PHYSICS

BOOKS - ARIHANT PHYSICS (HINGLISH)

WAVE MOTION

Level 1

1. A boy is jerking one end of a taut string. The wave train propagating to the right has been shown in the figure.

(a) Why the crests are farther apart as we move away from the boy.

(b) Which particle on the string a or b is having higher speed?

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2. A transverse wave is travelling along a horizontal string. The first figure is the shape of the string at an instant of time. The second picture is a graph of the vertical displacement of a point on the string as a function of time. How far does this wave travel along the string in one second? ,

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3.

The figure shows the shape of three strings on which sinusoidal transverse waves are propagating. The arrows in the diagram indicate the direction of wave propagation. Out of the 6 particles marked (1, 2, 3, 4, 5, 6) how many have their instantaneous velocity and acceleration both directed towards their mean position.

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4. Consider a function

$$y = 5.0e^{\left(-25x^2 - 9t^2 - 30xt \right)}$$

(a) Does this represent a travelling wave?

(b) What is direction of propagation of the wave?

(c) Find wave speed.

(d) Sketch the wave at t = 0

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5. A hypothetical pulse is travelling along positive x direction on a taut string. The speed of the pulse is $10cms^{-1}$. The shape of the pulse at t = 0 is given as

$$y = \frac{x}{6} + 1 \quad \text{for} \quad -6 < x \leq 0$$
$$= -x + 1 \quad \text{for} \quad 0 \leq x < 1$$
$$= 0 \quad \text{for all other values of x}$$

x and y are in cm.

(a) Find the vertical displacement of the particle at x = 1 cm at t = 0.2 s

(b) Find the transverse velocity of the particle at x = 1 cm at t = 0.2 s.

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6. Which of the following functions does not satisfy the differential wave equation -

(i) $y = 4e^{K(x - vt)}$

(ii) $y = 2\sin(5t)\cos(6\pi x)$

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7. A transverse harmonic wave of amplitude 4 mm and wavelength 1.5 m is travelling in positive x direction on a stretched string. At an instant, the particle at $x = 1.0$ m is at $y = +2$ mm and is travelling in positive y direction. Find the co-ordinate of the nearest particle $(x > 1.0m)$ which is at its positive extreme at this instant.

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8. A transverse harmonic wave travels along a taut string having a tension of $57.6N$ and linear mass density of $100g/m$. Two points A and B on the string are 5 cm apart and oscillate with a phase difference of $\frac{\pi}{6}$. How much does the phase of oscillation of point A change in a time interval of 5.0 ms?

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9. A distant source of sound has frequency 800 Hz. An observer is facing 90° away from the direction of the source. Estimate the phase difference between the oscillations of her left and right eardrums. Speed of sound in air $= 340ms^{-1}$.

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10. A sinusoidal wave travels along a taut string of linear mass density $0.1g/cm$. The particles oscillate along y-direction and the disturbance moves in the positive x-direction. The amplitude and frequency of oscillation are 2 mm and 50 Hz respectively. The minimum distance between two particles oscillating in the same phase is 4 m.

(a) Find the tension in the string.

(b) Find the amount of energy transferred through any point of the string in one second.

(c) If it is observed that the particle at $x = 2m$ is at $y = 1$ mm at $t = 2s$, and its velocity is in positive y-direction, then write the equation of this travelling wave.

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11. A and B are two point sources of sound (of same frequency) and are kept at a separation. At a point P, the intensity of sound is observed to be I_0 when only source A is put on. With only B on the intensity is observed to be $2I_0$. The distance AP is higher than distance BP by half the wavelength of the sound. Find the intensity recorded at P with both sources on. Give your answer for following cases:

(a) The sources are coherent and in phase.

(b) The sources are coherent and 180° out of phase.

(c) The sources are incoherent.

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12. Two sound sources oscillate in phase with a frequency of 100 Hz. At a point 1.74 m from one source and 1.16 m from the other, the amplitudes of sound from the two sources are A and 2 A respectively. Calculate the amplitude of the resultant disturbance at the point. [Speed of sound in air is $v = 348 ms^{-1}$]

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13. Two speakers S1 and S2 are a driven by same source. You walk along a line l that is perpendicular bisector of the line joining the two speakers and record the intensity at different points. Then you walk along a line m that is parallel to the line joining the speakers and record the intensity of sound at various points. On which path you observe the loudness to alternate between faint and loud? Explain.

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14. (i) A wire is stretched between two rigid supports. It is observed that the wire resonates at a frequency of 420 Hz. If a wooden bridge is placed at the midpoint of the wire (so that the midpoint becomes a node), it was observed that the smallest frequency at which the wire resonates is 420 Hz. Find the smallest frequency at which the wire will resonate when there is no wooden bridge.

(ii) A string of length L is fixed at one end and is under tension due to a weight hanging from the other end, as shown in the figure. The point of the string on the pulley behaves as a fixed point. Coordinate axes are chosen so that the horizontal segment of the string runs from $x = -L/2$ to $x = L/2$. The string is vibrating at one of its resonant frequencies with transverse displacement (y) given by

$$y(x, t) = 0.05\cos(12.0x)\sin(360t)$$

with x, y in meter and t in second. Write two smallest possible values of L consistent with the given equation?

15. Two strings of same material are joined to form a large string and is stretched between rigid supports. The diameter of the second string is twice that of the first. It was observed in an experiment that the whole string was oscillating in 4 loops with a node at the joint. Find the possible lengths of the second string if the length of first string is 90 cm.

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16. (i) The equation of wave in a string fixed at both end is $y = 2\sin \pi t \cos \pi x.$ Find the phase difference between oscillations of two points located at $x = 0.4m$ and $x = 0.6m.$

(ii) A string having length L is under tension with both the ends free to move. Standing wave is set in the string and the shape of the string at time $t = 0$ is as shown in the figure. Both ends are at extreme. The string is back in the same shape after regular intervals of time equal to T and the maximum displacement of the free ends at any instant is A. Write the equation of the standing wave.

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17. One type of steel has density $7800 kg/m^3$ and will break if the tensile stress exceeds $7.0 \times 10^8 N/m^2$. You want to make a guitar string using $4.0 g$ of this type of steel. While in use, the guitar string must be able to withstand a tension of $900 N$ without breaking.

(a) Determine the maximum length and minimum radius the string can have.

(b) Determine the highest possible fundamental frequency of standing waves on this string, if the entire length of the string is free to vibrate.

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18. A string, of length L, clamped at both ends is vibrating in its first overtone mode. Answer the following questions for the moment the string looks flat

(a) Find the distance between two nearest particles each of which have half the speed of the particle having maximum speed.

(b) How many particles in the string have one eighth the speed of the particle travelling at highest speed?

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19. Two transverse waves travel in a medium in same direction.

$$y_1 = a\cos\left(\omega t - \frac{2\pi}{\lambda_1}x\right), y_2 = a\cos\left(2\omega t - \frac{2\pi}{\lambda_2}x\right)$$

(a) Write the ratio of wavelengths $\left(\frac{\lambda_1}{\lambda_2}\right)$ for the two waves.

(b) Plot the displacement of the particle at $x = 0$ with time (t).

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20. A sine wave is travelling on a stretched string as shown in figure. The end A of the string has a small light ring which can slide on a smooth rod. The wave reaches A at time $t = 0$.

(i) Write the slope of the string at point A as function of time.

(ii) If the incoming wave has amplitude a, with what amplitude will the end A oscillate?

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21. Fundamental frequency of a stretched sonometer wire is f_0. When its tension is increased by 96% and length decreased by 35%, its fundamental frequency becomes $\eta_1 f_0$. When its tension is decreased by 36% and its length is increased by 30%, its fundamental frequency becomes $\eta_2 f_0$. Find $\frac{\eta_1}{\eta_2}$

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22. The linear mass density of the string shown in the figure is $\mu = 1g/m$. One end (A) of the string is tied to a prong of a tuning fork and the other end carries a block of mass M. The length of the string between the tuning fork and the pulley is $L = 2.0m$. When the tuning fork vibrates, the string resonates with it when mass M is either 16 kg or 25 kg. However, standing waves are not observed for any other value of M lying between 16 kg and 25 kg. Assume that end A of the string is practically at rest and calculate the frequency of the fork.

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23. Wavelength of two musical motes in air are $\frac{18}{35}m$ and $\left(\frac{90}{173}\right)m$. Each note produces four beats per second with a third note of frequency f_0. Calculate the frequency f_0.

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24. In a science -friction movie the crew of a ship observes a satellite. Suddenly the satellite blows up. The crew first sees the explosion and after a small time gap hears the sound. Do you think there was a technical lapse?

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25. A man is swimming at a depth d in a sea at a distance $L(>>d)$ from a ship (S). An explosion occurs in the ship and after hearing the sound the man immediately moves to the surface. It takes 0.8 s for the man to rise to the surface after he hears the sound of explosion. 0.2 s after reaching the surface he once again hears a sound of explosion. Calculate L.

Give: speed of sound in air $= 340ms^{-1}$, Bulk modulus of water $= 2 \times 10^9 Pa$

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26. Speed of sound in air is $331 ms^{-1}$ at $0^{\circ} C$. Prove that it increases at a rate of $0.6 ms^{-1} . ^{\circ} C^{-1}$ for small temperature increase.

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27. (a) Calculate the speed of sound in hydrogen gas at 300 K

(b) At what temperature the speed in oxygen will be same as above. [Assume oxygen molecules to remain diatomic]

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28. A harmonic source (S) is driving a taut string. The other end of the string is tied to a wall that is not so rigid. It is observed that standing waves are formed in the string with ratio of amplitudes at the antinodes to that at the nodes equal to 8. What percentage of wave energy is transmitted to the wall?

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29. (a) Two identical sinusoidal pulses move in opposite directions on a stretched string. Kinetic energy of each pulse is k. At the instant they overlap completely, what is kinetic energy of the resulting pulse?

(b) "A string clamped at both ends is vibrating. At the moment the string looks flat, the instantaneous transverse velocity of points along the string, excluding its end-points, must be same everywhere except at nodes." Is this statement correct?

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30. Sound of wavelength 100 cm travels in air. At a given point the difference in maximum and minimum pressure is $0.2 Nm^{-2}$. If the bulk modulus of air is $1.5 \times 10^5 Nm^{-2}$, find the amplitude of vibration of the particles of the medium.

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31. (i) An organ pipe has one end closed and at the other end there is a vibrating diaphragm. The diaphragm is a pressure node. The pipe resonates when the frequency of the diaphragm is 2 KHz. Distance between adjacent nodes is 8.0 cm. When

the frequency is slowly reduced, the pipe again resonates at 1.2 KHz.

(a) Find the length of the tube.

(b) Find the next frequency above 2 KHz at which the pipe resonates.

(ii) The figure shows an arrangement for measuring the speed of sound in air. A glass tube is fitted with a movable piston that allows the indicated length L to be adjusted. There is enough gap between the piston and the tube wall to allow the air to pass through it. A speaker is placed near the open end of the tube. A microphone is placed close to the speaker and it is connected to a waveform display. The display is a pure sinusoidal waveform making

750 oscillations in 5 s. Initially, the piston is held at end A and is then slowly pulled back. Loud sound is produced by the tube when $L = 50cm$ and $L = 157cm$. Calculate the speed of sound in air.

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32. A rigid cylindrical container having a cross sectional area of $0.2m^2$ is filled with water up to a height of $5.0m$. There is a piston of negligible mass over the water. Piston can slide inside the container without friction. When a weight of $2000kg$ is placed over the piston, it moves down by 0.25 mm compressing the water.

$\rho =$ Density of water $= 10^3 kg/m^2, P_{atm} =$ Atmospheric pressure $= 10^5 N/m^2$ and $g = 10m/s^2$. With this information calculate the speed of sound in water.

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33. A point source of sound is located inside sea water. Bulk modulus of sea water is $B_\omega = 2.0 \times 10^9 N/m^2$. A diver located at a distance of 10 m from the source registers a pressure amplitude of $\Delta P_0 = 3000\pi N/m^2$ and gives the equation of sound wave as

$y = A\sin(15\pi x - 21000\pi t)$, y and x are in meter

and t is in second.

(a) Find the displacement amplitude of the sound

wave at the location of the diver.

(b) Find the power of the sound source.

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34. A point source of sound is moving uniformly along positive x direction with velocity V_0. At time $t = 0$ the source was at origin and emitted a compression pulse C_1. After time T it emitted another compression pulse C_2. Write the equation of the wave front representing the compression pulse C_2 at time $t(>T)$. Speed of sound is V.

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35. (i) In a car race sound signals emitted by the two cars are detected by the detector on the straight track at the end point of the race. Frequency observed is 330 Hz and 360 Hz. The original frequency of horn is 300 Hz for both cars. Race ends with the separation of 1000 m between the cars. Assume both cars move with constant velocity and velocity of sound is 330 m/s. Find the time (in seconds) taken by the winning car to finish the race.

(ii) A source of sound of frequency f is dropped from rest from a height h above the ground. An observer O_1 is located on the ground and another observer O_2 is inside water at a depth d from the ground. Both O_1 and O_2 are vertically below the source. The velocity of sound in water is 4V and that in air is V. Find

(a) The frequency of the sound detected by O_1 and O_2 corresponding to the sound emitted the source initially.

(b) The frequency detected by both O_1 and O_2 corresponding to the sound emitted by the source at height $h/2$ from the ground.

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36. (i) A source of sound emits waves of frequency $f_0 = 1200 Hz$. The source is travelling at a speed of $v_1 = 30 m/s$ towards east. There is a large reflecting surface in front of the source which is travelling at a velocity of $v_2 = 60 m/s$ towards west. Speed of sound in air is $v = 330 m/s$.

(a) Find the number of waves arriving per second at the reflecting surface.

(b) Find the ratio of wavelength (λ_1) of sound in front of the source travelling towards the reflecting surface to the wavelength (λ_2) of sound in front of the source approaching it after getting reflected.

(ii) A sound source (S) and an observer (A) are moving towards a point O along two straight lines making an angle of 60° with each other. The velocities of S and A are $18 ms^{-1}$ and $12 ms^{-1}$ respectively and remain constant with time. Frequency of the source is $1000 Hz$ and speed of sound is $v = 330 ms^{-1}$.

(a) Find the frequency received by the observer when both the source and observer are at a distance of 180 m from point O (see figure). (b) Find the frequency received by the observer when she reaches point O.

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37. A source of sound, producing a sinusoidal wave, is moving uniformly towards an observer at a velocity of 20 m/s. The observer is moving away from the source at a constant velocity of 10 m / s. Frequency of the source is 200 Hz and speed of sound in air is of 340 m/s. (a) How many times, in an interval of 10 second, the eardrums of the observer will sense maximum change in pressure? (b) What will be apparent wavelength of sound for the observer?

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38. Two trains A and B are moving on parallel tracks in opposite direction at same speed of $30ms^{-1}$. Just when the engines of the two trains are about to cross, the engine of train A begins to sound a horn. The sound of the horn is composed of components varying in frequency from $900Hz$ to 1200 Hz. The speed of sound in air is $330ms^{-1}$.

(a) Find the frequency spread (range of frequencies) for the sound heard by a passenger in train A.

(b) Find the frequency spread heard by a passenger in train B.

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39. Two tuning forks produce 4 beats per second when they are sounded together. Now both the forks are moved towards the observer at same speed (u). The beat frequency now becomes 5 Hz. If the observer also begins to run with speed u towards both the forks, what beat frequency will he hear now?

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40. (i) A sound source emitting sound at a single frequency moves with constant speed along x-axis as shown in figure (a). A and B are two stationary observers. The three plots shown in figure (b) indicate the pressure function $P(x)$ of the sound wave as recorded by the observer A, by B, and by another observer C who is at rest in the frame of the source. Which plot (marked as 1, 2 and 3) correspond to which observer?

(ii) Each of the two figures is rough illustration of the resulting waveform (y versus t) due to overlapping of two waves. The four component waves have frequencies of 300 Hz, 200 Hz, 204 Hz and an unknown frequency $f = 300 + \Delta f$. Is Δf

higher than or less than $4Hz$?

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Level 2

1. A long taut string is plucked at its centre. The pulse travelling on it can be described as $y(x, t) = e^{-(x+2t)^2} + e^{-(x-2t)^2}$. Draw the shape of the string at time $t = 0$, a short time after $t = 0$ and a long time after $t = 0$.

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2. A sinusoidal harmonic wave is propagating along a string stretched along x – axis. A particle on the string at x = 1 m is found to be at its mean position travelling in positive y direction at $t = 1s$. The amplitude, wavelength and frequency of the wave are $0.01m$, $\frac{\pi}{2}m$ and $20Hz$ respectively. Write the equation of the wave if-

(a) it is travelling along negative X direction

(b) it is travelling along positive X direction.

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3. A circular loop of radius R is made of a perfectly elastic wire and is rotating with a constant angular velocity w lying on a smooth horizontal table. The rotation axis is vertical passing through the centre. A small radial push given to the loop at a point P on the table causes a transverse pulse to propagate on it. Find the smallest time in which the pulse will be back to its originating point P on the table.

4. Two waves $y_1 = a\sin\left(\frac{\pi}{2}x - \omega t\right)$ and $y_2 = a\sin\left(\frac{\pi}{2}x + \omega t + \frac{\pi}{3}\right)$ get superimposed in the region $x \geq 0$. Find the number of nodes in the region $0 \leq x \leq 6m$.

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5. Two sine waves of same frequency and amplitude, travel on a stretched string in opposite directions. Speed of each wave is 10 cm/s. These two waves superimpose to form a standing wave pattern on the string. The maximum amplitude in the standing wave pattern is 0.5 mm. The figure shows the snapshot of the string at t = 0.Write the equation of the two travelling waves.

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6. (i) A sinusoidal wave is travelling along positive x direction and the displacements at two positions $x = 0$ and $x = 1m$ are given by $y(0, t) = 0.2\cos(3\pi t)$ and $y(1, t) = 0.2\cos\left(3\pi t + \frac{\pi}{8}\right)$ Find all possible wavelength of the wave if it is known that wavelength is greater than 0.4 m.

(ii) A transverse sine wave of amplitude $a = 0.1cm$

is travelling along a string laid along the x-axis. The displacement (y) – time (t) graph of the string particle at $x = 0.1m$ is shown in first figure. The shape of the string at time $t = 0.1s$ is shown in second figure. At this time the particle at $x = 0.11m$ is having velocity in positive y direction write the equation of wave.

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7. (i) Two sinusoidal wave are given as $y_1 = a_1 \sin(\omega t + kx + \delta)$ and $y_2 = a_2 \sin(\omega t - kx)$. They superimpose.

(a) Calculate the resultant amplitude of oscillation at a position x. Is amplitude time dependent?

(b) Calculate the ratio of maximum and minimum amplitudes observed.

(ii) A speaker (producing a sound of a single wavelength l) and a microphone are placed as shown in the figure. The microphone detects the sound and converts it into electrical signal. This way we can obtain the waveform of the sound. Assume that there is no attenuation of the sound. The waveform detected by the microphone is sinusoidal with amplitude a. In one experiment 6 microphones are placed in front of the speaker with distance between two neighbouring microphones being $d = \frac{5\lambda}{6}$

(a) he output from all the 6 microphones is superimposed. What is amplitude of the resultant?

(b) If large number of microphone are kept with separation L between two consecutive ones, how will the combined output change with L? Given that $L \neq n\lambda (n = 1, 2, 3..........)$

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8. The figure shows y (transverse displacement) vs x (position) graph for a sinusoidal wave travelling along a stretched string. P is power transmitted through a cross section of the string at the instant shown. Plot the graph of P versus x.

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9. A string in a guitar is made of steel (density $7962 kg/m^3$). It is 63.5 cm long, and has diameter of 0.4 mm. The fundamental frequency is $f = 247 Hz$.

(a) Find the string tension (F).

(b) If the tension F is changed by a small amount ΔF, the frequency f changes by a small amount

Δf. Show that $\frac{\Delta f}{f} = \frac{1}{2}\frac{\Delta F}{F}$

(c) The string is tuned with tension equal to that calculated in part (a) when its temperature is $18^\circ C$. Continuous playing causes the temperature of the string to rise, changing its vibration frequency. Find Δf if the temperature of the string rises to $29^\circ C$. The steel string has a Young's modulus of $2.00 \times 10^{11} Pa$ and a coefficient of linear expansion of $1.20 \times 10^{-5} (.^\circ C)^{-1}$. Assume that the temperature of the body of the guitar remains constant. Will the vibration frequency rise or fall?

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10. A long taut string is connected to a harmonic oscillator of frequency f at one end. The oscillator oscillates with an amplitude a_0 and delivers power P_0 to the string. Due to dissipation of energy the amplitude of wave goes on decreasing with distance x from the oscillator given as $a = a_0 e^{-kx}$. In what length of the string $\left(\frac{3}{4}\right)th$ of the energy supplied by the oscillator gets dissipated?

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11. A transverse harmonic wave is propagating along a taut string. Tension in the string is 50 N and its linear mass density is $0.02 kgm^{-1}$ The string is driven by a $80 Hz$ oscillator tied to one end oscillating with an amplitude of 1mm. The other end of the string is terminated so that all the wave energy is absorbed and there is no reflection

(a) Calculate the power of the oscillator.

(b) The tension in the string is quadrupled. What is new amplitude of the wave if the power of the oscillator remains same?

(c) Calculate the average energy of the wave on a $1.0 m$ long segment of the string.

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12. A small steel ball of mass $m = 5g$ is dropped from a height of $2.0m$ on a hard floor. 0.001% of its kinetic energy before striking the floor gets converted into a sound pulse having a duration of $0.4s$. Estimate how far away the sound can be heard if minimum audible intensity is $2.0 \times 10^{-8} Wm^{-2}$ [Actually it is much less but to account for background sound we are assuming it to be high]. Assume no attenuation due to atmospheric absorption.

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13. Three travelling waves are superimposed. The equations of the wave are

$y_! = A_0 \sin(kx - \omega t)$, $y_2 = 3\sqrt{2}A_0 \sin(kx - \omega t + \phi)$

and $y_3 = 4A_0 \cos(kx - \omega t)$

find the value of $\phi(\text{given } 0 \le \phi \le \pi/2)$ if the phase difference between the resultant wave and first wave is $\pi/4$

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14. A sinusoidal wave having wavelength of $6m$ propagates along positive x direction on a string. The displacement (y) of a particle at $x = 2m$

varies with time (t) as shown in the graph

(a) Write the equation of the wave

(b) Draw y versus x graph for the wave at $t = 0$

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15. A string SQ is connected to a long heavier string at Q. Linear mass density of the heavier string is 4 times that of the string SQ. Length of SQ is $9.5cm$. Both the strings are subjected to same tension. A $50Hz$ source connected at S produces transverse disturbance in the string. Wavelength of the wave in string SQ is observed to be $1cm$. If the source is put on at time $t = 0$, calculate the smallest time (t) at which we can find a particle in the heavier string that oscillates in phase with the source at S.

16. The figure shows the snapshot at time $t = 0$ of a transverse pulse travelling on a string in positive x direction.

(a) Sketch the pulse at a slightly later time.

(b) With the help of the given sketch draw a graph of velocity of each string segment versus position.

Take upward direction as positive.

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17. A uniform string of length $6.5m$ is subjected to a tension of $40N$. Mass of the string is $162.5g$. One end of the string is fixed and the other end is tied to a source (s). which produces a transverse oscillation. The displacement of the end of the string tied to the source can be expressed as $y = (3mm)\sin(40\pi t)$, where 't' is time. Find the displacement of point P of the string at a distance of $3.75m$ from the fixed end, at time $t = 0.3s$.

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18. A longitudinal harmonic wave is travelling along positive x direction. The amplitude, wavelength and frequency of the wave are $8.0 \times 10^{-3}m$, $12cm$ and $6800Hz$ respectively. The displacement (s) versus position graph for particles on the x axis at an instant of time has been shown in figure. Find the separation at the instant shown, between the particles which were originally at $x_1 = 1cm$ and

$x_2 = 3cm$

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19. A sinusoidal wave $y = a\sin\left(\frac{2\pi}{\lambda}x - \omega t\right)$ is travelling on a stretched string. An observer is travelling along positive x direction with a velocity equal to that of the wave. Find the angle that the velocity of a particle on the string at $x = \frac{\lambda}{6}$ makes with $-x$ direction as seen by the observer at time $t = 0$.

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20. A standing wave $y = A \sin kx . \cos \omega t$ is established in a string fixed at its ends.

(a) What is value of instantaneous power transfer at a cross section of the string when the string is passing through its mean position?

(b) What is value of instantaneous power transfer at a cross section of the string when the string is at its extreme position?

(c) At what frequency is the power transmitted through a cross section changing with time?

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21. A sinusoidal transverse wave of small amplitude is travelling on a stretched string. The wave equation is $y = a\sin(kx - \omega t)$ and mass per unit length of the string is μ. Consider a small element of length Δx on the string at $x = 0$. Calculate the elastic potential energy stored in the element at time $t = 0$. Also write the kinetic energy of the element at $t = 0$.

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22. The figure shows the $y - x$ graph at an instant for a small amplitude transverse wave travelling on a stretched string. Three elements (1, 2 and 3) on the string have equal original lengths ($= \Delta x$). At the given instant-

(i) which element (among 1, 2 and 3) has largest kinetic energy?

(ii) which element has largest energy (i.e., sum of its kinetic and elastic potential energy)

(iii) Prove that energy per unit length $\frac{\Delta E}{\Delta x}$ of the string is constant everywhere equal to $T\left(\frac{\partial y}{\partial x}\right)^2$ where T is tension the string.

23. A string has linear mass density $m = 0.1 kg/m$. A $L = 60 cm$ segment of the string is clamped at A and B and is kept under a tension of $T = 160 N$ [The tension providing arrangement has not been shown in the figure]. A small paper rider is placed on the string at point R such that $BR = 20 cm$. The string is set into vibrations using a tuning fork of frequency f.

(a) Calculate all values of f below $1000 Hz$ for which the rider will not vibrate at all.

(b) Calculate all values of f below $1000 Hz$ for which the rider will have maximum oscillation amplitude among all points on the string.

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24. A sinusoidal longitudinal wave is travelling in positive x direction. Wave length of the wave is $0.5m$ At time $t=0$, the change in pressure at various points on the x axis can be represented as shown in figure. Consider five particles of the medium A, B, C, D and E whose x co-ordinates are $0.125m, 0.1875m, 0.250m, 0.375m$ and $0.50m$ respectively.

(a) Which of the above mentioned five particles of the medium are moving in positive x direction at $t=0$.

(b) Find the ratio of speed of particles B and D at $t = 0.$

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25. (i) Two cylindrical pipes are each of length $L = 30cm$. One of them contains hydrogen and the other has oxygen at the same temperature. The ends A, B, C and D of the pipes are fitted with flexible diaphragms. The diaphragms A and C are set into oscillations simultaneously using the same source having frequency $f = 600Hz$. Calculate the difference in phase of oscillations of the diaphragms D and B if it is known that the speed of sound in hydrogen at the temperature concerned is $1200 m/s$.

(ii) 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 $330 m/s$. P_0 is mean pressure in the pipe and ΔP_0 is maximum amplitude of pressure variation. Neglect end correction.

(a) Find the length L of air column.

(b) What is amplitude of pressure variation at the middle of the column?

(c) What is maximum and minimum pressure at the closed end?

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26. Speed of sound in atmosphere at a height h_0' is $1080 km hr^{-1}$. The variation of temperature and pressure of the atmosphere with height h from the surface is given by

$T = T_0 - \beta h$ and $P = P_0\left(1 - \frac{\beta h}{T_0}\right)^{\frac{Mg}{R\beta}}$

Where $T_0 =$ temperature at the surface of the earth $= 273K$,

$P_0 =$ atmospheric pressure at the surface of the earth,

$\beta = 0.006.^{\circ} C / m, M =$ molar mass of air $\cong 29 g mol^{-1}, g = 9.8 m s^{-2}$

$R =$ gas constant $= 8.31 J mol^{-1} K^{-1}$

consider air to be a mixture of diatomic hases and calculate the atmospheric temperature and pressure at height h_0. Also find h_0. Take $(0.82)^{5.7} = 0.32.$

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27. In resonance column experiment a tuning fork of frequency $f = 400 Hz$ is held above the pipe as shown in figure. The reservoir is raised and lowered to change the level of water and thus the length of the column of air in the tube. The area of cross section of the reservoir is 6 times that of the pipe. Initially, the reservoir is kept so that the pipe is full up to the brim. Tuning fork is sounded and the reservoir is lowered. When the reservoir is lowered by $21cm$, first resonance is recorded. When the reservoir is lowered further by $49cm$ the second resonance is heard. Find the speed of sound in air.

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28. (i) In a travelling sinusoidal longitudinal wave, the displacement of particle of medium is represented by $s = S(x, t)$. The midpoint of a compression zone and an adjacent rarefaction zone are represented by letter ‘C’ and ‘R’ respectively. The difference in pressure at ‘C’ and ‘R’ is ΔP and the bulk modulus of the medium is B.

(a) How is $\left|\frac{\partial s}{\partial x}\right|$ related to $\left|\frac{\partial}{\partial}\right|$

(b) Write the value of $\left|\frac{\partial s}{\partial x}\right|_C$ in terms of ΔP and B.

(c) What is speed of a medium particle located mid-way between ‘C’ and ‘R’.

(ii) A standing wave in a pipe with a length of

$L = 3m$ is described by $s = A\cos\left(\frac{3\pi x}{L}\right)\sin\left(\frac{3\pi vt}{L}\right)$ where v is wave speed. The atmospheric pressure and density are P_0 and ρ respectively.

(a) At $t = \frac{L}{18v}$ the acoustic pressure at $x = \frac{L}{2}$ is 0.2 percent of the atmospheric pressure . Find the displacement amplitude A.

(b) In which overtone is the pipe oscillating?

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29. Two sources A and B give out sound waves in coherence and in phase. The sources are located at co-ordinates $(0, 0)$ and $(0, 9m)$ in xy plane. There is a detector located at $(40m, 0)$. It was found that the detector records continuous increase in intensity of sound when it is moved in positive y-direction for $4.5m$ but the intensity was found to fall for some distance when it is moved in negative y direction. What frequency of sound is consistent with these observations? Speed of sound $= 340ms^{-1}$.

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30. In the figure shown, S_1 and S_2 are two identical point sources of sound which are coherent 180°

out of phase. Taking S_1 as centre, two circular arcs l and m of radii 1 m and $2m$ are drawn. Taking S_2 as centres, two circular arcs p and q are drawn having radii $2m$ and $4m$ respectively. Out of the four intersection points A, B, C and D which point will record maximum intensity and which will record the least intensity of sound?

It is given that wavelength of wave produced by each source is $4.0m$.

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31. Stationary wave of frequency 5 K Hz is produced in a tube open at both ends and filled with air at $300K$. The tube is oscillating in its first overtone mode.

(a) Find the length of the tube assuming that air contains only nitrogen and oxygen in molar ratio of $3:1$.

(b) What shall be the frequency of sound wave used so that the same tube oscillates in its second overtone mode?

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32. The string of a musical instrument was being tuned using a tuning fork of known frequency, $f_0 = 1024Hz$. The tuning fork and the string were set to vibrate together. Both vibrated together for $10s$ and no beat was heard. What prediction can be made regarding the frequency of the string?

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33. A wooden platform can be rotated about its vertical axis with constant angular speed ω with the help of a motor. A buzzer is fixed at the circumference of the platform and it rotates in a circle of radius R. The buzzer produces sound of frequency f_0. A mic is placed just beneath the platform near its circumference. An electronic frequency analyzer connected to the mic records the frequency (f) received by the mic. Take time (t) to be zero when the buzzer is just above the mic and express f as a function of time. Plot f versus t. Speed of sound $= V_0$.

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34. (i) A harmonic wave in a stationary medium is represented by $y = a\sin(kx - \omega t)$. Write the equation of this wave for an observer who is moving in negative x direction with constant speed v_0.

(ii) The Doppler flow meter is a device that measures the speed of blood flow, using transmitting and receiving elements that are placed directly on the skin. The transmitter emits a continuous sound wave whose frequency is $5MHz$. When the sound is reflected from the red blood cells, its frequency is changed in a kind of Doppler effect. The cells are moving with the same velocity as the blood. The receiving element detects the reflected sound, and an electronic counter measures its frequency, which is Doppler- shifted relative to the transmitter frequency. From the change in frequency the speed of the blood flow can be determined. Typically, the change in frequency is around $600Hz$ for flow speeds of about $0.1m/s$. Assume that the red blood cell is directly moving away from the source and the receiver. (a) Estimate the speed of the sound wave in the blood?

(b) A segment of artery is narrowed down by plaque to half the normal cross-sectional area. What will be the Doppler change in frequency due to reflection from the red blood cell in that region?

35. A sound source emits waves of frequency f_0 and wavelength λ_0 in still air. When there is a wind blowing with speed u from left to right what will be wavelength of sound to the right of the source and to the left of the source.

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36. There are two horns $H1$ and $H2$ in a car. When sounded together, the driver records 35 beats in 10 second. With horn $H2$ blowing and car moving towards a wall at a speed of $5ms^{-1}$, the driver noticed a beat frequency of $5Hz$ with the echo.

When frequency of $H1$ is decreased the beat frequency with two horns sounded together increases. Calculate the frequency of two horns. Speed of sound $= 332ms^{-1}$

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37. A toy train in a children amusement park runs on an elliptical orbit having major and minor axis in the ratio of $4:3$. The length of the train is exactly equal to half the perimeter of the elliptical track. The train is travelling at a constant speed of $20ms^{-1}$. The engine sounds a whistle when its acceleration is minimum. The whistle has a frequency of $f_0 = 3460 Hz$ and speed of sound in air is $V = 330 ms^{-1}$

(a) What frequency of whistle is received by a passenger in the last compartment of the train?

(b) What frequency of whistle is received by a passenger sitting in the central compartment of the train?

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38. A small source of sound has mass M and is attached to a spring of force constant K. It is oscillating with amplitude $A = \frac{V}{20}\sqrt{\frac{M}{K}}$ where V is speed of sound in air. The source of sound produces a sound of frequency $f_0 = 399 Hz$.

(a) Find the frequency of sound registered by a stationary observer standing at a distant point O.

(b) Let Δt_1 be the time interval during which the registered frequency changes from 420 Hz to $\left(399 \times \frac{40}{39}\right) Hz$ and Δt_2 be the time interval during which the observed frequency changes from $399 Hz$ to $\left(399 \times \frac{40}{41}\right) Hz$. Which is large Δt_1 or Δt_2?

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39. (i) A straight railway track is at a distance 'd' from you. A distant train approaches you travelling at a speed $u(<$ speed of sound$)$ and crosses you. How does the apparent frequency (f) of the whistle change with time (f_0 is the original frequency of the whistle). Draw a rough f vs t graph.

(ii) A bat is tracking a bug. It emits a sound, which reflects off the bug. The bat hears the echo of the sound 0.1 seconds after it originally emitted it. The bat can tell if the insect is to the right or left by comparing when the sound reaches its right ear to when the sound reaches its left ear. Bat's ears are only $2cm$ apart. Bats also use the frequency change of the sound echo to determine the flight direction of the bug. While hovering in the air (not moving), the bat emits a sound of $40.0kHz$. The frequency of the echo is $40.4kHz$. Assume that the speed of sound is $340m/s$.

(a) How far away is the bug?

(b) How much time delay is there between the echo reaching the two ears if the bug is directly to the right of the bat?

(c) What is the speed of the bug?

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40. A source of sound is located in a medium in which speed of sound is V and an observer is located in a medium in which speed of sound is 2V. Both the source and observer are moving directly towards each other at velocity $\frac{V}{5}$. The source has a frequency of f_0.

(a) Find the wavelength of wave in the medium in which the observer is located.

(b) Find the frequency received by the observer.

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41. A transverse wave $y=A\sin\omega\left(\frac{x}{V_1}-t\right)$ is travelling in a medium with speed V_1. Plane $x=0$ is the boundary of the medium. For $x>0$ there is a different medium in which the wave travels at a different speed V_2. Part of the wave is reflected and part is transmitted. For $x<0$ the wave function is described as

$$y_{-}=A_1\sin\omega\left(\frac{x}{V_1}-t\right)+A_2\sin\omega\left(\frac{x}{V_2}+t\right)$$

while for $x>0$, $y_{+}=A_3\sin\omega\left(\frac{x}{V_2}-t\right)$

(a) Using the fact that the wave function must be continuous at $x=0$, show that $A_1-A_2=A_3$

(b) Using the fact that $\frac{\partial y}{\partial x}$ must be continuous at $x=0$, prove that $\frac{V_2}{V_1}A_1=A_3-A_2$

(c) Show that $A_3 = \frac{2V_2 A_1}{V_1 + V_2}$ and $A_2 = \frac{V_1 - V_2}{V_1 + V_2} A_1$

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42. A longitudinal wave is travelling at speed u in positive x direction in a medium having average density r0. The displacement (s) for particles of the medium versus their position (x) has been shown in the figure.

Answer following questions for $0 < x \leq 10cm$

(a) Write x co-ordinates of all positions where the particles of the medium have maximum negative acceleration. What is density at these locations – higher than ρ_0, less than ρ_0 or equal to r_0?

(b) Write x co-ordinates of all locations where the particles of the medium have negative maximum velocity. What do you think about density at these positions?

(c) Knowing that the change in density $(\Delta\rho)$ is proportional to negative of the slope of s versus x graph, prove that $\frac{d\rho}{dx} \propto -a$ where a is accelerationof the particles at position x. At which point $(0 < x \leq 10)$ is $\frac{d\rho}{dx}$ positive maximum.

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43. Two sound waves trevelling in same direction can be represented as

$$y_1 = (0.02mm)\sin\left[\left(400\pi rad s^{-1}\right)\left(\frac{x}{330ms^{-1}} - t\right)\right]$$

And

$$y_2 = (0.02mm)\sin\left[\left(404\pi rad s^{-1}\right)\left(\frac{x}{330ms^{-1}} - t\right)\right]$$

The waves superimpose.

(i) Find distance between two nearest points where an intensity maximum is recorded simultaneously.

(ii) Find the time gap between two successive intensity maxima at a given point.

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44. There are three sinusoidal waves A, B and C represented by equations-

$A \rightarrow Y = A \sin kx, B \rightarrow y = \frac{A}{2} \sin 2kx,$
$C \rightarrow y = \frac{A}{2} \sin 3kx$

(a) To get a waveform of nearly the shape given in fig (a) which of the two waves B or C shall be superimposed with wave A?

(b) To get a waveform close to that in fig (b) which of the two waves B or C shall be superimposed with A?

45. A taut string is made of two segments. To the left of A it has a linear mass density of $\mu kg/m$ and to

the right of A its linear mass density is $4\mu kg/m$. A sinusoidal pulse of amplitude a is travelling towards right on the lighter string with a speed $V = 2cm/s$.

Draw the shape of the string after

(a) 1 s

(b) 2.5 s

46. A wire having mass per unit length m and length L is fixed between two fixed vertical walls at a separation L. Due to its own weight the wire sags. The sag in the middle is $d(< \; < L)$. Assume that tension is practically constant along the wire, owing to its small mass. Calculate the speed of the transverse wave on the wire.

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47. A shock wave is a region of high acoustic pressure propagating at speed of sound (v).

Assume that the pressure in one such shock wave is $2P_0$ where P_0 is the atmospheric pressure. This shock wave is travelling horizontally along x direction and hits a small wedge whose dimensions are as shown in the figure. The wedge has a mass m and is lying on a smooth horizontal surface. Determine the velocity u acquired by the wedge immediately after the shock wave passes through it. The velocity acquired by the wedge should be assumed to be much lower than the velocity of the wave $(u < < v)$.

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