and assuming the velocity of sound in air to be 340 ms^{-1}. Find at the point A : (Use $d_{air} = \frac{225\pi}{544}$ kg m^{-3} ; $\pi^2 = \frac{100}{3 \times 3.375}$)
(a) The pressure oscillation amplitude $(\Delta p)_m$.
(b) The oscillation amplitude of particles of the medium.

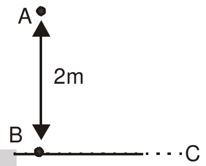
Section (D) : Interference

D 1. Two point sound sources A and B each of power 25π W and frequency 850 Hz are 1 m apart. The sources are in phase

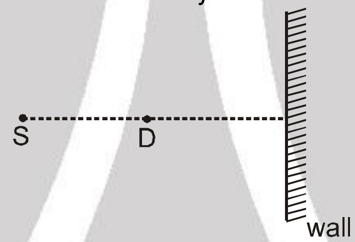


(a) Determine the phase difference between the waves emitting from A and B received by detector D as shown in figure.
(b) Also determine the intensity of the resultant sound wave as recorded by detector D. Velocity of sound = 340 m/s.

D 2. Two identical loudspeakers are located at points A & B, 2 m apart. The loudspeakers are driven by the same amplifier (coherent and are in phase). A small detector is moved out from point B along a line perpendicular to the line connecting A & B. Taking speed of sound in air as 332 m/s, find the frequency below which there will be no position along the line BC at which destructive interference occurs.

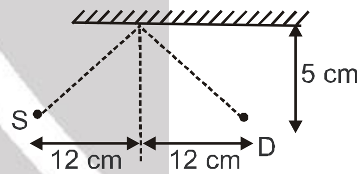


D 3. A sound source, detector and a movable wall are arranged as shown in figure. In this arrangement detector is detecting the maximum intensity. If the speed of sound is 330 m /s in air and frequency of source is 660 Hz, then find the minimum distance by which the wall should be moved away from source, so that detector detects minimum intensity.



D 4. Two sources of sound, S_1 and S_2, emitting waves of equal wavelength 2 cm, are placed with a separation of 3 cm between them. A detector can be moved on a line parallel to S_1S_2 and at a distance of 24 cm from it. Initially, the detector is equidistant from the two sources. Assuming that the waves emitted by the sources are in phase, find the minimum distance through which the detector should be shifted to detect a minimum of sound.

D 5. A sound source, detector and a cardboard are arranged as shown in figure. The wave is reflected from the cardboard at the line of symmetry of source and detector. Initially the path difference between the reflected wave and the direct wave is one third of the wavelength of sound. Find the minimum distance by which the cardboard should be moved upwards so that both waves are in phase.



Section (E) : Reflection of sound equation of stationary waves

E 1. A metallic rod of length 1 m is rigidly clamped at its end points. Longitudinal stationary waves are setup in the rod in such a way that there are six antinodes of displacement wave observed along the rod. The amplitude of the antinode is 2×10^{-6} m. Write the equations of the stationary wave and the component waves at the point 0.1 m from the one end of the rod. [Young's modulus = 7.5×10^{10} N/m^2, density = 2500 kg/m^3]

E 2. 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 is in seconds . The specific gravity of the medium is 10^{-3}. Density of water = 10^3 kg/m^3. Find :
(a) Wavelength, frequency and velocity of the progressive waves.
(b) Bulk modulus of the medium and the pressure amplitude.
(c) Minimum distance between pressure antinode and a displacement antinode.
(d) Intensity at the displacement nodes.

Section (F) : Organ Pipes and Resonance

F 1. 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.

F 2. The speed of sound in an air column of 80 cm closed at one end is 320 m/s. Find the natural frequencies of air column between 20 Hz and 2000 Hz.

F 3. In an organ pipe the distance between the adjacent nodes is 4 cm. Find the frequency of source if speed of sound in air is 336 m/s

F 4. Two pipes P_1 and P_2 are closed and open respectively. P_1 has a length of 0.3 m. Find the length of P_2, if third harmonic of P_1 is same as first harmonic of P_2.

F 5. Two adjacent resonance frequencies of an open organ pipe are 1800 and 2100 Hz. Find the length of the tube. The speed of sound in air is 330 m/s.

F 6. A closed organ pipe of length ℓ = 100 cm is cut into two unequal pieces. The fundamental frequency of the new closed organ pipe piece is found to be same as the frequency of first overtone of the open organ pipe piece. Determine the length of the two pieces and the fundamental tone of the open pipe piece. Take velocity of sound = 320 m/s.

F 7. Find the number of possible natural oscillations of air column in a pipe whose frequencies lie below f_0 = 1250 Hz. The length of the pipe is ℓ = 85 cm. The velocity of sound is v = 340 m/s.
Consider the two cases :
(a) The pipe is closed from one end (b) The pipe is opened from both ends.
The open ends of the pipe are assumed to be the antinodes of displacement.

F-8. In a resonance tube experiment to determine the speed of sound in air, a pipe of diameter 5 cm is used. The air column in pipe resonates with a tuning fork of frequency 480 Hz when the minimum length of the air column is 16 cm. If the speed of sound in air at room temperature = 6η (in m/sec.) Find η **[JEE - 2003, 2/60]**

F-9. A person hums in a well and finds strong resonance at frequencies 60Hz, 100Hz and 140Hz. What is the fundamental frequency of the well? Explain ? How deep is the well ? (velocity of sound = 344m/s).

Section (G) : Beats

G 1. A source of sound with adjustable frequency produces 4 beats per second with a tuning fork when its frequency is either 474 Hz. or 482 Hz. What is the frequency of the tuning fork?

G 2. Two identical piano wires have a fundamental frequency of 600 vib/sec, when kept under the same tension. What fractional increase in the tension of one wire will lead to the occurrence of six beats per second when both wires vibrate simultaneously.

G 3. A metal wire of diameter 1 mm, is held on two knife edges separated by a distance of 50 cm. The tension in the wire is 100 N. The wire vibrating in its fundamental frequency and a vibrating tuning fork together produces 5 beats per sec. The tension in the wire is then reduced to 81 N. When the two are excited, beats are again at the same rate. Calculate
(a) The frequency of the fork (b) The density of the material of the wire.

G 4. A string 25 cm long fixed at both ends and having a mass of 2.5 g is under tension. A pipe closed from 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 the beat frequency. If the speed of sound in air is 320 m/s. Find tension in the string.

Section (H) : Doppler Effect

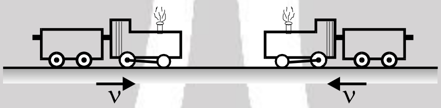
H 1. An observer rides with a sound source of frequency f and moving with velocity v towards a large vertical wall. Considering the velocity of sound waves as c, find :
(i) The number of waves striking the surface of wall per second
(ii) The wavelength of the reflected wave
(iii) The frequency of reflected wave as observed by observer.
(iv) Beat frequency heard by the observer.

H 2. A stationary source emits single frequency sound. A wall approaches it with velocity u = 33 cm/s. The propagation velocity of sound in the medium is v = 330 m/s. In what way and how much, in per cent, does the wavelength of sound change on reflection from the wall ?

H 3. A source of sonic oscillations with frequency f_0 = 1000 Hz moves at right angles to the wall with a velocity u = 0.17 m/s. Two stationary receivers R_1 and R_2 are located on a straight line, coinciding with the trajectory of the source, in the following succession : R_1 – source – R_2 – wall. Which receiver registers the beatings and what is the beat frequency ? The velocity of sound is equal to v = 340 m/s.

H 4. A sound wave of frequency f propagating through air with a velocity C, is reflected from a surface which is moving away from the source with a constant speed V. Find the frequency of the reflected wave, measured by the observer at the position of the source.

H 5. Two trains move towards each other with the same speed. Speed of sound is 340 ms^{-1}. If the pitch of the tone of the whistle of one when heard on the other changes to 9/8 times, then the speed of each train is :



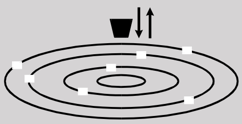
H 6. A tuning fork P of unknown frequency gives 7 beats in 2 sec with another tuning fork Q. When Q runs towards the wall with a speed of 5 m/s it gives 5 beats per sec with its echo. On loading wax on P it gives 5 beats per second with Q. What is the original frequency of P ? Assume speed of sound = 332 m/s.

PART - II : ONLY ONE OPTION CORRECT TYPE

Section (A) : Equation of sound wave, wavelength, frequency, Pressure and Displacement amplitude

A 1. When sound wave is refracted from air to water, which of the following will remain unchanged?
(A) wave number (B) wavelength (C) wave velocity (D) frequency

A 2. A piece of cork is floating on water in a small tank. The cork oscillates up and down vertically when small ripples pass over the surface of water. The velocity of the ripples being 0.21 ms^{-1}, wave length 15 mm and amplitude 5 mm, the maximum velocity of the piece of cork is ($\pi = \frac{22}{7}$)

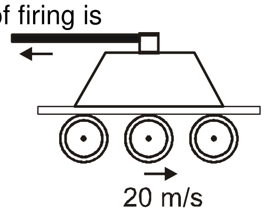


(A) 0.44 ms^{-1} (B) 0.24 ms^{-1} (C) 2.4 ms^{-1} (D) 4.4 ms^{-1}

A 3. The frequency of a man's voice is 300 Hz and its wavelength is 1 meter. If the wavelength of a child's voice is 1.5 m, then the frequency of the child's voice is:
(A) 200 Hz (B) 150 Hz (C) 400 Hz (D) 350 Hz

Section (B) : Speed of sound

B 1. A machine gun is mounted on an armored car moving with a speed of 20 ms^{-1}. The gun can point against the direction of motion of car. The muzzle speed of bullet is equal to speed of sound in air i.e., 340 ms^{-1}. The time difference between bullet actually reaching and sound of firing reaching at a target 544 m away from car at the instant of firing is



(A) 1.2 s (B) 0.1 s (C) 1 s (D) 10 s

B 2. The ratio of speed of sound in a monoatomic gas to that in water vapours at any temperature is. (when molecular weight of gas is 40 gm/mol and for water vapours is 18 gm/mol)
(A) 0.75 (B) 0.73 (C) 0.68 (D) None of these

B 3. Under similar conditions of temperature and pressure, In which of the following gases the velocity of sound will be largest.
(A) H_2 (B) N_2 (C) He (D) CO_2

B 4. If v_{rms} = root mean square speed of molecules
v_{av} = average speed of molecules
v_{mp} = most probable speed of molecules
v_s = speed of sound in a gas
Then, identify the correct relation between these speeds.
(A) $v_{rms} > v_{av} > v_{mp} > v_s$ (B) $v_{av} > v_{mp} > v_{rms} > v_s$ (C) $v_{mp} > v_{av} > v_{rms} > v_s$ (D) $v_{rms} > v_{av} > v_s > v_{mp}$

Section (C) : Intensity of sound, Decibel scale

C 1. A sound of intensity I is greater by 3.0103 dB from another sound of intensity 10 nW cm^{-2}. The absolute value of intensity of sound level I in Wm^{-2} is :
(A) 2.5×10^{-4} (B) 2×10^{-4} (C) 2.0×10^{-2} (D) 2.5×10^{-2}

C 2. For a sound source of intensity I W/m^2, corresponding sound level is B_0 decibel. If the intensity is increased to 4I, new sound level becomes approximately :
(A) $2B_0$ dB (B) $(B_0 + 3)$dB (C) $(B_0 + 6)$dB (D) $4B_0$ dB

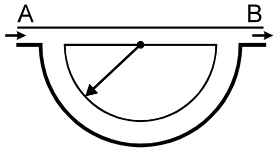
C 3. The sound intensity is 0.008 W/m^2 at a distance of 10 m from an isotropic point source of sound. The power of the source is approximately :
(A) 2.5 watt (B) 0.8 watt (C) 8 watt (D) 10 watt

Section (D) : Interference

D 1. What happens when a sound wave interferes with another wave of same frequency and constant phase difference ?
(A) Energy is gained
(B) Energy is lost
(C) Redistribution of energy occurs changing with time
(D) Redistribution of energy occurs not changing with time

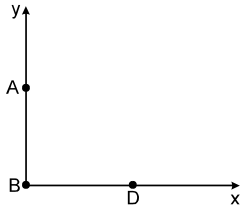
D 2. Sound waves from a tuning fork F reach a point P by two separate routes FAP and FBP (when FBP is greater than FAP by 12 cm there is silence at P). If the difference is 24 cm the sound becomes maximum at P but at 36 cm there is silence again and so on. If velocity of sound in air is 330 ms^{-1}, the least frequency of tuning fork is :
(A) 1537 Hz (B) 1735 Hz (C) 1400 Hz (D) 1375 Hz

D 3. Sound signal is sent through a composite tube as shown in the figure. The radius of the semicircular portion of the tube is r. Speed of sound in air is v. The source of sound is capable of giving varied frequencies in the range of ν_1 and ν_2 (where $\nu_2 > \nu_1$). If n is an integer then frequency for maximum intensity is given by :



(A) $\frac{nv}{r}$ (B) $\frac{nv}{r(\pi - 2)}$ (C) $\frac{nv}{\pi r}$ (D) $\frac{nv}{(r-2)\pi}$

D 4. An interference is observed due to two coherent sources 'A' & 'B' separated by a distance 4λ along the y-axis where λ is the wavelength of the source. A detector D is moved on the positive x-axis. The number of points on the x–axis excluding the points, $x = 0$ & $x = \infty$ at which maximum will be observed is –



(A) three (B) four (C) two (D) infinite

D-5. A person is talking in a small room and the sound intensity level is 60 dB everywhere within the room. If there are eight people talking simultaneously in the room, what is the sound intensity level ?
(A) 60 dB (B) 69 dB (C) 74 dB (D) 81 dB

Section (E) : Reflection of sound equation of stationary waves

E 1. When a sound wave is reflected from a wall, the phase difference between the reflected and incident pressure wave is:
(A) 0 (B) π (C) $\pi/2$ (D) $\pi/4$

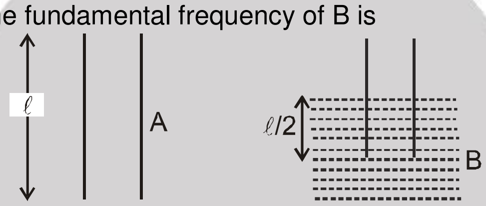
Section (F) : Organ Pipes and Resonance

F 1. If λ_1, λ_2, λ_3 are the wavelengths of the waves giving resonance in the fundamental, first and second overtone modes respectively in a open organ pipe, then the ratio of the wavelengths $\lambda_1 : \lambda_2 : \lambda_3$, is :
(A) 1 : 2 : 3 (B) 1 : 3 : 5 (C) 1 : 1/2 : 1/3 (D) 1 : 1/3 : 1/5

F 2. The maximum variation of pressure in an open organ pipe of length ℓ vibrating in fundamental mode is at.
(A) ends (B) middle of pipe (C) $\frac{L}{4}$ from centre (D) $\frac{3L}{8}$ from centre

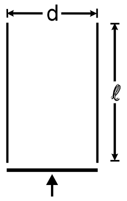
F 3. The fundamental frequency of a closed organ pipe is same as the first overtone frequency of an open pipe. If the length of open pipe is 50 cm, the length of closed pipe is
(A) 25 cm (B) 12.5 cm (C) 100 cm (D) 200 cm

F 4. Two identical tubes A and B are kept in air and water respectively as shown. If the fundamental frequency of A is f_0, then the fundamental frequency of B is



(A) $\frac{f_0}{4}$ (B) $\frac{f_0}{2}$ (C) f_0 (D) $2 f_0$

F 5. A tube of diameter d and of length ℓ unit is open at both the ends. Its fundamental frequency of resonance is found to be ν_1. The velocity of sound in air is 330 m/sec. One end of tube is now closed. The lowest frequency of resonance of tube is now ν_2. Taking into consideration the end correction, $\frac{\nu_2}{\nu_1}$ is



(A) $\frac{(\ell+0.6d)}{(\ell+0.3d)}$ (B) $\frac{1}{2}\frac{(\ell+0.3d)}{(\ell+0.6d)}$ (C) $\frac{1}{2}\frac{(\ell+0.6d)}{(\ell+0.3d)}$ (D) $\frac{1}{2}\frac{(d+0.3\ell)}{(d+0.6\ell)}$

F 6. The second overtone of an open pipe A and a closed pipe B have the same frequencies. The ratio of fundamental frequency of A to the fundamental frequency of B is:
(A) 3: 5 (B) 5: 3 (C) 5: 6 (D) 6: 5

F 7. A resonance tube is resonated with tuning fork of frequency 256 Hz. If the length of first and second resonating air columns are 32 cm and 100 cm, then end correction will be
(A) 1 cm (B) 2 cm (C) 4 cm (D) 6 cm

Section (G) : Beats

G 1. A sound source of frequency 512 Hz is producing 6 beats with a guitar. If the string of guitar is stretched slightly then beat frequency decreases. The original frequency of guitar is
(A) 506 Hz (B) 512 Hz (C) 518 Hz (D) 524 Hz

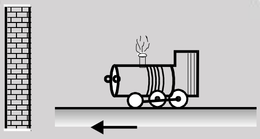
G 2. The number of beats heard per second if there are three sources of sound of frequencies (n – 1), n and (n + 1) of equal intensities sounded together is :
(A) 2 (B) 1 (C) 4 (D) 3

G 3. A closed organ pipe and an open pipe of same length produce 4 beats when they are set into vibrations simultaneously. If the length of each of them were twice their initial lengths, the number of beats produced will be [Assume same mode of vibration in both cases]
(A) 2 (B) 4 (C) 1 (D) 8

Section (H) : Doppler Effect

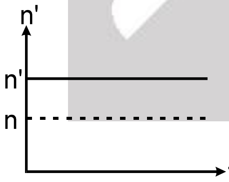
H 1. Which of the following does not affect the apparent frequency in doppler effect ?
(A) Speed of source (B) Speed of observer
(C) Frequency of source (D) Distance between source and observer

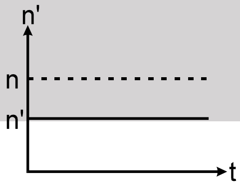
H 2. An engine driver moving towards a wall with velocity of 50 ms^{-1} emits a note of frequency 1.2 kHz. The frequency of note after reflection from the wall as heard by the engine driver when speed of sound in air is 350 ms^{-1} is :

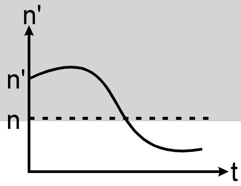


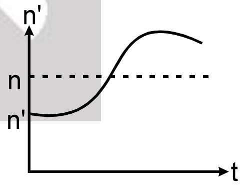
(A) 1 kHz (B) 1.8 kHz (C) 1.6 kHz (D) 1.2 kHz

H 3. Source and observer both start moving simultaneously from origin, one along X-axis and the other along Y-axis with speed of source equal to twice the speed of observer. The graph between the apparent frequency (n') observed by observer and time t would be : (n is the frequency of the source)

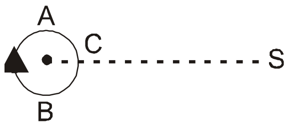
(A) 

(B) 

(C) 

(D) 

H 4. An observer moves on a circle as shown in fig. and a small sound source is at S. Let at $\upsilon_1, \upsilon_2, \upsilon_3$ be the frequencies heard when the observer is at A, B, and C respectively.



(A) $\upsilon_1 > \upsilon_2 > \upsilon_3$ (B) $\upsilon_1 = \upsilon_2 > \upsilon_3$ (C) $\upsilon_2 > \upsilon_3 > \upsilon_1$ (D) $\upsilon_1 > \upsilon_3 > \upsilon_2$

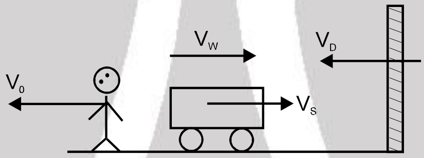
H-5. Two factories are sounding their sirens at 400 Hz each. A man walks from one factory towards the other at a speed of 2 m/s. the speed of sound is 320 m/s. The number of beats heard per second by the man is. **[Olympiad 2016 stage–I]**
(A) 6 (B) 5 (C) 2.5 (D) 7.5

PART - III : MATCH THE COLUMN

1. **Match the Column:**

Column-I	**Column-II**
(A) $y = 4 \sin (5x - 4t) + 3 \cos (4t - 5x + \pi/6)$	(p) Particles at every position are performing SHM
(B) $y = 10 \cos\left(t - \frac{x}{330}\right) \sin (100) \left(t - \frac{x}{330}\right)$	(q) Equation of travelling wave
(C) $y = 10 \sin (2\pi x - 120t) + 10 \cos (120t + 2\pi x)$	(r) Equation of standing wave
(D) $y = 10 \sin (2\pi x - 120\ t) + 8 \cos (118t - 59/30\pi x)$	(s) Equation of Beats

2. S, O & W represent source of sound (of frequency f), observer & wall respectively. V_O, V_S, V_D, V are velocity of observer, source, wall & sound (in still air) respectively. V_W is the velocity of wind. They are moving as shown. Then match the following : where $f_r = \frac{V + V_w + V_D}{V + V_w - V_S} f$



Column-I	**Column-II**
(A) The wavelength of the waves coming towards the observer from source.	(p) $(V - V_W - V_D)/f_r$
(B) The wavelength of the waves incident on the wall.	(q) $(V - V_W - V_O)f_r /(V - V_W - V_D)$
(C) The wavelength of the waves coming towards observer from the wall.	(r) $(V - V_W + V_S)/f$
(D) Frequency of the waves (as detected by O) coming from wall after reflection.	(s) $(V + V_W - V_S)/f$

3. To resonate a 1m tube closed at one end, if we use different tuning forks, we get different results. Match the following according to result of using tuning fork of certain frequency. (Velocity of sound = 320 m/s)

Tuning fork	Result
(A) 240 Hz	(p) Moderate sound will be generated
(B) 320 Hz	(q) Violent sound will be generated
(C) 400 Hz	(r) Only third harmonic will be activated
(D) 500 Hz	(s) Only fifth harmonic will be activated

Exercise-2

✍ **Marked Questions can be used as Revision Questions.**

PART - I : ONLY ONE CORRECT OPTION TYPE

1.✍ When we clap our hands, the sound produced is best described by

(A) $p = p_0 \sin (kx - \omega t)$ (B) $p = p_0 \sin kx \cos \omega t$

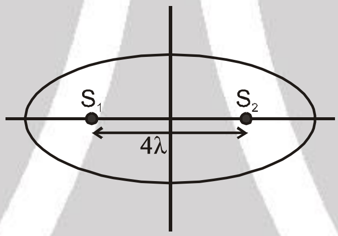
(C) $p = p_0 \cos kx \sin \omega t$ (D) $p = \Sigma\, p_{on} \sin (k_n x - \omega_n t)$

Here p denotes the change in pressure from the equilibrium value.

2. A light pointer fixed to one prong of a tuning fork touches a vertical plate. The fork is set vibrating and the plate is allowed to fall freely. Eight complete oscillations are counted when the plate falls through 10 cm, then the frequency of the fork is : ($g = 9.8\ m/s^2$)

(A) 65 Hz (B) 56 Hz (C) 46 Hz (D) 64 Hz

3. S_1, S_2 are two coherent sources (having initial phase difference zero) 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 :

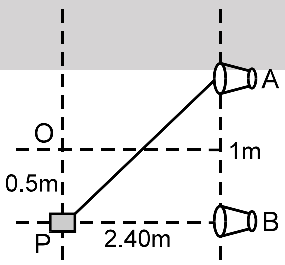


(A) 16 (B) 12 (C) 8 (D) 4

4. Consider the superposition of N harmonic waves of equal amplitude and frequency. If N is a very large number determine the resultant intensity in terms of the intensity (I_0) of each component wave for the conditions when the component waves have identical phases.

(A) NI_0 (B) N^2I_0 (C) $\sqrt{N}\, I_0$ (D) I_0

5.✍ Two speakers A and B, placed 1m apart, each produce sound waves of frequency 1800 Hz in phase. A detector moving parallel to line of speakers distant 2.4 m away detects a maximum intensity at O and then at P. Speed of sound wave is :



(A) 330 ms^{-1} (B) 360 ms^{-1} (C) 350 ms^{-1} (D) 340 ms^{-1}

6.✍ In a Hall, a person receives direct sound waves from a source 120m away. He also receives wave from the same source which reach him after being reflected from the 25m high ceiling at a point half way between them. The two waves interfere constructively for wave length (in meters).

(A) 10, 10/2, 10/3, 10/4 (B) 20, 20/3, 20/5, 20/7,...........

(C) 30, 20, 10,............ (D) 10, 10/3, 10/5,10/7..........

7. The displacement sound wave in a medium is given by the equation Y = A cos(ax + bt) where A, a and b are positive constants. The wave is reflected by an denser obstacle situated at x = 0. The intensity of the reflected wave is 0.64 times that of the incident wave. Mark the incorrect statement(s).

(A) the wavelength and frequency of the wave are $2\pi/a$ and $b/2\pi$ respectively

(B) the amplitude of the reflected wave is 0.8 A

(C) the resultant wave formed after reflection is y = A cos(ax + bt) + [– 0.8 A cos (ax – bt)] and V_{max} (maximum particle speed) is 1.8 bA

(D) the equation of the standing wave so formed is y = 1.8 A sin ax cos bt

8. The ratio of speed of sound in nitrogen gas to that in helium gas at 300 K is **[JEE - 1999, 2/200]**

(A) $\sqrt{2/7}$ (B) $\sqrt{1/7}$ (C) $\sqrt{3}\ /5$ (D) $\sqrt{6/5}$

9. Two monoatomic ideal gases 1 and 2 of molecular masses m_1 and m_2 respectively are enclosed in separate containers kept at the same temperature. The ratio of the speed of sound in gas 1 to that in gas 2 is given by **[JEE (Scr) - 2000, 2/105]**

(A) $\sqrt{\frac{m_1}{m_2}}$ (B) $\sqrt{\frac{m_2}{m_1}}$ (C) $\frac{m_1}{m_2}$ (D) $\frac{m_2}{m_1}$

10. A closed pipe resonates at its fundamental frequency of 300 Hz. Which one of the following statements is wrong ? **[REE - 1993]**

(A) If the temperature rises, the fundamental frequency increases.

(B) If the pressure rises, the fundamental frequency increases.

(C) The first overtone is of frequency 900 Hz.

(D) An open pipe with the same fundamental frequency has twice the length.

11. A closed pipe and an open pipe have their first overtones identical in frequency. Their lengths are in the ratio- **[REE - 1999]**

(A) 1 : 2 (B) 2 : 3 (C) 3 : 4 (D) 4 : 5

12. An open pipe is suddenly closed at one end with the result that the frequency of third harmonic of the closed pipe is found to be higher by 100 Hz than the fundamental frequency of the open pipe. The fundamental frequency of the open pipe is - **[JEE - 1996, 2]**

(A) 200 Hz (B) 300 Hz (C) 240 Hz (D) 480 Hz

13. There is a set of four tuning forks, one with the lowest frequency vibrating at 550 Hz. By using any two tuning forks at a time, the following beat frequencies are heard: 1, 2, 3, 5, 7, 8. The possible frequencies of the other three forks are:

(A) 552, 553, 560 (B) 557, 558, 560 (C) 552, 553, 558 (D) 551, 553, 558

14. Two sound sources produce progressive waves given by y_1 =12 cos $100\pi t$ and y_2 = 4 cos $102\pi t$ near the ear of an observer. When sounded together, the observer will hear

(A) 2 beats per two sound source with an intensity ratio of maximum to minimum nearly 4 : 1

(B) 1 beat per second with an intensity ratio of maximum to minimum nearly $\sqrt{2}$: 1

(C) 2 beats per second with an intensity ratio of maximum to minimum nearly 9 : 1

(D) 1 beat per second with an intensity ratio of maximum to minimum nearly 4 : 1

15. A fixed source of sound emitting a certain frequency appears as f_a when the observer is approaching the source with speed v and frequency f_r when the observer recedes from the source with the same speed. The frequency of the source is

(A) $\frac{f_r + f_a}{2}$ (B) $\frac{f_a - f_r}{2}$ (C) $\sqrt{f_a f_r}$ (D) $\frac{2f_r f_a}{f_r + f_a}$

16. When a train approaches a stationary observer, the apparent frequency of the whistle is n' and when the same train recedes away from the observer, the apparent frequency is n''. Then the apparent frequency n when the observer sitting in the train is : **[REE 1997, 5]**

(A) $n = \frac{n' + n''}{2}$ (B) $n = \sqrt{n' n''}$ (C) $n = \frac{2n'n''}{n' + n''}$ (D) $n = \frac{2n'n''}{n' - n''}$

17. A police car moving at 22 m/s, chases a motorcyclist. The police man sounds his horn at 176 Hz, while both of them move towards a stationary siren of frequency 165 Hz. Calculate the speed of the motorcycle, if it is given that he does not observe any beats. (velocity of sound = 330 m/s) **[JEE-2003 (screening), 3/84]**

(A) 33 m/s (B) 22 m/s (C) zero (D) 11 m/s

18. 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 **[JEE - 2002 (Screening), 3/90]**

(A) $\frac{242}{252}$ (B) 2 (C) $\frac{5}{6}$ (D) $\frac{11}{6}$

19. A train moves towards a stationary observer with speed 34m/s. The train sounds a whistle and its frequency registered by the observer is f_1. If the train's speed is reduced to 17m/s, the frequency registered is f_2. If the speed of sound is 340m/s then the ratio f_1/f_2 is **[JEE - 2000 Screening, 1/35]**

(A) 18/19 (B) 1/2 (C) 2 (D) 19/18

20. A train blowing its whistle moves with a constant velocity v away from an observer on the ground. The ratio of the natural frequency of the whistle to that measured by the observer is found to be 1.2. If the train is at rest and the observer moves away from it at the same velocity, this ratio would be given by: **[JEE - 1993]**

(A) 0.51 (B) 1.25 (C) 1.52 (D) 2.05

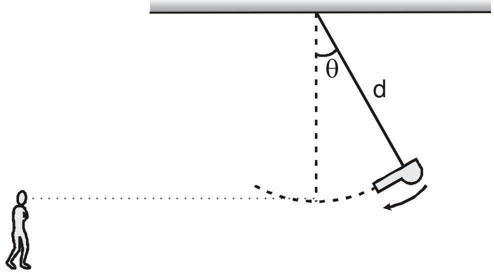
21. In the case of sound waves, wind is blowing from source to receiver with speed U_W. Both source and receiver are stationary. If λ_0 is the original wavelength with no wind and V is speed of sound in air then wavelength as received by the receiver is given by :

(A) λ_0 (B) $\left(\frac{V + U_w}{V}\right)\lambda_0$ (C) $\left(\frac{V - U_w}{V}\right)\lambda_0$ (D) $\left(\frac{V}{V + V_w}\right)\lambda_0$

22. Two sound sources each emitting sound of wavelength λ are fixed some distance apart. A listener moves with a velocity u along the line joining the two sources. The number of beats heard by him per second is

(A) $\frac{2u}{\lambda}$ (B) $\frac{u}{\lambda}$ (C) $\frac{u}{3\lambda}$ (D) $\frac{2\lambda}{u}$

23. A source on a swing which is covering an angle θ from the vertical is producing a frequency ν. The source is distant d from the place of support of swing. If velocity of sound is c, acceleration due to gravity is g, then the maximum and minimum frequency heard by a listener in front of swing is



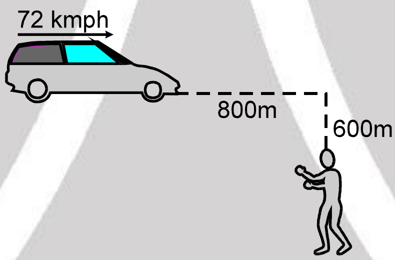
(A) $\frac{c\nu}{\sqrt{2gd}-c}$, $\frac{c\nu}{\sqrt{2gd}+c}$

(B) $\frac{c\nu}{\sqrt{2gd(1-\cos\theta)}-c}$, $\frac{c\nu}{\sqrt{2gd(1-\cos\theta)}+c}$

(C) $\frac{c\nu}{c-\sqrt{2gd(1-\cos\theta)}}$, $\frac{c\nu}{c+\sqrt{2gd(1-\cos\theta)}}$

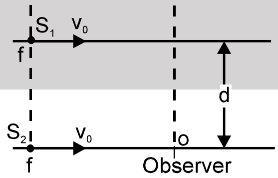
(D) $\frac{c\nu}{c-\sqrt{2gd(1-\sin\theta)}}$, $\frac{c\nu}{c+\sqrt{2gd(1-\sin\theta)}}$

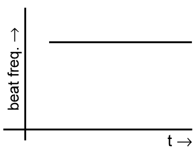
24. A car is approaching a railway crossing at a speed of 72 kmph. It sounds a horn, when it is 800 m away, at 600 Hz. If velocity of sound in air is 330 ms^{-1}, the apparent frequency as received by a man at rest near the railway track perpendicular to the road at a distance of 600 m from the crossing is

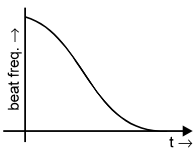


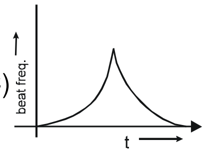
(A) 653 Hz (B) 365.5 Hz (C) 630.5 Hz (D) 563.5 Hz

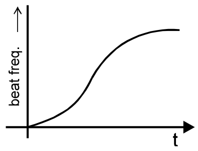
25. Two identical sources moving parallel to each other at separation ' d ' are producing sounds of frequency ' f ' and are moving with constant velocity v_0. A stationary observer ' O ' is on the line of motion of one of the sources. Then the variation of beat frequency heard by O with time is best represented by: (as they come from large distance and go to a large distance)



(A) 

(B) 

(C) 

(D) 

26. A source which is emitting sound of frequency f is initially at (– r, 0) and an observer is situated initially at (2r, 0). If observer and source both are moving with velocities $\vec{v}_{observer} = -\sqrt{2}V\hat{i} - \sqrt{2}V\hat{j}$ and $\vec{v}_{source} = \frac{V}{\sqrt{2}}\hat{i} + \frac{V}{\sqrt{2}}\hat{j}$, then which of the following is correct option ?

(A) Apparent frequency first increases, then decreases and observer observes the original frequency once during the motion.
(B) Apparent frequency first increases, then decreases and observer observes the original frequency twice during the motion.
(C) Apparent frequency first increases, then decreases during the motion and observer never observes the initial frequency.
(D) Apparent frequency continuously decreases and once during the motion, observer hears the original frequency.

27. Two identical loudspeakers, placed close to each other inside a room, are supplied with the same sinusoidal voltage. One can imagine a pattern around the loudspeakers with areas of increased and decreased sound intensity alternately located. Which of the following actions will NOT change the locations of these areas ? **[Olympiad 2016 stage–I]**
(A) Moving one of the speakers.
(B) Changing the amplitude of the signal voltage
(C) Changing the frequency of the signal voltage
(D) Replacing the air in the room with a different gas.

28. The frequency of the sound produced by a siren increases from 400 Hz to 1200 Hz while its amplitude remains the same. Therefore, the ratio of the intensity of the 1200 Hz wave to that of the 400 Hz wave is **[Olympiad 2016 stage–I]**
(A) 1 : 1 (B) 3 : 1 (C) 1 : 9 (D) 9 : 1

29._ A whistle whose air column is open at both ends has a fundamental frequency 500 Hz. The whistle is dipped in water such that half of it remains out of water. What will be the fundamental frequency now ? (speed of sound in air is 340 ms^{-1}) **[Olympiad (State-1) 2017]**
(A) 250 Hz (B) 125 Hz (C) 500 Hz (D) 1000 Hz

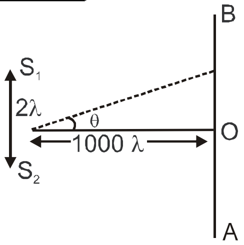
30._ A man stands at rest in front of a large wall. A sound source of frequency 400 Hz is placed between him and the wall. The source is now moved towards the wall at a speed of 1 m/s. The number of beats heard per second will be (speed of sound in air is 345 m/s) **[Olympiad (State-1) 2017]**
(A) 0.8 (B) 0.58 (C) 1.16 (D) 2.32

PART - II : SINGLE AND DOUBLE VALUE INTEGER TYPE

1. The temperature of air in a 900 m long tunnel varies linearly from 100 K at one end to 900 K at other end. If the speed of sound in air at 400 K is 360 m/s then time taken by sound to cross the tunnel is K second. Find 2K ?

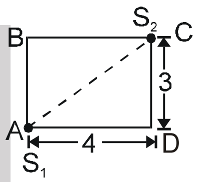
2. At certain instant the shape of a simple train of plane wave is y = 12 sin $\frac{\pi x}{50}$ (x and y are in cm.). The velocity of the wave propagation is 100 cm/s in a positive direction away from the origin. The equation giving the shape of the wave 0.25s later is y = 12 sin $\left(\frac{\pi x}{5a} - \frac{\pi}{b}\right)$. Find a × b

3.



Two coherent sources S_1 and S_2 (in phase with each other) are placed at a distance of 2λ as shown where λ is wavelength of sound. A detector moves on line A B parallel to S_1 S_2. If detector detects maximum intensity at finite distance from O at $\theta = \pm\left(\frac{\pi}{n}\right)$. Find n

4. Two coherent sources are placed at the corners of a rectangular track of sides 3 m & 4 m. The source S_1 lags S_2 by phase angle π. A detector is moved along path ABC. Then find:
The ratio of total number of minima detected on line AB to the total number of minima on line BC is $\frac{P}{Q}$ (in lowest form). Find P.Q [Velocity of sound = 330 m/s; Frequency of sources S_1 and S_2 = 165 Hz]



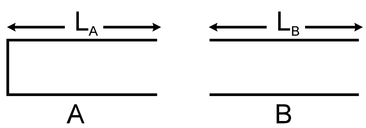
5. A man standing infront of a mountain beats a drum at regular intervals. The drumming rate is gradually increased and he finds that the echo is not heard distinctly when the rate becomes 40 per minute. He then moves near to the mountain by 90m and finds that the echo is again not heard when the drumming rate becomes 60 per minute. If the distance (in metre) between the mountain and the initial position of the man is x, Find x/10. **[JEE 1974]**

6. Loudness of sound from an isotropic point source at a distance of 10m is 20dB. If the distance at which it is not heard is 10^K in meters find K.

7. The equation of a longitudinal stationary wave in a metal rod is given by, $y = 0.002 \sin \frac{\pi x}{3} \sin 1000\pi t$, where x & y are in cm and t is in seconds. If maximum change in pressure (the maximum tensile stress) at the point x = 2cm is $\frac{1}{n}\times10^{-3}$ dyne/cm^2, Find n. Given young's modulus of the material is $\frac{3}{8\pi}$ dynes/cm^2.

8. A standing wave $\xi = a \sin kx.\cos \omega t$ is maintained in a homogeneous rod with cross-sectional area S and density ρ. If the total mechanical-energy confined between the sections corresponding to the adjacent displacement nodes is $\frac{1}{p}\ \pi S\rho\omega^2a^2/k$ Find p.

9. The two pipes are submerged in sea water, arranged as shown in figure. Pipe A with length L_A = 1.5 m and one open end, contains a small sound source that sets up the standing wave with the second lowest resonant frequency of that pipe. Sound from pipe A sets up resonance in pipe B, which has both ends open. The resonance is at the second lowest resonant frequency of pipe B. The length of the pipe B in meters is :



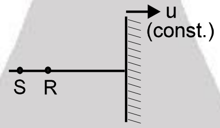
10. Two narrow cylindrical pipes A and B have the same length. Pipe A is open at both ends and is filled with a monoatomic gas of molar mass M_A. Pipe B is open at one end and closed at the other end, and is filled with a diatomic gas of molar mass M_B. Both gases are at the same temperature. Given the 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. Now If the open end of pipe B is also closed (so that the pipe is closed at both ends). The ratio of the fundamental frequency in pipe A to that in pipe B equal to p/q (in lowest form). Find pq

11. In the experiment for the determination of the speed of sound in air using the resonance column method, the length of the air column that resonates in the fundamental mode, with a tuning fork is 0.1 m. When this length is changed to 0.35 m, the same tuning fork resonates with first overtone. Calculate the end correction (in mm). **[JEE- 2003 (Screening), 3/84]**

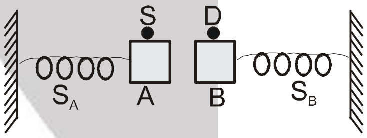
12. When a tuning fork vibrates with 1.0 m or 1.05 m long wire (both in same mode), 5 beats per second are produced in each case. If the frequency of the tuning fork is 5f (in Hz) find f. **[REE - 1998]**

13. A train moving towards a tunnel in a huge mountain with a speed of 12 m/s sounds its whistle. Sound is reflected from the mountain. If the driver hears 6 beats per second & speed of sound in air is 332 m/s, the frequency of the whistle is

14. S is source R is receiver. R and S are at rest. Frequency of sound from S is f. The beat frequency registered by R is $\frac{kuf}{v+u}$. Find k. Given, velocity of sound is v.



15. A source S emitting sound of 300 Hz is fixed on block A which is attached to the free end of a spring S_A as shown in figure. The detector D fixed on block B attached to free end of spring S_B detects this sound. The blocks A and B are simultaneously displaced towards each other through a distance of 2.0m and then left to vibrate. If the product of maximum and minimum frequencies of sound detected by D is K × 10^4 (sec^{-2}). Find K. Given the vibrational frequencies of each block is $5/\pi$ Hz. speed of sound in air = 300 m/s **[REE - 2001]**



16. Two vehicles A and B are moving towards each other with same speed u = 25m/s. They blow horns of the same frequency f = 550 Hz. Wind is blowing at speed w = 20 m/s in the direction of motion of A. The driver of vehicle A hears the sound of horn blown by vehicle B and the sound of horn of his own vehicle after reflection from the vehicle B. If difference of wavelength of both sounds received by A is $\frac{5}{P}$. Find P. Velocity of sound is = 320 m/s.

17. A source of sound revolving in a circle of radius 5 m is emitting a signal of frequency 320 Hz. It completes one revolution in $\frac{\pi}{2}$ seconds. If the difference between maximum and minimum frequencies of the signal heard at a point 30 m from the centre of the circle = $\frac{25}{7}P$. Find P. (Given speed of sound = 300 ms^{-1})] **[REE - 2000 Mains, 3]**

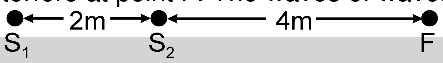
18. A source of sonic oscillations with frequency ν_0 = 1700 Hz and a receiver are located on the same normal to a wall. Both the source and the receiver are stationary, and the wall recedes from the source with velocity u = 6.0 m/s. Find the beat frequency (in Hz) registered by the receiver. The velocity of sound is equal to v = 340 m/s.

PART - III : ONE OR MORE THAN ONE OPTIONS CORRECT TYPE

1. In a wave motion $y = a \sin (kx - \omega t)$, y can represent : **[JEE - 1999, 3/200]**
(A) electric field (B) magnetic field (C) displacement (D) z pressure change

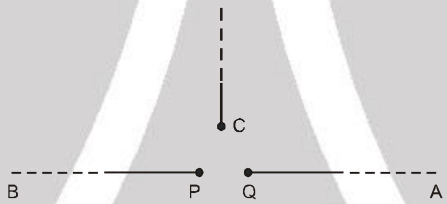
2. Which one of the following statements is incorrect for stable interference to occur between two waves?
(A) The waves must have the same wave length **[REE - 1993]**
(B) The waves must have a constant phase difference
(C) The waves must be transverse only
(D) The waves must have equal amplitudes.

3. S_1 and S_2 are two sources of sound emitting sine waves. The two sources are in phase. The sound emitted by the two sources interfere at point F. The waves of wavelength :



(A) 1 m will result in constructive interference (B) $\frac{2}{3}$ m will result in constructive interference
(C) 2m will result in destructive interference (D) 4m will result in destructive interference

4. Two monochromatic sources of electromagnetic wave, P and Q emit waves of wavelength $\lambda = 20$ m and separated by 5m as shown. A, B and C are three points where interference of these waves is observed. If phase of a wave generated by P is ahead of wave generated by Q by $\pi/2$ then (given intensity of both waves is I) :



C is symmetrical with respect to P and Q
(A) phase difference of these waves at B is 180°
(B) intensities at A,B and C are in the ratio 2 : 0 : 1 respectively.
(C) intensities at A,B and C are in the ratio 1 : 2 : 0 respectively.
(D) phase difference at A is 0°.

5. The energy per unit area associated with a progressive sound wave will be doubled if :
(A) the amplitude of the wave is doubled
(B) the amplitude of the wave is increased by 50%
(C) the amplitude of the wave is increased by 41%
(D) the frequency of the wave is increased by 41%

6. As a wave propagates : **[JEE - 1999, 3/200]**
(A) the wave intensity remains constant for a plane wave
(B) the wave intensity decreases as the inverse of the distance from the source for a spherical wave
(C) the wave intensity decreases as the inverse square of the distance from the source for a spherical wave
(D) total power of the spherical wave over the spherical surface centered at the source remains constant at all times .

7. At the closed end of an organ pipe :
(A) the displacement is zero (B) the displacement amplitude is maximum
(C) the pressure amplitude is zero (D) the pressure amplitude is maximum

8. A cylindrical tube, open at one end and closed at the other, is in acoustic unison (resonance) with an external source of sound of single frequency held at the open end of the tube, in its fundamental note. Then :
(A) the displacement wave from the source gets reflected with a phase change of π at the closed end
(B) the pressure wave from the source get reflected without a phase change at the closed end
(C) the wave reflected from the closed end again gets reflected at the open end
(D) the wave reflected from the closed end does not suffer reflection at the open end

9. The effect of making a hole exactly at ($1/3^{rd}$) of the length of the pipe from its closed end is such that
(A) its fundamental frequency is an octave higher than the open pipe of same length
(B) its fundamental frequency is thrice of that before making a hole
(C) the fundamental frequency is 3/2 time of that before making a hole
(D) the fundamental alone is changed while the harmonics expressed as ratio of fundamentals remain the same

10. It is desired to increase the fundamental resonance frequency in a tube which is closed at one end. This can be achieved by **[REE - 2000]**
(A) replacing the air in the tube by hydrogen gas (B) increasing the length of the tube
(C) decreasing the length of the tube (D) opening the closed end of the tube

11. In a resonance tube experiment, a closed organ pipe of length 120 cm is used. Initially it is completely filled with water. It is vibrated with tuning fork of frequency 340 Hz. To achieve resonance the water level is lowered then (given v_{air} = 340 m/sec., neglect end correction) :
(A) minimum length of water column to have the resonance is 45 cm.
(B) the distance between two successive nodes is 50 cm.
(C) the maximum length of water column to create the resonance is 95 cm.
(D) the distance between two successive nodes is 25 cm.

12. Two narrow organ pipes, one open (length ℓ_1) and the other closed (length ℓ_2) are sounded in their respective fundamental modes. The beat frequency heard is 5 Hz. If now the pipes are sounded in their first overtones, then also the beat frequency heard is 5 Hz. Then:
(A) $\frac{\ell_1}{\ell_2} = \frac{1}{2}$ (B) $\frac{\ell_1}{\ell_2} = \frac{1}{1}$ (C) $\frac{\ell_1}{\ell_2} = \frac{3}{2}$ (D) $\frac{\ell_1}{\ell_2} = \frac{2}{3}$

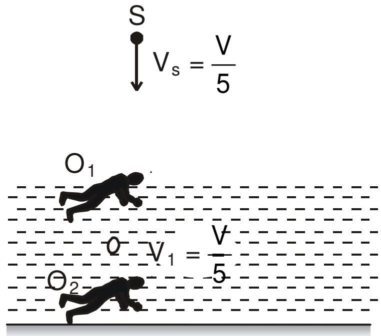
13. Two identical straight wires are stretched so as to produce 6 beats/sec. when vibrating simultaneously. n changing the tension slightly in one of them, the beat frequency remains unchanged. Denoting by T_1, T_2, the higher & the lower initial tensions in the strings, then it could be said that while making the above changes in tension: **[JEE 1991, 2]**
(A) T_2 was decreased (B) T_2 was increased (C) T_1 was increased (D) T_1 was decreased

14. A source and an observer are at rest w.r.t ground. Which of the following quantities will remain same, if wind blows from source to observer ?
(A) Frequency (B) speed of sound (C) wavelength (D) Time period

15. A girl stops singing a pure note. She is surprised to hear an echo of higher frequency, i.e., a higher musical pitch. Then :
(A) there could be some warm air between the girl and the reflecting surface
(B) there could be two identical fixed reflecting surfaces, one half a wavelength of the sound wave away from the other
(C) the girl could be moving towards a fixed reflector
(D) the reflector could be moving towards the girl

16*. A sound wave of frequency ν travels horizontally to the right. It is reflected from a large vertical plane surface moving to left with a speed u. The speed of sound in medium is c. **[JEE - 1995]**
(A) The number of waves striking the surface per second is $\frac{(c+u)}{c}\nu$
(B) The wavelength of reflected wave is $\frac{c(c-u)}{\nu(c+u)}$
(C) The frequency of the reflected wave as observed by the stationary observer is $\nu\frac{(c+u)}{(c-u)}$
(D) The number of beats heard by a stationary listener to the left of the reflecting surface is $\frac{u\nu}{c-u}$

17. In the figure shown an observer O_1 floats (static) on water surface with ears in air while another observer O_2 is moving upwards with constant velocity $V_1 = V/5$ in water. The source moves down with constant velocity $V_s = V/5$ and emits sound of frequency 'f'. The velocity of sound in air is V and that in water is 4V. For the situation shown in figure :



(A) The wavelength of the sound received by O_1 is $\frac{4V}{5f}$

(B) The wavelength of the sound received by O_1 is V/f

(C) The frequency of the sound received by O_2 is $\frac{21f}{16}$

(D) The wavelength of the sound received by O_2 is $\frac{16V}{5f}$

18. A tuning fork is vibrating with constant frequency and amplitude. If the air is heated without changing pressure the following quantities will increase.
(A) Wavelength (B) Frequency (C) Velocity (D) Time period

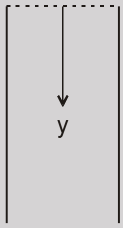
19. Two sound waves move in the same direction in the same medium. The pressure amplitude of the waves are equal but the wavelength of the first wave is double that of the second. Let the average power transmitted across a cross section by the two wave be P_1 and P_2 and their displacement amplitudes be s_1 and s_2 then
(A) $P_1/P_2 = 1$ (B) $P_1/P_2 = 2$ (C) $s_1/s_2 = 1/2$ (D) $s_1/s_2 = 2/1$

20. Two tuning forks A & B produce notes of frequencies 256 Hz & 262 Hz respectively. An unknown note sounded at the same time with A produces beats. When the same note is sounded with B, beat frequency is twice as large. The unknown frequency could be:
(A) 268 Hz (B) 250 Hz (C) 260 Hz (D) 258 Hz

PART - IV : COMPREHENSION

Comprehension-1

In an organ pipe (may be closed or open) of 99 cm length standing wave is setup, whose equation is given by longitudinal displacement $\xi = (0.1 \text{ mm}) \cos \frac{2\pi}{80} (y + 1 \text{ cm}) \cos 2\pi(400)\, t$ where y is measured from the top of the tube in centimeters and t in second. Here 1 cm is the end correction.



1. The upper end and the lower end of the tube are respectively:
(A) open – closed (B) closed – open (C) open – open (D) closed – closed

2. The air column is vibrating in
(A) First overtone (B) Second overtone (C) Third harmonic (D) Fundamental mode

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

(A) $P_{ex} = (125\, \pi \text{N/m}^2) \sin \frac{2\pi}{80} (y + 1 \text{ cm}) \cos 2\pi(400t)$

(B) $P_{ex} = (125\, \pi \text{N/m}^2) \cos \frac{2\pi}{80} (y + 1 \text{ cm}) \sin 2\pi(400t)$

(C) $P_{ex} = (225\, \pi \text{N/m}^2) \sin \frac{2\pi}{80} (y + 1 \text{ cm}) \cos 2\pi(200t)$

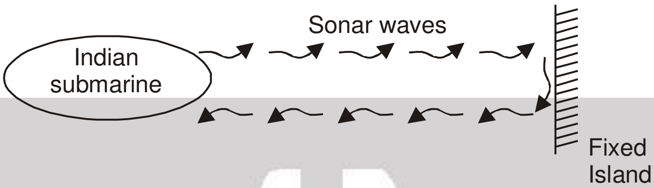
(D) $P_{ex} = (225\, \pi \text{N/m}^2) \cos \frac{2\pi}{80} (y + 1 \text{ cm}) \sin 2\pi(200t)$

4. Assume end correction approximately equals to (0.3) × (diameter of tube), estimate the approximate number of moles of air present inside the tube (Assume tube is at NTP, and at NTP, 22.4 litre contains 1 mole)

(A) $\frac{10\pi}{36 \times 22.4}$ (B) $\frac{10\pi}{18 \times 22.4}$ (C) $\frac{10\pi}{72 \times 22.4}$ (D) $\frac{10\pi}{60 \times 22.4}$

Comprehension-2

An Indian submarine is moving in "Arab Sagar" with a constant velocity. To detect enemy it sends out sonar waves which travel with velocity 1050 m/s in water. Initially the waves are getting reflected from a fixed island and the reflected waves are coming back to submarine. The frequency of reflected waves are detected by the submarine and found to be 10% greater than the sent waves.



Now an enemy ship comes in front, due to which the frequency of reflected waves detected by submarine becomes 21% greater than the sent waves.

5. The speed of Indian submarine is
(A) 10 m/sec (B) 50 m/sec (C) 100 m/sec (D) 20 m/sec.

6. The velocity of enemy ship should be :
(A) 50 m/sec. toward Indian submarine. (B) 50 m/sec. away from Indian submarine.
(C) 100 m/sec. toward Indian submarine. (D) 100 m/sec. away from Indian submarine.

7. If the wavelength received by enemy ship is λ' and wavelength of reflected waves received by submarine is λ'' then $\left(\frac{\lambda'}{\lambda''}\right)$ equals
(A) 1 (B) 1.1 (C) 1.2 (D) 2

8. Bulk modulus of sea water should be approximately ($\rho_{water} = 1000$ kg/m^3)
(A) 10^8 N/m^2 (B) 10^9 N/m^2 (C) 10^{10} N/m^2 (D) 10^{11} N/m^2

Exercise-3

*** Marked Questions may have more than one correct option.**
Marked Questions can be used as Revision Questions.

PART - I : JEE (ADVANCED) / IIT-JEE PROBLEMS (PREVIOUS YEARS)

Paragraph for Question Nos. 1 to 3

Two plane harmonic sound waves are expressed by the equations. **[JEE' 2006, 5 × 3 = 15 /184]**

$y_1(x, t) = A \cos (0.5\ \pi x - 100\ \pi t)$

$y_2(x, t) = A \cos (0.46\ \pi x - 92\ \pi t)$

(All parameters are in MKS) :

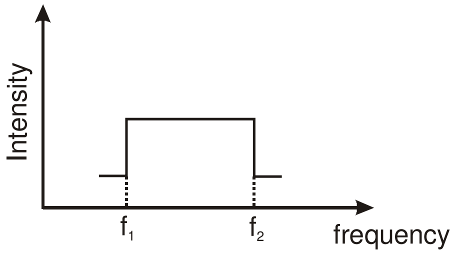
1. How many times does an observer hear maximum intensity in one second ?
(A) 4 (B) 10 (C) 6 (D) 8

2. What is the speed of the sound ?
(A) 200 m/s (B) 180 m/s (C) 192 m/s (D) 96 m/s

3. At x = 0 how many times $y_1 + y_2$ is zero in one second ?
(A) 192 (B) 48 (C) 100 (D) 96

Paragraph for Question Nos. 4 to 6

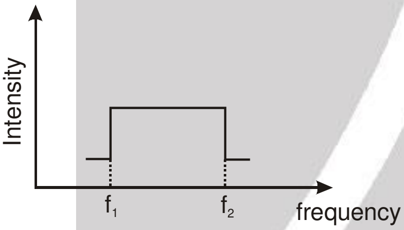
Two trains A and B are moving with speeds 20 m/s and 30 m/s respectively in the same direction on the same straight track, with B ahead of A. The engines are at the front ends. The engines of train A blows a long whistle. **[JEE' 2007, 4 × 3 = 12 /81]**

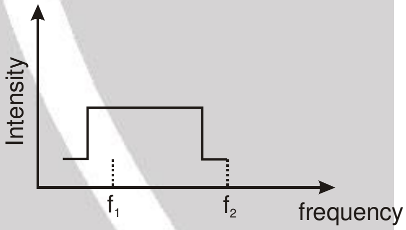


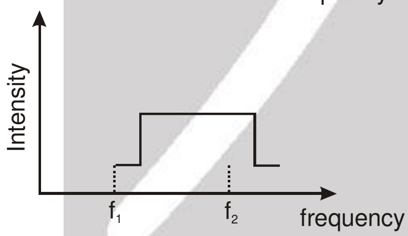
Assume that the sound of the whistle is composed of components varying in frequency from f_1 = 800 Hz to f_2 = 1120 Hz, as shown in the figure. The spread in the frequency (highest frequency – lowest frequency) is 320 Hz. The speed of sound in still air is 340 m/s. **[JEE' 2007, 4 × 3 = 12 /81]**

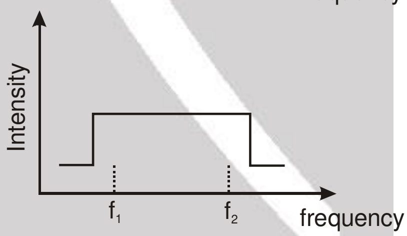
4. The speed of sound of the whistle is
(A) 340 m/s for passengers in A and 310 m/s for passengers in B
(B) 360 m/s for passengers in A and 310 m/s for passengers in B
(C) 310 m/s for passengers in A and 360 m/s for passengers in B
(D) 340 m/s for passengers in both the trains

5. The distribution of the sound intensity of the whistle as observed by the passengers in train A is best represented by

(A) 

(B) 

(C) 

(D) 

6. The spread of frequency as observed by the passengers in train B is
(A) 310 Hz (B) 330 Hz (C) 350 Hz (D) 290 Hz

7. A vibrating string of certain length ℓ under a tension T resonates with a mode corresponding to the first overtone (third harmonic) of an air column of length 75 cm inside a tube closed at one end. The string also generates 4 beats per second when excited along with a tuning fork of frequency n. Now when the tension of the string is slightly increased the number of beats reduces to 2 per second. Assuming the velocity of sound in air to be 340 m/s, the frequency n of the tuning fork in Hz is **[JEE' 2008, 3/163]**
(A) 344 (B) 336 (C) 117.3 (D) 109.3

8.* A student performed the experiment to measure the speed of sound in air using resonance air-column method. Two resonances in the air-column were obtained by lowering the water level. The resonance with the shorter air-column is the first resonance and that with the longer air-column is the second resonance. Then, **[JEE' 2009, 4/160, –1]**
(A) the intensity of the sound heard at the first resonance was more than that at the second resonance
(B) the prongs of the tuning fork were kept in a horizontal plane above the resonance tube
(C) the amplitude of vibration of the ends of the prongs is typically around 1 cm
(D) the length of the air-column at the first resonance was somewhat shorter than 1/4th of the wavelength of the sound in air. **[JEE' 2009, 4/160, –1]**

9. A stationary source is emitting sound at a fixed frequency f_0, which is reflected by two cars approaching the source. The difference between the frequencies of sound reflected from the cars is 1.2% of f_0. What is the difference in the speeds of the cars (in km per hour) to the nearest integer ? The cars are moving at constant speeds much smaller than the speed of sound which is 330 ms^{-1}. **[JEE' 2010, 3/163]**

10. A hollow pipe of length 0.8 m is closed at one end. At its open end a 0.5 m long uniform string is vibrating in its second harmonic and it resonates with the fundamental frequency of the pipe. If the tension in the wire is 50 N and the speed of sound is 320 ms^{-1}, the mass of the string is : **[JEE' 2010, 5/163, –2]**

(A) 5 grams (B) 10 grams (C) 20 grams (D) 40 grams

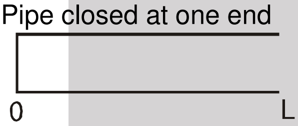
11. A police car with a siren of frequency 8 kHz is moving with uniform velocity 36 km/hr towards a tall building which reflects the sound waves. The speed of sound in air is 320 m/s. The frequency of the siren heard by the car driver is **[JEE' 2011, 3/160, –1]**

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

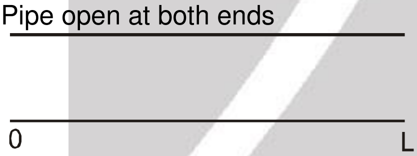
12. Column I shows four systems, each of the same length L, for producing standing waves. ' The lowest possible natural frequency of a system is called its fundamental frequency, whose wavelength is denoted as λ_f. Match each system with statements given in Column II describing the nature and wavelength of the standing waves. **[JEE' 2011, 8/160]**

Column I

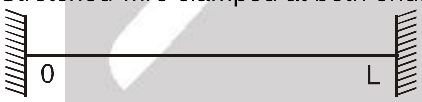
(A) Pipe closed at one end



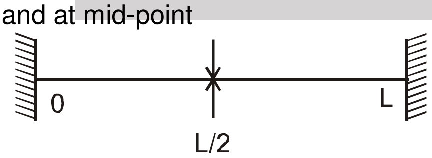
(B) Pipe open at both ends



(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) $\lambda_f = 4L$

13*. 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. **[IIT-JEE-2012, Paper-1; 4/70]**

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

14. A student is performing the experiment of Resonance Column. The diameter of the column tube is 4cm. The distance 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. When first resonance occurs, the reading of the water level in the column is

[IIT-JEE-2012, Paper-2; 3/66, –1]

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

15*. Two vehicles, each moving with speed u on the same horizontal straight road, are approaching each other. Wind blows along the road with velocity w. One of these vehicles blows a whistle of frequency f_1. An observer in the other vehicle hears the frequency of the whistle to be f_2. The speed of sound in still air is V. The correct statement(s) is (are) : **[JEE (Advanced) 2013, P-2, 3/60, –1]**

(A) If the wind blows from the observer to the source, $f_2 > f_1$.
(B) If the wind blows from the source to the observer, $f_2 > f_1$.
(C) If the wind blows from the observer to the source, $f_2 < f_1$.
(D) If the wind blows from the source to the observer, $f_2 < f_1$.

16. 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 ± 0.005) m, the gas in the tube is **[JEE (Advanced) 2014, P-1, 3/60]**

(Useful information) : $\sqrt{167RT} = 640 j^{1/2}$ $mole^{-1/2}$; $\sqrt{140RT} = 590 j^{1/2}$ $mole^{-1/2}$. The molar masses M in grams are given in the options. Take the value of $\sqrt{\frac{10}{M}}$ for each gas as given there.)

(A) Neon (M = 20, $\sqrt{\frac{10}{20}} = \frac{7}{10}$) (B) Nitrogen (M = 28, $\sqrt{\frac{10}{28}} = \frac{3}{5}$)

(C) Oxygen (M = 32, $\sqrt{\frac{10}{32}} = \frac{9}{16}$) (D) Argon (M = 36, $\sqrt{\frac{10}{36}} = \frac{17}{32}$)

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

[JEE (Advanced) 2015 ; P-2,4/88]

18 A stationary source emits sound of frequency f_0 = 492 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 ; P-1, 3/61]

19. 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 ; P-1, 3/60]

20*. 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 ; P-2, 3/60, –2]**

(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

PART - II : JEE (MAIN) / AIEEE PROBLEMS (PREVIOUS YEARS)

1. A whistle producing sound waves of frequencies 9500 Hz and above is approaching a stationary person with speed v ms^{-1}. The velocity of sound in air is 300 ms^{-1}. If the person can hear frequencies upto a maximum of 10,000 Hz, the maximum value of v upto which he can hear the whistle is: **[AIEEE 2006, 3/180]**

(1) 30 ms^{-1} (2) $15\sqrt{2}$ ms^{-1} (3) $\frac{15}{\sqrt{2}}$ ms^{-1} (4) 15 ms^{-1}

2. A sound absorber attenuates the sound level by 20 dB. The intensity decreases by a factor of :
[AIEEE 2007, 3/120, –1]

(1) 1000 (2) 10000 (3) 10 (4) 100

3. The speed of sound in oxygen (O_2) at a certain temperature is 460 ms^{-1}. The speed of sound in helium (He) at the same temperature will be (assume both gases to be ideal) : **[AIEEE 2008, 3/105, –1]**

(1) 500 ms^{-1} (2) 650 ms^{-1} (3) 330 ms^{-1} (4) 460 ms^{-1}

4. While measuring the speed of sound by performing a resonance column experiment, a student gets the first resonance condition at a column length of 18 cm during winter. Repeating the same experiment during summer, she measures the column length to be x cm for the second resonance. Then **[AIEEE 2008, 3/105, –1]**

(1) x > 54 (2) 54 > x > 36 (3) 36 > x > 18 (4) 18 > x

5. A motor cycle starts from rest and accelerates along a straight path at 2 m/s^2. At the starting point of the motor cycle there is a stationary electric siren. How far has the motor cycle gone when the driver hears the frequency of the siren at 94% of its value when the motor cycle was at rest? (Speed of sound = 330 ms^{-1}) **[AIEEE 2009, 4/144]**

(1) 98 m (2) 147 m (3) 196 m (4) 49 m

6. 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, 4/120, –1]

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

7. 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; 4/120, –1]**

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

8. A pipe open at both ends has 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; 4/120, –1]**

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

9. An observer is moving with half the speed of light towards stationary microwave source emitting waves at frequency 10GHz. What is the frequency of the microwave measured by the observer ? (speed of light = $3 \times 10^8 ms^{-1}$) **[JEE (Main) 2017 ; 4/120, –1]**

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

10. A granite rod of 60 cm length is clamped at its middle point and is set into longitudinal vibrations. The density of granite is 2.7×10^3 kg/m^3 and its Young's modulus is 9.27×10^{10} Pa. What will be the fundamental frequency of the longitudinal vibrations ? **[JEE (Main) 2018; 4/120, –1]**

(1) 10kHz (2)7.5kHz (3) 5kHz (4) 2.5kHz

Answers

EXERCISE-1

PART - I

Section (A) :

A-1. 16 mm, 16 m

A-2. (a) $2\pi f\Delta t = 64\pi$ (b) $\frac{2\pi f\Delta x}{v} = \frac{\pi}{10}$

A-3. (a) $\frac{kA}{2\pi} = \frac{1}{20\pi}$ (b) $kA = \frac{1}{10}$

A-4. $\frac{P_0\lambda}{2\pi S_0} = \frac{8\times10^5}{\pi}$ N/m^2

A-5. 7.5 cm, 75 m

Section (B) :

B-1. $\frac{1000}{3}$ m/s **B-2.** 16

B-3. (a) ≈ 400.9 m/s (b) $\frac{1}{6}$ %

B-4. $V \cong 303.5$ m/s

Section (C) :

C-1. (a) $\frac{P_{0_w}}{P_{0_a}} = 60$ (b) $\frac{P_w}{P_a} = \frac{1}{3600}$

C-2. (a) 5Nm^{-2}, (b) 3 μm

Section (D) :

D-1. (a) π

(b) $I = \left(\sqrt{I_A} - \sqrt{I_B}\right)^2 = (25/312)^2$

D-2. 83 Hz **D-3.** 12.5cm **D-4.** 8.5 cm

D-5. 4 cm

Section (E) :

E-1. $y(x, t) = 2\times10^{-6} \sin 6\pi x \cos(6\sqrt{30}\,\pi \times 10^3 t + \theta)$

at x = 0.1

$y(0.1, t) = 2\times10^{-6}\sin\frac{6\pi}{10}\cos(6\sqrt{30}\,\pi\times10^3\, t + \theta)$

$y_1(x, t) = 1\times10^{-6}\sin(6\pi x + 6\sqrt{30}\,\pi\times10^3 t + \theta_1)$

$y_2(x, t) = 1\times10^{-6}\sin(6\pi x - 6\sqrt{30}\,\pi\times10^3 t + \theta_2)$

at x = 0.1

$y_1(0.1, t) = 1\times10^{-6}\sin(\frac{6\pi}{10} + 6\sqrt{30}\,\pi\times10^3 t + \theta_1)$

$y_2(0.1, t) = 1\times10^{-6}\sin(\frac{6\pi}{10} - 6\sqrt{30}\,\pi\times10^3 t + \theta_2)$

E-2. (a) f = 50 Hz, λ = 0.2 m, v = 10 ms^{-1}
(b) P_m = 62.8 Nm^{-2} = 20π Nm^{-2}, B = 100Nm^{-2}
(c) $\lambda/4$ = 0.05 m
(d) $I = 20\pi^2 \cong 200$ wm^{-2}

Section (F) :

F-1. a

F-2. 100 (2n + 1) Hz where n = 0, 1, 2, 3, ..., 9

F-3. 4.2 kHz **F-4.** 20 cm

F-5. 55 cm

F-6. 20, 80 cm, 200 Hz

F-7. (a) $v_n = \frac{v}{4\ell}(2n+1)$; six oscillations

(b) $v_n = \frac{v}{2\ell}(n+1)$, also six oscillations.

Here n = 0, 1, 2, ...

F-8. 56

F-9. fundamental frequency n = 20 Hz, depth of the well = 4.3

Section (G) :

G-1. 478 Hz **G-2.** 2 %

G-3. (a) 95 Hz (b) $\frac{40}{\pi}\times10^3$ kg/m^3

G-4. 27.0400 N

Section (H) :

H-1. (i) $f' = \frac{fc}{c-v}$

(ii) $\lambda' = \lambda - \left(\frac{v}{f}\right) = \left(\frac{c}{f}\right) - \left(\frac{v}{f}\right) = \left(\frac{c-v}{f}\right)$

(iii) $f'' = f\,\frac{c\ \ +v}{c-v}$

(iv) $f_{beat} = f\,\frac{2v}{c-v}$

H-2. decreases by $\frac{2u}{(v+u)} = 0.2$ %

H-3. R_1, $f_{beat} = 2f_0 vu/(v^2 - u^2) \approx \frac{2f_0 u}{v} = 1.0$ Hz

H-4. $\frac{c-v}{c+v}f$ **H-5.** 20 m/s

H-6. 160 Hz

PART - II

Section (A) :

A 1.	(D)	**A 2.**	(A)	**A 3.**	(A)

Section (B) :

B 1.	(B)	**B 2.**	(A)	**B 3.**	(A)
B 4.	(A)				

Section (C) :

C 1.	(B)	**C 2.**	(C)	**C 3.**	(D)

Section (D) :

D 1.	(D)	**D 2.**	(D)	**D 3.**	(B)
D 4.	(A)	**D-5.**	(B)		

Section (E) :

E 1.	(A)

Section (F) :

F 1.	(C)	**F 2.**	(B)	**F 3.**	(B)
F 4.	(C)	**F 5.**	(C)	**F 6.**	(B)
F 7.	(B)				

Section (G) :

G 1.	(A)	**G 2.**	(B)	**G 3.**	(A)

Section (H) :

H 1.	(D)	**H 2.**	(C)	**H 3.**	(B)
H 4.	(D)	**H-5.**	(B)		

PART - III

1. (A) $\rightarrow$ p, q ; (B) $\rightarrow$ q, s ; (C) $\rightarrow$ r ; (D) $\rightarrow$ s,q
2. (A) $\rightarrow$ (r); (B) $\rightarrow$ (s); (C) $\rightarrow$ (p); (D) $\rightarrow$ (q)
3. (A) $\rightarrow$ q, r ; (B) $\rightarrow$ p ; (C) $\rightarrow$ q, s ; (D) $\rightarrow$ p

EXERCISE-2

PART - I

1.	(D)	**2.**	(B)	**3.**	(A)
4.	(B)	**5.**	(B)	**6.**	(A)
7.	(D)	**8.**	(C)	**9.**	(B)
10.	(B)	**11.**	(C)	**12.**	(A)
13.	(D)	**14.**	(D)	**15.**	(A)
16.	(C)	**17.**	(B)	**18.**	(B)
19.	(D)	**20.**	(B)	**21.**	(B)
22.	(A)	**23.**	(C)	**24.**	(C)
25.	(C)	**26.**	(D)	**27.**	(B)
28.	(D)	**29.**	(C)	**30.**	(D)

PART - II

1.	5	**2.**	20	**3.**	6
4.	6	**5.**	27	**6.**	2
7.	8	**8.**	4	**9.**	2
10.	12	**11.**	25	**12.**	41
13.	80	**14.**	2	**15.**	9
16.	73	**17.**	12	**18.**	59

PART - III

1.	(ABCD)	**2.**	(CD)	**3.**	(ABD)
4.	(ABD)	**5.**	(CD)	**6.**	(ACD)
7.	(AD)	**8.**	(ABC)	**9.**	(BD)
10.	(ACD)	**11.**	(ABC)	**12.**	(BC)
13.	(BD)	**14.**	(AD)	**15.**	(CD)
16.	(ABC)	**17.**	(ACD)	**18.**	(AC)
19.	(AD)	**20.**	(BD)		

PART - IV

1.	(A)	**2.**	(B)	**3.**	(A)
4.	(A)	**5.**	(B)	**6.**	(A)
7.	(B)	**8.**	(B)		

EXERCISE-3

PART - I

1.	(A)	**2.**	(A)	**3.**	(C)
4.	(B)	**5.**	(A)	**6.**	(A)
7.	(A)	**8.**	(AD)	**9.**	7
10.	(B)	**11.**	(A)		
12.	(A) – p,t , (B) – p,s, (C) – q,s, (D) – q, r				
13.	(BD)	**14.**	(B)	**15.**	(AB)
16.	(D)	**17.**	3	**18.**	6
19.	5.00	**20.**	(AC)		

PART - II

1.	(4)	**2.**	(4)	**3.**	[BONUS]
4.	(1)	**5.**	(1)	**6.**	(3)
7.	(2)	**8.**	(3)	**9.**	(4)
10.	(3)				

High Level Problems (HLP)

SUBJECTIVE QUESTIONS

1. A whistle emitting a sound of frequency 440 Hz is tied to a string of 1.5 m length and rotated with an angular velocity of 20 rad s^{-1} in the horizontal plane. Calculate the range of frequencies heard by an observer stationed at a large distance from the whistle in same horizontal plane. (v_{sound} = 330 m/s) **[JEE - 1996, 3]**

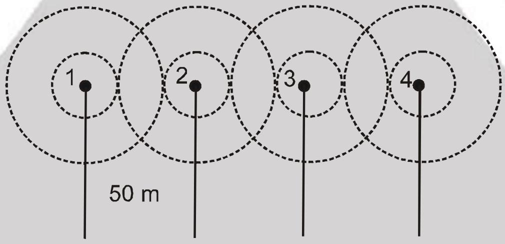
2. When 0.98 m long metallic wire is stretched, an extension of 0.02 m is produced. An organ pipe 0.5 m long & open at both ends, when sounded with this stressed metallic wire, produces 8 beats in its fundamental mode of both the instruments. By decreasing the strain in the wire, the number of beats are found to decrease. Find Young's modulus of the wire. The density of metallic wire is 10^4 kgm^{-3} & sound velocity in air is 292 ms^{-1}. **[REE – 1996, 5]**

3. A point sound source is located on the perpendicular to the plane of a ring drawn through the centre O of the ring. The distance between the point O and the source is ℓ = 1.00 m, the radius of the ring is R = 0.50 m. If the mean energy flow rate across the area enclosed by the ring is x_0 (in μW). Find $\frac{x_0}{5}$.
Given, at the point O the intensity of sound is equal to I_0 = 30 μW/m^2 and assuming the damping of the waves is negligible.

4. Two observers A and B carry identical sound sources of frequency 256 Hz. If A is stationary while B moves away from A at a speed of 10 m/s, how many beats per second are heard by A and B ? (c = 343 m/s)

5. Two transverse sine waves, each of amplitude 4mm wavelength 2m and time period 1s and in phase at x = 0, t = 0 are travelling along the x-axis in opposite direction. Obtain the equation of the resultant wave and comment on its nature calculate the maximum displacement at x = 2.333 m. Also locate the antinodes and nodes.

6. A radio station broadcasting at a frequency of 1500 kHz generates a directional beam by using an array of 4 point source antennas driver in phase with each other by the same transmitter. The antennas are arranged along an east west line so that each antenna is 50 m from the next one.



(a) In what direction will be radiated signal be greatest ?
(b) How much signal radiates in east west direction.

7. Two organ pipes are identical except that one is filled with oxygen and other filled with a mixture of oxygen and nitrogen. The temperature and total pressure in each pipe are also the same. When the two are sounded together a note of 440 Hz is heard and beats once every second. What is the percentage partial pressure of the nitrogen in the mixture ? Assume that the molecular weight of oxygen is 32 and of nitrogen 28, and their principal specific heats are identical.

8. A tube 1.0 m long is closed at one end. A wire of length 0.3 m and mass 1 × 10^{-2} kg is stretched between two fixed ends and is placed near the open end. When the wire is plucked at its mid point the air column resonates in its 1st overtone. Find the tension in the wire if it vibrates in its fundamental mode. [V_{sound} = 330 m/s]

9. The first overtone of an open organ pipe beats with the first overtone of a closed organ pipe with a beat frequency of 2.2 Hz. The fundamental frequency of the closed organ pipe is 110 Hz. Find the lengths of the pipes. (v_{sound} = 330 m/s) **[JEE - 1997, 5]**

10. A band playing music at a frequency f is moving towards a wall at a speed v_b. A motorist is following the band with a speed v_m. If v is the speed of sound, obtain an expression for the beat frequency heard by the motorist. **[JEE - 1997, 5]**

11. A 3 m long organ pipe open at both ends is driven to third harmonic standing wave. If the amplitude of pressure oscillation is 0.1 % of the mean atmospheric pressure ($P_0 = 10^5$ N/m^2). Find the amplitude of : (i) particle oscillation and (ii) density oscillation. Speed of sound v = 330 m/s, density of air $\rho_0 = 1.0$ kg/m^3.

12. 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.
(i) Find the length L of the air column. **[JEE - 1998, 8/200]**
(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 ?

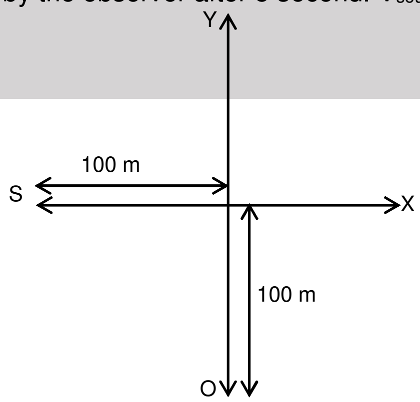
13. A source of sonic oscillations with frequency f = 1700 Hz and a receiver are located at the same point. At the moment t = 0 the source starts receding from the receiver with constant acceleration a = 10.0 m/s^2. Find the oscillation frequency registered by the stationary receiver at t = 10.0 second after the start of the motion, assuming the velocity of the sound to be equal to v = 340m/s. [You can find the answer in variables]

14. A source is moving across a circle given by the equation $x^2 + y^2 = R^2$ with constant speed $v_S = \dfrac{330\pi}{6\sqrt{3}}$ m/s. in clockwise sense. A detector is stationary at the point (2R, 0) w.r.t. the centre of the circle. The frequency emitted by the source is f_S
(a) What are the co-ordinates of the source when the detector records the maximum and minimum frequencies.
(b) Find these frequencies. Take speed of sound v = 330 m/s.

15. A sonar system fixed in a submarine operates at a frequency 40 KHz. An enemy submarine moves towards the sonar with a speed of 360 Km/h. What is frequency (approximate) of sound received to sonar system, reflected by the submarine? Given : V_{sound} = 1450 m/s in water.

16. A road passes at some distance from a standing man. A truck is coming on the road with some acceleration. The truck driver blows a whistle of frequency 500 Hz when the line joining the truck and the man makes an angle θ with the road. The man hears a note having a frequency of 600 Hz when the truck is closest to him. Also the speed of truck has got doubled during this time. Find the value of 'θ'.

17. At t = 0, a source of sonic oscillations S and on observer O start moving along x and y axes with 5 m/s and 10 m/s. The figure shows their positions at t = 0. If frequency of source is 1000 Hz. Find the frequency of signals received by the observer after 5 second. V_{sound} = 330 m/sec.



18. A point sound source is located on the perpendicular to the plane of a ring drawn through the centre O of the ring. The distance between the point O and the source is ℓ = 1.00 m, the radius of the ring is R = 0.50 m. Find the mean energy flow rate across the area enclosed by the ring if at the point O the intensity of sound is equal to I_0 = 30 μW/m^2. The damping of the waves is negligible.

HLP Answers

1. $f_{max} = 484$ Hz, $f_{min} = 403.3$ Hz **2.** $Y = 1.76 \times 10^{11}$ N/m^2 **3.** 4

4. Number of beats = 7.5 s^{-1} and 0.725 s^{-1}

5. $y_1 + y_2 = 4 \times 10^{-3}\left[\sin 2\pi\left(t - \frac{x}{2}\right) + \sin 2\pi\left(t + \frac{x}{2}\right)\right]$

At t = 0 and x = 0, $y_1 + y_2 = 0$
At x = 2.333, $y_1 + y_2 = 4 \times 10^{-3}$ m
Autinodes at x = 1, 2

Nodes at x = $\frac{1}{2}$, $\frac{3}{2}$

6. (a) maximum in a direction perpendicular to the array (b) net signal in EW direction is zero.

7. 3.6% **8.** 735 N **9.** $L_c = 0.75$ m ; $L_o = 0.99$ m or 1.006 m

10. $\frac{2v_b(v + v_m)f}{v^2 - v_b^2}$ **11.** (i) $\frac{1}{1089\,\pi}$ m (ii) $\frac{1}{1089}$ kg/m^3

12. (i) $L = \frac{15}{16}$ m (ii) $\frac{\Delta P_0}{\sqrt{2}}$ (iii) $P_{max} = P_{min} = P_0$ (iv) $P_{max} = P_0 + \Delta P_0$, $P_{min} = P_0 - \Delta P_0$

13. $f = \frac{2\,V\,v_0^2}{2v_0\sqrt{V^2 + 2aVt} + a} \cong \frac{V\,v_0}{\sqrt{V^2 + 2aVt}} \cong 1.35$ khz

14. $\left(\frac{\sqrt{3}R}{2}, \frac{R}{2}\right)$, (0, – R) $f'_{min} = \frac{6\sqrt{3}}{6\sqrt{3} + \pi}\,f_S$; $f'_{max} = \frac{6\sqrt{3}}{6\sqrt{3} - \pi}\,f_S$

15. 46 KHz **16.** $\theta = 60^{\circ}$ **17.** $\frac{33\sqrt{13} + 2}{33\sqrt{13} - 1.5} \equiv 1030$ Hz

18. $< \phi > = 2\pi\ell^2 I_0\left(1 - \frac{1}{\sqrt{1 + (R/\ell)^2}}\right) = 20\ \mu W.$