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Q1. Examine whether the following functions of Y represent a travelling wave.

(a) $(x - vt)^2$ (b) $\frac{1}{x + vt}$

Q2. When a stone is thrown on the surface of the water, wave travels out. From where does the energy come?

Q3. What is longitudinal wave?

Q4. What is transverse wave?

Q5. Why is sound heard more intense in carbon dioxide in comparison to air?

Q6. What is the distance between a compression and its nearest rarefaction in a longitudinal wave?

Q7. What is the phase difference between the waves $y = a \cos(\omega t + kx)$ and $y = a \sin(\omega t + kx)$?

Q8. Why are longitudinal waves called pressure waves?

Q9. Is it possible to have longitudinal waves on a string a transverse wave in a steel rod?

Q10. Name the factors affecting the velocity of sound in a medium.

Q11. What characteristic of a solid determine the speed of transverse waves through it?

Q12. Which properties of a medium are responsible for propagation of waves through it?

Q13. Can transverse waves be produced in air?

Q14. An ultrasonic source emits sound of frequency 220 kHz in air. If this sound meets a water surface, what is the wavelength of (a) the reflected sound, (b) the transmitted sound? At the atmospheric temperature, speed of sound in air = 352 ms^{-1} and in water = 1,496 ms^{-1}.

Q15. The audible frequency range of a human ear is 20 Hz – 20 kHz. Convert this into the corresponding wavelength range. Take the speed of sound in air at ordinary temperatures to be 340 ms^{-1}.

Q16. A string of mass 0.08 kg is under a tension of 10 N. The length of the stretched string is 0.5 m. The string is made to vibrate transversely. If a transverse wave sets out at the one end of the string, how long does the disturbance take to reach the other end?

Q17. A steel wire has a length of 1.2 m and a mass of 0.6 kg. What should be the tension in the wire, so that the speed of a transverse wave travelling on the wire is equal to 332 ms^{-1}?

Q18. A tuning fork vibrates with a frequency of 256. If the speed of sound is 345 ms^{-1}, find the wavelength and the distance, which the sound travels during the time, the fork makes 60 vibrations.

Q19. Define longitudinal wave motion. What are the essential conditions required for the formation of longitudinal wave motion?

Q20. If $Y = 3 \sin(36t + .018x + \pi/4)$ cm, find the amplitude, velocity and frequency of the wave.

Q21. A tuning fork sends out waves of wavelength 68.75 cm and 3 m in air and hydrogen respectively. If the velocity of sound in air is 330 ms^{-1} find the velocity of sound in hydrogen. Also, find the frequency of the tuning fork.

Q22. The equation for the transverse wave on a string is $y = 4 \sin 2\pi\left(\frac{t}{0.05} - \frac{x}{50}\right)$ with length expressed in cm and time in second. Calculate the wave velocity and maximum particle velocity.

Q23. Deferential between longitudinal wave and transverse wave.

Q24. Given below are some examples of wave motion. State in each case if the wave motion is transverse or longitudinal or a combination of both:

(a) Motion of kink in a long coil spring produced by displacing one end of the spring sideways.

(b) Waves produced in a cylinder containing liquid by moving its piston back and forth.

(c) Wave produced by motorboat sailing in water.

(d) Ultrasonic waves in air produced by a vibrating quartz crystal.

Q25. Equation of a wave travelling on a string is $y = 0.1 \sin(300t - 0.01x)$. Here x is in cm and t is in seconds. Find:

(a) Wavelength of the wave;

(b) Time taken by the wave to travel 1 m.

Q26. A wave travelling along a string is described by equation $y(x, t) = 0.05 \sin(40x - 5t)$, in which the numerical constants are in SI units (0.05 m, 40 rad m^{-1} and 5 rad s^{-1}).

Calculate the (a) amplitude (b) wavelength (c) time period and (d) frequency of wave. Also calculate the displacement at distance 35 cm and time 10 sec.

Q27. (a) What is progressive wave? Write its three properties.

(b) A simple harmonic wave is expressed by equation:

$$y = 7 \times 10^{-6} \sin\left(800\pi t - \frac{\pi}{42.5}x\right).$$

Where y and x are in cm and t in second. Calculate the Amplitude, Frequency, Wavelength, Wave-velocity and Phase difference between two particles separated by 17.0 cm.

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S1. Both the functions are not continuous and definite at all values of x and θ. So, they do not represent a wave.

S2. The energy of the surface wave spreading on the surface of water comes from the kinetic energy of the stone shared by the water molecules, on which it falls.

S3. Longitudinal wave may be defined as when the wave motion in which the individual particles of the medium execute the SHM about their mean position along the direction of propagation of the wave this wave called longitudinal wave.

S4. Transverse wave may be defined as, in wave motion in which the individual particle of the medium execute SHM about their mean position in a direction perpendicular to the direction of propagation of the wave. This wave is called the transverse wave.

S5. The intensity of sound increases with increase in density of the medium.

S6. Distance between a compression and adjoining rarefaction is $\lambda/2$.

S7. Phase difference = $\pi/2 = 90°$

S8. This is because propagation of longitudinal waves through a medium involves changes in pressure and volume of air, when compressions and rarefactions are formed.

S9. No, because string is not stretchable. It can neither the compressed nor rarefied. Yes, transverse waves are possible in steel rod, because steel has elasticity of shape.

S10. Temperature, density and ratio γ affect the velocity of sound in a medium.

S11. The density and modulus of rigidity of the solid.

S12. Properties of elasticity and inertial.

S13. No, for air, the modulus of rigidity is zero. In other words, gases do not possess the property of cohesion. Therefore, transverse waves cannot be produced in air.

S14. Given: $\nu = 220$ kHz $= 220 \times 10^3 = 2.2 \times 10^5$ Hz; Speed of sound in air, $v_a = 352$ ms^{-1}; Speed of sound in water, $v_w = 1{,}496$ ms^{-1}

(a) ***The Wavelength Reflected Sound:*** After reflection, the ultrasonic sound continues to travel in air. If λ_a is wavelength in air, then

$$\lambda_a = \frac{v_a}{\nu} = \frac{352}{2.2 \times 10^5} = \mathbf{1.6 \times 10^{-3}\ m}.$$

(b) ***The Wavelength Transmitted Sound:*** The transmitted ultrasonic sound travels in water. If λ_w is wavelength of ultrasonic sound in water, then

$$\lambda_w = \frac{v_w}{\nu} = \frac{1,496}{2.2 \times 10^5} = \mathbf{6.8 \times 10^{-3}\ m}.$$

S15. Given: $v = 340\ \text{ms}^{-1}$;

Frequency range = 20 Hz to 20 kHz

= 20 Hz to 20×10^3 Hz

Now, $\lambda = \dfrac{u}{\nu}$.

As $\lambda \propto 1/\nu$, the lower limit of the wavelength range will correspond to the upper limit of the frequency range and vice-versa.

Therefore, upper limit of the wavelength range

$$= \frac{340}{20} = \mathbf{17\ m}$$

and lower limit of the wavelength range

$$= \frac{340}{20 \times 10^3}\ 17 \times 10^{-3}\ \text{m} = \mathbf{17\ mm}.$$

Therefore, corresponding wavelength is 17 m to 17 mm.

S16. Given: $T = 10\ \text{N}$; Length of the string, $l = 0.5\ \text{m}$; Total mass of the string = 0.08 kg

Therefore, mass per unit length of the string,

$$m = \frac{0.08}{0.5} = 0.16\ \text{kg m}^{-1}$$

Now, $v = \sqrt{\dfrac{T}{m}} = \sqrt{\dfrac{10}{0.16}} = 7.91\ \text{ms}^{-1}$

Therefore, time taken by the transverse wave to reach the other end,

$$t = \frac{l}{v} = \frac{0.5}{7.91} = \mathbf{0.063\ s}.$$

S17. Given: Speed of sound in air, $v = 332\ \text{ms}^{-1}$, Length of the wire, $l = 1.2\ \text{m}$; Total mass of the wire, $M = 0.6\ \text{kg}$.

Therefore, mass per unit length of the wire,

$$m = \frac{M}{l} = \frac{0.6}{1.2} = 0.5\ \text{kg m}^{-1}$$

Now, speed of sounds (v) $\quad v = \sqrt{\dfrac{T}{m}}$

or $\quad T = v^2 m = (332)^2 \times 0.5 = \mathbf{55,112\ N}$.

S18. Given: $\quad \nu = 256$ Hz; $\quad v = 345.6\ \text{ms}^{-1}$

$\therefore \quad \lambda = \dfrac{v}{\nu} = \dfrac{345.6}{256} = 1.35$ m

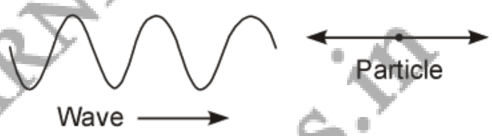
Time taken by the tuning fork to complete 60 vibrations,

$$t = 60 \times \frac{1}{256}\ \text{s}$$

Therefore, the required distance travelled by the sound,

$$S = v \times t = \frac{345.6 \times 60 \times 1}{256} = \mathbf{81\ m}.$$

S19. It is that wave motion in which the particles of the medium through which the wave is travelling vibrate in a direction parallel to the direction of the motion of the wave. In the figure given below, the wave is travelling from left to right and the particles of the medium vibrate in the horizontal direction simple harmonically. It represents the longitudinal wave motion.



For their propagation, the medium must possess

(a) elasticity,

(b) inertia,

(c) absence of frictional resistance.

S20. Here, $\quad Y = 3 \sin (36t + .018x + \pi/4)$

Amplitude = 3 cm

$$\text{Velocity of wave} = \frac{\omega}{k} = \frac{36}{0.018} = \frac{36 \times 10^3}{18} = \mathbf{2 \times 10^3\ cm/sec}.$$

$$\omega = 36$$

$$2\pi\nu = 36$$

$$\nu = \frac{36}{2\pi} = \mathbf{\frac{18}{\pi}\ s^{-1}}..$$

S21. **In hydrogen:** $\quad \lambda_H = 3$ m

If v_H is velocity of sound in hydrogen, then

$$v_H = \nu \times \lambda_H = 480 \times 3 = \mathbf{1{,}440\ ms^{-1}}.$$

In air: $\quad \lambda_a = 68.75$ cm $= 0.6875$ m; $\quad v_a = 330\ \text{ms}^{-1}$

Let ν be the frequency of the tuning fork. Then.

$$\nu = \frac{v_a}{\lambda_a} = \frac{330}{0.6875} = \mathbf{400\ Hz}.$$

S22. Given

$$y = 4\sin\left(\frac{2\pi t}{0.05} - \frac{2\pi x}{50}\right)\text{cm}$$

$$\text{Wave velocity } \frac{\omega}{k} = \frac{2\pi/0.05}{2\pi/50} = \frac{50}{0.05}\text{ cm/sec}$$

$$= 1000\text{ cm/sec} = 10\text{ ms}^{-1}.$$

$$\text{Particle velocity} = \frac{dy}{dt} = 4\times\frac{2\pi}{0.05}\cos\left(\frac{2\pi t}{0.05} - \frac{2\pi x}{50}\right)$$

$$\text{Maximum particle velocity} = 4\times\frac{2\pi}{0.05} = 502.4\text{ cms}^{-1}.$$

S23.

Longitudinal Waves	*Transverse Waves*
1. The particles of the medium vibrate along the direction of propagation of the wave.	1. The particles of the medium vibrate at right angles to the direction of propagation of the wave.
2. The longitudinal waves travel in the form of alternate compressions (condensations) and rarefactions. One compression and one rarefaction constitute one wave.	2. The transverse waves travel in the form of alternate crest and troughs. One crest and one trough constitute one wave.
3. These waves can be formed in any medium (solid, liquid or gas).	3. These waves can be formed in solids and on the surfaces of liquids only.
4. When longitudinal waves propagate, there are pressure changes in the medium.	4. When transverse waves propagate, there are no pressure changes in the medium.

S24. (a) Transverse (b) Longitudinal (c) Transverse and Longitudinal (d) Longitudinal

S25. (a) Since, $K = 0.01\text{ cm}^{-1}$, we get

$$\frac{2\pi}{\lambda} = 0.01$$

or $$\lambda = \frac{2\pi}{0.01} = \frac{2 \times 3.14}{0.01} = 6.28\text{ m}$$

(b) Since $$\omega = 300$$

$$T = \frac{2\pi}{300}\text{ for travelling }\lambda$$

$$\text{Time for travelling 1 m} = \frac{T}{\lambda\text{ in }m} = \frac{2\pi}{300\times 6.28} = \frac{1}{300} = 3.33\text{ ms}.$$

S26. Given, $y(x, t) = 0.05 \sin(40x - 5t)$. ... (i)

Comparing with standard equation,

$$y(x, t) = A \sin\left(\frac{2\pi x}{\lambda} - \frac{2\pi t}{T}\right) \quad \text{... (ii)}$$

Compare the Eq. (i) and w.r.t. (ii)

(a) Amplitude (A) = 0.05 m

(b) $$\frac{2\pi}{\lambda} = 40$$

Wavelength $\lambda = +\frac{\pi}{20}$ m

(c) Time period $= -\frac{2\pi t}{T} = -5t$

$$T = \frac{2\pi}{5} \text{ seconds}$$

(d) Frequency of wave

$$\nu = \frac{1}{T} = \frac{5}{2\pi} = 0.8 \text{ Hz}$$

$y = 0.05 \sin(+40 \times 0.35 - 5 \times 10)$ ... [$\because$ $x = 0.35$ m, $t = 10$ s]

$= 0.05 \sin(-36°)$

$= \mathbf{-0.05 \sin 36°}$.

S27. (a) The wave which travels continuously in a medium in the same direction without any charge in its amplitude is called a progressive wave

Properties of Progressive Wave:

(i) The disturbance always travels forward and is handed over from one particle of the medium to the next after some constant.

(ii) Each particle of the medium possesses a constant amplitude but its phase charges as the wave propagates

(iii) Each particle come to rest. Which passing through their extreme position.

(b) Comparing the given equation with $Y = a \sin(\omega t - kx)$, we get

Amplitude (A) = $\mathbf{7 \times 10^{-6}}$ **cm**.

$$\text{Frequency } (\nu) = \frac{\omega}{2\pi} = \frac{800\pi}{2\pi} = \mathbf{400\,Hz}.$$

$$\text{Wavelength } (\lambda) = \frac{2\pi}{k} = \frac{2\pi}{\left(\frac{\pi}{42.5}\right)} = \mathbf{85\,cm}.$$

$$\text{Wave-velocity } (v) = \frac{\omega}{k} = \frac{800\pi}{\left(\frac{\pi}{42.5}\right)}$$

$$= 34000\ \text{cm s}^{-1} = \mathbf{340\ ms^{-1}}.$$

Using = $\frac{\phi}{2\pi} = \frac{x}{\lambda}$, we get,

$$\text{Phase difference} = \phi = \frac{2\pi}{85} \times 17 = \mathbf{\frac{2\pi}{5}}\ \textbf{radian}.$$

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Q1. What is the condition to be satisfied by a mathematical relation between time and displacement to describe a periodic motion?

Q2. The quality of music from a group of instruments is independent of the listener's distance from the instruments. Why?

Q3. How is energy transmitted in wave motion?

Q4. Explain, why there is usually a time interval between observing a flash and hearing a thunder.

Q5. The velocity of sound in a tube containing air at 27°C and a pressure of 76 cm of mercury is 330 ms^{-1}. What will be its velocity, when the pressure is increased to 100 cm of mercury and the temperature is kept constant?

Q6. If you set your watch by the sound of a distant siren, will it go fast or slow?

Q7. An explosion occurs inside a lake. What type of waves are produced inside the water?

Q8. Explosions on other planets are not heard on earth. Why?

Q9. If an alarm clock is placed in vacuum, no sound will be heard. Why?

Q10. Sound is produced due to vibratory motion. But a vibrating pendulum does not produce sound. Why?

Q11. You have learnt that a travelling wave in one dimension is represented by a function $y = f(x, t)$ where x and t must appear in the combination $x - v\,t$ or $x + v\,t$, *i.e.*, $y = f(x \pm v\,t)$. Is the converse true? Examine if the following functions for y can possibly represents a travelling wave:

(a) $(x - vt)^2$ (b) $\log[(x + vt)/x_0]$ (c) $1/(x + vt)$

Q12. Name the waves which do not require any material medium for their propagation.

Q13. Is air a material medium? Name two characteristics of the material medium necessary for the onward propagation of momentum and energy.

Q14. What is the nature of thermal changes in air, when a sound wave propagates through it?

Q15. Frequency is the most fundamental property of a wave. Why?

Q16. What is meant by non-dispersive medium?

Q17. One end of a long metal pipe is struck a blow. What does the listener hear at the other end of the pipe?

Q18. The velocity of sound is generally greater in solids than in gases at N.T.P. Why?

Q19. Sound can be heard over longer distance on a rainy day. Why?

Q20. Calculate the speed of a transverse wave travelling in a copper wire of radius 1 mm stretched under a load of 1.4 kgf. Given. density of copper = 8.8 g cm^{-3}.

Q21. A tuning fork of frequency 220 Hz produces sound waves of wavelength 1.5 m in air at N.T.P. Calculate the increase in wavelength, when temperature of air is 27°C.

Q22. The speed of sound in hydrogen at N.T.P. is 1,328 ms^{-1}. What will be its value in air at N.T.P., if density of hydrogen is $1/16^{th}$ that of air?

Q23. Estimate the speed of sound in air at standard temperature and pressure. The mass of 1 mole of air is 29.0×10^{-3} kg.

Q24. A wave pulse is travelling on a string of linear mass density 6.4×10^{-3} kg m^{-1} under a load of 80 kgf. Calculate the time taken by the pulse to traverse the string, if its length is 0.7 m.

Q25. When a train is at a distance of 2 km, its engine sounds a whistle. A man near the railway track hears the whistle directly and by placing his ear against the track of the train. If the two sounds are heard at an interval of 5.2 s, find the speed of the sound in iron (material of the rail track). Given that velocity of sound in air is 330 ms^{-1}.

Q26. If the Earth is moving towards a stationary star at a speed of 30 km/s, find the apparent wavelength of light emitted from the star. The real wavelength has the value 5875 Å.

Q27. The speed of sound wave depends on temperature but speed of light waves does not. Why?

Q28. Audible range of frequencies to which human ear responds varies between 20 Hz to 20 kHz. Express the range in terms of (a) wavelengths in air and (b) time period. The speed of sound in air is 350 ms^{-1}.

Q29. What is mean by RADER and SONAR? How are long distances measured using these techniques?

Q30. Define standing wave. Displacement of a string in which standing wave is formed is given as $y = (20 \sin 157x \cos 314t)$. Find (a) Amplitude of individual waves (b) Velocity of wave.

Q31. Give two differences between progressive wave and stationary wave.

Q32. A narrow sound pulse (for example, a short pip by a whistle) is sent across a medium. (a) Does the pulse have a definite (i) frequency, (ii) wavelength, (iii) speed of propagation? (b) If the pulse rate is 1 after every 20 s, (that is the whistle is blown for a split of second after every 20 s), is the frequency of the note produced by the whistle equal to $\frac{1}{20}$ or 0.05 Hz?

Q33. For the wave described in Exercise 15.8, plot the displacement (y) versus (t) graphs for x = 0, 2 and 4 cm. What are the shapes of these graphs? In which aspects does the oscillatory motion in travelling wave differ from one point to another: amplitude, frequency or phase?

Q34. A transverse harmonic wave on a string is described by

$$y(x, t) = 3.0 \sin\left(36t + 0.018x + \frac{\pi}{4}\right)$$

Where x and y are in cm and t in s. The positive direction of x is from left to right.

Is this a travelling wave or a stationary wave?

If it is travelling, what are the speed and direction of its propagation?

What are its amplitude and frequency?

What is the initial phase at the origin?

What is the least distance between two successive crests in the wave?

Q35. A wave travelling along a string is described by, $y(x, t) = 0.005 \sin(80.0x - 3.0t)$, in which the numerical constants are in SI units (0.005 m, 80.0 rad m^{-1}, and 3.0 rad s^{-1}). Calculate (a) the amplitude, (b) the wavelength, and (c) the period and frequency of the wave. Also, calculate the displacement y of the wave at a distance x = 30.0 cm and time t = 20 s?

Q36. Prove that if a_1 and a_2 are the amplitudes of two interfering waves and ϕ is their phase difference, the amplitude of the resultant wave is given by $a^2 = a_1^2 + a_2^2 + 2a_1 a_2 \cos\phi$.

Q37. A travelling harmonic wave on a string is described by

$$y(x, t) = 7.5 \sin\left(0.0050x + 12t + \frac{\pi}{4}\right)$$

What are the displacement and velocity of oscillation of a point at x = 1 cm, and t = 1 s? Is this velocity equal to the velocity of wave propagation?

Locate the points of the string which have the same transverse displacements and velocity as the x = 1 cm point at t = 2 s, 5 s and 11 s.

Q38. For the travelling harmonic wave, $y = 2.0 \cos 2\pi(10t - 0.008x + 0.35)$, where x and y are in cm and t in s. What is the phase difference between oscillatory motion at two points separated by a distance of (a) 4 m, (b) 0.5 m, (c) $\lambda/2$, (d) $3\lambda/4$.

Q39. From the equation $y = r \sin \frac{2\pi}{\lambda}(vt - x)$, establish the relation between particle velocity, and wave velocity.

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S1. $y = a \sin(\omega t - \phi_0)$. Similar displacement should happen at regular time intervals.

S2. It is because, the speed of sound in air is independent of the frequency of sound waves.

S3. During wave motion, the particles of the medium are set into oscillations about their mean positions. An oscillating particle of the medium hands over its motion to a particle just ahead of it with some constant phase difference. In this manner, energy is transmitted in a wave motion from one part to the other part of the medium.

S4. The velocity of light is much larger than that of sound. Due to this, the flash of light reaches us earlier than the sound of thunder does.

S5. At a given temperature, the velocity of sound in a gas is independent of pressure. Since the pressure is increased at constant temperature, the velocity of sound in the tube will remain $330\,ms^{-1}$.

S6. The speed of sound in air has a finite value (approximately $250\ ms^{-1}$ at the room temperature). The sound of the distant siren will take a finite time to reach us. Hence, the watch set by the sound of distant siren will go a little slower.

S7. Longitudinal waves. It is because, a liquid possesses volume elasticity. The modulus of rigidity is practically zero for liquids.

S8. Since no material medium is present in the space between the planets and the earth, the sound (due to explosions) cannot propagate upto the earth.

S9. Sound waves require material medium to propagate.

S10. The frequency of vibration of a simple pendulum is quite small and much below the lower limit of the audible range.

S11. Now the converse is not true. The basic requirement for a wave function to represent a travelling wave is that for all values of *k* and *t*, wave function must have a finite value.

Out of the given functions for '*y*', no one satisfies this condition. Therefore, none can represent travelling wave.

S12. Non-mechanical or electromagnetic wave.

S13. Yes, Inertia and elasticity.

S14. When a sound wave travels through air, the changes in pressure and volume are adiabatic, *i.e.*, temperature rises in the region of compression and temperature falls in the region of rarefaction.

S15. When a wave travels from one medium to another, its wavelength and velocity change. However, frequency of the wave remains unchanged. For this reason, frequency is considered as to be most fundamental property of a wave.

S16. A medium, in which the speed of wave motion is independent of the frequency of the wave motion, is called non-dispersive medium

Air is non-dispersive medium for sound waves.

S17. The listener at the other end of the pipe will hear two sounds, one through the air and the other through the metal (material of the pipe). It may be pointed out that the listener will hear the sound through the pipe earlier and it will be more intense (loud).

S18. Both the elasticity and density of the solids are very large as compared to that of the gases. The effect of high value of elasticity of solids is to increase the speed of the sound, whereas the effect of density is to decrease. However, the effect of elasticity weighs heavier upon the effect of density and hence the speed of sound is greater in solids than in gases.

S19. On a rainy day, the air contains a large amount of water vapour. The moist air has lesser value of the density as compared to that of the dry air. Due to this, sound travels faster in moist air and hence it can be heard over longer distances on a rainy day.

S20. Given: $T = 1.4\,\text{kgf} = 1.4 \times 9.8\,\text{N}$; $\rho = 8.8\,\text{g cm}^{-3} = 8.8 \times 10^3\,\text{kg m}^{-3}$; radius of cross-section of the wire,

$$a = \pi r^2 = \pi \times (10^{-3})^2 = \pi \times 10^{-6}\,\text{m}^2$$

Volume of 1 m long wire, $V = a \times 1$

$$= \pi \times 10^{-6} \times 1 = \pi \times 10^{-6}\,\text{m}^3$$

Therefore, mass per unit length of the wire,

$$m = V \times \rho = \pi \times 10^{-6} \times 8.8 \times 10^3$$

$$= \pi \times 8.8 \times 10^{-3}\,\text{kgm}^{-1}$$

Now, $v = \sqrt{\frac{T}{m}} = \sqrt{\frac{1.4 \times 9.8}{\pi \times 8.8 \times 10^{-3}}} = \mathbf{22.28\ ms^{-1}}$.

S21. Given: $\nu = 220$ Hz; $T = 273 + 27 = 300\,\text{K}$

Wavelength of sound waves at N.T.P.,

$$\lambda_0 = 1.5\,\text{m}$$

Therefore, speed of the sound waves at NTP.,

$$v_0 = \nu\lambda_0 = 220 \times 1.5 = 330\,\text{ms}^{-1}.$$

Let v be the speed of sound wave at temperature T. Then,

$$\frac{v}{v_0} = \sqrt{\frac{T}{T_0}} = \sqrt{\frac{300}{273}}$$

or $$v = v_0\sqrt{\frac{300}{273}} = 330 \times \sqrt{\frac{300}{273}} = 345.93 \text{ ms}^{-1}$$

The wavelength of sound waves at 27°C is given by

$$\lambda = \frac{v}{\nu} = \frac{345.93}{220} = \mathbf{1.57\ m}.$$

Therefore, increase in wavelength

$$= 1.57 \text{ m} - 1.5 \text{ m} = \mathbf{0.07\ m}.$$

S22. Given: $$v_H = 1328 \text{ ms}^{-1}; \quad \rho_H = \frac{1}{16}\rho_{air}$$

Let v_{air} be the velocity of sound in air at N.T.P.,

Now, $$\frac{v_{air}}{v_H} = \sqrt{\frac{\rho_H}{\rho_{air}}}$$

or $$v_{air} = v_H\sqrt{\frac{\rho_H}{\rho_{air}}}$$

or $$v_{air} = 1328 \times \sqrt{\frac{\rho_{air}/16}{\rho_{air}}} = 1328\sqrt{\frac{1}{16}} = \frac{1328}{4} = \mathbf{332\ ms^{-1}}.$$

S23. At NTP., $P = 1.013 \times 10^5 \text{ Nm}^{-2}$

Volume of air, $V = 22400 \text{ cm}^3 = 2.24 \times 10^{-2} \text{ m}^3$

Mass of 1 mole of air, $M = 29.0 \times 10^{-3}$ kg

Therefore, density of air at NTP.,

$$\rho = \frac{M}{V} = \frac{29.0 \times 10^{-3}}{2.24 \times 10^{-2}} = 1.295 \text{ kg m}^{-3}$$

Now, $$v = \sqrt{\frac{P}{\rho}} = \sqrt{\frac{1.013 \times 10^{-5}}{1.295}} = \mathbf{279.7\ ms^{-1}}.$$

S24. Given: $T = 80$ kgf $= 80 \times 9.8$ N; $m = 6.4 \times 10^{-3} \text{ kg m}^{-1}$

Now, $$v = \sqrt{\frac{T}{m}} = \sqrt{\frac{80 \times 9.8}{6.4 \times 10^{-3}}} = \mathbf{350\ ms^{-1}}.$$

Therefore, time taken by the wave pulse to traverse 0.7 m length of the string,

$$t = \frac{l}{v} = \frac{0.7}{350} = \mathbf{2 \times 10^{-3}\ s}.$$

S25. Given: S = 2 km = 2,000 m; v_{air} = 330 ms^{-1}

Therefore, time taken by sound to travel through air,

$$t_{air} = \frac{S}{v_{air}} = \frac{2,000}{330} = 6.06 \text{ s}$$

As the two sounds (through air and iron rails) are heard at an interval of 5.2 s, time taken by sound to travel through iron rails,

$$t_{iron} = t_{air} - 5.2$$

$$= 6.06 - 5.2 = 0.86 \text{ s}$$

Therefore, velocity of sound in iron,

$$v_{iron} = \frac{S}{t_{iron}} = \frac{2,000}{0.86} = \mathbf{2,325.6\ ms^{-1}}.$$

S26. Given speed of Earth $u_e = 3 \times 10^4$ m/s, λ = 5875 Å

We know, $$\lambda = \frac{u_e \lambda}{c} = \frac{3 \times 10^4 \times 5875 \text{ Å}}{3 \times 10^8} = 5875 \times 10^{-4} \text{ Å}$$

The apparent wave length,

$$\lambda' = \lambda - \Delta\lambda = 5875 \text{ Å} - (5875 \times 10^{-4} \text{ Å})$$

$$= 0.9999 \times 5875 \text{ Å} = \mathbf{5874.4\ Å}.$$

S27. Sound waves are mechanical waves whose velocity $v = \sqrt{\gamma_0 RT/m}$. Light waves are non-mechanical waves or electromagnetic waves for which $c = 1/\sqrt{\mu_0, \varepsilon_0}$, where μ_0 is absolute electrical permittivity of free space. Therefore, v depends upon T, but c does not.

S28. (a) Here, $v = 350 \text{ m s}^{-1}$

Frequency range = 20 Hz to 20 kHz

= 20 Hz to 20×10^3 Hz

Now, $$\lambda = \frac{v}{\nu}$$

As $\lambda \propto 1/\nu$, the lower limit of the wavelength range will correspond to the upper limit of the frequency range and vice-versa.

Therefore, upper limit of the wavelength range

$$= \frac{350}{20} = 17.5 \text{ m}$$

and lower limit of the wavelength range

$$= \frac{350}{20 \times 10^3} = 17.5 \times 10^{-3} \text{ m} = 17.5 \text{ mm}$$

Therefore, corresponding wavelength range is 17.5 m to 17.5 mm.

(b) Now, $T = \frac{1}{\nu}$

Therefore, time period corresponding to ν = 20 Hz,

$$T = \frac{1}{20} = \mathbf{5 \times 10^{-2}\ s}$$

and time period corresponding to ν = 20,000 Hz,

$$T = \frac{1}{20,000} = \mathbf{5 \times 10^{-5}\ s}$$

Therefore, the corresponding range of time period is $\mathbf{5 \times 10^{-5}\ s}$ **to** $\mathbf{5 \times 10^{-2}\ s}$.

S29. RADER: Radio Detection and Ranging.

SONAR: Sound Navigation and Ranging.

The waves sent from them are reflected by the bodies in front and reach them back. If the time taken for the to and fro journey and the speed of the wave is known, the distance can be found.

S30. A standing wave is a pattern generated due to the superposition of two waves moving in opposite direction. It has varying amplitude.

$$Y = 20 \sin 157x \cos 314t \qquad \ldots \text{(i)}$$

$$Y = 2A \sin kx \cos \omega t \qquad \ldots \text{(ii)}$$

Compare the Eq. (i) w.r.t (ii)

We have:

(a) Amplitude = 10 units.

(b) Velocity of wave = $\frac{\omega}{k} = \frac{314}{157}$ = 2 units.

S31. Two differences between progressive wave and stationary wave:

1. In a progressive wave, disturbance travels forward in the medium; while in a stationary wave, the disturbance does not move forward or backward.

2. In a progressive wave, there is transmission of energy; While in a stationary wave, there is no transmission of energy.

S32. (a) (i) No (ii) No (iii) Yes

(b) No

Explanation: The narrow sound pulse does not have a fixed wavelength or frequency. However, the speed of the sound pulse remains the same, which is equal to the speed of sound in that medium.

The short pip produced after every 20 s does not mean that the frequency of the whistle is $\frac{1}{20}$ or 0.05 Hz. It means that 0.05 Hz is the frequency of the repetition of the pip of the whistle.

S33. All the waves have different phases.

The given transverse harmonic wave is:

$$y(x,\ t) = 3.0 \sin\left(36t + 0.018x + \frac{\pi}{4}\right) \quad \ldots \text{(i)}$$

For $x = 0$, the equation reduces to:

$$y(0,\ t) = 3.0 \sin\left(36t + \frac{\pi}{4}\right)$$

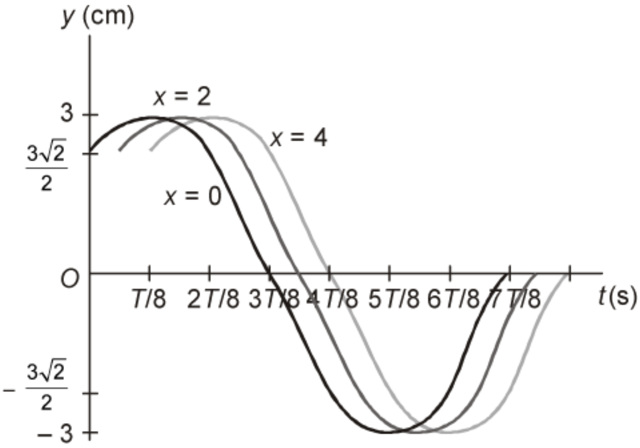
Also, $$w = \frac{2\pi}{T} = 36 \text{ rad/s}^{-1}$$

$\therefore$ $$T = \frac{\pi}{8} \text{ s}$$

Now, plotting y vs. t graphs using the different values of t, as listed in the given table.

t (s)	0	$\frac{T}{8}$	$\frac{2T}{8}$	$\frac{3T}{8}$	$\frac{4T}{8}$	$\frac{5T}{8}$	$\frac{6T}{8}$	$\frac{7T}{8}$
y (cm)	$\frac{3\sqrt{2}}{2}$	3	$\frac{3\sqrt{2}}{2}$	0	$\frac{-3\sqrt{2}}{2}$	-3	$\frac{-3\sqrt{2}}{2}$	0

For $x = 0$, $x = 2$, and $x = 4$, the phases of the three waves will get changed. This is because amplitude and frequency are invariant for any change in x. The y-t plots of the three waves are shown in the given figure.



S34. Yes; Speed = 20 m/s, Direction = Right to left

3 cm; 5.73 Hz

3.49 m

Explanation: The equation of a progressive wave travelling from right to left is given by the displacement function:

$$y(x, t) = a \sin(\omega t + kx + \Phi) \quad \ldots \text{(i)}$$

The given equation is:

$$y(x, t) = 3.0 \sin\left(36t + 0.018x + \frac{\pi}{4}\right) \quad \ldots \text{(ii)}$$

On comparing both the equations, we find that equation (*ii*) represents a travelling wave, propagating from right to left.

Now, using equations (i) and (ii), we can write:

$$\omega = 36 \text{ rad/s} \quad \text{and} \quad k = 0.018 \text{ m}^{-1}$$

We know that: $\nu = \frac{\omega}{2\pi}$ and $\lambda = \frac{2\pi}{k}$

Also, $v = \nu\lambda$

$$\therefore \quad v = \left(\frac{\omega}{2\pi}\right) \times \left(\frac{2\pi}{k}\right) = \frac{\omega}{k}$$

$$= \frac{36}{0.018} = 2000 \text{ cm/s} = 20 \text{ m/s}$$

Hence, the speed of the given travelling wave is 20 m/s.

Amplitude of the given wave, $a = 3$ cm

Frequency of the given wave:

$$\nu = \frac{\omega}{2\pi} = \frac{36}{2 \times 3.14} = 5.73 \text{ Hz}$$

On comparing equations (i) and (ii), we find that the initial phase angle, $\phi = \frac{\pi}{4}$.

The distance between two successive crests or troughs is equal to the wavelength of the wave.

Wavelength is given by the relation:

$$k = \frac{2\pi}{\lambda} \qquad [k = \text{Angular wave number}]$$

$$\therefore \qquad \lambda = \frac{2\pi}{k} = \frac{2 \times 3.14}{0.018} = 348.89\ \text{cm} = 3.49\ \text{m}$$

S35. On comparing this displacement equation with,

$$y(x, t) = a \sin (kx - \omega t),$$

we find

(a) the amplitude of the wave is 0.005 m = 5 mm.

(b) the angular wave number k and angular frequency ω are:

$$k = 80.0\ \text{m}^{-1} \quad \text{and} \quad \omega = 3.0\ \text{s}^{-1}$$

We then relate the wavelength λ to k through,

$$\lambda = 2\pi/k = \frac{2\pi}{80.0\ \text{m}^{-1}} = 7.85\ \text{cm}$$

(c) Now we relate T to ω by the relation

$$T = 2\pi/\omega = \frac{2\pi}{3.0\ \text{s}^{-1}} = 2.09\ \text{s}$$

and frequency, $\qquad v = 1/T = 0.48\ \text{Hz}$

The displacement y at x = 30.0 cm and time t = 20 s is given by

$$y = (0.005\ \text{m}) \sin (80.0 \times 0.3 - 3.0 \times 20)$$

$$= (0.005\ \text{m}) \sin (-36 + 12\pi)$$

$$= (0.005\ \text{m}) \sin (1.699)$$

$$= (0.005\ \text{m}) \sin (97°) \simeq 5\ \text{mm}.$$

S36. Let

$$y_1 = a_1 \cos \omega t, \qquad \text{... (i)}$$

$$y_2 = a_2 \cos (\omega t + \phi), \qquad \text{... (ii)}$$

Add the Eq. (i) and (ii)

On superposition,

$$y = y_1 + y_2$$

$$= a_1 \cos \omega t + a_2 \cos (\omega t + \phi)$$

$$= a_1 \cos \omega t + a_2 \cos \omega t \cos \phi - a_2 \sin \omega t \sin \phi$$

$$= (a_1 + a_2 \cos\phi)\cos\omega t - (a_2 \sin\phi)\sin\omega t \quad \text{... (iii)}$$

Put $$a_1 + a_2 \cos\phi = a\cos\theta \quad \text{... (iv)}$$

$$a_2 \sin\phi = a\sin\theta \quad \text{... (v)}$$

Squaring and adding Eq. (iv) and (v), we get

$$a^2 = a_1^2 + a_2^2 + 2a_1 a_2 \cos\phi \quad \text{... (vi)}$$

Putting Eq. (iv) and (v) in (ii), we get

$$y = a\cos\theta\cos\omega t - a\sin\theta\sin\omega t$$

$$= a\cos(\omega t + \theta)$$

Put the value '*a*' from Eq. (vi), we get

$$\therefore \quad y = \left(a_1^2 + a_2^2 + 2a_1a_2\cos\phi\right)^{1/2}\cos(\omega t + \theta)$$

where $$\theta = \tan^{-1}\left(\frac{a_2\sin\phi}{a_1 + a_2\cos\phi}\right).$$

S37. The given harmonic wave is:

$$y(x, t) = 7.5\sin\left(0.0050x + 12t + \frac{\pi}{4}\right)$$

For $x = 1$ cm and $t = 1$s,

$$y = (1, 1) = 7.5\sin\left(0.0050 + 12 + \frac{\pi}{4}\right)$$

$$= 7.5\sin\left(12.0050 + \frac{\pi}{4}\right)$$

$$= 7.5\sin\theta$$

Where, $$\theta = 12.0050 + \frac{\pi}{4} = 12.0050 + \frac{3.14}{4} = 12.79 \text{ rad}$$

$$= \frac{180}{3.14}\times 12.79 = 732.81°$$

$$\therefore \quad y = (1, 1) = 7.5\sin(732.81°)$$

$$= 7.5\sin(90\times 8 + 12.81°) = 7.5\sin 12.81°$$

$$= 7.5\times 0.2217$$

$$= 1.6629 \approx 1.663 \text{ cm}$$

The velocity of the oscillation at a given point and time is given as:

$$v = \frac{d}{dt} y(x, t) = \frac{d}{dt}\left[7.5 \sin\left(0.0050\, x + 12\, t + \frac{\pi}{4}\right)\right]$$

$$= 7.5 \times 12 \cos\left(0.0050\, x + 12\, t + \frac{\pi}{4}\right)$$

At $x = 1$ cm and $t = 1$s,

$$v = y(1,\ 1) = 90 \cos\left(12.005 + \frac{\pi}{4}\right)$$

$$= 90 \cos (732.81°) = 90 \cos (90 \times 8 + 12.81°)$$

$$= 90 \cos (12.81°)$$

$$= 90 \times 0.975 = 87.75 \text{ cm/s}$$

Now, the equation of a propagating wave is given by:

$$y(x,\ t) = a \sin (kx + wt + \phi)$$

Where, $k = \frac{2\pi}{\lambda}$ [k = Angular wave number]

$\therefore$ $\lambda = \frac{2\pi}{k}$

And $\omega = 2\pi\nu$

$\therefore$ $\nu = \frac{\omega}{2\pi}$

Speed, $v = \nu\lambda = \frac{\omega}{k}$

Where, $\omega = 12$ rad/s

$k = 0.0050 \text{ m}^{-1}$

$\therefore$ $\nu = \frac{12}{0.0050} = 2400$ cm/s

Hence, the velocity of the wave oscillation at $x = 1$ cm and $t = 1$ s is not equal to the velocity of the wave propagation.

Propagation constant is related to wavelength as:

$$k = \frac{2\pi}{\lambda}$$

$\therefore$ $\lambda = \frac{2\pi}{k} = \frac{2 \times 3.14}{0.0050}$

$$= 1256 \text{ cm} = 12.56 \text{ m}$$

Therefore, all the points at distances $n\lambda$ ($n = \pm 1, \pm 2$, ... and so on), *i.e.*, ± 12.56 m, ± 25.12 m, … and so on for $x = 1$ cm, will have the same displacement as the $x = 1$ cm points at $t = 2$ s, 5 s, and 11 s.

S38.

$$y = 2.0 \cos [2\pi (10t - 0.0080x) + 2\pi \times 0.35]$$

$$y = 2.0 \cos \left[2\pi \times 0.0080 \left(\frac{10t}{0.0080} - x\right) + 0.7\pi\right] \quad \text{... (i)}$$

Compare it with the standard equation of a travelling harmonic wave,

$$y = a \cos \left[\frac{2\pi}{\lambda}(V_t - x) + \phi\right] \quad \text{... (ii)}$$

Compare the Eq (i) w.r.t. (ii), we get

$$\frac{2\pi}{\lambda} = 2\pi \times 0.0080$$

Phase difference

$$\phi = \frac{2\pi}{\lambda} x$$

(a) When, $x = 4 \text{ m} = 400 \text{ cm}$,

$$\phi = 6.4\,\pi \text{ rad}.$$

(b) When, $x = 0.5 \text{ m} = 50 \text{ cm}$

$$\phi = 2\pi \times 0.0080 \times 50 = 0.8\,\pi \text{ rad}.$$

(c) When, $x = \lambda/2$

$$\phi = \frac{2\pi}{\lambda} \times \frac{\lambda}{2} = \pi \text{ rad}.$$

(d) When, $x = 3\lambda/4$

$$\phi = \frac{2\pi}{\lambda} \times \frac{3\lambda}{4} = \frac{3\pi}{2} \text{ rad}.$$

S39.

$$y = r \sin \frac{2\pi}{\lambda}(vt - x)$$

Velocity of particle

$$u(x, t) = \frac{d}{dt}[y(x, t)] = \frac{d}{dt}\left[r \sin\left\{\frac{2\pi}{\lambda}(vt - x)\right\}\right]$$

$$u(x, t) = \frac{2\pi}{\lambda} v \left[r \cos\left\{\frac{2\pi}{\lambda}(vt - x)\right\}\right] \quad \text{,,, (i)}$$

Also, $$\frac{d}{dx}[y(x, t)] = r \cos\left\{\frac{2\pi}{\lambda}(vt - x)\right\}\left(\frac{-2\pi}{\lambda}\right) \quad \text{... (ii)}$$

Dividing Eq. (i) and (ii), we get

$$\frac{u(x, t)}{\frac{d}{dx}\{y(x, t)\}} = -v$$

or $$u(x, t) = -v \frac{d}{dx}\{y(x, t)\}$$

Date: 13/10/2021

Q1. What is a harmonic wave function?

Q2. How does particle velocity differ from wave velocity?

Q3. What are the maximum values of particle velocity and acceleration of a simple harmonic wave?

Q4. What change is observed when a wave gets reflected from hard, rigid support?

Q5. What is the difference between a tone and a note?

Q6. What is the effect on the velocity of waves in a string if only $\left(\frac{1}{4}\right)^{th}$ of the original length is used with the same tension?

Q7. Can two astronauts talk on the surface on moon as they do on earth?

Q8. What is the source of the non-mechanical waves?

Q9. Give one similarity and one difference between a S.H.M. and a Wave.

Q10. In a dispersive medium, a how will you express the velocity of wave motion.

Q11. Fundamental frequency of oscillation of a close pipe is 400 Hz. What will be the fundamental frequency of oscillation of an open pipe of same length?

Q12. Which characteristics of the medium, determine the velocity of longitudinal sound waves in a medium?

Q13. How does the speed of sound in air vary with temperature?

Q14. Calculate the speed of sound in O_2 from following data. The mass of 22.4 liter of O_2 at STP ($T = 273$ K) and $P = 1.0 \times 10^5$ N/m^2 is 32 g. The molar heat capacity of O_2 at constant volume is $C_v = 2.5\,R$ and constant pressure is $C_P = 3.5\,R$.

Q15. Velocity of sound in air at N.T.P. is 332m/s. What will be the velocity, when pressure is doubled and temperature is kept constant?

Q16. What is the nature of the thermal changes in air, when a sound wave propagates through it?

Q17. Why does sound travel faster in iron than in air?

Q18. The density of oxygen is 16 times the density of hydrogen. What is the relation between the speeds of sound in the two gases?

Q19. A child blows air at one end of a straw and slowly cuts pieces of the straw from the other end. What will be the outcome that will be observed?

Q20. A steel wire 0.72 m long has a mass of 5.0×10^{-3} kg. If the wire is under a tension of 60 N, what is the speed of transverse waves on the wire?

Q21. The displacement y of a particle in a medium can be expressed as

$$y = 10^{-6} \sin (100\,t + 20\,x + \pi/4),$$

Where t is in second and x in metre. What is the speed of the wave?

Q22. Distinguish between the harmonic and overtones?

Q23. A wave is expressed by the equation, $y = 0.5 \sin \pi (0.01x - 3t)$, where y and x are in metres and t in seconds. Find the speed of propagation.

Q24. The equation of a transverse wave travelling along the X-axis is

$$y = 10 \sin \pi (0.01x - 2t),$$

where x, y are in cm and t in seconds. Find the amplitude, frequency, velocity and wavelength of the wave.

Q25. If the equation for the transverse wave in a string is given by

$$y = 5 \sin 2\pi \left(\frac{t}{0.02} - \frac{x}{50} \right)$$

with lengths expressed in cm and time period in seconds, calculate the wave velocity and maximum particle velocity.

Q26. Show graphically, the intensity variation of beats formation?

Q27. An open pipe resonates with a frequency v, When half of it is immersed in a dense liquid, what is the fundamental frequency?

Q28. Air gets thinner as we go up in the atmosphere. Will the velocity of sound change?

Q29. Set up a relation between speed of sound in a gas and root mean square velocity of the molecules of that gas.

Q30. A steel wire has a length of 12.0 m and a mass of 2.10 kg. What should be the tension in the wire so that the speed of transverse wave on the wire equals the speed of sound in dry air at 20 °C? Take the speed of sound at 20 °C = 343 m/s.

Q31. If the frequency of a tuning fork is 256 Hz and speed of sound in air is 320 m/s, find how far does the sound travel when the fork executes 64 vibrations?

Q32. In an experiment, it was found that a tuning fork and a Sonometer wire gave 5 beats per second, both when the length of the wire was 1 m, and 1.05 m. Calculate the frequency of the fork.

Q33. The transverse displacement of a string (clamped at its two ends) is given by

$$y(x, t) = 0.06 \sin \frac{2\pi}{3} x \cos 120\,\pi t,$$

where x, y are in m and t is in s.

(a) Do all the points on the string oscillate with the same (i) frequency, (ii) phase, (iii) amplitude? Explain your answers.

(b) What is the amplitude of a point 0.375 m away from one end?

Q34. Given below are some functions of x and t to represent the displacement (transverse or longitudinal) of an elastic wave. State which of these represent (i) a traveling wave, (ii) a stationary wave or (iii) none at all:

$$y = 2\cos(3x)\sin(10t)$$

$$y = 2\sqrt{x - vt}$$

$$y = 3\sin(5x - 0.5t) + 4\cos(5x - 0.5t)$$

$$y = \cos x \sin t + \cos 2x \sin 2t$$

Q35. (a) Write the differences between a progressive and a stationary wave

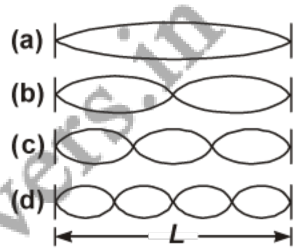
(b) A wire is under tension of 32 N and length between the two bridges is 1 m. A 10 m length of the sample of the wire has a mass of 2 g. Deduce the speed of transverse waves on the wire and frequency of the fundamental.

Q36. Define kinetic energy density of a wave. Derive an expression for its maximum value. Using it, prove that the intensity of the wave is, $I = \frac{1}{2}\rho\omega^2 A^2 v$.

Q37. A displacement wave is represented by $y = 0.34\cos(3{,}000\,t + 0.74\,x)$ where y and t are in mm and seconds respectively.
Deduce (a) amplitude (b) frequency and angular frequency (c) period, and (d) initial phase.

Q38. A wire stretched between two rigid supports vibrates in the fundamental mode with a frequency of 90 Hz. The mass of the wire is 0.045 kg and its linear density is 0.036 kg m^{-1}. Find (a) the speed of a transverse wave on the string and (b) the tension in the string.

Q39. The figure Shows different standing wave patterns on a string of linear mass density 4.0×10^{-2} kgm^{-1} under a tension of 100N. The amplitude of antinodes is indicated in each figure. The length of the string is 2.0 m. Obtain the frequencies of the fundamental mode and its different harmonics shown in the figure.



Q40. (a) A stretched wire emits a fundamental note of 256 Hz. Keeping the stretching force constant and reducing the length of wire by 10 cm, the frequency becomes 320 Hz. Calculate the original length of the wire.

(b) If the frequency of a tuning fork is 256 Hz and speed of sound in air is 320 m/s, find how far does the sound travel when the fork executes 64 vibrations?

Q41. (a) Discuss Newton's formula for the velocity of longitudinal waves in air. What correction was applied by Laplace? Explain.

(b) Estimate the speed of sound in air at standard temperature and pressure. The mass of 1 mol of air is 29.0×10^{-3} kg.

Q42. (a) What are stationary waves? How are they formed in string? Draw the various modes of vibration in them.

(b) The length of the Sonometre wire between two fixed ends is 100 cm, where should two bridges be placed so as to divide the wire into three segment whose fundamental frequencies are in the ratio of 1 : 2 : 3.

Date: 13/10/2021

S1. A periodic wave function, whose functional form is sine or cosine is called a ***harmonic wave function***.

S2. The particle velocity varies both with position and time, whereas wave velocity for a wave motion remains the same.

S3. Maximum particle velocity,

$$v_{max} = r\omega.$$

Maximum particle acceleration,

$$a_{max} = -r\omega^2.$$

S4. A phase change of π radians

S5. Note is sound of particular frequency, while tone is of a particular intensity.

S6. Since $\frac{m}{l}$ is not altered and tension is same, velocity will remain the same.

S7. For propagation of sound, a material medium is necessary. Since the moon has no atmosphere, sound waves from one astronaut cannot travel to the other and hence they cannot talk to each other.

S8. They are produced due to the charges of the electric and magnetic fields associated with the moving changes.

S9. Similarity – periodic nature.

Difference – Wave is a function of position and time, while a SHM is a function of time only.

S10. Speed of a wave is expressed as $\frac{d\omega}{dk}$ for dispersive medium.

S11. 800 Hz.

S12. The velocity of sound waves in a medium is determined by the elasticity and density of the medium.

S13. The speed of sound in air increases directly as the square root of the absolute temperature of the air *i.e.*,

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

S14. We know,

$$\gamma = \frac{C_P}{C'_v} = \frac{3.5R}{2.5R} = 1.4$$

$$P = 1.0 \times 10^5\ \text{N m}^{-2}$$

$$\rho = \frac{32 \times 10^{-3}}{22.4 \times 10^{-3}} = \frac{32}{22.4}$$

$$v = \sqrt{\frac{\gamma P}{\rho}} = \sqrt{\frac{1.4 \times 10^5 \times 22.4}{32}} = \mathbf{313\ m\,s^{-1}}.$$

S15. v = 332 m/s, as there is no effect of change in pressure when temperature remains constant.

S16. When the sound waves travel through air, adiabatic changes take place in the medium.

S17. Sound travels faster in solids. It is because, solids are highly elastic as compared to liquids and gases.

S18. Given, $\rho_{O_2} = 16\,\rho_{H_2}$

We know, $v = \sqrt{\frac{n}{\rho}} \quad \Rightarrow \quad v \propto \frac{1}{\sqrt{\rho}}$

$$\frac{v_{H_2}}{v_{O_2}} = \sqrt{\frac{\rho_{O_2}}{\rho_{H_2}}}$$

$$\frac{v_{H_2}}{v_{O_2}} = \sqrt{\frac{16\,\rho_{H_2}}{\rho_{H_2}}}$$

$$v_{H_2} = 4\,v_{O_2}$$

Therefore, the speed of sound in hydrogen is four times that in oxygen.

S19. As the pipe gets cut, the length of the resonating column varies, and so at a particular length, there will be an audible frequency that will be heard.

S20. Mass per unit length of the wire,

$$\mu = \frac{5.0 \times 10^{-3}\ \text{kg}}{0.72\ \text{m}}$$

$$= 6.9 \times 10^{-3}\ \text{kg m}^{-1}$$

Tension, $T = 60\ \text{N}$

The speed of wave on the wire is given by

$$v = \sqrt{\frac{T}{\mu}} = \sqrt{\frac{60\ \text{N}}{6.9 \times 10^{-3}\ \text{kg m}^{-1}}} = 93\ \text{m s}^{-1}.$$

S21. Given: $y = 10^{-6} \sin(100\,t + 20\,x + \pi/4)$ ... (i)

The equation of a travelling wave is given by

$y = a \sin(\omega t + kx + \phi)$ ... (ii)

Comparing the equation (i) and (ii), we get

$$\omega = 100 \text{ rad s}^{-1} \quad \text{and} \quad \frac{2\pi}{\lambda} = k = 20 \text{ rad m}^{-1}$$

Now, velocity of the wave.

$$v = \nu\lambda = \frac{2\pi\nu}{2\pi/\lambda} = \frac{\omega}{k} = \frac{100}{20} = \mathbf{5\ ms^{-1}}.$$

S22. The minimum frequencies, with which a body can vibrate, is called its fundamental frequency (ν). A body can be set into vibration with frequencies integral multiple of its fundamental frequencies *i.e.*, with frequencies 2ν, 3ν, 4ν ... The frequencies of ν, 2ν, 3ν, 4ν, ... are called the frequencies of various harmonics, while the frequencies 2ν, 3ν, 4ν, ... are called frequencies of the overtones produced.

S23. Given: $y = 0.5 \sin \pi (0.01x - 3t)$,

or $y = 0.5 \sin (0.01\pi x - 3\pi t)$ ... (i)

On comparing the given equation for the wave with the equation

$$y = r \sin (kx - \omega t),$$

we get, $r = 0.5$ m; $k = 0.01\pi \text{ rad m}^{-1}$ and $\omega = 3\pi \text{ rad s}^{-1}$

Now, $k = \frac{2\pi}{\lambda}$ or $\lambda = \frac{2\pi}{k}$

$\therefore$ $$\lambda = \frac{2\pi}{0.01\pi} = 200 \text{ m}$$

Also, $$\nu = \frac{\omega}{2\pi} = \frac{3\pi}{2\pi} = 1.5 \text{ s}^{-1}$$

$\therefore$ $n = \nu\lambda = 1.5 \times 200 = \mathbf{300\ ms^{-1}}$.

S24. Given: $y = 10 \sin \pi (0.01x - 2t)$,

or $y = 10 \sin 0.01\,\pi (x - 200t)$ ... (i)

On comparing the given equation for the wave with the equation

$$y = a \sin \frac{2\pi}{\lambda}(x - vt), \quad \text{... (ii)}$$

Compare the Eq. (i) w.r.t. (i), we have

$$a = 10 \text{ cm}; \quad v = 200 \text{ cm s}^{-1} \quad \text{and} \quad \frac{2\pi}{\lambda} = 0.01\pi \quad \text{or} \quad \lambda = 200 \text{ cm}$$

Now, $$\nu = \frac{v}{\lambda} = \frac{200}{200} = \mathbf{1\ Hz}.$$

S25. Given:

$$y = 5 \sin 2\pi\left(\frac{t}{0.02} - \frac{x}{50}\right),$$

or $$y = 5 \sin \frac{2\pi}{50}(2500t - x) \qquad \text{... (i)}$$

On comparing the given equation for the wave with the equation

$$y = a \sin \frac{2\pi}{\lambda}(vt - x) \qquad \text{... (ii)}$$

Compare the Eq. (i) w.r.t. (i), we have

$$a = 5 \text{ cm}; \quad \lambda = 50 \text{ cm}; \quad v = 2{,}500 \text{ cm s}^{-1}$$

Thus, wave velocity

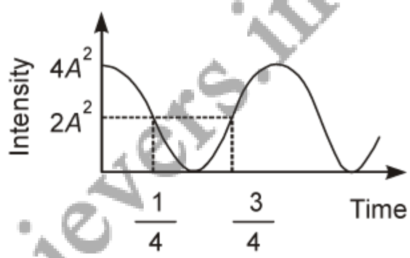
$$v = \mathbf{2{,}500 \text{ cm s}^{-1}}$$

Now, maximum particle velocity,

$$u_{max} = r\omega = r \times 2\pi n = \frac{r \times 2\pi v}{\lambda}$$

$$= \frac{5 \times 2\pi \times 2{,}500}{50} = \mathbf{1{,}570.8 \text{ cm s}^{-1}}.$$

S26. When beats are formed by two sources having same amplitude but slightly different frequencies, the amplitude is given by $2A \cos 2\pi\nu_m t$ where $\nu_m = \frac{\nu_1 - \nu_2}{2}$.



Intensity = $4A^2 \cos^2(2\pi\nu_m t)$ and is shown graphically here.

S27. $\nu = \frac{v}{2l}$ with fundamental frequency. When half immersed in a denser liquid, it will act as a closed pipe of length $\frac{l}{2}$.

$\therefore$ $$\nu' = \frac{v}{4l'} = \frac{v}{4l/2} = \frac{v}{2l}$$

So, $$\nu = \nu'.$$

S28. As we move up, the pressure (P) of air and density of air (ρ), both decrease. As $v = \sqrt{\frac{\gamma RT}{m}}$, therefore velocity of sound will not change so long as temperature T of air remains constant.

S29. Speed of sound in gas is

$$v = \sqrt{\gamma \frac{P}{\rho}} \qquad \text{... (i)}$$

According to kinetic theory of gases, root mean square velocity ($v_{r.m.s.}$) of molecules of gas is obtained from the relation.

$$P = \frac{1}{3}\rho v_{r.m.s.}^2, \quad v_{r.m.s.} = \sqrt{\frac{3P}{\rho}} \qquad \text{... (ii)}$$

Dividing Eq. (i) by (ii), we get

$$\frac{v}{v_{r.m.s.}} = \sqrt{\frac{\gamma}{3}} \quad \text{or} \quad v = \sqrt{\frac{\gamma}{3}} \times v_{r.m.s.}$$

This is the required relation.

S30. Given, $l = 12\,\text{m}$ and $M = 2.10\,\text{kg}$

$\therefore$ $\mu = \frac{2.10}{12} = 0.175\,\text{kg/m}$

and $v = 343\,\text{m/s}$

Using, $v = \sqrt{\frac{T}{\mu}}$

or $T = v^2\mu = (343)^2 \times 0.175$

$= \mathbf{20.5 \times 10^4\,N}$.

S31. Here,

$$\lambda = \frac{v}{\nu} = \frac{320\,\text{m/s}}{256\,\text{s}^{-1}} = \frac{320}{256}\,\text{m}$$

Distance covered in n vibrations = $\frac{64 \times 320}{256} = \mathbf{80\,m}$.

S32. We know

$$\nu = \frac{1}{2l}\sqrt{\frac{T}{\mu}}$$

Case I: $\nu_1 = \frac{1}{2 \times 1}\sqrt{\frac{T}{\mu}}$ ... (i)

Case II: $\nu_2 = \frac{1}{2 \times 1.05}\sqrt{\frac{T}{\mu}}$ ... (ii)

Let ν be the frequency of the tuning fork, therefore,

$$\nu_1 - \nu = 5 \quad \text{and} \quad \nu - \nu_2 = 5$$

or $\nu_1 = \nu + 5$

and $\nu_2 = \nu - 5$ or $\frac{\nu_1}{\nu_2} = \frac{\nu + 5}{\nu - 5}$

From Eq. (i) and (ii), we have

$$\frac{\nu + 5}{\nu - 5} = \frac{1}{2} \times 2 \times 1.05 = 1.05$$

or $$\frac{\nu + 5}{\nu - 5} = \frac{105}{100} = \frac{21}{20}$$

$\Rightarrow$ ν = **205 Hz**.

S33. (a) The transverse displacement is given by

$$y(x, t) = 0.06 \sin \frac{2\pi}{3} x \cos 120\,\pi t$$

(i) The time dependent part of the equation of a stationary wave ($\cos 2\pi\nu t$) defines the frequency of the wave motion. Since this part *i.e.*, $\cos 120\,\pi t$ in the given equation is independent of x, hence frequency of oscillation of all the points on the string is ***same***.

(ii) The phase of all the points on the string is same for the reasons stated in (a).

(iii) The amplitude of stationary wave is given by

$$A = 0.06 \sin \frac{2\pi}{3} x \qquad \text{(time independent part)}$$

As A depends on x, amplitude of all the points on the string is ***not same***.

(b) Now, amplitude at a point 0.375 m away from one end is given by

$$A = 0.06 \sin \frac{2\pi}{3} \times 0.375 = 0.06 \sin \frac{\pi}{4}$$

$$= 0.06 \times 0.707 = \mathbf{0.402\ m}.$$

S34. The given equation represents a stationary wave because the harmonic terms kx and ωt appear separately in the equation.

The given equation does not contain any harmonic term. Therefore, it does not represent either a travelling wave or a stationary wave.

The given equation represents a travelling wave as the harmonic terms kx and ωt are in the combination of $kx - \omega t$.

The given equation represents a stationary wave because the harmonic terms kx and ωt appear separately in the equation. This equation actually represents the superposition of two stationary waves.

S35. (a)

Progressive Wave	***Stationary Wave***
(a) All particles have same phase and amplitude	(a) Amplitude varies with position
(b) Speed of motion is same.	(b) Speed varies with position
(c) Energy is transported.	(c) Energy is not transported.
(d) Same change in pressure and density is with every point.	(d) Pressure and density varies with Point

(b) Given $T = 32$ N; $\mu = \frac{2g}{10m} = \frac{0.002}{10}$ kgm^{-1}; $l = 1$ m

$$v = \sqrt{\frac{T}{\mu}} = \sqrt{\frac{32 \times 10}{0.002}}\ \text{ms}^{-1} = \mathbf{400\ ms^{-1}}$$

Also, $$\nu = \frac{1}{2l}\sqrt{\frac{T}{\mu}} = \frac{1}{2 \times 1} \times 400\ \text{Hz} = \mathbf{200\ Hz}.$$

S36. For a travelling wave, $y = A \sin(\omega t - Kr)$, be the displacement. The velocity of particles is given by $v_p = \frac{dy}{dt} = \omega A \cos(\omega t - Kr)$.

K.E. per unit volume $= \frac{1}{2}\frac{m}{V}v^2 = \frac{1}{2}\rho v^2$

$= \frac{1}{2}\rho\omega^2 A^2 \cos^2(\omega t - Kr)$

$\therefore$ K.E. density defined as K.E. per unit volume is given by $\frac{1}{2}\rho\omega^2 A^2 \cos^2(\omega t - Kr)$.

Maximum value of energy density

$$= \frac{1}{2}\rho\omega^2 A^2$$

Intensity is the energy falling per unit area per unit time.

So, $$I = \frac{\Delta E}{\Delta t S} = \frac{P}{S}$$

$\therefore$ $$I = \frac{\frac{1}{2}\rho\omega^2 A^2 . S\Delta x}{S\Delta t} = \frac{1}{2}\rho\omega^2 A^2 v$$

S37. Here, $y = 0.34 \cos(3{,}000\,t + 0.74\,x)$

$= 0.34 \cos 0.74\,(4{,}054.1\,t + x)$

or $y = 0.34 \sin[0.74\,(4{,}054.1\,t + x) + \pi/2]$ ... (i)

On comparing the given equation for the wave with the equation

$$y = A \sin\left[\frac{2\pi}{\lambda}(vt - x) + \phi_v\right],$$

we get, $A = 0.34$; $v = 4{,}054.1$ mm s^{-1}; $\phi_0 = \pi/2$ rad

and $\frac{2\pi}{\lambda} = 0.74$ mm^{-1}

(a) The amplitude, $A = \mathbf{0.34\ mm}$.

(b) Now, $\frac{2\pi}{\lambda} = 0.74$ or $\lambda = \frac{2\pi}{0.74} = 8.49\ \text{mm}$

$$\nu = \frac{v}{\lambda} = \frac{4,054.1}{8.49} = 477.5\ \text{s}^{-1}$$

Also, $\omega = 2\pi\nu = 2\pi \times 477.5\ \text{s}^{-1} = \mathbf{3,000\ rad\ s^{-1}}$.

(c) Again, $T = \frac{1}{\nu} = \frac{1}{477.5} = \mathbf{2.094 \times 10^{-3}\ s}$.

(d) The initial phase, $\phi = \mathbf{\pi/2\ rad}$.

S38. Here, frequency of fundamental mode, ν = 90 Hz; mass of the wire, M = 0.045 kg and linear density (mass per unit length) of the wire,

$$m = 0.036\ \text{kg m}^{-1}$$

Therefore, length of the wire,

$$L = \frac{M}{m} = \frac{0.045}{0.035} = 1.25\ \text{m}$$

(a) When, wire vibrates in its fundamental mode, then

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

or $\lambda = 2L = 2 \times 1.25 = 2.5\ \text{m}$

Therefore, velocity of the transverse waves,

$$v = \nu\lambda = 90 \times 2.5 = \mathbf{225\ ms^{-1}}.$$

(b) The velocity of transverse waves in a wire is given by

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

$$T = v^2 m = (225)^2 \times 0.036 = 1,822.5\ \text{N}.$$

S39. Here, linear mass density, $m = 4.0 \times 10^{-2}\ \text{kg m}^{-1}$; T = 100 N; Length of string, L = 2.0 m

Now, $v = \sqrt{\frac{T}{m}} = \sqrt{\frac{100}{4.0 \times 10^{-2}}} = 50\ \text{ms}^{-1}$

Figure (a): As the string is vibrating in one segment,

$$L = \lambda/2$$

or $\lambda = 2L = 2 \times 2.0 = 4.0\ \text{m}$

If ν is the frequency of vibration, then

$$\nu = \frac{v}{\lambda} = \frac{50}{4} = \mathbf{12.5\ Hz}.$$

Figure (b): Let λ_1 be the wavelength and ν_1 be the frequency of vibration.

As the string is vibrating in two segments,

$$\lambda_1 = L = 2.0 \text{ m}$$

$$\therefore \quad \nu_1 = \frac{50}{2.0} = \mathbf{25\ Hz}.$$

Figure (c): Here, $$\frac{3\lambda_2}{2} = L = 2.0 \text{ m}$$

or $$\lambda_2 = \frac{4}{3} \text{ m}$$

$$\nu_2 = \frac{50}{4/3} = \mathbf{37.5\ Hz}.$$

Figure (d): Here, $$2\lambda_3 = L = 2.0 \text{ m}$$

or $$\lambda_3 = 1.0 \text{ m}$$

$$\therefore \quad \nu_3 = \frac{50}{1.0} = \mathbf{50\ Hz}.$$

S40. (a) The frequency of fundamental note is given by

$$\nu = \frac{1}{2L}\sqrt{\frac{T}{m}}$$

In First Case: Given, ν = 256

$$\therefore \quad 256 = \frac{1}{2L}\sqrt{\frac{T}{m}} \qquad \text{... (i)}$$

In Second Case: Here, on decreasing length by 10 cm, frequency of vibration of the wire becomes 320 Hz.

$$320 = \frac{1}{2(L-10)}\sqrt{\frac{T}{m}} \qquad \text{... (ii)}$$

Dividing the equation (ii) by (i), we get

$$\frac{320}{256} = \frac{2L}{2(L-10)} \quad \text{or} \quad \frac{L}{L-10} = \frac{5}{4} \quad \text{or} \quad \mathbf{L = 50\ m}.$$

(b) Here, $$\lambda = \frac{v}{\nu} = \frac{320 \text{ m/s}}{256 \text{ s}^{-1}} = \frac{320}{256} \text{ m}$$

Distance covered in n vibrations = $\frac{64 \times 320}{256} = \mathbf{80\ m}$.

S41. (a) According to Newton, as wave propagates through a medium, temperature is a constant and so propagation is an isothermal process, satisfying PV = Constant. Differentiating, we get.

$$PV = K \qquad (T = \text{Constant})$$

$$PdV + VdP = 0$$

$$\Rightarrow \qquad P = -\frac{(dP)}{\left(\frac{dV}{V}\right)} = \frac{\text{Stress}}{\text{Strain}} = \text{(isothermal) Elasicity } E_i$$

Since velocity of sound waves is $v = \sqrt{\frac{E_i}{P}}$, we have $v = \sqrt{\frac{P}{\rho}}$

When sound waves travel in air, the changes in the volume and pressure take placed rapidly and air or gas is bad conductor of heat.

Due to these factors, the compressed air become warm and stay warm, whereas the verified air suddenly cool and stay cool. For adiabatic changes in pressure and volume

$$PV^{\gamma} = \text{Constant}$$

Now, differentiate

$$P\gamma V^{\gamma-1} dV + V^{\gamma} dP = 0$$

(b) We know that 1 mol of any gas occupied 22.4 liter at STP.

Density of air at STP

$$\rho_0 = \frac{\text{Mass of one mole of air}}{\text{Volume of one mole of air STP}}$$

$$\frac{29.0 \times 10^{-3}}{22.4 \times 10^{-3}} = 1.29 \text{ kg m}^{-3}$$

for air $\qquad \gamma = \frac{7}{5}$

Using Laplace's formula

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

we get $\qquad = \sqrt{\frac{7}{5} \times \frac{1.01 \times 10^5}{1.29}} = \mathbf{331.1\ ms^{-1}}$.

S42. (a) Formed by two waves moving in opposite directions interacting. They may have equal or unequal amplitudes and generally equal frequencies. $Y = \pm 2A \sin kx \cos \omega t$ refers to a standing wave, where nodes and antinodes are alternatively formed with a separation $\lambda/2$

Given wave : $Y_i = A \sin(\omega t - kx)$

Reflected wave: $Y_r = A \sin(\omega t + kx + \pi)$

In strings, stationary waves formed produce frequencies, multiple of $\left(\frac{v}{2l}\right)$ or harmonics of $\left(\frac{v}{2l}\right)$, *i.e.*, $\frac{nv}{2l} = \frac{n}{2l}\sqrt{\frac{T}{\mu}}$

Since $\nu = \frac{nv}{2l}$, the pattern can be shown as below:

$n = 1$, I harmonic $l = \frac{\lambda}{2}$  $\nu = \frac{v}{2l}$

$n = 2$, II harmonic $l = 2\frac{\lambda}{2}$  $\nu = 2\frac{v}{2l}$

$n = 3$, III harmonic $l = 3\frac{\lambda}{2}$  $\nu = 3\frac{v}{2l}$

Applying superposition principle,

$$y = Y_i + Y_r$$
$$= A \sin(\omega t - kx) - A \sin(\omega t + kx)$$
$$y = 2A \sin kx \cos \omega t$$

Since amplitude $2A \sin kx$ varies with position, it represents a standing wave.

(b) Let l_1, l_2 and l_3 be the length of the three segments then,

$$l_1 + l_2 + l_3 = 100 \text{ cm}$$

Let ν_1, ν_2 and ν_3 be the fundamental frequencies of the three segments

Now, $\frac{\nu_1}{\nu_2} = \frac{1}{2}$ and $\frac{\nu_2}{\nu_3} = \frac{2}{3}$

Applying the law of length

$$l_1 = \frac{\nu_2 l_2}{\nu_1} = 2l_2$$

$$l_3 = \frac{\nu_2 l_2}{\nu_3} = \frac{2}{3} l_2$$

$$l_1 + l_2 + l_3 = 2l_2 + l_2 + \frac{2}{3} l_2 = 100$$

$$l_2 = 27.27 \text{ cm}$$

$l_1 = 54.54$ cm

$l_3 = 18.18$ cm.

Date: 13/10/2021

Q1. Why are the stationary waves called so?

Q2. When are stationary waves produced?

Q3. Name the two instruments based on superposition of waves.

Q4. How the frequency of a vibrating wire is affected, when the load attached is immersed in water?

Q5. Explain, why the pitch of an organ pipe on a hot summer day is higher.

Q6. How sounds of different frequencies are produced by opening or closing the different holes of a flute?

Q7. Where does the pressure of larger magnitude exist at nodes or at antinodes?

Q8. What is a periodic wave function?

Q9. The intensity maxima due to two interfering waves of equal amplitude $a_1 = a_2 = a$ is $4a^2$. Does this violate the law of conservation of energy? Justify.

Q10. Define temperature coefficient of the velocity of sound.

Q11. If a balloon is filled will CO_2 gas, then how can it behave as a lens for sound waves? If it was filled with hydrogen gas, then what will happen?

Q12. What is the velocity of the particle of the medium in a simple harmonic wave at a point at distance x and at time t?

Q13. A wire of length 1.5 m is stretched by force of 44 N. The diameter of the wire is 3 mm and its density is 1.4 g cm^{-3}. Calculate the frequency of the fundamental note emitted by it.

Q14. State the principle of super position. Is it valid for light waves?

Q15. A travelling wave in a stretched string is described by the equation $y = A \sin (kx - \omega t)$. What is the maximum particle velocity

Q16. A stretched wire emits a fundamental note of 256. Keeping the stretching force constant and reducing the length of wire by 10 cm, the frequency becomes 320. Calculate the original length of wire.

Q17. A sitar wire is 80 cm long and it emits a note of 288 vibrations per second. How far from the top, it may be pressed so that it emits a note of 312 vibrations per second?

Q18. If the frequency of a tuning fork is 400 Hz and the velocity of sound in air is 320 m/s, find how far does the sound travel when the fork executes 30 vibrations.

Q19. The apparent frequency of the whistle of an engine changes in the ratio 3 : 2 as the engine passes a stationary observer. If the velocity of sound is 320 m/s, calculate the velocity of the engine.

Q20. A wire of density 9 g cm^{-3} is stretched between two clamps 1 m apart and is subjected to an extension of 0.05 cm. What is the lowest frequency of transverse vibrations in the wire? Given, $Y = 9 \times 10^{10}$ Nm^{-2}.

Q21. A pipe 30.0 cm long is open at both ends. Which harmonic mode of the pipe is resonantly excited by a 1.1 kHz source? Will resonance with the same source be observed, if one end of the pipe is closed? Take the speed of sound in air as 330 ms^{-1}.

Q22. A stone dropped from the top of a tower of height 300 m high splashes into the water of a pond near the base of the tower. When is the splash heard at the top given that the speed of sound in air is 340 m s^{-1}? ($g = 9.8$ m s^2)

Q23. An open pipe is suddenly closed at one end with the result that the frequency of the third harmonic of the closed pipe is found to be higher by 200 Hz than the fundamental frequency of the open pipe. What is the fundamental frequency of the open pipe.

Q24. (a) A copper wire is held at the two ends by rigid supports. At 30°C, the wire is just taut with negligible tension. Given that $\alpha = 1.7 \times 10^{-5}$ °C^{-1}, $Y = 1.3 \times 10^{11}$ Nm^{-2} and $p = 9 \times 10^3$ kg m^{-3}.

(b) A travelling wave in a stretched string is described by the equation $y = A \sin (kx - \omega t)$. What is the maximum particle velocity.

Q25. A pipe, 30.0 cm long, is open at both ends. Which harmonic mode of the pipe resonates a 1.1 kHz source? Will resonance with the same source be observed if one end of the pipe is closed? Take the speed of sound in air as 330 m s^{-1}.

Q26. (a) Give any three differences between progressive waves and stationary waves. A stationary wave is $y = 12 \sin 300t \cos 2x$. What is the distance between two nearest nodes?

(b) The two harmonic wave have same displacement amplitude of 4×10^{-5} cm and their another frequencies are 500 rad s^{-1}. Calculate (i) particle velocity amplitude and (ii) particle acceleration amplitude.

Date: 13/10/2021

S1. In a stationary wave, the particles of the medium vibrate about their mean positions, but disturbance does not travel in any direction.

S2. When two progressive waves of same frequency moving with same speed in opposite directions in a medium superpose on each other, the stationary waves are produced.

S3. (a) Sonometer (b) Organ pipe.

S4. On immersing load in water, the apparent weight of the load and hence the tension in the string decreases. Since $\nu \propto \sqrt{T}$, the frequency of the vibrating wire decreases.

S5. On a hot day, the velocity of sound will be more. Since $\nu \propto v$, the frequency of sound and hence its pitch increases.

S6. The frequency of the sound produced by a flute (pipe) depends on its length. When holes of a flute are opened or closed, its effective length changes and sounds of different frequencies are produced.

S7. Pressure is maximum at points of minimum displacement. So, it is maximum at nodes.

S8. A wave function $y(x, t)$ of position and time, which satisfies the following periodicity conditions, is called periodic wave function:

(a) $y(x + m\lambda, t) = y(x_1 t)$ (b) $y(x, t + nT) = y(x; t)$

S9. No. The average intensity of maxima and minima will be $I_{av} = \frac{4a^2 + 0}{2} = 2a^2$, which is the sum of their intensities. So, energy conservation is obeyed, but redistribution of energy has taken place.

S10. The temperature coefficient of the velocity of sound is defined as the change in the velocity of sound, when the temperature changes by 1 °C (or 1 K). It is denoted by α.

S11. Velocity of sound in CO_2 is less than that in air. Therefore, balloon will behave as a convex lens for sound waves.

In hydrogen, velocity of sound is greater than that in air. Therefore, balloon filled with hydrogen will behave as a concave lens.

S12. Suppose that the displacement of a simple harmonic wave at a distance x and at time t is given by

$$y = r \sin \frac{2\pi}{\lambda} (\nu t - x).$$

Then, the velocity of the particle of the medium at a point at distance x and at time t is given by

$$u = \frac{dy}{dt} = \frac{2\pi r \nu}{\lambda} \cos \frac{2\pi}{\lambda}(\nu t - x).$$

S13. Given: $L = 1.5$ m; $T = 44$ N; $D = 2$ mm $= 2 \times 10^{-3}$ m; $\rho = 1.4$ g cm^{-3} $= 1.4 \times 10^3$ kg m^{-3}

Now, $$m = \frac{\pi D^2}{4} \times \rho = \frac{\pi \times (2 \times 10^{-3})^2}{4} \times 1.4 \times 10^3$$

$$= 4.4 \times 10^{-3} \text{ kg m}^{-1}$$

Now, $$\nu = \frac{1}{2L}\sqrt{\frac{T}{m}} = \frac{1}{2 \times 1.5}\sqrt{\frac{44}{4.4 \times 10^{-3}}} = \mathbf{33.333\ Hz}.$$

S14. When two or more waves travel in a medium in such a way that each wave represents its separate motion individually, then the resultant displacement of particle of the medium at any time is equal to the vector sum of the individual displacements.

The principle is valid for light waves also.

S15. Given: $$y = A \sin(kx - \omega t)$$

Now, particle velocity, $$u = \frac{dy}{dt} = \frac{d}{dt}[A \sin(kx - \omega t)$$

$$= -A\omega \cos(kx - \omega t)$$

Therefore, maximum particle velocity,

$$u_{max} = A\omega \quad \text{(in magnitude)}.$$

S16. Given: $\nu_1 = 256$ Hz; $L_2 = (L_1 - 10)$ cm and $\nu_2 = 320$ Hz

Now, $$L_2 = \frac{\nu_1}{\nu_2} \times L_1$$

or $$L_1 - 10 = \frac{256}{320} \times L_1 \quad \text{or} \quad 5(L_1 - 10) = 4L_1$$

or $$L_1 = \mathbf{50\ cm}.$$

S17. Given: $L_1 = 80$ cm; $\nu_1 = 288$ Hz and $\nu_2 = 312$ Hz

Now, $$\frac{\nu_1}{\nu_2} = \frac{L_2}{L_1} \quad \text{or} \quad L_2 = \frac{\nu_1}{\nu_2} \times L_1$$

or $$L_2 = \frac{288}{312} \times 80 = \mathbf{73.85\ cm}.$$

Therefore, distance from the top, the string may be pressed,

$$L_1 - L_2 = 80 - 73.85 = \mathbf{6.15\ cm}.$$

S18. Given $v = 320$ m/s; $\nu = 400$ Hz

$$\therefore \quad \lambda = \frac{v}{\nu} = \frac{320}{400} = 0.8 \text{ m}$$

$\therefore$ The required distance travelled during the time the fork makes 30 vibrations = $30 \times 0.8 = 24$ m.

S19. Here,
$$\frac{\nu_1}{\nu_2} = \frac{c + u_0}{c - u_0} = \frac{3}{2}$$

Solving we get,
$$u_0 = \frac{c}{5} = \frac{330}{5} = \mathbf{66\ ms^{-1}}.$$

S20. Here, $Y = 9 \times 10^{10}\,\text{Nm}^{-2}$; $\rho = 9\,\text{g cm}^{-3} = 9 \times 10^3\,\text{kg m}^{-3}$; $L = 1$ m; $\Delta L = 0.05$ cm $= 5 \times 10^{-4}$ m.

Let T be the tension in the wire and a, the area of cross-section of the wire.

Now,
$$Y = \frac{T/a}{\Delta L/L} \quad \text{or} \quad T = \frac{Ya\Delta L}{L}$$

or
$$T = \frac{9 \times 10^{10} \times a \times 5 \times 10^{-4}}{1} = 4.5 \times 10^7 a.$$

The frequency of the fundamental note is lowest and is given by

$$\nu = \frac{1}{2L}\sqrt{\frac{T}{m}} \quad \text{... (i)}$$

Here, m = mass of unit length = $1 \times a \times \rho$

$= 1 \times a \times 9 \times 10^3 = 9 \times 10^3$ a

In Eq. (i), substituting for L, T and m, we get

$$\nu = \frac{1}{2 \times 1}\sqrt{\frac{4.5 \times 10^7 a}{9 \times 10^3 a}} = \mathbf{35.36\ vibrations\ s^{-1}}.$$

S21. Here, $L = 30.0$ cm $= 0.3$ m; $v = 330$ ms^{-1}.

The frequency of n^{th} harmonic in a pipe open at both the ends,

$$\nu_n = \frac{nv}{2L} = \frac{n \times 330}{2 \times 0.3} = 550\,n\,\text{Hz} = 0.55\,n\,\text{kHz}.$$

For $n = 1$, $\nu_1 = 0.55 \times 1 = 0.55$ kHz

For $n = 2$, $\nu_2 = 0.55 \times 2 = 1.1$ kHz

Therefore, the source of frequency 1.1 kHz will excite the second harmonic.

When the pipe is closed at one end:

The frequency of n^{th} harmonic is given by

$$v_n = \frac{(2n-1)v}{4L} = \frac{(2n-1)\times 330}{4\times 0.3}$$

$$= 275\ (2n - 1)\text{ Hz} = \mathbf{0.275\ (2n - 1)\ kHz}.$$

For $n = 1$, $v_1 = 0.275 \times 1\ (2 \times 1 - 1) = 0.275$ kHz

For $n = 2$, $v_2 = 0.275 \times 1\ (2 \times 2 - 1) = 0.825$ kHz

For $n = 3$, $v_3 = 0.275 \times 1\ (2 \times 3 - 1) = 1.375$ kHz

It follows that the source of frequency 1.1 kHz will *not excite* any harmonic in the pipe, if it is closed at one end.

S22. Height of the tower, $s = 300$ m

Initial velocity of the stone, $u = 0$

Acceleration, $a = g = 9.8\ m/s^2$

Speed of sound in air = 340 m/s

The time (t_1) taken by the stone to strike the water in the pond can be calculated using the second equation of motion, as:

$$s = ut_1 + \frac{1}{2}gt_1^2$$

$$300 = 0 + \frac{1}{2}\times 9.8 \times t_1^2$$

$$\therefore \quad t_1 = \sqrt{\frac{300\times 2}{9.8}} = 7.82\text{ s}$$

Time taken by the sound to reach the top of the tower,

$$t_2 = \frac{300}{340} = 0.88\text{ s}$$ [$\because$ Speed of sound has no effect of acceleration due to gravity $\therefore$ g = O]

Therefore, the time after which the splash is heard,

$$t = t_1 + t_2$$
$$= 7.82 + 0.88 = 8.7\text{ s}$$

S23. Let L be the length of the pipe and v, the velocity of sound in air.

When pipe is open at both the ends:

Let v be the frequency of the fundamental note produced by the open pipe and λ, wavelength of the wave produced. When an open pipe produces fundamental note, the length of the pipe is equal to $\lambda/2$ *i.e.*,

$$L = \frac{\lambda}{2} \quad \text{or} \quad \lambda = 2L$$

$$\nu = \frac{v}{\lambda'} = \frac{v}{2L}. \qquad \text{... (i)}$$

When pipe is closed at one end:

Let ν' be the frequency of the third harmonic produced by the pipe closed at one end and λ', wavelength of the waves produced. When a pipe closed at one end produces third harmonic, the length of the pipe is equal to $3\lambda'/4$ *i.e*,

$$L = \frac{3\lambda'}{4} \quad \text{or} \quad \lambda' = \frac{4}{3}L$$

$$\therefore \qquad \nu' = \frac{v}{\lambda'} = \frac{v}{\frac{4}{3}L} = \frac{3v}{4L} \qquad \text{... (ii)}$$

Here, $\nu' - \nu = 100$ Hz.

Using the Eq. (i) and (ii), we get

$$\frac{3v}{4L} - \frac{v}{2L} = 100$$

or $$\frac{v}{4L} = 100$$

or $$v = 400\,\text{L}$$

Therefore, fundamental frequency of open pipe,

$$\nu = \frac{v}{2L} = \frac{400L}{2L} = \mathbf{200\ Hz.}$$

S24. (a) Given, $Y = 1.3 \times 10^{11}\ \text{Nm}^{-2}$; $\rho = 9 \times 10^{3}\ \text{kg m}^{-3}$; $\alpha = 1.7 \times 10^{-5}\,{}^\circ\text{C}^{-1}$

Let L be the length and a, the area of cross-section of the wire. When the temperature of wire decreases from 30°C to 10°C, decrease in length of the wire,

$$\Delta L = L\alpha\Delta T = L \times 1.7 \times 10^{-5} \times (30 - 10) = 3.4 \times 10^{-4} L$$

Let T be tension produced in the wire, Then,

$$Y = \frac{T/a}{\Delta L/L} \quad \text{or} \quad T = \frac{Ya\Delta L}{L}$$

or $$T = \frac{1.3 \times 10^{11} \times a \times 3.4 \times 10^{-4} L}{L} = 4.42 \times 10^{7} a.$$

Also, mass per unit length of the wire,

$$m = 1 \times a \times \rho = 1 \times a \times 9 \times 10^3 = 9 \times 10^3 a$$

If v is speed of the transverse waves, then

$$v = \sqrt{\frac{T}{m}} = \sqrt{\frac{4.42 \times 10^7}{9 \times 10^3}} = \mathbf{70.08\ ms^{-1}}.$$

(b) Given: $y = A \sin (kx - \omega t)$

Now, particle velocity, $u = \frac{dy}{dt} = \frac{d}{dt}[A \sin(kx - \omega t)$

$= -A\omega \cos (kx - \omega t)$

Therefore, maximum particle velocity,

$$u_{max} = A\omega \quad \text{(in magnitude).}$$

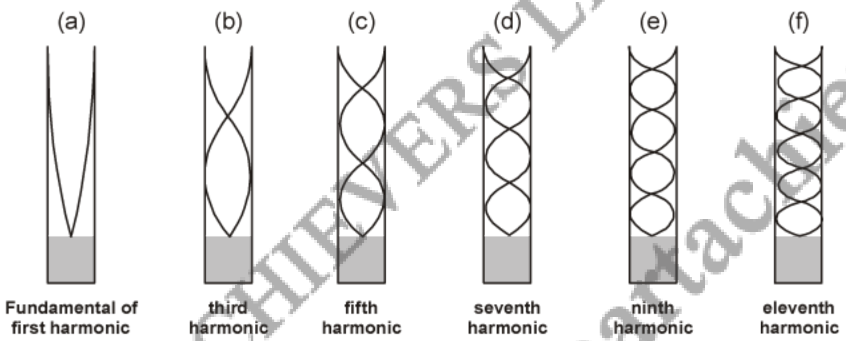
S25. The first harmonic frequency is given by

$$\nu_1 = \frac{v}{\lambda_1} = \frac{v}{2L} \quad \text{(open pipe)}$$

where L is the length of the pipe. The frequency of its n^{th} harmonic is:

$$\nu_n = \frac{nv}{2L}, \quad \text{for} \quad n = 1, 2, 3, \ldots \quad \text{(open pipe)}$$

First few modes of an open pipe are shown in figure:



For $L = 30.0$ cm, $v = 330\ m\,s^{-1}$,

$$\nu_n = \frac{n \times 330\ (m\,s^{-1})}{0.6\ (m)} = 550\ n\,s^{-1}.$$

Clearly, a source of frequency 1.1 kHz will resonate at v_2, *i.e.*, the ***second harmonic***.

Now if one end of the pipe is closed (Fig. 15.15), it follows from Eq. (14.50) that the fundamental frequency is

$$\nu_1 = \frac{v}{\lambda_1} = \frac{v}{4L} \quad \text{(pipe closed at one end)}$$

and only the odd numbered harmonics are present:

$$\nu_3 = \frac{3v}{4L}, \qquad \nu_5 = \frac{5v}{4L}, \quad \text{and so on.}$$

For L = 30 cm and v = 330 m s^{-1}, the fundamental frequency of the pipe closed at one end is 275 Hz and the source frequency corresponds to its fourth harmonic. Since this harmonic is not a possible mode, no resonance will be observed with the source, the moment one end is closed.

S26. (a)

Progressive Wave	*Stationary Wave*
(a) All particles have same phase and amplitude.	(a) Amplitude varies with position
(b) Speed of motion is same	(b) Speed varies with position
(c) Energy is transported	(c) Energy is not transported

$$y = .12 \sin 300\,t \cos 2x$$

Comparing with equation of stationary wave

$$y = 2A \sin \omega t \cos kx$$

$$k = 2$$

Distance between two consecutive nodes = $\frac{\lambda}{2}$.

Where λ is wavelength

$$k = \frac{2\pi}{\lambda}$$

$\Rightarrow$ $$\frac{\pi}{(\lambda/2)} = 2$$

$\therefore$ $$\frac{\lambda}{2} = \frac{\pi}{2}$$

So, the distance between two nearest nodes is $\frac{\pi}{2}$.

(b) Given, Amplitude (a) = 4×10^{-5} cm

$$\omega = 500 \text{ rad s}^{-1}$$

(i) Particle velocity amplitude

$$a\omega = 4 \times 10^{-5} \times 500$$

$$= \mathbf{2 \times 10^{-2}\ cm\ s^{-1}}.$$

Particle acceleration amplitude

$$a\omega^2 = 4 \times 10^{-5} \times (500)^2$$

$$= \mathbf{10\ cm\ s^{-2}}.$$

(ii) When, ω = 5000 rad s^{-1}

Particle velocity amplitude

$$a\omega = 4 \times 10^{-5} \times 5000$$

$$= \mathbf{0.2\ cm\ s^{-1}}.$$

Particle acceleration amplitude

$$a\omega^2 = 4 \times 10^{-5} \times (5000)^2$$

$$= \mathbf{10^3\ cm\ s^{-2}}.$$

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Q1. **The beats are not heard, if the difference in frequencies of the two sounding notes is more than 10. Why?**

Q2. **Beats can ascertain distances, directions, nature and size of the obstacles without any eyes. Explain, why.**

Q3. **Why do stationary waves not transport energy?**

Q4. **What is the nature of waves produced in a tuning fork?**

Q5. **Why should the difference between the frequencies be less than ten to produce beats?**

Q6. **What causes the rolling sound of thunder?**

Q7. **Which type of waves exhibit polarisation?**

Q8. **Why a diver under water is unable to hear the sound produced in air?**

Q9. **When you shout in front of a hill, your own shout is repeated. Why?**

Q10. **How does the frequency of a tuning fork change, when the temperature is increased?**

Q11. **Why is a tuning fork made with two prongs? Would a tuning fork be of any use, if one of the prongs is cut-off?**

Q12. **Tube *A* has both ends open, while tube *B* has one end closed. Otherwise the two tubes are identical. What is the ratio of fundamental frequency of the tubes *A* and *B*?**

Q13. **What is the nature of sound waves in air? How is the speed of sound waves in atmosphere affected by the (a) humidity (b) temperature?**

Q14. **A spring of mass 2.50 kg is under a tension of 200 N. The length of the stretched string is 20.0 m. If a transverse jerk is struck at one end of the string, how long does the disturbance take to reach the other end?**

Q15. **What is the change in frequency when a source goes past a stationary observer with velocity v_s? (Given: velocity of sound is c and the frequency is ν).**

Q16. **Prove that a pipe of length $2l$ open at both ends has the same fundamental frequency as another pipe of length l closed at the other end. Also state, if the total sound is identical for two pipes.**

Q17. **A bat emits ultrasonic sound of frequency 1000 kHz in air. If the sound meets a water surface, what is the wavelength of (a) the reflected sound, (b) the transmitted sound? Speed of sound in air is 340 $m\,s^{-1}$ and in water 1486 $m\,s^{-1}$.**

Q18. **A hospital uses an ultrasonic scanner to locate tumours in a tissue. What is the wavelength of sound in the tissue in which the speed of sound is 1.7 $km\,s^{-1}$ operating frequency of the scanner is 4.2 MHz.**

Q19. A wire stretched between two rigid supports vibrates in its fundamental mode with a frequency of 45 Hz. The mass of the wire is 3.5×10^{-2} kg and its linear mass density is 4.0×10^{-2} kg m^{-1}. What is (a) the speed of a transverse wave on the string, and (b) the tension in the string?

Q20. Show that in the case of a closed organ pipe, the ratio of the frequencies of the harmonics is 1 : 3 : 5 : 7.

Q21. One end of a long string of linear mass density 8.0×10^{-3} kg m^{-1} is connected to an electrically driven tuning fork of frequency 256 Hz. The other end passes over a pulley and is tied to a pan containing a mass of 90 kg. The pulley end absorbs all the incoming energy so that reflected waves at this end have negligible amplitude. At $t = 0$, the left end (fork end) of the string $x = 0$ has zero transverse displacement ($y = 0$) and is moving along positive y-direction. The amplitude of the wave is 5.0 cm. Write down the transverse displacement y as function of x and t that describes the wave on the string.

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S1. If beats produced are more than 10 per second, then due to persistence of hearing, the rise and fall in intensity of sound cannot be made out.

S2. Beats emit ultrasonic waves of very small wavelengths (high frequencies). The reflected waves from an obstacle in their path give them idea about the distance, direction, nature and size of the obstacle.

S3. Since nodes and antinodes formed remain stationary, the energy remains confined to one region. It cannot overcome the pressure maxima at nodes. So, energy is not transmitted by standing waves.

S4. In tuning forks, standing waves are produced with antinodes at the free ends.

S5. Human ear cannot identify any change in intensity in less $\left(\frac{1}{10}\right)^{th}$ of a second. So, difference should be less than 10.

S6. The rolling sound of thunder is due to multiple reflection of sound of lightning.

S7. Transverse waves.

S8. A sound produced in air is reflected back into the air, when it is incident on water surface. Only a little fraction ($\approx$ 0.1%) of the incident sound is refracted into the water. For this reason, the diver under water is unable to hear the sound produced in air.

S9. When we shout in front of a hill, the sound reaches back to us after reflection from the hill. This reflected sound, called ***echo***, is heard by us as the repeated shout. For echo to be clearly heard, the reflected sound should reach the observer after an interval of time of 0.1 s, called persistence of hearing.

S10. When the temperature is increased, length of the prong of the tuning fork will increase. In other words, the wavelength of the stationary wave setup in the tuning fork will increase. Since frequency is inversely proportional to the wavelength, frequency of the tuning fork will ***decrease***.

S11. When a tuning fork is set into vibrations, its two prongs move in opposites phases and the centre of gravity of the two prongs always remains at the middle point, where the handle joins the two prongs. Therefore, a tuning fork having two prongs can be set into vibrations by holding its handle in the hand. While it vibrates, its centre of gravity always remains at the same point and no external force is required to maintain the vibrations.

If one of the prongs is cut off, then the centre of gravity of its only prong will change during vibrations. If its handle is simply held in hand, it will not vibrate. So that it can oscillate, an external force is required for a tuning fork, whose one prong is cut off.

S12. Let L be the length of each of the two tubes and v be the velocity of sound.

For Tube A: Since tube A is open at both the ends, its fundamental frequency of vibration,

$$\nu_A = \frac{v}{2L}.$$

For Tube B: Since tube B is closed at one end, its fundamental frequency of vibration,

$$\nu_B = \frac{v}{4L}$$

$$\therefore \qquad \frac{\nu_A}{\nu_B} = \frac{v/2L}{v/4L} = \mathbf{2}.$$

S13. Longitudinal.

(a) Increases with increase in humidity.

(b) Increases with increase in temperature.

S14. Given $T = 200\text{ N}$, $l = 20\text{ m}$

$$\mu = \frac{2.50}{20}\text{ kg/m}$$

$$v = \sqrt{\frac{T}{\mu}} = \sqrt{\frac{200}{2.5/20}} = 40\text{ ms}^{-1}$$

$$t = \frac{20}{40} = \mathbf{0.5\ s}.$$

S15. When a source approaches a stationary observer,

$$\nu' = \nu\left(\frac{c}{c - v_s}\right)$$

When the source goes away,

$$\nu'' = \nu\left(\frac{c}{c + v_s}\right)$$

$\therefore$ Change when the source goes past stationary observer is,

$$\nu' - \nu'' = \nu c\left[\frac{1}{c - v_s} - \frac{1}{c + v_s}\right] = \frac{2\nu c v_s}{(c^2 - v_s^2)}$$

S16. Let L_1 and L_2 be the length of the pipe open at both the ends and of the pipe closed at one end respectively. Then,

$$L_1 = 2L \quad \text{and} \quad L_2 = L$$

Now, the fundamental note produced by the open pipe,

$$\nu_1 = \frac{v}{2L_1} = \frac{v}{2 \times 2L} = \frac{v}{4L} \qquad \text{... (i)}$$

and the fundamental note produced by the closed pipe,

$$\nu_2 = \frac{v}{4L_2} = \frac{v}{4 \times L} = \frac{v}{4L} \qquad \ldots \text{(ii)}$$

From the equations (i) and (ii), we get

$$\nu_1 = \nu_2$$

The quality of the sound produced by a pipe is determined by the frequencies of the overtones produced by it in addition to the frequency of the fundamental note. Since the open and closed pipes do not produce the identical notes (even harmonics are absent in a closed pipe), the sounds produced by the two pipes are ***not*** identical.

S17. Frequency of the ultrasonic sound, ν = 1000 kHz = 10^6 Hz

Speed of sound in air, v_a = 340 m/s

The wavelength (λ_r) of the reflected sound is given by the relation:

$$\lambda_r = \frac{v}{\nu} = \frac{340}{10^6} = 3.4 \times 10^{-4}\ \text{m}$$

Frequency of the ultrasonic sound, ν = 1000 kHz = 10^6 Hz

Speed of sound in water, v_w = 1486 m/s

The wavelength of the transmitted sound is given as:

$$\lambda_r = \frac{1486}{10^6} = 1.49 \times 10^{-3}\ \text{m}.$$

S18. Speed of sound in the tissue, v = 1.7 km/s = 1.7 × 10^3 m/s

Operating frequency of the scanner, ν = 4.2 MHz = 4.2

The wavelength of sound in the tissue is given as:

$$\lambda = \frac{v}{\nu} = \frac{1.7 \times 10^3}{4.2 \times 10^6} = 4.1 \times 10^{-4}\ \text{m}.$$

S19. Mass of the wire, $m = 3.5 \times 10^{-2}$ kg

Linear mass density, $\mu = \frac{m}{l} = 4.0 \times 10^{-2}\ \text{kg m}^{-1}$

Frequency of vibration, ν = 45 Hz

$\therefore$ Length of the wire, $l = \frac{m}{\mu} = \frac{3.5 \times 10^{-2}}{4.0 \times 10^{-2}} = 0.875$ m

The wavelength of the stationary wave (λ) is related to the length of the wire by the relation:

$$\lambda = \frac{2l}{n}$$

Where, n = Number of nodes in the wire

For fundamental node, $n = 1$:

$$\lambda = 2l$$
$$\lambda = 2 \times 0.875 = 1.75 \text{ m}$$

The speed of the transverse wave in the string is given as:

$$v = \nu\lambda = 45 \times 1.75 = 78.75 \text{ m/s}$$

The tension produced in the string is given by the relation:

$$T = v^2\mu$$
$$= (78.75)^2 \times 4.0 \times 10^{-2} = 248.06 \text{ N.}$$

S20. Displacement at position x and time t in incident wave,

$$y_1 = A \sin \frac{2\pi}{\lambda}(vt + x)$$

Wave reflected at closed end of pipe suffers a phase reversal of π.

$\therefore$ For reflected wave

$$y_2 = A \sin\left[\frac{2\pi}{\lambda}(vt - x) + \pi\right]$$

$$= -A \sin \frac{2\pi}{\lambda}(vt - x)$$

According to superposition principle,

$$y = y_1 + y_2$$

$$y = A\left[\sin \frac{2\pi}{\lambda}(vt + x) - \sin \frac{2\pi}{\lambda}(vt - x)\right]$$

$$y = 2A \cos \frac{2\pi}{\lambda} vt . \sin \frac{2\pi}{\lambda} x$$

At closed end of pipe $\quad x = 0$

$\therefore \quad \sin \frac{2\pi}{\lambda} x = \sin \theta = 0$

$y = 0$, *i.e.*, a node is formed.

At the open end of the pipe of length, $x = L$ an antinode is to be formed, *i.e.*, y = max

$$y = 2A \cos \frac{2\pi}{\lambda} vt . \sin \frac{2\pi}{\lambda} L$$

y will be max, when

$$\frac{2\pi L}{\lambda} = \max = \pm 1$$

$$= \sin(2n-1)\frac{\pi}{2}$$

where $n = 1, 2, 3, \ldots\ldots\ldots\ldots$

$$\frac{2\pi L}{\lambda} = (2n-1)\frac{\pi}{2}$$

$$\lambda = \frac{4L}{(2n-1)}$$

For first normal mode of vibration, Let λ_1 = wavelength corresponding to $n = 1$

$$\lambda = \frac{4L}{(2\times 1-1)} = 4L$$

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

Frequency $\nu_1 = \frac{v}{\lambda_1} = \frac{v}{4L}$

$$\nu_1 = \frac{v}{4L} \quad \text{Fundamental frequency}$$

For second normal mode of vibration, λ_2 wavelength of standing waves corresponding to $n = 2$.

$$\lambda_2 = \frac{4L}{2\times 2-1} = \frac{4L}{3}$$

$$\nu_2 = \frac{v}{\lambda_2} = \frac{v}{4L/3} = \frac{3v}{4L} = 3\nu_1$$

$$\nu_2 = 3v_1 \quad \text{third harmonic.}$$

For third normal mode of vibration, λ_3 = wavelength of standing waves corresponding to $n = 3$.

$$\lambda_3 = \frac{4L}{2\times 3-1} = \frac{4L}{5}$$

$$\nu_3 = \frac{v}{\lambda_3} = \frac{v}{4L/5} = \frac{3v}{4L} = 5\,\frac{v}{4L}$$

$$\nu_3 = 5\nu_1 \quad \text{fifth harmonic.}$$

In general

$$\nu_n = \frac{(2n-1)v}{4L} = (2n-1)\,\nu_1$$

$\therefore$ Ratio of frequencies of harmonics is 1 : 3 ; 5 : 7.

S21. The equation of a travelling wave propagating along the positive *y*-direction is given by the displacement equation:

$$y(x, t) = a \sin(wt - kx) \quad \dots \text{(i)}$$

Linear mass density (mass per unit length),

$$\mu = 8.0 \times 10^{-3}\,\text{kg m}^{-1}$$

Frequency of the tuning fork, $\nu = 256$ Hz

Amplitude of the wave, $a = 5.0$ cm $= 0.05$ m … (ii)

Mass of the pan, $m = 90$ kg

Tension in the string, $T = mg = 90 \times 9.8 = 882$ N

The velocity of the transverse wave *v*, is given by the relation:

$$v = \sqrt{\frac{T}{\mu}}$$

$$= \sqrt{\frac{882}{8.0 \times 10^{-3}}} = 332 \text{ m/s}$$

Angular frequency, $\omega = 2\pi\nu$

$$= 2 \times 3.14 \times 256$$

$$= 1608.5 = 1.6 \times 10^3 \text{ rad/s} \quad \dots \text{(iii)}$$

Wavelength, $\lambda = \frac{v}{\nu} = \frac{332}{256}$ m

∴ Propagation constant, $k = \frac{2\pi}{\lambda}$

$$= \frac{2 \times 3.14}{\frac{332}{256}} = 4.84 \text{ m}^{-1} \quad \dots \text{(iv)}$$

Substituting the values from equations (ii), (iii), and (iv) in equation (i), we get the displacement equation:

$$y(x, t) = 0.05 \sin(1.6 \times 10^3 t - 4.84\,x)\ m$$

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Q1. What travels faster – a rifle bullet or the sound of a shot?

Q2. Why should a bat be able to sense high frequencies?

Q3. An observer is stationed at $x = 10$ cm. When a train moves in the y-axis with a velocity 10 m/s, what is the apparent frequency?

Q4. Why is it difficult some times to recognise your friend's voice on phone?

Q5. How is the vibration of the air column in a flute different from that of a string in a sitar?

Q6. Why is sound heard in water more intense in comparison to sound heard in air?

Q7. When a source moves at a speed greater than that of sound, will Doppler formula hold? What will happen?

Q8. What type of mechanical waves do you expect to exist in (a) vacuum (b) air (c) inside the water (d) rock (e) on the surface of water?

Q9. When will Doppler effect in sound be symmetrical?

Q10. An open pipe makes a good musical instrument, in comparison to a closed pipe. Why?

Q11. What will be the apparent frequency (ν') of the sound, if the source of sound emits waves of frequency ν and is moving with a speed u_s (a) towards the listener (b) away from the listener?

Q12. Does Doppler effect also hold for electromagnetic waves?

Q13. A rocket is moving at a speed of 200 $m\,s^{-1}$ towards a stationary target. While moving, it emits a wave of frequency 1000 Hz. Some of the sound reaching the target gets reflected back to the rocket as an echo. Calculate (a) the frequency of the sound as detected by the target and (b) the frequency of the echo as detected by the rocket.

Q14. An observer is moving towards a wall at 2 ms^{-1}. He hears a sound from a source at some distance behind him directly as well as after its reflection from the wall. Calculate the beat frequency between these two sounds, if the true frequency of the source is 680 Hz. Velocity of sound = 340 ms^{-1}.

Q15. An observer moves towards a stationary source of sound with a velocity one-fifth of the velocity of sound. What is the percentage increase in the apparent frequency?

Q16. The sirens of two fire engines have a frequency of 600 Hz each. A man hears the sirens from the two engines, one approaching him with a speed of 36 $km\,h^{-1}$ and another receding him at speed of 54 km/h. What is the difference in frequency of two sirens heard by the man? Take the speed of sound to be 340 ms^{-1}.

Q17. The wavelength of yellow sodium line (5,896 Å) emitted by a star is red shifted to 6,010 Å. What is the component of the star's recessional velocity along the line of sight? Speed of light = 3×10^8 ms^{-1}.

Q18. A source and a listener are approaching closer with a relative velocity of 40 ms^{-1}. If the true source frequency is 1,200 Hz, calculate the observed frequency under these conditions: (a) The source alone is moving, (b) The listener alone is moving. Take speed of sound in air to be 340 ms^{-1}.

Q19. The sirens of two fire engines have a frequency of 650 Hz each. A man hears the sirens from the two engines, one approaching him with a speed of 36 $km\,h^{-1}$ and the other reading from him at as speed of 54 $km\,h^{-1}$. What is the difference in frequency of the two sirens heard by the man? Take the speed of sound to be 340 ms^{-1}.

Q20. A siren emitting a sound of frequency 1,000 Hz is moving with a speed of 10 ms^{-1}. What will be the frequency of sound, which a listener will hear, when (a) the siren is moving towards him? (b) the siren is moving away from him? Speed of sound in air = 340 ms^{-1}.

Q21. A policeman on duty detects a drop of 10% in the pitch of the horn of a motor car as it crosses him. If the velocity of sound is 330 ms^{-1}. Calculate the speed of the car.

Q22. A listener is moving towards a source of sound. What should be his velocity so that the apparent frequency of the sound is double of its actual value?

Q23. Whistle of the approaching railway engine is shriller than the receding engine. Why?

Q24. What is mean by symmetric Doppler effect?

Q25. Will there by any Doppler's effect, if both the source of sound and the listener are moving with the same velocity and in the same direction?

Q26. Explain graphically that number of beats formed per second is $n = \nu_1 - \nu_2$ where ν_1 and ν_2 be the frequency of two superimposing waves.

Q27. A closed and an open pipe are sounded for same frequency. What is the ratio of their lengths?

Q28. Two engines pass each other in opposite directions, one of them blowing its whistle, the frequency of the note being 540. Calculate the frequency as heard on the other engine before and after they have crossed each other, The velocity of either engine is 72 $km\,h^{-1}$ and that of sound is 332 ms^{-1}.

Q29. Prove that when a source approaches the stationary listener with a particular velocity, the apparent frequency is higher than that, if the listener approaches a stationary source with the same velocity.

Q30. Obtain an expression for apparent frequency of sound when the source is moving with a velocity v_s towards the stationary listener.

Q31. A train, standing at the outer signal of a railway station blows a whistle of frequency 400 Hz in still air. (a) What is the frequency of the whistle for a platform observer when the train (i) approaches the platform with a speed of 10 $m\,s^{-1}$, (ii) recedes from the platform with a speed of 10 $m\,s^{-1}$? (b) What is the speed of sound in each case? The speed of sound in still air can be taken as 340 $m\,s^{-1}$.

Q32. Two sitar strings *A* and *B* playing the note '*Ga*' are slightly out of tune and produce beats of frequency 6 Hz. The tension in the string *A* is slightly reduced and the beat frequency is found to reduce to 3 Hz. If the original frequency of *A* is 324 Hz, what is the frequency of *B*?

Q33. A Policeman on duty detects a drop of 15% in the pitch of the horn of a motor car as it crosses him. If the velocity of sound is 330 m/sec, calculate the speed of the car.

Q34. Explain Doppler effect in sound. Obtain an expression for apparent frequency of sound when source and listener are approaching each other.

Q35. (a) A source of sound is coming towards a stationary observer with a constant velocity. Deduce the formula for the apparent frequency heard by observer.

(b) A railway engine and a car are moving on parallel tracks in opposite directions with speeds of 144 km h^{-1} and 72 km h^{-1} respectively. The engine is continuously sounding a whistle of frequency 500 Hz. The velocity of sound is 340 m s^{-1}. Calculate the frequency of sound in the car when (i) the car and the engine are approaching each other, (ii) the two are moving away from each other.

Q36. A train, standing in a station-yard, blows a whistle of frequency 400 Hz in still air. The wind starts blowing in the direction from the yard to the station with at a speed of 10 m s^{-1}. What are the frequency, wavelength, and speed of sound for an observer standing on the station's platform? Is the situation exactly identical to the case when the air is still and the observer runs towards the yard at a speed of 10 m s^{-1}? The speed of sound in still air can be taken as 340 m s^{-1}.

Q37. Explain Doppler effect in sound. Obtain an expression for apparent frequency of sound when source moves.

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S1. Rifle bullet travels faster than the sound of shot. The ratio of v_b and v_s is nearly 3 : 1.

S2. Due to less inertia, the ear drum of bats can resonate faster than human ears. So they can receive high frequencies.

S3. There is no Doppler shift in perpendicular direction, so no apparent frequency.

S4. Due to modulation.

S5. The nodes in a sitar are replaced by the antinodes in a flute.

S6. This is because intensity of sound increases with increase in density of the medium.

S7. No, as it is valid only when $v_u < v$. When $v_s > v$, shock waves are produced.

S8. (a) No wave

(b) Longitudinal waves

(c) Longitudinal

(d) Transverse or longitudinal or both (separately)

(e) Combined longitudinal and transverse (ripples).

S9. When the velocity of the source or observer is very much less than the velocity of sound.

S10. In open pipe, all harmonics are possible, while in a closed pipe, only odd harmonics are possible.

S11. (a) $\nu' = \frac{v}{v - u_s}\nu$

(b) $\nu' = \frac{v}{v + u_s}\nu$

S12. Yes.

S13. (a) The observer is at rest and the source is moving with a speed of 200 m s^{-1}. Since this is comparable with the velocity of sound, 330 m s^{-1}, we must use Eq. (15.50) and not the approximate Eq. (15.51). Since the source is approaching a stationary target, $v_o = 0$, and v_s must be replaced by $-v_s$. Thus, we have

$$v = v_0 \left(1 - \frac{\nu_S}{\nu}\right)^{-1}$$

$$v = 1000\,\text{Hz} \times [1 - 200\text{ m s}^{-1}/330\text{ m s}^{-1}]^{-1}$$
$$\simeq 2540\,\text{Hz}$$

(b) The target is now the source (because it is the source of echo) and the rocket's detector is now the detector or observer (because it detects echo). Thus, $v_s = 0$ and v_0 has a positive value. The frequency of the sound emitted by the source (the target) is v, the frequency intercepted by the target and not v_0. Therefore, the frequency as registered by the rocket is

$$v_2 = v\left(\frac{\nu + \nu_0}{\nu}\right)$$

$$= 2540\,\text{Hz} \times \left(\frac{200\text{ m s}^{-1} + 330\text{ m s}^{-1}}{330\text{ m s}^{-1}}\right)$$

$$\simeq 4080\,\text{Hz}$$

S14. Here, $v = 340\,\text{ms}^{-1}$; $u_0 = 2\text{ ms}^{-1}$; $\nu = 680\,\text{Hz}$

The apparent frequency of sound received directly from the source by the observer, when he moves towards the wall (*i.e.*, away from the source) is given by

$$\nu' = \frac{v - u_0}{v}\nu = \frac{340 - 2}{340} \times 680 = 676\text{ Hz.}$$

The apparent frequency of sound received by the observer after reflection from the wall, when he moves towards the wall is given by

$$\nu'' = \frac{v + u_0}{v}\nu = \frac{340 + 2}{340} \times 680 = 684\text{ Hz.}$$

Therefore, beat frequency,

$$b = \nu'' - \nu' = 684 - 676 = \mathbf{8\,Hz}.$$

S15. When the observer moves towards a stationary source, the apparent is given by

$$\nu' = \frac{v + u_0}{v}\nu$$

Here, $u_0 = \nu / 5$

$\therefore$ $$\nu' = \frac{v + v/5}{v}\nu = 1.2\,\nu$$

Hence, percentage increase in the apparent frequency

$$= \frac{\nu' + \nu}{\nu} \times 100 = \frac{1.2\,\nu - \nu}{\nu} \times 100 = \mathbf{20\%}.$$

S16. Given; $v = 340\ ms^{-1}$; $\nu = 600$ Hz

For engine approaching the stationary man:

$$u_s = 36\ km\,h^{-1} = 10\ ms^{-1}$$

Therefore, apparent frequency,

$$\nu = \frac{v}{v - u_s}\nu = \frac{340}{340 - 10} \times 600 = 618.2 \text{ Hz}$$

For Engine Going Away from the Stationary Man:

$$u_s = 54\ km\ h^{-1} = 15\ ms^{-1}$$

Therefore, apparent frequency,

$$\nu'' = \frac{v}{v + u_s}\nu = \frac{340}{340 + 15} \times 600 = 574.6 \text{ Hz}$$

Therefore, difference in frequencies of the two sirens heard by the man,

$$\nu' - \nu'' = 618.2 - 574.6 = \mathbf{43.6\ Hz}.$$

S17. Given: $c = 3 \times 10^8 ms^{-1}$; $\lambda = 5{,}896$ Å $= 5{,}896 \times 10^{-10}$ m; $\lambda' = 6{,}010$ Å $= 6{,}010 \times 10^{-10}$ m

$\therefore$ $$\Delta\lambda = \lambda' - \lambda = 6{,}010 \times 10^{-10} - 5{,}896 \times 10^{-10} = 114 \times 10^{-10} \text{ m}.$$

Let the component of the star's recessional velocity along the line of sight be v.

For the source of light and observer moving away from each other, Doppler shift is given by

$$\Delta\lambda = \frac{v}{c}\lambda$$

or $$v = \frac{\Delta\lambda}{\lambda}c = \frac{114 \times 10^{-10}}{5{,}896 \times 10^{-10}} \times 3 \times 10^8$$

$$= \mathbf{5.8 \times 10^6\ ms^{-1}}.$$

S18. Give: $\nu = 1{,}200$ Hz; $v = 340\ ms^{-1}$

(a) Now, $u_s = 40\ ms^{-1}$

$\therefore$ $$\nu' = \frac{v}{v - u_s}\nu = \frac{340}{340 - 40} \times 1{,}200 = \mathbf{1{,}360\ Hz}$$

(b) Now, $u_0 = 40\ ms^{-1}$

$$\nu' = \frac{v + u_0}{v}\nu = \frac{340 + 40}{340} \times 1{,}200 = \mathbf{1{,}341.2\ Hz}.$$

S19. Given: $\nu = 650$ Hz; $v = 340$ ms^{-1}

For the approaching engine:

Here, $u_s = 36$ km h^{-1} = 10 ms^{-1}

Now, $$\nu' = \frac{v}{v - u_s}\nu = \frac{340}{340 - 40} \times 650 = \textbf{669.7 Hz}$$

For the receding engine:

Here, $u_s = 54$ km h^{-1} = 15 ms^{-1}

Now, $$\nu'' = \frac{v}{v + u_s}\nu = \frac{340}{340 + 15} \times 650 = \textbf{622.5 Hz}$$

Therefore, difference in apparent frequencies of the two sirens,

$$\nu' - \nu'' = 669.7 - 622.5 = \textbf{47.2 Hz}.$$

S20. (a) ***When siren is moving towards the listener:***

Now, $$\nu' = \frac{v}{v - u_s}\nu$$

or $$\nu' = \frac{340}{340 - 10} \times 1{,}000 = \textbf{1,030.3 Hz}.$$

(b) ***When siren is moving away from the listener:***

Now, $$\nu' = \frac{v}{v + u_s}\nu$$

or $$\nu' = \frac{340}{340 + 10} \times 1{,}000 = 971.4\ \textbf{Hz}$$

S21. Given: $$\nu' = \frac{\nu \times 90}{100} = 0.9\,\nu;\quad v = 330\ \text{ms}^{-1}$$

Now, $$\nu' = \frac{v}{v + u_s}\nu$$

or $$0.9\,\nu = \frac{330}{330 + u_s}\nu$$

or $$330 + u_s = \frac{330}{0.9}$$

or $$u_s = 366.67 - 330 = \textbf{36.67 ms}^{-1}.$$

S22. Now,

$$\nu' = \frac{v + u_0}{v}\,\nu$$

For $\nu' = 2\nu$, we get

$$2\nu = \frac{v + u_0}{v}\,\nu$$

or $$u_0 = v.$$

S23. When the source of sound (engine) moves towards the listener, the apparent frequency,

$$\nu_1 = \frac{v}{v - u_s}\,\nu.$$

On the other hand, if the source of sound moves away from the listener, the apparent frequency

$$\nu_2 = \frac{v}{v + u_s}\,\nu.$$

If follows that $\nu_1 > \nu_2$. Since pitch of a sound depends on frequency, the whistle of the approaching engine is shriller than the receding engine.

S24. Doppler effect is said to be symmetrical, if change in frequency of waves due to the motion of the source of waves towards the observer with a certain relative velocity is same as the change in frequency due to the motion of the observer with the same relative velocity towards the source.

Doppler effect in light is symmetrical, whereas Doppler effect in sound is a symmetrical.

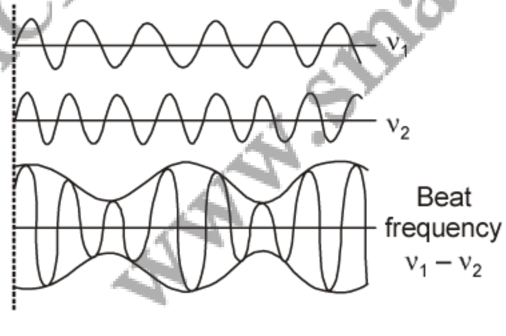
S25. In such a case, the apparent frequency is given by

$$\nu' = \frac{v - u_0}{v - u_s}\,\nu$$

If $u_0 = u_s$, then $\nu' = \nu$.

i.e., no ***Doppler effect*** will be observed.

S26.



S27. Here,

$$\nu_0 = \frac{nv}{2l_0} \cdot \nu_c = (2n - 1) \times \frac{v}{4l_c}$$

since the velocity of medium is same and frequencies are equal,

$$\frac{v}{2l_0} = \frac{v}{4l_c}$$

$$\therefore \quad \frac{l_c}{l_0} = \frac{2}{4} = \frac{1}{2} = \mathbf{1:2}.$$

S28. Given: $u_s = u_0 = 72\ \text{km h}^{-1} = 20\ \text{ms}^{-1}$; $v = 332\ \text{ms}^{-1}$; $\nu = 540\ \text{Hz}$.

Apparent frequency, before the engines cross each other:

Here, $$\nu' = \frac{v + u_0}{v - u_s}\nu = \frac{332 + 20}{332 - 20} \times 540 = \mathbf{609.2\ Hz}$$

Apparent frequency after the engines cross each other:

Here, $$\nu' = \frac{v - u_0}{v + u_s}\nu = \frac{332 - 20}{332 + 20} \times 540 = \mathbf{478.64\ Hz}.$$

S29. Suppose that the source emits sound waves of frequency v. Let v be the velocity of sound.

When source moves with velocity u towards the stationary listener,

$$\nu' = \frac{v}{v - u}\nu \quad \text{... (i)}$$

When listener moves with velocity u towards the stationary source.

$$\nu'' = \frac{v + u}{v}\nu \quad \text{... (ii)}$$

From Eq. (i) and (ii), we get

$$\therefore \quad \nu' - \nu'' = \frac{v}{v - u}\nu - \frac{v + u}{v}\nu = \left[\frac{v}{v - u} - \frac{v + u}{v}\right]\nu$$

$$= \left[\frac{v^2 - v^2 + u^2}{v(v - u)}\right]\nu = \left[\frac{u^2}{v(v - u)}\right]\nu.$$

In practice, v is usually quite greater than u. Therefore, R.H.S. of the above equation and hence $v' - v''$ is positive.

S30. Let v be the velocity of sound and v_s be the velocity of source towards observer.

As the source approaches, the space between source and observer gets reduced but should accommodate the same number of waves (as frequency). So, wavelength reduces. The new wavelength is,

$$\lambda' = \frac{\text{Velocity of sound w.r.t. source}}{\text{Frequency}} = \frac{v - v_s}{\nu}$$

Also, $\lambda' = \dfrac{v}{\nu'}$

$\therefore$ $\nu' = \nu\left(\dfrac{v}{v - v_s}\right).$

S31. (a) Frequency of the whistle, $\nu = 400$ Hz

Speed of the train, $v_T = 10$ m/s

Speed of sound, $v = 340$ m/s

The apparent frequency (v') of the whistle as the train approaches the platform is given by the relation:

$$v' = \left(\frac{v}{v - v_T}\right)v = \left(\frac{340}{340 - 10}\right) \times 400 = 412.12 \text{ Hz}$$

The apparent frequency (v'') of the whistle as the train recedes from the platform is given by the relation:

$$v'' = \left(\frac{v}{v + v_T}\right)v = \left(\frac{340}{340 + 10}\right) \times 400 = 388.57 \text{ Hz}$$

The apparent change in the frequency of sound is caused by the relative motions of the source and the observer. These relative motions produce no effect on the speed of sound. Therefore, the speed of sound in air in both the cases remains the same, *i.e.*, 340 m/s.

S32. Frequency of string *A*, $f_A = 324$ Hz

Frequency of string, $B = f_B$

Beat's frequency, $n = 6$ Hz

Beat's frequency is given as:

$$n = |f_A \pm f_B|$$

$$6 = 324 \pm f_B$$

$$f_B = 330 \text{ Hz or } 318 \text{ Hz}$$

Frequency decreases with a decrease in the tension in a string. This is because frequency is directly proportional to the square root of tension. It is given as:

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

Hence, the beat frequency cannot be 330 Hz

$\therefore$ $f_B = 318$ Hz.

S33. Before crossing, source is moving towards listener,

$\therefore$ $$\nu' = \frac{u\nu}{v - v_s} \qquad \text{... (i)}$$

After crossing, source is moving away from listener

$$\nu'' = \frac{u\nu}{v + v_s} \qquad \dots \text{(ii)}$$

Dividing (ii) by (i), we get

$$\frac{\nu''}{\nu'} = \frac{v - v_s}{v + v_s}$$

Drop of 15% means

$$\frac{\nu''}{\nu'} = \frac{85}{199}$$

$$\frac{85}{199} = \frac{330 - v_s}{330 + v_s}$$

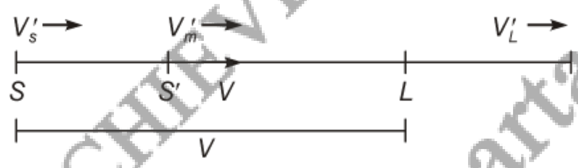
$$v_s = \mathbf{26.7\ m/s}.$$

S34. Whenever there is a relative motion between a source of sound and listener, the apparent frequency of sound heard by listener is different from actual frequency of sound emitted by the source.

Let S be a source of sound and L, the listener of sound, both initially at rest. Let ν be the actual frequency of sound emitted by the source and λ be the actual wavelength of sound emitted. If v is velocity of sound in still air, then

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

Let the distance between source and listener be S, so that waves from the source reach listener in 1 second. v_m = Velocity of medium, v_s = Velocity of source, v_L = Velocity of listener



Resultant velocity of sound along

$SL = (v + v_m)$

SS' = distance proved by source in 1 sec.

$= v_s$ along SL

$\therefore$ Relative velocity of sound w.r.t. source = $[(v + v_m) - v_s]$

As the frequency remains unchanged.

$\therefore$ v waves emitted in one second occupy the distance $[(v + v_m) - v_s]$

$$\lambda' = \frac{[(v + v_m) - v_s]}{\nu}$$

$LL' = v_L$ Relative vel. of sound waves w.r.t listener $(v + v_m) - v_L$

Apparent frequency of sound waves heard by listener is

$$\nu' = \frac{(v + v_m) - v_L}{\lambda'}$$

$$\nu' = \frac{[(v + v_m) - v_L]}{(v + v_m) - v_S}\,\nu$$

when both approach each other

$$v_S = (+), \quad v_L = (-)$$

$$\nu' = \frac{v - (-v_L)}{v - v_S}\,\nu = \left(\frac{v + v_L}{v - v_S}\right)\nu\,.$$

S35. (a) Let S and O be the source and observer. If ν is the frequency of sound with velocity v released by the source, then number of waves will be received by the observer at rest. When the source approaches the stationary observer, the number of waves received increases due to the apparent shortening of the wavelength. Wavelength perceived

$$\lambda' = \frac{\text{Velocity of sound w.r.t. moving source}}{\text{Frequency}}$$

$\therefore$ $$\lambda' = \frac{u - u_s}{\nu}$$

Using, $\lambda' = \frac{u}{\nu'}$ we get,

and $$\frac{u}{\nu'} = \frac{u - u_s}{\nu}; \qquad \nu' = \nu\left(\frac{v}{u - u_s}\right)$$

(b) Given, $$v_s = 144 \times \frac{5}{18} = \mathbf{40\ m\,s^{-1}}$$

$$v_o = 72 \times \frac{5}{18} = \mathbf{20\ m\,s^{-1}}$$

$$\nu = 500\text{ Hz}, \qquad v = 340\text{ m s}^{-1}$$

(i) $$\nu' = \frac{340 + 20}{340 - 40} \times 500\text{ Hz} = \mathbf{600\ Hz}.$$

(ii) $$\nu' = \frac{340 - 20}{340 + 40} \times 500\text{ Hz} = \mathbf{421.05\ Hz}.$$

S36. For the stationary observer: 400 Hz; 0.875 m; 350 m/s

For the running observer: Not exactly identical

For the stationary observer:

Frequency of the sound produced by the whistle, ν = 400 Hz

Speed of sound = 340 m/s

Velocity of the wind, v = 10 m/s

As there is no relative motion between the source and the observer, the frequency of the sound heard by the observer will be the same as that produced by the source, *i.e.*, 400 Hz.

The wind is blowing toward the observer. Hence, the effective speed of the sound increases by 10 units, *i.e.*,

Effective speed of the sound, v_e = 340 + 10 = 350 m/s

The wavelength (λ) of the sound heard by the observer is given by the relation:

$$\lambda = \frac{v_e}{\nu} = \frac{350}{400} = 0.875 \text{ m}$$

For the running observer:

Velocity of the observer, v_o = 10 m/s

The observer is moving toward the source. As a result of the relative motions of the source and the observer, there is a change in frequency (ν').

This is given by the relation:

$$\nu' = \left(\frac{v + v_0}{v}\right)\nu$$

$$= \left(\frac{340 + 10}{340}\right) \times 400 = 411.76 \text{ Hz}$$

Since the air is still, the effective speed of sound = 340 + 0 = 340 m/s

The source is at rest. Hence, the wavelength of the sound will not change, *i.e.*, λ remains 0.875 m.

Hence, the given two situations are not exactly identical.

S37. ***Doppler Effect:*** The phenomena of apparent change in pitch of sound caused due to relative motion between a source and an observer is called Doppler effect.

Let S and O be the source and observer. If ν is the frequency of sound with velocity v released by the source, then a number of waves will be received by the observer at rest.

(i) When the source approaches the stationary listener, the number of waves received, increases due to the apparent shortening of the wavelength.

$$\text{Wavelength perceived } \lambda' = \frac{\text{Velocity of sound w.r. to moving source}}{\text{Frequency}}$$

$$\therefore \qquad \lambda' = \frac{v - v_s}{\nu}$$

Using $\lambda' = \frac{v}{\nu'}$ we get,

and $\frac{v}{\nu'} = \frac{v - v_s}{\nu}$

$$\nu' = \nu\left(\frac{v}{v - v_s}\right)$$

(ii) When the source is moving away from the listener who is at rest, then velocity of source is negative.

$$\nu' = \frac{v}{v - (-v_s)}\,\nu = \frac{v}{v + v_s}\,\nu .$$

Date: 13/10/2021

Q1. Two sound sources produce 12 beats in 4 seconds. By how much do their frequencies differ?

Q2. Two sounds of very close frequencies, say 256 Hz and 260 Hz are produced simultaneously. What is the frequency of resultant sound and also write the number of beats heard in one second?

Q3. How many beats are formed when two sources vibrate in unison?

Q4. The frequencies of two tuning forks *A* and *B* are 250 Hz and 255 Hz respectively. Both are sounded together. How many beats will be hard in 5 sec.

Q5. When beat are produced?

Q6. What is the physical reason to take both + 1 and – 1 as the cosine maxima in beats formation?

Q7. Explain why (or how): In a sound wave, a displacement node is a pressure antinode and vice versa.

Q8. Explain why (or how): Bats can ascertain distances, directions, nature, and sizes of the obstacles without any "eyes".

Q9. Explain why (or how): A violin note and sitar note may have the same frequency, yet we can distinguish between the two notes.

Q10. Explain why (or how): Solids can support both longitudinal and transverse waves, but only longitudinal waves can propagate in gases.

Q11. Explain why (or how): The shape of a pulse gets distorted during propagation in a dispersive medium.

Q12. Two sitar strings *A* and *B* playing the note '*Dha*' are slightly out of tune and produce beats of frequency 5 Hz. The tension of the string *B* is slightly increased and the beat frequency is found to decrease to 3 Hz. What is the original frequency of *B* if the frequency of *A* is 427 Hz?

Q13. A sitar wire and a tabla, when sounded together give 4 beats per second. What do you conclude from this? As the tabla membrane is tightened, the beat rate may decrease or increase. Explain.

Q14. Two organ pipes of same length open at both ends produce sound of different frequencies, if their radii are different. Why?

Q15. If oil of density higher than of water is used in place of water in a resonance tube, how does the frequency change?

Q16. How are two musical instruments tuned? Explain.

Q17. A tuning fork of unknown frequency, when sounded together with the one of frequency 288 Hz gives 4 beats per second. When loaded with wax, it again gives 4 beats per second. How do you account for this and what was the unknown frequency?

Q18. The frequencies of two tuning forks *A* and *B* are 250 Hz and 255 Hz respectively. Both are sounded together. How many beats will be heard in 5 seconds?

Q19. A tuning fork *B* produces 6 beats per second with another tuning fork *A* of frequency 288 Hz. The tuning fork of unknown frequency is field and the number of beats, now produced is 4 per second. Calculate the frequency of the tuning fork.

Q20. Write a formula for the frequency of vibration of a stretched string in the case of a Sonometer.

Q21. Two vibrating wires *A* and *B* are slightly out of tune and produce beats of frequency 8 Hz. The tension in the string *A* is slightly increased and the beat frequency is found to reduce to 5 Hz. If the original frequency of *A* is 480 Hz, what is the frequency of *B*?

Q22. The tuning fork *A* of frequency 256 Hz produces 4 beats per second with another tuning fork *B*. When the prongs of *B* are loaded with 1 gram weight, the number of beats is 1 per second and when loaded with 2 gram weight, the number of beats become 2 per second. What is the frequency of *B*?

Q23. A steel rod 100 cm long is clamped at its middle. The fundamental frequency of longitudinal vibrations of the rod is given to be 2.53 kHz. What is the speed of sound in steel?

Q24. A metre-long tube open at one end, with a movable piston at the other end, shows resonance with a fixed frequency source (a tuning fork of frequency 340 Hz) when the tube length is 25.5 cm or 79.3 cm. Estimate the speed of sound in air at the temperature of the experiment. The edge effects may be neglected.

Q25. Two sources of sound are producing waves of frequency ν_1 and ν_2, where $(\nu_1 - \nu_2)$ is small, show mathematically that the beat frequency is $(\nu_1 - \nu_2)$.

Q26. Four beats per second are produced when two tuning forks are sounded simultaneously. One fork is in unison with a length of 128 cm of monochord string under constant tension while the other with 130 cm of the string under similar conditions. Calculate the frequencies of the forks.

Q27. A SONAR system fixed in a submarine operates at a frequency 40.0 kHz. An enemy submarine moves towards the SONAR with a speed of 360 $km\,h^{-1}$. What is the frequency of sound reflected by the submarine? Take the speed of sound in water to be 1450 $m\,s^{-1}$.

Q28. A pipe 20 cm long is closed at one end. Which harmonic mode of the pipe is resonantly excited by a 430 Hz source? Will the same source be in resonance with the pipe if both ends are open? (Speed of sound in air is 340 $m\,s^{-1}$).

Q29. What is meant by beats? Two sound notes of wavelengths 2.04 m and 2.08 m produce 200 beats per minute in a gas. Find the velocity of sound in the gas.

Q30. Two tuning forks *A* and *B* produce 4 beats per second. On loading *B* with wax, 6 beats per second are produced. If the quantity of wax is reduced, the number of beats per second again becomes 4. Find the frequency of *B*, the frequency of *A* is 480.

Q31. A bat is flitting about in a cave, navigating via ultrasonic beeps. Assume that the sound emission frequency of the bat is 40 kHz. During one fast swoop directly toward a flat wall surface, the bat is moving at 0.03 times the speed of sound in air. What frequency does the bat hear reflected off the wall?

Q32. Earthquakes 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 4.0 km s^{-1}, and that of *P* wave is 8.0 km s^{-1}. 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, at what distance does the earthquake occur?

Q33. Two air columns (closed at one end) 100 cm and 101 cm long give 17 beats in 20 s, when each is sounding its fundamental note, Find the velocity of sound.

Date: 13/10/2021

S1. Number of beats per second, $b = 12/4 = 3\,s^{-1}$

$$\nu_1 - \nu_2 = b = 3.$$

S2. Given frequencies of sounds $\nu_1 = 256$ Hz and $\nu_2 = 260$ Hz

No. of beats $\nu = \nu_2 - \nu_1$

$$= 260 - 256 = 4$$

Frequency of resultant sound is the average of the two frequencies 258 Hz.

S3. No beats are formed, since $\nu_b = \nu_1 - \nu_2$.

S4. Given, $\nu_1 = 250$ Hz; $\nu_2 = 255$ Hz

No. of beats per sound, $m = 255 - 250 = 5$

No. of beats of in 5 sec $= 5 \times 5 = 25$.

S5. When two wave of slightly different frequencies moving with the same velocity in same direction give rise to the phenomena of beats

S6. Since Intensity $\propto$ (Amplitude)^2, both + 1 and – 1 are to be considered in beats.

S7. A node is a point where the amplitude of vibration is the minimum and pressure is the maximum. On the other hand, an antinode is a point where the amplitude of vibration is the maximum and pressure is the minimum.

Therefore, a displacement node is nothing but a pressure antinode, and vice versa.

S8. Bats emit very high-frequency ultrasonic sound waves. These waves get reflected back toward them by obstacles. A bat receives a reflected wave (frequency) and estimates the distance, direction, nature, and size of an obstacle with the help of its brain senses.

S9. The overtones produced by a sitar and a violin, and the strengths of these overtones, are different. Hence, one can distinguish between the notes produced by a sitar and a violin even if they have the same frequency of vibration.

Solids have shear modulus. They can sustain shearing stress. Since fluids do not have any definite shape, they yield to shearing stress. The propagation of a transverse wave is such that it produces shearing stress in a medium. The propagation of such a wave is possible only in solids, and not in gases.

S10. Both solids and fluids have their respective bulk moduli. They can sustain compressive stress. Hence, longitudinal waves can propagate through solids and fluids.

S11. A pulse is actually is a combination of waves having different wavelengths. These waves travel in a dispersive medium with different velocities, depending on the nature of the medium. This results in the distortion of the shape of a wave pulse.

S12. Increase in the tension of a string increases its frequency. If the original frequency of $B(\nu_B)$ were greater than that of $A(\nu_A)$, further increase in ν_B should have resulted in an increase in the beat frequency. But the beat frequency is found to decrease. This shows that $\nu_B < \nu_A$. Since $\nu_A - \nu_B = 5$ Hz, and $\nu_A = 427$ Hz, we get $\nu_B = 422$ Hz.

S13. Let ν_1 and ν_2 be the frequencies of sitar wire and the tabla respectively. As the two produce 4 beats per second,

$$\nu_1 - \nu_2 = 4$$

If tabla membrane is tightened (tension increased), frequency of sound produced by the table *i.e.*, ν_2 will increase. If $\nu_1 > \nu_2$, beat frequency will decrease.

On the other hand, if $\nu_1 < \nu_2$, then beat frequency will increase.

S14. In an open pipe, the fundamental frequency produced is given by

$$\nu = \frac{v}{2(L + 0.3D)},$$

where D is diameter of the tube and 0.3 D is called ***end correction***. If follows that the two equal pipes but of different radii will produce sound of different frequencies.

S15. In a resonance tube, the vibrations are set up in the air column. The liquid in the tube only reflects the waves, which upon superposition produce stationary waves. Therefore, if oil of density higher than that of water is used, there will be no effect on the frequency of the waves set up.

S16. The two musical instruments are sounded together and the number of beats produced is noted. Now, the frequency of one of the two instruments is kept fixed, while that of the other is increased (by increasing tension in the string). The number of beats may increase or decrease.

If the number of beats decrease, the tension in the string is gradually increased, till the two instruments become in unison *i.e.*, when no beats are heard.

On the other hand, if the number of beats increase on increasing the tension in the string, then the tension is gradually decreased so as to bring the two instruments in unison.

S17. Here, frequency of the known tuning fork,

$$\nu_1 = 288 \text{ Hz}.$$

Let ν_2 be the frequency of the unknown tuning fork. Then,

$$\nu_2 = \nu_1 \pm 4 = 288 \pm 4 = 292 \quad \text{or} \quad 284 \text{ Hz}$$

When loaded with wax, suppose that frequency of the known tuning fork becomes v_2'. Since number of beats per second remains 4 s^{-1}.

$$\nu_2' = \nu_1 \pm 4 = 288 \pm 4 = 292 \quad \text{or} \quad 284 \text{ Hz}.$$

Since on loading with wax, frequency decreases, the frequency of unknown tuning fork is 292 Hz.

S18. Given, $\nu_1 = 250$ Hz, $\nu_2 = 255$ Hz

No. of beats per second or beat frequency = 255 – 250 = 5.

No. of beats heard in 5 seconds = $5 \times 5 = 25$.

S19. Let ν_1 and ν_2 be the frequencies of the tuning fork *A* and *B* respectively.

Here, $\nu_1 = 288$ Hz; $b = 6\ s^{-1}$

$\therefore$ $\nu_2 = \nu_1 \pm 6 = 288 \pm 6 = 294$ or 282 Hz

On filing the tuning fork B: Let ν_2' be frequency of the tuning fork *B*, when it is filed.

Then $\nu_2' = \nu_1 \pm 4 = 288 \pm 4 = 292$ or 284 Hz

Since on filing, the frequency decreases, the frequency of the tuning fork *B* is 282 Hz.

S20. Frequency of vibration, ν_s given by

$$\nu = \frac{k}{l}\sqrt{\frac{T}{\mu}}$$

where *l* is the length of the string between wedges, *T* is the tension in the string, and μ is mass per unit length of the string. *k* is a constant which depends upon the mode of vibration of the string.

S21. Here, frequency of the wire *A*, $\nu_1 = 480$ Hz; beat frequency $b = 8$ Hz.

Let frequency of the wire *B* be equal to ν_2.

Then, $\nu_2 = \nu_1 \pm b = \nu_1 \pm 8 = 480 \pm 8$

$= 488$ Hz or 472 Hz.

Now, the frequency of vibration of a wire is given by

$$\nu = \sqrt{\frac{T}{m}}.$$

Therefore, when the tension in the wire *A* is increased, it implies that the frequency of the wire *A* will increase a little *i.e.*, it must become more than its original frequency of 480 Hz. As on increasing the tension in the wire *A*, the beat frequency becomes 5 Hz, the following two cases arise:

(a) If the frequency of *B* is 472 Hz, then to produce 5 beats per second, the frequency of a must become 467 or 477 Hz. Now, on increasing the tension, the frequency of the wire *A* must increase. As both these values (467 or 477 Hz) are less than the original frequency of *A*, the frequency of *B* cannot be 472 Hz.

(b) If the frequency of *B* is 488 Hz, then to produce 5 beats per second, the frequency of *A*, must become 493 Hz or 483 Hz. Since on increasing the tension, the frequency of the wire *A* must increase, its frequency has become 493 Hz.

S22. Let ν_1 and ν_2 the frequencies of the tuning forks *A* and *B* respectively.

Here, $\nu_1 = 256$ Hz; $b = 4\,s^{-1}$

$\therefore$ $\nu_2 = \nu_1 \pm 4 = 256 \pm 4 = 260$ or 252 Hz.

When tuning fork B is loaded with 2 gf : Let ν_2' be frequency of the tuning fork on loading it with 1 *gf*.

Here, $b = 1\,s^{-1}$

$\therefore$ $\nu_2' = \nu_1 \pm 1 = 256 \pm 1 = 257$ or 255 Hz.

When tuning fork B is loaded with 2 gf : Let ν_2'' be frequency of the tuning fork on loading it with 2 *gf*.

Here, $b = 4\,s^{-1}$

$\therefore$ $\nu_2'' = \nu_1 \pm 2 = 256 \pm 2 = 258$ or 254 Hz.

Since on increases the load, frequency of the tuning fork decreases, the frequency of tuning fork *B* is 260 Hz.

S23. Length of the steel rod, $l = 100$ cm = 1 m

Fundamental frequency of vibration, $\nu = 2.53$ kHz $= 2.53 \times 10^3$ Hz

When the rod is plucked at its middle, an antinode (A) is formed at its centre, and nodes (N) are formed at its two ends, as shown in the given figure.

The distance between two successive nodes is $\frac{\lambda}{2}$. [Condition of resonance]

$$\therefore \quad l = \frac{\lambda}{2}$$

$$\lambda = 2l = 2 \times 1 = 2\text{m}$$

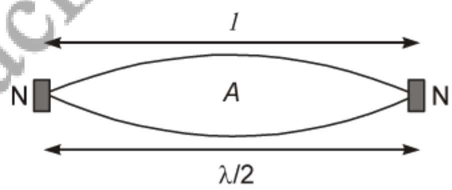
The speed of sound in steel is given by the relation:

$$v = \nu\lambda$$

$$= 2.53 \times 10^3 \times 2$$

$$= 5.06 \times 10^3 \text{ m/s}$$

$$= 5.06 \text{ km/s}$$

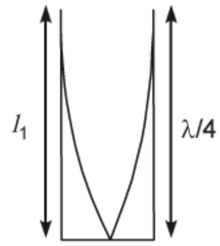


S24. Frequency of the turning fork, $\nu = 340$ Hz

Since the given pipe is attached with a piston at one end, it will behave as a pipe with one end closed and the other end open, as shown in the given figure.

Such a system produces odd harmonics. The fundamental note in a closed pipe is given by the relation:

$$l_1 = \frac{\lambda}{4}$$



Where,

Length of the pipe, $l_1 = 25.5 \text{ cm} = 0.255 \text{ m}$

$$\lambda = 4l_1 = 4 \times 0.255 = 1.02 \text{ m}$$

The speed of sound is given by the relation:

$$v = \nu\lambda = 340 \times 1.02 = 346.8 \text{ m/s}$$

S25. When ν_1 and ν_2 are two frequencies represented by $y_1 = A \sin 2\pi \nu_1 t$ and $y_2 = A \sin 2\pi \nu_2 t$, we get on superposition, $y = y_1 + y_2$.

$$= 2A \cos \pi \left(\frac{\nu_1 - \nu_2}{2}\right) t \sin 2\pi \left(\frac{\nu_1 + \nu_2}{2}\right) t$$

Amplitude = $2A \cos 2\pi \left(\frac{\nu_1 - \nu_2}{2}\right) t$ becomes maximum, when

$$2\pi t \left(\frac{\nu_1 - \nu_2}{2}\right) = 0, \quad \pi, 2\pi, ..., N\pi$$

i.e., $$\nu_1 - \nu_2 = \frac{2N\pi}{2\pi t} = \frac{N}{t} = N.\nu .$$

where ν is the beat frequency – the number of times the maxima and minima is repeated in one second.

S26. Given, $\frac{\nu_1}{\nu_2} = \frac{130}{128}$, $\frac{\nu_1}{\nu_2} - 1 = \frac{130}{128} - 1$

$$= \frac{2}{128} = \frac{1}{64}; \quad \nu_1 - \nu_2 = \mathbf{4}.$$

S27. Operating frequency of the SONAR system, $\nu = 40$ kHz

Speed of the enemy submarine, $v_e = 360$ km/h = 100 m/s

Speed of sound in water, $v = 1450$ m/s

The source is at rest and the observer (enemy submarine) is moving toward it. Hence, the apparent frequency (ν') received and reflected by the submarine is given by the relation:

$$\nu' = \left(\frac{v + v_e}{v}\right)\nu = \left(\frac{1450 + 100}{1450}\right) \times 40 = 42.76 \text{ kHz}.$$

The frequency (ν'') received by the enemy submarine is given by the relation:

$$\nu'' = \left(\frac{v}{v + v_s}\right)\nu'$$

Where, v_s = 100 m/s

$$\therefore \quad \nu'' = \left(\frac{1450}{1450-100}\right)\times 42.76 = 45.93 \text{ kHz.}$$

S28. **Answer:** First (Fundamental); No

Length of the pipe, l = 20 cm = 0.2 m

Source frequency = n^{th} normal mode of frequency,

ν_n = 430 Hz

Speed of sound, v = 340 m/s

In a closed pipe, the n^{th} normal mode of frequency is given by the relation:

$$\nu_n = (2n-1)\frac{\nu}{4l}; \qquad n \text{ is an integer} = 0, 1, 2, 3, \ldots$$

$$430 = (2n-1)\frac{340}{4\times 0.2}$$

$$2n - 1 = \frac{430\times 4\times 0.2}{340} = 1.01$$

$$2n = 2.01$$

$$n \sim 1$$

Hence, the first mode of vibration frequency is resonantly excited by the given source.

In a pipe open at both ends, the n^{th} mode of vibration frequency is given by the relation:

$$\nu_n = \frac{n\nu}{2l}$$

$$n = \frac{2l\nu_n}{\nu} = \frac{2\times 0.2\times 430}{340} = 0.5$$

Since the number of the mode of vibration (n) has to be an integer, the given source does not produce a resonant vibration in an open pipe.

S29. ***Beats:*** The waxing and waning of sound due to interaction between two slightly different frequencies. If v_1 and v_2 are the two frequencies, $v_b = |v_1 - v_2|$.

Let ν_1 and ν_2 be the frequencies of the two notes of wavelengths λ_1 and λ_2 respectively.

Here, λ_1 = 2.04 m; λ_2 = 2.08 m

In v is velocity of sound, then

$$\nu_1 = \frac{v}{2.04} \quad \text{and} \quad \nu_2 = \frac{v}{2.08}$$

It follows that ν_1 is greater than ν_2. If the number of beats produced per second is b, then,

$$b = \nu_1 - \nu_2 = \frac{v}{2.04} - \frac{v}{2.08} \qquad \ldots \text{(i)}$$

But, $b = 200$ per minute $= \frac{200}{60} = \frac{10}{3} s^{-1}$ ... (ii)

From the Eq. (i) and (ii), we get

$$\frac{v}{2.04} - \frac{v}{2.08} = \frac{10}{3}$$

or $$v\left[\frac{2.08 - 2.04}{2.08 \times 2.08}\right] = \frac{10}{3}$$

or $$v = \frac{10 \times 2.04 \times 2.08}{3(2.08 - 2.04)} = \mathbf{353.6\ ms^{-1}}.$$

S30. Let ν_1 and ν_2 the frequencies of the tuning forks *A* and *B* respectively.

Here, $\nu_1 = 480$ Hz; $b = 4\ s^{-1}$

$\therefore$ $\nu_2 = \nu_1 \pm 4 = 480 \pm 4 = 484$ or 476 Hz.

When tuning fork B is loaded with max : Let ν_2' be frequency of the tuning fork *B* on loading it with max.

Here, $b = 6\ s^{-1}$

$\therefore$ $\nu_2' = \nu_1 \pm 6 = 480 \pm 6 = 486$ or 474 Hz.

When tuning fork B is reduced: Let ν_2'' be frequency of the tuning fork *B*, when wax is reduced.

Here, $b = 4\ s^{-1}$

$\therefore$ $\nu_2'' = \nu_1 \pm 4 = 480 \pm 4 = 484$ or 474 Hz.

Since there is still some wax on the prong of the tuning fork *B*, Its frequency cannot be 476. Hence frequency of the tuning fork *B* is 484 Hz.

S31. Ultrasonic beep frequency emitted by the bat, $\nu = 40$ kHz

Velocity of the bat, $v_b = 0.03$

Where, v = velocity of sound in air

The apparent frequency of the sound striking the wall is given as:

$$\nu' = \left(\frac{v}{v - v_b}\right)\nu$$

$$= \left(\frac{v}{v - 0.03v}\right) \times 40$$

$$= \frac{40}{0.97} \text{ kHz.}$$

This frequency is reflected by the stationary wall ($v_s = 0$) toward the bat.

The frequency (ν'') of the received sound is given by the relation:

$$\nu'' = \left(\frac{v + v_b}{v}\right)\nu$$

$$= \left(\frac{v + 0.03v}{v}\right) \times \frac{40}{0.97}$$

$$= \frac{1.03 \times 40}{0.97} = 42.47\text{kHz}.$$

S32. Let v_S and v_P be the velocities of *S* and *P* waves respectively.

Let *L* be the distance between the epicentre and the seismograph.

We have:

$$L = v_S t_S \quad \dots (i)$$

$$L = v_P t_P \quad \dots (ii)$$

Where,

t_S and t_P are the respective times taken by the *S* and *P* waves to reach the seismograph from the epicentre

It is given that:

$$v_P = 8 \text{ km/s}$$

$$v_S = 4 \text{ km/s}$$

From equations (i) and (ii), we have:

$$v_S t_S = v_P t_P$$

$$4tS = 8\, t_P$$

$$t_S = 2\, t_P \quad \dots (iii)$$

It is also given that:

$$t_S - t_P = 4 \text{ min} = 240 \text{ s}$$

$$2t_P - t_P = 240$$

$$t_P = 240$$

And $\quad t_S = 2 \times 240 = 480 \text{ s}$

From equation (ii), we get:

$$L = 8 \times 240 = 1920 \text{ km}$$

Hence, the earthquake occurs at a distance of 1920 km from the seismograph.

S33. Let L_1, L_2 be the lengths of the two air columns closed at one end and ν_1, ν_2 be their respective fundamental frequencies. If *v* is velocity of sound in air, then

$$\nu_1 = \frac{v}{4L_1} = \frac{v}{4 \times 100} = \frac{v}{400} \quad \dots (i)$$

and $$\nu_2 = \frac{v}{4L_2} = \frac{v}{4 \times 101} = \frac{v}{404} \quad \ldots \text{(ii)}$$

Number of beats produced per second,

$$b = \frac{17}{20}\, s^{-1}$$

$\therefore$ $$\nu_1 = \nu_2 + b = \nu_2 \pm \frac{17}{20}$$

From the equations (i) and (ii), it follows that $\nu_1 > \nu_2$.

$$\nu_1 = \nu_2 \pm \frac{17}{20} \quad \text{or} \quad \frac{v}{400} = \frac{v}{404} + \frac{17}{20}$$

or $$v = 34340 \text{ cm s}^{-1} = \mathbf{343.4\ ms^{-1}}.$$