

**CH15 – WAVES**

**Q1.** A string of mass 2.50 kg is under a tension of 200 N. The length of the stretched string is 20.0 m. If the transverse jerk is struck at one end of the string, how long does the disturbance take to reach the other end?

**Answer:**

Given,

Mass of the string,  $M = 2.50 \text{ kg}$

Tension in the string,  $T = 200 \text{ N}$

Length of the string,  $l = 20.0 \text{ m}$

Mass per unit length,  $\mu = M / l = 5/40 = 0.125 \text{ kg / m}$

We know,

Velocity of the transverse wave,  $v =$

$=$

$= 40 \text{ m/s}$

Therefore, the time taken by the transverse wave to reach the other side is 40 m/s.

**Q2.** A stone dropped from the top of a tower of height 300 m 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  $340 \text{ m s}^{-1}$ ? ( $g = 9.8 \text{ m s}^{-2}$ )

**Answer:**

Given,

Height of the bridge,  $s = 300 \text{ m}$

The initial velocity of the stone,  $u = 0$

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

Speed of sound in air  $= 340 \text{ m/s}$

Let  $t$  be the time taken by the stone to hit the water's surface

We know,

$$s = ut + \frac{1}{2} gt^2$$

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

Therefore,  $t = 7.82 \text{ s}$

The time taken by the sound to reach the bridge,  $t' = 300/340 = 0.88 \text{ s}$

Therefore, from the moment the stone is released from the bridge, the sound of it splashing the water is heard after  $= t + t' = 7.82 \text{ s} + 0.88 \text{ s} = 8.7 \text{ s}$ .

**Q3. 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 a transverse wave on the wire equals the speed of sound in dry air at 20 °C = 343 m s<sup>-1</sup>.**

**Answer:**

Given,

Length of the steel wire,  $l = 12 \text{ m}$

Mass of the steel wire,  $m = 2.0 \text{ kg}$

Velocity of the transverse wave,  $v = 343 \text{ m/s}$

Mass per unit length,  $\mu = M / l = 2.10/12 = 0.175 \text{ kg / m}$

We know,

Velocity of the transverse wave ,  $v =$

Therefore,  $T = v^2 \mu$

$= 343^2 \times 0.175 = 2.06 \times 10^4 \text{ N}$

Therefore, the tension in the wire is  $343^2 \times 0.175 = 2.06 \times 10^4 \text{ N}$ .

**Q4. Using the formula  $v =$**

**, explain why the speed of sound in air**

**(a) does not depend upon pressure.**

**(b) increases with temperature and humidity.**

**(c) increases with humidity.**

**Answer:**

Given,

$v =$

We know,

$PV = nRT$  ( for  $n$  moles of ideal gas )

$\Rightarrow PV = RT (m/M)$

Where,  $m$  is the total mass, and  $M$  is the molecular mass of the gas.

Therefore,  $P = m (RT/M)$

$\Rightarrow P =$

$\Rightarrow$

**(a) For a gas at a constant temperature,**

**= constant**

Thus, as  $P$  increases  $\rho$  and vice versa. This means that the  $P/\rho$  ratio always remains constant, meaning

$v =$

= constant, i.e. velocity of sound does not depend upon the pressure of the gas.

**(b) Since,**

$$v =$$

$$= v =$$

We can see that  $v$

, i.e. speed of sound increases with temperature.

(c) When humidity increases, the effective density of the air decrease. This means

, thus velocity increases.

**Q5.** We know that the function  $y = f(x, t)$  represents a wave travelling in one direction, where  $x$  and  $t$  must appear in the combination  $x + vt$  or  $x - vt$  or, i.e.  $y = f(x \pm vt)$ . Is the converse true?

Can the following functions for  $y$  possibly represent a travelling wave:

(i)  $(x - vt)^2$

(ii)  $\log[(x + vt)/x_0]$  (iii)  $1/(x + vt)$

**Answer:**

No, the converse is not true because it is necessary for a wave function representing a travelling wave to have a finite value for all values of  $x$  and  $t$ .

As none of the above functions satisfies the given condition, none of the options represents a travelling wave.

**Q6.** A bat emits the ultrasonic sound of frequency 1000 kHz in air. If the sound meets a water surface, what is the wavelength of (a) the reflected sound and (b) the transmitted sound? The speed of sound in air is  $340 \text{ m s}^{-1}$ , and in water,  $1486 \text{ m s}^{-1}$ .

**Answer:**

Given,

Frequency of the ultrasonic sound,  $\nu = 1000 \text{ kHz} = 10^6 \text{ Hz}$

Speed of sound in air,  $v_A = 340 \text{ m/s}$

We know,

(a) The wavelength ( $\lambda_R$ ) of the reflected sound is:

$$\lambda_R = v_A / \nu$$

$$= 340 / 10^6 = 3.4 \times 10^{-4} \text{ m}$$

(b) Speed of sound in water,  $v_W = 1486 \text{ m/s}$

Therefore, the wavelength ( $\lambda_T$ ) of the transmitted sound is:

$$\lambda_T = 1486 / 10^6$$

$$= 1.49 \times 10^{-3} \text{ m.}$$

**Q7.** An ultrasonic scanner operating at 4.2 MHz is used to locate tumours in tissues. If the speed of sound is 2 km/s in a certain tissue, calculate the wavelength of sound in this tissue.

**Answer:**

Given,

Speed of sound in the tissue,  $v_T = 2 \text{ km/s} = 2 \times 10^3 \text{ m/s}$

Operating frequency of the scanner,  $\nu = 4.2 \text{ MHz} = 4.2 \times 10^6 \text{ Hz}$

Therefore, the wavelength of sound:

$$\lambda = v_T / \nu$$

$$= (2 \times 10^3) / (4.2 \times 10^6)$$

$$= 4.76 \times 10^{-4} \text{ m.}$$

**Q8.** A transverse harmonic wave on a wire is expressed as:

$$y(x, t) = 3 \sin (36t + 0.018x + \pi/4).$$

(i) Is it a stationary wave or a travelling one?

(ii) If it is a travelling wave, give the speed and direction of its propagation.

(iii) Find its frequency and amplitude.

(iv) Give the initial phase at the origin.

(v) Calculate the smallest distance between two adjacent crests in the wave.

[X and y are in cm and t in seconds. Assume the left to the right direction as the positive direction of x]

**Answer:**

Given,

$$y(x, t) = 3 \sin (36t + 0.018x + \pi/4) \dots\dots\dots (1)$$

(i) We know the equation of a progressive wave travelling from right to left is:

$$y(x, t) = a \sin (\omega t + kx + \Phi) \dots\dots\dots (2)$$

Comparing equation (1) to equation (2), we see that it represents a wave travelling from right to left and also we get:

$$a = 3 \text{ cm, } \omega = 36 \text{ rad/s, } k = 0.018 \text{ cm and } \phi = \pi/4.$$

(ii) Therefore, the speed of propagation,  $v = \omega/k = 36/0.018 = 20 \text{ m/s.}$

(iii) Amplitude of the wave,  $a = 3 \text{ cm}$

Frequency of the wave  $\nu = \omega / 2\pi$

$$= 36 / 2\pi = 5.7 \text{ hz.}$$

(iv) Initial phase at the origin  $= \pi/4$

(v) The smallest distance between two adjacent crests in the wave,  $\lambda = 2\pi/$

$$k = 2\pi / 0.018$$

$$= 349 \text{ cm.}$$

**Q9.** For the wave in the above question (Q8), plot the displacement (y) versus (t) graphs for x = 0, 2 and 4 cm.

(i) Give the shapes of these plots.

(ii) With respect to which aspects (amplitude, frequency or phase) does the oscillatory motion in a travelling wave differ from one point to another?

**Answer:**

(i) Given,

$$y(x, t) = 3 \sin (36t + 0.018x + \pi/4) \quad \dots\dots\dots (1)$$

For x= 0, the equation becomes:

$$y(0, t) = 3 \sin (36t + 0 + \pi/4) \quad \dots\dots\dots (2)$$

Also,

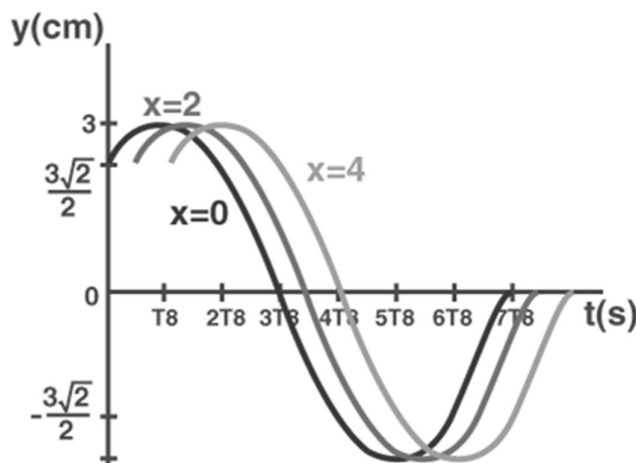
$$\omega = 2\pi/t = 36 \text{ rad/s}$$

$$\Rightarrow t = \pi/18 \text{ secs.}$$

Plotting the displacement (y) vs (t) graphs using different values of t listed below:

t	0	T/8	2T/8	3T/8	4T/8	5T/8	6T/8	7T/8	T
y		3		0		-3		0	

(ii) Similarly, graphs are obtained for x = 0, x = 2 cm, and x = 4 cm. The oscillatory motion in the travelling wave is different from each other only in terms of phase. Amplitude and frequency are invariant for any change in x. The y-t plots of the three waves are shown in the given figure:



Q10. A travelling harmonic wave is given as:  $y(x, t) = 2.0 \cos 2\pi (10t - 0.0080x + 0.35)$ .

What is the phase difference between the oscillatory motion of two points separated by a distance of:

- (i) 8 m
- (ii) 1 m
- (iii)  $\lambda/2$
- (iv)  $6\lambda/4$

[ X and y are in cm, and t is in secs ].

Answer:

Given,

The equation for a travelling harmonic wave:

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

$$= 2.0 \cos (20\pi t - 0.016\pi x + 0.70\pi)$$

Where,

Propagation constant,  $k = 0.0160\pi$

Amplitude,  $a = 2$  cm

Angular frequency,  $\omega = 20\pi$  rad/s

We know,

Phase difference  $\Phi = kx = 2\pi/\lambda$

(i) For  $x = 8$  m = 800 cm

$$\Phi = 0.016\pi \times 800 = 12.8\pi \text{ rad.}$$

(ii) For  $x = 1$  m = 100 cm

$$\Phi = 0.016\pi \times 100 = 1.6\pi \text{ rad.}$$

(iii) For  $x = \lambda/2$

$$\Phi = (2\pi/\lambda) \times (\lambda/2) = \pi \text{ rad.}$$

(iv) For  $x = 6\lambda/4$

$$\Phi = (2\pi/\lambda) \times (6\lambda/4) = 3\pi \text{ rad.}$$

Q11. The transverse displacement of a wire (clamped at both its ends) is described as:

$y(x, t) =$

The mass of the wire is  $6 \times 10^{-2}$  kg, and its length is 3m.

Provide answers to the following questions:

- (i) Is the function describing a stationary wave or a travelling wave?
- (ii) Interpret the wave as a superposition of two waves travelling in

opposite directions. Find the speed, wavelength and frequency of each wave.

(iii) Calculate the wire's tension.

[X and y are in meters and t in secs]

Answer:

We know,

The standard equation of a stationary wave is described as:

$$y(x, t) = 2a \sin kx \cos \omega t$$

The given equation  $y(x, t) =$

is similar to the general equation.

(i) Thus, the given function describes a stationary wave.

(ii) We know a wave travelling in the positive x-direction can be represented as:

$$y_1 = a \sin(\omega t - kx)$$

Also,

A wave travelling in the negative x-direction is represented as:

$$y_2 = a \sin(\omega t + kx)$$

Super-positioning these two waves gives:

$$y = y_1 + y_2$$

$$= a \sin(\omega t - kx) - a \sin(\omega t + kx)$$

$$= a \sin(\omega t) \cos(kx) - a \sin(kx) \cos(\omega t) - a \sin(\omega t) \cos(kx) - a \sin(kx) \cos(\omega t)$$

$$= -2a \sin(kx) \cos(\omega t)$$

$$=$$

$$\dots\dots\dots (1)$$

The transverse displacement of the wires is described as:

$$\dots\dots\dots (2)$$

Comparing equations (1) and (2), we get

$$2\pi/\lambda = 2\pi/3$$

Therefore, wavelength  $\lambda = 3\text{m}$

$$\text{Also, } 2\pi v/\lambda = 120\pi$$

Therefore, speed  $v = 180 \text{ m/s}$

And, Frequency  $= v/\lambda = 180/3$

$$= 60 \text{ Hz}$$

(iii) Given,

The velocity of the transverse wave,  $v = 180 \text{ m/s}$

The string's mass,  $m = 6 \times 10^{-2} \text{ kg}$

String length,  $l = 3 \text{ m}$

Mass per unit length of the string,  $\mu = m/l = (6 \times 10^{-2})/3$   
 $= 2 \times 10^{-2} \text{ kg/m}$

Let the tension in the wire be T

Therefore,  $T = v^2 \mu$

$= 180^2 \times 2 \times 10^{-2}$

$= 648 \text{ N.}$

**Q12. Considering the wave described in the above question (Q11), answer the following questions:**

(a) Are all the points in the wire oscillating at the same values of (i) frequency, (ii) phase, and (iii) amplitude? Justify your answers.

(b) Calculate the amplitude of a point 0.4 m away from one end.

**Answer:**

(a) As the wire is clamped at both ends, the ends behave as nodes, and the whole wire vibrates in one segment. Thus,

(i) Except at the ends, which have zero frequency, all the particles in the wire oscillate with the same frequency.

(ii) All the particles in the wire lie in one segment; thus, they all have the same phase. Except for the nodes.

(iii) Amplitude, however, is different for different points.

(b) Given the equation,

$y(x, t) =$

For  $x = 0.4\text{m}$  and  $t = 0$

Amplitude = displacement =

=

= 0.044 m.

**Q13. Given below are functions of x and t to describe the displacement (longitudinal or transverse) of an elastic wave. Identify the ones describing (a) a stationary wave, (b) a travelling wave and (c) neither of the two:**

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

(ii)  $y = \cos x \sin t + \cos 2x \sin 2t.$

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

(iv)  $y =$

**Answer:**



- (i) This equation describes a travelling wave, as the harmonic terms  $\omega t$  and  $kx$ , are in the combination of  $kx - \omega t$ .
- (ii) This equation describes a stationary wave because the harmonic terms  $\omega t$  and  $kx$  appear separately in the equation. In fact, this equation describes the superposition of two stationary waves.
- (iii) This equation describes a stationary wave because the harmonic terms  $\omega t$  and  $kx$  appear separately.
- (iv) This equation does not contain any harmonic term. Thus, it is neither a travelling wave nor a stationary wave.

**Q14.** A string clamped at both ends is stretched out, it is then made to vibrate in its fundamental mode at a frequency of 45 Hz. The linear mass density of the string is  $4.0 \times 10^{-2} \text{ kg/m}$ , and its mass is  $2 \times 10^{-2} \text{ kg}$ .

Calculate:

- (i) The velocity of a transverse wave on the string  
(ii) The tension in the string

**Answer:**

Given,

Mass of the string,  $m = 2 \times 10^{-2} \text{ kg}$

Linear density of the string  $= 4 \times 10^{-2} \text{ kg/m}$

Frequency,  $\nu_F = 45 \text{ Hz}$

We know the length of the wire  $= m/\mu$   
 $= (2 \times 10^{-2}) / (4 \times 10^{-2}) = 0.5 \text{ m}$

We know,  $\lambda = 2l/n$

Where,  $n$  = number of nodes in the wire.

For the fundamental node,  $n = 1$

$\Rightarrow \lambda = 2l$

$= 2 \times 0.5 = 1 \text{ m}$

(i) Therefore, the speed of the transverse wave,  $v = \lambda \nu_F$   
 $= 1 \times 45 = 45 \text{ m/s}$ .

(ii) Tension in the string  $= \mu v^2$   
 $= 4 \times 10^{-2} \times 45 = 81$

**Q15.** A 1 m long pipe with a movable piston at one end and an opening at the other will be in resonance with a tuning fork vibrating at 340 Hz, if the length of the pipe is 79.3 cm or 25.5 cm. Calculate the speed of sound in the air. Neglect the edge effects.

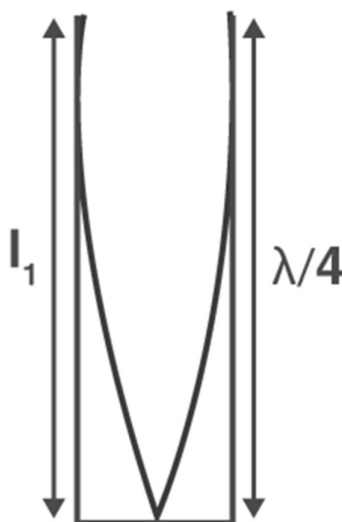
**Answer:**

Given,

Frequency of the tuning fork,  $\nu_F = 340 \text{ Hz}$

Length of the pipe,  $l_1 = 0.255 \text{ m}$

As the given pipe has a piston at one end, it will behave as a pipe with one end closed and the other end open, as depicted in the figure below:



This kind of system creates odd harmonics. We know that the fundamental note in a closed pipe is written as:

$$l_1 = \lambda / 4$$

$$0.255 \times 4 = \lambda = 1.02 \text{ m}$$

Therefore, the speed of sound,  $v = \lambda \nu_F$

$$= 340 \times 1.02 = 346.8 \text{ m/s.}$$

**Q16.** A steel bar of length 200 cm is nailed at its midpoint. The fundamental frequency of the longitudinal vibrations of the rod is 2.53 kHz. At what speed will the sound be able to travel through steel?

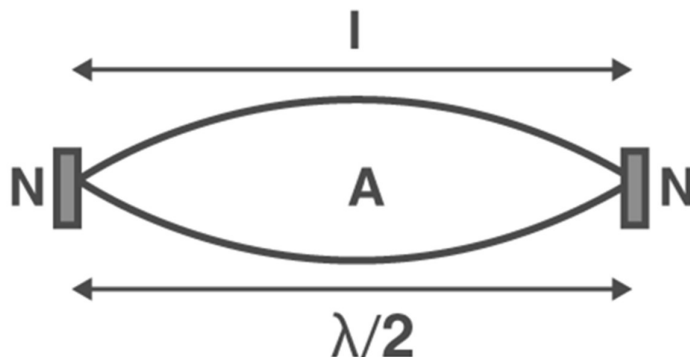
**Answer:**

Given,

Length,  $l = 200 \text{ cm} = 2 \text{ m}$

Fundamental frequency of vibration,  $\nu_F = 2.53 \text{ kHz} = 2.53 \times 10^3 \text{ Hz}$

The bar is then plucked at its midpoint, forming an antinode (A) at its centre and nodes (N) at its two edges, as depicted in the figure below:



The distance between two successive nodes is  $\lambda / 2$

$$\Rightarrow l = \lambda / 2$$

$$\text{Or, } \lambda = 2 \times 2 = 4\text{m}$$

Thus, sound travels through steel at a speed of  $v = v\lambda$

$$v = 4 \times 2.53 \times 10^3$$

$$= 10.12 \text{ km/s.}$$

**Q17.** One end of A 20 cm long tube is closed. Find the harmonic mode of the tube that will be resonantly excited by a source of frequency 430 Hz. If both ends are open, can the same source still produce resonance in the tube? (Sound travels in air at 340 m /s).

**Answer:**

Given,

Length of the pipe,  $l = 20 \text{ cm} = 0.2 \text{ m}$

Frequency of the source =  $n^{\text{th}}$

the normal mode of frequency,  $v_N = 430 \text{ Hz}$

Speed of sound,  $v = 340 \text{ ms}^{-1}$

We know that in a closed pipe, the  $n^{\text{th}}$  normal mode of frequency  $v_N = (2n - 1)v/4l$

where  $n$  is an integer  $= 0, 1, 2, 3, 4, \dots$

$$430 = (2n - 1)(340/4 \times 0.2)$$

$$2n = 2.01$$

$$n \approx 1$$

Thus, the given source resonantly excites the first mode of vibration frequency

Now, for a pipe open at both ends, the  $n^{\text{th}}$  mode of vibration frequency:

$$V_R = nv/2l$$

$$n = V_R 2l/v$$

$$n = (2 \times 0.2 \times 430)/340 = 0.5$$

As the mode of vibration ( $n$ ) has to be an integer, this source is not in resonance with the tube.

**Q18.** Guitar strings X and Y striking the note 'Ga' are a little out of tune and give beats at 6 Hz. When the string X is slightly loosened, and the beat frequency becomes 3 Hz. Given that the original frequency of X is 324 Hz, find the frequency of Y.

**Answer:**

Given,

Frequency of X,  $f_X = 324$  Hz

Frequency of Y =  $f_Y$

Beat's frequency,  $n = 6$  Hz

Also,

$$n =$$

$$6 =$$

$$\Rightarrow f_Y = 330 \text{ Hz or } 318 \text{ Hz}$$

As frequency drops with a decrease in tension in the string, thus  $f_Y$  cannot be 330 Hz

$$\Rightarrow f_Y = 318 \text{ Hz.}$$

**Q19.** Explain how:

(i) A sound wave's pressure antinode is a displacement node and vice versa.

(ii) The Ganges river dolphin, despite being blind, can manoeuvre and swim around obstacles and hunt down prey.

(iii) A guitar note and violin note are being played at the same frequency, however, we can still make out which instrument is producing which note.

(iv) Both transverse and longitudinal waves can propagate through solids, but only longitudinal waves can move through gases.

(v) In a dispersive medium, the shape of a pulse propagating through it gets distorted.

**Answer:**

(i) An antinode is a point where pressure is the minimum, and the amplitude of vibration is the maximum. On the other hand, a node is a point where pressure is the maximum, and the amplitude of vibration is the minimum.

(ii) The Ganges river dolphin sends out click noises which return back as a vibration, informing the dolphin about the location and distances of objects in front of it. Thus, allowing it to manoeuvre and hunt down prey with minimum vision.

(iii) The guitar and the violin produce overtones of different strengths. Thus, one can differentiate between the notes coming from a guitar and a violin, even if they are vibrating at the same frequencies.

(iv) Both solids and fluids have a bulk modulus of elasticity. Thus, they both allow longitudinal waves to propagate through them. However, unlike solids, gases do not have a shear modulus. Thus, transverse waves cannot pass through gases.

(v) A pulse is a combination of waves of un-similar wavelengths. These waves move at different velocities in a dispersive medium. This causes distortion in its shape.

**Q20.** A train, standing at the outer signal of a railway station, blows a whistle of frequency 400 Hz in still air. (i) What is the frequency of the whistle for a platform observer when the train (a) approaches the platform with a speed of  $10 \text{ m s}^{-1}$ , (b) recedes from the platform with a speed of  $10 \text{ m s}^{-1}$ ? (ii) What is the speed of sound in each case? The speed of sound in still air can be taken as  $340 \text{ m s}^{-1}$ .

**Answer:**

Frequency of the whistle = 400 Hz

Speed of sound in still air =  $340 \text{ m/s}$

(i)

(a) Train approaches the platform at speed,  $v_s = 10 \text{ m/s}$

Frequency of the whistle for a platform observer  
= 412 Hz.

(b) Train recedes from the platform at speed,  $v_s = 10 \text{ m/s}$

Frequency of the whistle for a platform observer  
= 389 Hz.

(ii) The speed of the sound will not change. It will remain at  $340 \text{ m/s}$ .

**Q21.** 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 a speed of  $10 \text{ m s}^{-1}$ . 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  $10 \text{ m s}^{-1}$ ? The speed of sound in still air can be taken as  $340 \text{ m s}^{-1}$ .

**Answer:**

Frequency of the whistle =  $400 \text{ Hz}$

Speed of wind,  $v_w = 10 \text{ m/s}$

Speed of sound in still air,  $v = 340 \text{ m/s}$

The effective speed of the sound for an observer standing on the platform

$$v' = v + v_w = 340 + 10 = 350 \text{ m/s}$$

There is no relative motion between the source and the observer; therefore, the frequency of the sound heard by the observer will be the same.

Therefore,  $f = 400 \text{ Hz}$

Wavelength of the sound heard by the observer = speed of wave/frequency  
 $= 350/400 = 0.875 \text{ m}$

When the air is still, and the observer runs towards the yard at a speed of  $10 \text{ m s}^{-1}$ , then there is a relative motion between the observer and the source with respect to the medium.

The medium is at rest. Therefore,

$$v' = v = 340 \text{ m/s}$$

The change in frequency,  $f' = [(v + v_o)/v] \times f$

$$= [(340 + 10)/340] \times 400 = 411.76 \text{ Hz}$$

$$\text{Wavelength} = 340/411.76 = 0.826 \text{ m}$$

Obviously, the situations in the two cases are entirely different.

**Q22. A travelling harmonic wave on a string is described by  $y(x, t) = 7.5 \sin(0.0050x + 12t + \pi/4)$ .**

**(a) What are the displacement and velocity of oscillation of a point at  $x = 1 \text{ cm}$  and  $t = 1 \text{ s}$ ? Is this velocity equal to the velocity of wave propagation?**

**(b) Locate the points of the string which have the same transverse displacements and velocity as the  $x = 1 \text{ cm}$  point at  $t = 2 \text{ s}$ ,  $5 \text{ s}$  and  $11 \text{ s}$ .**

**Answer:**

(a) The travelling harmonic wave is  $y(x, t) = 7.5 \sin(0.0050x + 12t + \pi/4)$

At  $x = 1 \text{ cm}$  and  $t = 1 \text{ s}$

$$y(1, 1) = 7.5 \sin(0.0050(1) + 12(1) + \pi/4)$$

$$= 7.5 \sin(12.0050 + \pi/4) \text{ --- (1)}$$

$$= 7.5 \sin \theta$$

$$\theta = (12.0050 + \pi/4) \times (180/3.14)$$

$$= 12.0050 + (3.14/4) = 12.79 \times (180/3.14)$$

$$\theta = 733.18^\circ$$

$$\begin{aligned}y(1,1) &= 7.5 \sin (733.18^\circ) \\&= 7.5 \sin (90 \times 8 + 13.18^\circ) \\&= 7.5 \sin (13.18^\circ) \\&= 7.5 \times 0.228 \\&= 1.71\end{aligned}$$

The velocity of oscillation,

At  $x = 1 \text{ cm}$  and  $t = 1 \text{ s}$

$$\begin{aligned}\theta &= (12.005 + \pi/4) \\&= (12.005 + \pi/4) \times 180/\pi \\&= 12.79 \times 180/3.14 \\ \theta &= 12.79 \times 57.32 = 733.18 \\v &= 90 \cos (733.18) \\&= 90 \cos (720 + 13.18) \\&= 90 \cos 13.18 \\&= 90 \times 0.97 \text{ cm/s} \\&= 87.63 \text{ cm/s}\end{aligned}$$

The standard equation is given as

We get

here,  $k = 2\pi/\lambda$

and  $\omega = 2\pi v$

Comparing the given equation with the standard equation,

$$a = 7.5 \text{ cm}$$

$$\omega = 12 \text{ rad/s}$$

$$\Rightarrow 2\pi f = 12 \text{ rad/s}$$

$$\text{Therefore, } f = 12/2\pi = 6/\pi$$

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

$$2\pi/\lambda = 0.0050 \text{ cm}^{-1}$$

$$\Rightarrow \lambda = 2\pi/0.0050 = 400 \pi$$

The velocity of the wave propagation,  $v = f\lambda$

$$= (6/\pi) \times 400 \pi = 2400 \text{ cm/s}$$

Velocity at  $x = 1 \text{ cm}$  and  $t = 1 \text{ s}$  is not equal to the velocity of wave propagation

(b) Propagation constant,  $k = 2\pi/\lambda$

here  $\lambda$  is the wavelength

$$\Rightarrow \lambda = 2\pi/k = (2 \times 3.14)/0.0050$$

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

All the points at a distance  $\pm\lambda, \pm2\lambda, \dots$  from  $x = 1$  cm will have the same transverse displacement and velocity. As  $\lambda = 12.56$  m, the points  $\pm12.56\text{m}, \pm25.12\text{m}, \dots$  and so on for  $x = 1$  cm, will have the same displacement as the  $x = 1$  cm points at  $t = 2\text{s}, 5\text{s}$  and  $11\text{s}$ .

**Q23.** 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, and (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 seconds after every 20 s), is the frequency of the note produced by the whistle equal to  $1/20$  or  $0.05$  Hz?

**Answer:**

(a) The speed of propagation is definite, it is equal to the speed of the sound in air. The wavelength and frequency will not be definite.

(b) The frequency of the note produced by a whistle is not  $1/20 = 0.05$  Hz. However,  $0.05$  Hz is the frequency of repetition of the short pip of the whistle.

**Q24.** One end of a long string of linear mass density  $8.0 \times 10^{-3} \text{ kg m}^{-1}$  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 displacements ( $y = 0$ ) and is moving along the positive  $y$ -direction. The amplitude of the wave is  $5.0$  cm. Write down the transverse displacement  $y$  as a function of  $x$  and  $t$  that describes the wave on the string.

**Answer:**

Linear mass density of the string,  $\mu = 8.0 \times 10^{-3} \text{ kg m}^{-1}$

Frequency of the tuning fork =  $256$  Hz

Mass on the pan =  $90$  kg

Tension on the string,  $T = 90 \times 9.8 = 882$  N

Amplitude,  $A = 0.05$  m

For a transverse wave, the velocity is given by the relation.  
 $= 332 \text{ m/s}$

Angular frequency,  $\omega = 2\pi f$

$= 2 \times 3.14 \times 256 = 1608.5 \text{ rad/sec}$

Wavelength,  $\lambda = v/f = 332/256 = 1.296 \text{ m}$

Propagation constant,  $k = 2\pi/\lambda = (2 \times 3.14)/1.296$



$$= 4.845 \text{ m}^{-1}$$

The general equation of the wave is

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

Substituting all the values, we get

$$y(x,t) = A \sin(1608.5t - 4.845x)$$

x and y are in metres, and t is in seconds.

**Q25.** A SONAR system fixed in a submarine operates at a frequency of 40.0 kHz. An enemy submarine moves towards the SONAR with a speed of 360 km h<sup>-1</sup>. What is the frequency of sound reflected by the submarine? Take the speed of sound in water to be 1450 m s<sup>-1</sup>.

**Answer:**

Frequency of the SONAR system,  $f = 40 \text{ kHz} = 40 \times 10^3 \text{ Hz}$

Speed of sound in water,  $v = 1450 \text{ m/s}$

Speed of the enemy submarine,  $v_0 = 360 \text{ km/h} = 360 \times (5/18) = 100 \text{ m/s}$

The SONAR is at rest, and the enemy submarine moves towards it.

Therefore, the apparent frequency is given by the relation

$$f' = [(v + v_0)/v]f$$

$$= [(1450 + 100)/1450] \times 40 \times 10^3$$

$$= 42.75 \times 10^3$$

This frequency ( $f'$ ) is reflected by the enemy submarine, and it is observed by the SONAR. Therefore,  $v_s = 360 \text{ km/s} = 100 \text{ m/s}$

$$f'' = (v/(v - v_s)) \times f'$$

$$= (1450/(1450 - 100)) \times 42.75 \times 10^3$$

$$= (1450/1350) \times 42.75 \times 10^3$$

$$= 45.91 \times 10^3.$$

**Q26.** 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 the S wave is about 4.0 km s<sup>-1</sup>, and that of the P wave is 8.0 km s<sup>-1</sup>. 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 a straight line, at what distance does the earthquake occur?

**Answer:**

Let the speeds of S and P be  $v_1$  and  $v_2$ , respectively. The time taken by the S and P waves to reach the position of the seismograph is  $t_1$  and  $t_2$ , respectively

$$l = v_1 t_1 = v_2 t_2$$

The speed of S wave,  $v_1 = 4.0 \text{ km s}^{-1}$

The speed of P wave,  $v_2 = 8.0 \text{ km s}^{-1}$

$$4t_1 = 8t_2$$

$$t_1 = 2t_2$$

The first P wave arrives 4 min before the S wave.

$$t_1 - t_2 = 4 \text{ min} = 4 \times 60 \text{ s} = 240 \text{ s}$$

$$2t_2 - t_2 = 240 \text{ s}$$

$$t_2 = 240 \text{ s}$$

$$t_1 = 2t_2 = 2 \times 240 = 480 \text{ s}$$

Therefore, the distance at which the earthquake occurs,  $l = v_1 t_1 = 4 \times 480 = 1920 \text{ km}$ .

**Q27.** 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 the air. What frequency does the bat hear reflected off the wall?

**Answer:**

The sound emission frequency of the bat = 40 kHz

The velocity of the bat,  $v_b = 0.03 v$

Where  $v$  is the velocity of the sound in the air

The apparent frequency of the sound hitting the wall

$$= 40/0.97 \text{ kHz}$$

The frequency gets reflected by the wall and is received by the bat moving towards the wall

$$= (1.03 \times 40 / 0.97) = 42.47 \text{ kHz}.$$

**Q28.** A man standing at a certain distance from an observer blows a horn of frequency 200 Hz in still air. (a) Find the horn's frequency for the observer when the man (i) runs towards him at 20 m/s (ii) runs away from him at 20 m/s.

(b) Find the speed of sound in both cases.

[Speed of sound in still air is 340 m/s]

**Answer:**

Given,

Frequency of the horn,  $v_H = 200 \text{ Hz}$

Velocity of the man,  $v_T = 20 \text{ m/s}$

Velocity of sound,  $v = 340 \text{ m/s}$

(a) We know,

(i) The apparent frequency of the horn as the man approaches the observer

is:

$$v' = v_H [ v / (v - v_T) ] = 200 [ 340 / (340 - 20) ] = 212.5 \text{ Hz.}$$

(ii) The apparent frequency of the horn as the man runs away from the observer is:

$$v'' = v_H [ v / (v + v_T) ] = 200 [ 340 / (340 + 20) ] = 188.88 \text{ Hz.}$$

(b) The speed of sound is 340 m/s in both cases. The apparent change in frequency is a result of the relative motions of the observer and the source.

**Q29. A truck parked outside a petrol pump blows a horn of frequency 200 Hz in still air. The wind then starts blowing towards the petrol pump at 20 m/s. Calculate the wavelength, speed, and frequency of the horn's sound for a man standing at the petrol pump. Is this situation completely identical to a situation when the observer moves towards the truck at 20 m/s and the air is still?**

**Answer:**

For the standing observer:

Frequency,  $v_H = 200 \text{ Hz}$

Velocity of sound,  $v = 340 \text{ m/s}$

Speed of the wind,  $v_W = 20 \text{ m/s}$

The observer will hear the horn at 200 Hz itself because there is no relative motion between the observer and the truck.

Given that the wind blows in the observer's direction at 20 m/s.

Effective velocity of the sound,  $v_E = 340 + 20 = 360 \text{ m/s}$

The wavelength ( $\lambda$ ) of the sound :

$$\lambda = v_E / v_H = 360 / 200$$

$$\lambda = 1.8 \text{ m}$$

For the observer running towards the train:

Speed of the observer,  $v_o = 20 \text{ m/s}$

We know,

The apparent frequency of the sound as the observers move towards the truck is:

$$v' = v_H [ (v + v_o) / v ] = 200 [ (20 + 340) / 340 ] = 211.764 \text{ Hz}$$

As the air is still, the effective velocity of sound is still 340 m/s.

As the truck is stationary, the wavelength remains 1.8 m.

Thus, the two cases are not completely identical.

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