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Unit VI : WAVES and SOUND

CHAPTERS

OSCILLATIONS

WAVES

SOUND

STATIONARY WAVES

ACOUSTICS OF BUILDINGS

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SYNOPSIS

- Restoring force on the particle: $F = -k\,y$

  k – force constant.

- Displacement of the particle executing SHM

  $$y = A \sin\omega t$$

- Velocity: $v = A\,\omega \cos\omega t = \omega.\sqrt{A^2 - y^2}$

- Velocity amplitude or maximum velocity:

  $$v_{max} = A\,\omega$$

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- Particle acceleration: $a = -A\omega^2 \sin\omega t = -\omega^2 y$
- Maximum acceleration: $a_{max} = A\,\omega^2$
- The velocity is

  zero at extreme positions and

  maximum at mean position.
- The acceleration SHM is

  zero at mean position and

  maximum at extreme positions.

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Energy of the particle executing SHM

- Kinetic energy: $K = \frac{1}{2} m\omega^2 (A^2 - y^2)$
- Potential energy: $U = \frac{1}{2} m\omega^2 y^2$
- Total energy: $E = K + U = \frac{1}{2} m\omega^2 A^2$
- Total energy is constant.

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- Time period of oscillation of a loaded spring:

$$T = 2\pi\sqrt{\frac{m}{k}}$$

m – mass attached and k – spring constant.

- Time period of oscillation of a simple pendulum:

$$T = 2\pi\sqrt{\frac{L}{g}}$$: L – length of the pendulum

g – acceleration due to gravity

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WAVES

- Phase difference = $\frac{2\pi}{\lambda}$ (path difference)
- Wave velocity: $v = \frac{\lambda}{T} = f\lambda = \frac{\omega}{k}$
- $k = \frac{2\pi}{\lambda}$ is called as propagation constant.
- Unit of k is rad/m
- When a wave travels from one medium to another its <u>frequency remains same</u> but velocity and wavelength change.

Different forms of progressive wave equn.:

- $y = A\sin\omega\left(t - \frac{x}{v}\right) = A\sin(\omega t - kx)$

  Using $\omega = \frac{2\pi}{T}$, $k = \frac{2\pi}{\lambda}$ and $v = \frac{\omega}{k}$

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

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

Newton's formula:

- Velocity of longitudinal waves $v = \sqrt{\frac{E}{\rho}}$

For solids E = Y, For fluids E = B,

For gas B= P, Hence $v = \sqrt{\frac{P}{\rho}}$

Newton–Laplace formula: $B = \gamma P$

- Velocity of sound in a gas: $v = \sqrt{\frac{\gamma P}{\rho}} = \sqrt{\frac{\gamma RT}{M}}$

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- Effect of temperature on velocity of sound: $v \propto \sqrt{T}$

$$\Rightarrow \quad \frac{v_2}{v_1} = \sqrt{\frac{T_2}{T_1}} = \sqrt{\frac{t_2+273}{t_1+273}}$$

T_1 and T_2 are in K, t_1 and t_2 are in °C

- Velocity of sound at t °C is

$$v_t \approx v_o + 0.61\, t$$

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- Among the gases velocity of sound is highest in hydrogen.
- Sound travels faster in moist air than in dry air, i.e., $v_m > v_d$
- There is no effect of frequency on the speed of sound.
- Velocity of sound in different media:

  $v_{solid} > v_{liquid} > v_{gas}$

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- Intensity of a mechanical wave is $I = 2\pi^2 f^2 A^2 \rho v$
- Intensity level of sound: $I_L = \log\left[\frac{I}{I_o}\right]$ in bel (B)
- $I_o = 10^{-12}\ Wm^{-2}$
- Intensity level: $I_L = 10 \log\left(\frac{I}{I_o}\right)$ in deci bel (dB)
- Frequency range of audible sound: 20Hz to 20kHz.
- Audible range of intensity: $10^{-12}\ Wm^{-2}$ to $1\ Wm^{-2}$
- Audible range of intensity level:

  $0 < I_L < 120\text{dB}$ or $0 < I_L < 12$ bel at 1000 Hz

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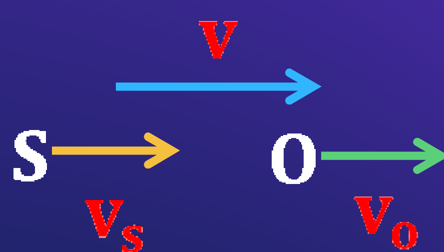
BEATS:

- Beat frequency: $f_B = f_1 \sim f_2$
- Beat period: $T_B = 1/f_B$

DOPPLER EFFECT:

- When the Source moving towards an observer and observer moving away from the source



Apparent frequency: $f' = f\left(\frac{v-v_O}{v-v_S}\right)$

- Doppler effect is <u>asymmetric in sound</u> and <u>symmetric in light</u>.

STATIONARY WAVES

- If $y_1 = A \sin(\omega t - kx)$ and $y_2 = A \sin(\omega t + kx)$ then $y = y_1 + y_2 = (2A \cos kx) \sin\omega t = R \sin\omega t$
- Distance between any two consecutive nodes or two antinodes is $\lambda/2$.
- Distance between a node and neighboring antinode is $\lambda/4$.
- Velocity of transverse wave along the stretched string: $v = \sqrt{\frac{T}{m}}$ T is tension and $m = \frac{\text{mass}}{\text{length}}$

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- Fundamental frequency of stretched string

$$f_1 = \frac{1}{2L}\sqrt{\frac{T}{m}}$$

- ✓ $f_1 : f_2 : f_3 :$ ….. = 1: 2: 3 : ……
- For closed pipe: Fundamental frequency: $f_1 = \frac{v}{4\,L}$
- ✓ $f_1 : f_2 : f_3 :$ ….. = 1: 3: 5 : ……
- For open pipe: Fundamental frequency: $f_1 = \frac{v}{2\,L}$
- ✓ $f_1 : f_2 : f_3 :$ ….. = 1: 2: 3 : ……

f_2 & f_3 are the frequencies of first & second overtones.

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- End correction: $e = 0.3d$,

  d is diameter of pipe.

- For a closed pipe:

  Fundamental frequency: $f_1 = \frac{v}{4\,(L+e)}$

- For an open pipe:

  Fundamental frequency: $f_1 = \frac{v}{2\,(L+2e)}$

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ACOUSTICS OF BUILDINGS:

- Sabine's formula for reverberation time:

$$t = \frac{0.165\ V}{\sum aS}$$

V is volume of hall and

$$\sum a\,S = a_1S_1 + a_2S_2 + \ldots\ldots\ldots$$

- Optimum reverberation time:

  For speech 0.5 s to 1s and for music 1s to 2s.

- Absorption coefficient of open window is equal to one.

1. In simple harmonic motion, the particle is

1) always accelerated

2) always retarted

3) alternatively accelerated and retarded

4) neither accelerated nor retarded.

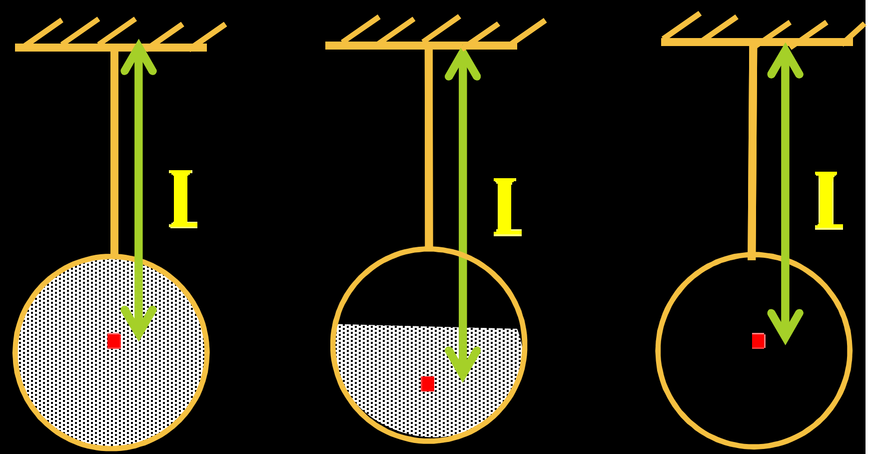
2. A hollow ball is filled with water and then used as a bob of the simple pendulum. If the water drains out of a small hole at the bottom, then the time period

1) decreases
2) increases
3) remains same
4) first increases, then decreases and ultimately acquires the initial value.

Answer:

$$T = 2\pi\sqrt{\frac{L}{g}}$$

$$\Rightarrow T \propto \sqrt{L}$$



L increases and then decreases to initial value.

Answer: (4)

The time period first increases, then decreases and ultimately acquires the initial value.

KEA

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3. **A particle executing SHM has potential energy (PE), kinetic energy (KE) and total energy (TE) are measured as a function of displacement 'x'.**

Which of the following statements is TRUE?

1) PE is maximum when x = 0

2) KE is maximum when x = 0

3) TE is maximum when x = 0

4) KE is maximum when x is maximum.

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4. Two simple harmonic waves are represented by $y_1 = 5\sin\left(2\pi t + \frac{\pi}{4}\right)$ and $y_2 = 5\left(\sin 2\pi t + \sqrt{3}\cos 2\pi t\right)$. The ratio of their amplitudes is

1) 1:1
2) 2:1
3) 3:1
4) 1:2

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Solution:

$$y_1 = 5\sin\left(2\pi t + \frac{\pi}{4}\right)$$

$$y_2 = 5(\sin 2\pi t + \sqrt{3}\cos 2\pi t)$$

$$= 5\times 2\left(\frac{1}{2}\sin 2\pi t + \frac{\sqrt{3}}{2}\cos 2\pi t\right)$$

$$= 10\sin\left(2\pi t + \frac{\pi}{3}\right)$$

Required ratio: $\frac{A_1}{A_2} = \frac{5}{10} = \frac{1}{2}$

Answer: (4)

5. Both light and sound waves

1) Travel in vacuum

2) Can be polarized

3) Carry energy and momentum

4) Are electromagnetic in nature.

6. Maximum particle velocity in a wave motion is half the wave velocity. The amplitude of the wave is equal to

1) $\frac{\lambda}{2\pi}$ 2) λ

3) $\frac{\lambda}{4\pi}$ 4) $\frac{2\lambda}{\pi}$

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Solution:

$$\text{Max. particle velocity} = \frac{\text{Wave velocity}}{2}$$

$$\text{i.e.,} \qquad A\,\omega = \frac{\omega/k}{2}$$

$$\Rightarrow \quad A = \frac{1}{2k} = \frac{1}{2}\,\frac{\lambda}{2\pi} = \frac{\lambda}{4\pi}$$

Answer: (3)

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7. The equation of a simple harmonic wave is given by $y = 6 \sin \pi(2t - 0.1x)$, where x and y are in mm and t in seconds. The phase difference between two particles 2mm apart at any instant is

1) 18^{o} 2) 36^{o}

3) 54^{o} 4) 72^{o}

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Solution:

$$y = 6 \sin \pi(2t - 0.1x)$$

$$= 6 \sin (2\pi t - 0.1\pi x)$$

Comparing with $y = A \sin (\omega t - kx)$

$$k = 0.1\pi = \frac{2\pi}{\lambda}$$

Phase difference = $\frac{2\pi}{\lambda}$ (path difference)

$$\phi = (0.1\pi)(2) = 0.2 \times 180^\circ = 36^\circ$$

Answer: (2)

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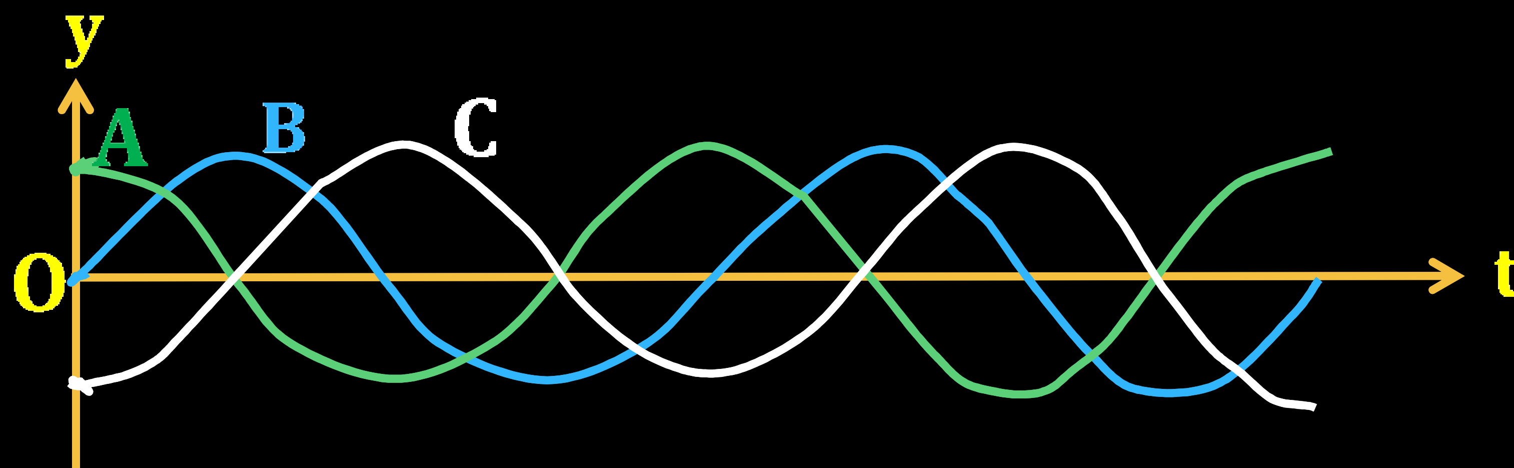
8. Three progressive waves A, B and C are shown in the diagram. With respect to the wave B, the wave C



1) Lags behind in phase by π/2 and A leads by π/2.
2) Leads in phase by π and A lags behind π.
3) Leads in phase by π/2 and A lags behind by π/2.
4) Lags behind in phase by π and A leads by π.

9. Two sound waves represented by

$y_1 = 0.2 \sin(218\pi t - kx)$ and

$y_2 = 0.2 \sin(210\pi t - kx)$ superpose.

The time interval between two consecutive maxima is

1) 0.125 s
2) 1/3 s
3) 0.25 s
4) 0.2 s

Solution:

$y_1 = 0.2\sin(218\pi t - kx)$

$y_2 = 0.2\sin(210\pi t - kx)$

$\omega_1 = 218\pi = 2\pi f_1 \Rightarrow f_1 = 109$ Hz

And $f_2 = 105$ Hz

Beat frequency: $f_B = f_1 \sim f_2 = 4$ Hz

Beat period: $T_B = 1/f_B = 1/4$ s $= 0.25$ s

Answer: (3)

10. A particle executing a simple harmonic motion has a period of T second. The time taken by the particle to move from the mean position to half the amplitude, starting from the mean position is

1) T/2 s 2) T/3 s 3) T/4 s 4) T/12 s

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Solution:

$$y = A\sin\omega t = A\sin\left(\frac{2\pi}{T}\right)t$$

$$\frac{A}{2} = A\sin\left(\frac{2\pi}{T}\right)t$$

$$\frac{1}{2} = \sin\left(\frac{2\pi}{T}\right)t$$

$$\Rightarrow \quad \left(\frac{2\pi}{T}\right)t = \frac{\pi}{6} \Rightarrow t = \frac{T}{12}$$

Answer: (4)

11. Two trains, one leaving and the other approaching a station with equal speeds of 36kmph, sound their whistles each of natural frequency 100 Hz.

The number of beats per second as heard by the person standing on the platform is (velocity of sound = 330 ms^{-1})

1) 0 2) 3 3) 6 4) 9

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Solution:

f =100 Hz and $v_o = 0$

For the train approaching, apparent frequency

$$f_1 = f\left(\frac{v}{v-v_S}\right) = 100\left(\frac{330}{330-10}\right) = 100\left(\frac{33}{32}\right)$$

For the train receding, apparent frequency

$$f_2 = f\left(\frac{v}{v+v_S}\right) = 100\left(\frac{330}{330+10}\right) = 100\left(\frac{33}{34}\right)$$

Beat frequency: $f_1 - f_2 = 100\left(\frac{33}{32} - \frac{33}{34}\right)$

$$= 100 \times 33\left(\frac{2}{32 \times 34}\right) \approx 6$$

Answer: (3)

12. An empty vessel is partially filled with water. The frequency of the air column in the vessel

1) Decreases
2) Increases
3) Remains the same
4) Depends on purity of water.

13. Reverberation time cannot be altered by

1) The size of the window

2) The volume of the hall

3) changing carpet

4) temperature of the hall.

Answer:

$$t = \frac{0.165\ V}{\sum aS}$$

$\Rightarrow$ Reverberation time is independent of temperature.

Answer: (4)

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14. A wire under certain condition vibrates with a frequency of 250 Hz.
What is the fundamental frequency if the wire is taken half long, twice as thick and under one-fourth tension of the initial?

1) 250 Hz
2) 125 Hz
3) 100 Hz
4) 50 Hz

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Solution:

$$f = \frac{1}{2L}\sqrt{\frac{T}{m}} \qquad m = \frac{\text{mass}}{\text{length}} = \frac{\rho\, V}{\text{length}} = \frac{\rho\, l\, A}{l} = A\,\rho$$

$$= \frac{1}{2L}\sqrt{\frac{T}{A\,\rho}} = \frac{1}{2\,L\,r}\sqrt{\frac{T}{\pi\,\rho}} = 250\text{ Hz (given)}$$

$$f' = \frac{1}{2\left(\frac{L}{2}\right)(2r)}\sqrt{\frac{\left(\frac{T}{4}\right)}{\pi\,\rho}} = \left(\frac{1}{2}\right)\left(\frac{1}{2\,L\,r}\sqrt{\frac{T}{\pi\,\rho}}\right)$$

$$= \left(\frac{1}{2}\right)(250) = 125\text{ Hz}$$

Answer: (2)

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Solution:

$$f \propto \frac{\sqrt{T}}{L\,r} = 250\ \text{Hz (given)}$$

$$f' \propto \frac{\sqrt{\frac{T}{4}}}{\left(\frac{L}{2}\right)(2r)}$$

$$= \left(\frac{1}{2}\right)\left(\frac{\sqrt{T}}{L\,r}\right) = \left(\frac{1}{2}\right)(250) = 125\ \text{Hz}$$

Answer: (2)

15. The fundamental frequency of an open organ pipe is 300 Hz. The frequency of its first overtone is equal to the frequency of the first overtone of an organ pipe closed at one end. The length of the closed organ pipe is (velocity of sound in air = 332 ms^{-1})

1) 20 cm
2) 41.5 cm
3) 83 cm
4) 166 cm

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Answer:

For open pipe: f_1= 300 Hz and

frequency of first overtone f_2= 600 Hz

For closed pipe,

Frequency of first overtone= $3\left(\frac{v}{4\,L_c}\right)$ = 600 Hz

$$\Rightarrow \quad L_C = \frac{332}{4\,(200)} = 0.415 \text{ m} = 41.5\text{cm}$$

Answer: (2)

16. A source producing a sound of some frequency is moving along a circle, then

1) person standing inside the circle hears same frequency.
2) person standing outside the circle hears same frequency.
3) person standing at the centre of the circle hears same frequency.
4) Both 1) and 2)

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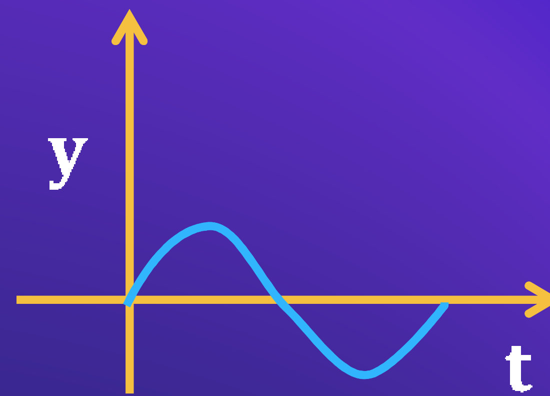
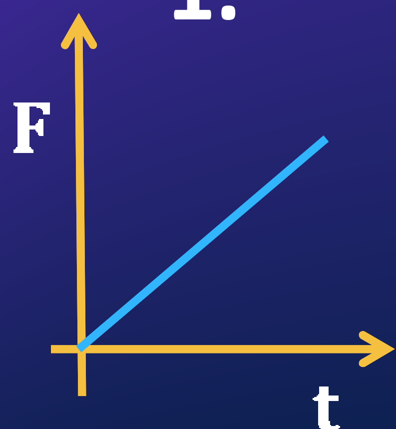
17. The displacement time graph of a particle executing S.H.M. is as shown in the figure.



The corresponding force-time graph of the particle is

1.



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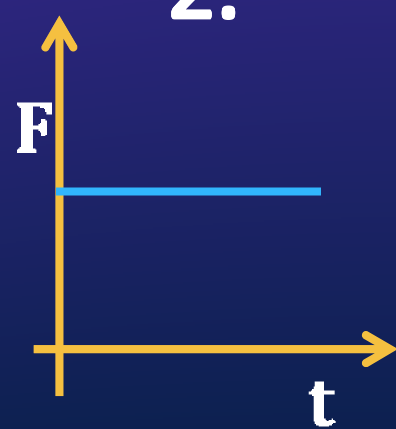

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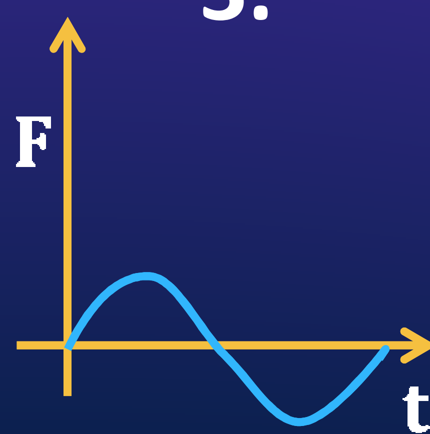

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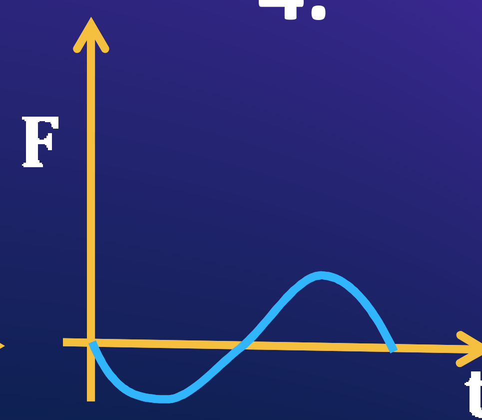

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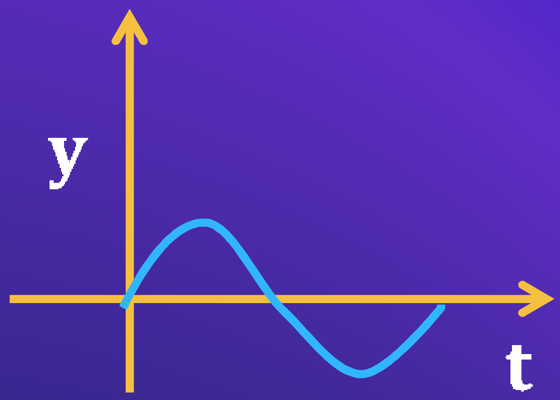
Answer:

$F = -k\,y$

$\Rightarrow F \propto -y$



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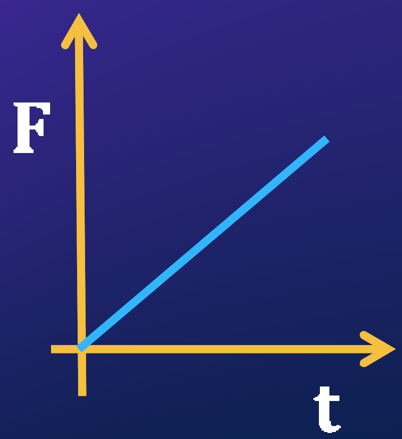

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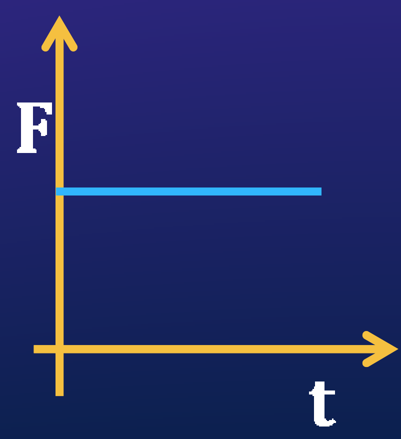

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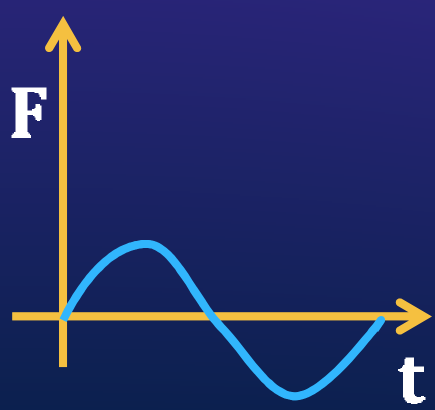

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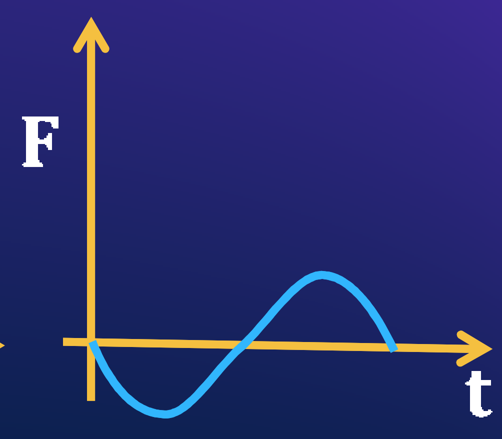

18. For a stationary wave

$$y = 4\cos\left[\frac{\pi x}{15}\right]\sin 100\pi t,$$

where x and y are in cm and t is in seconds. The distance between the node and the next antinode is

1) 7.5cm 2) 15cm 3) 30cm 4) 50cm

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Answer:

$$y = 4\cos\left[\frac{\pi x}{15}\right]\sin 100\pi t$$

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

$$\Rightarrow k = \frac{\pi}{15} = \frac{2\pi}{\lambda} \Rightarrow \lambda = 30\text{cm}$$

The distance between the node and the next antinode is $= \lambda/4 = 7.5\text{cm}$

Answer: (1)

19. A tuning fork A when sounded with another tuning fork B of frequency 256 Hz produces 4 beats per second. When A is filed, 4 per second are heard again when sounded with the same fork B. The frequency of fork A before filing is

1) 252 Hz
2) 260 Hz
3) 256 Hz
4) 264 Hz

Solution:

f_B = 256Hz, beat frequency = 4Hz

$\therefore$ Before filing, frequency of A can be either 260Hz or 252Hz

On filing frequency of A increases.

Number of beats heard = 4.

$\therefore$ Frequency of A before filing must be 252Hz and after filing 260Hz.

Answer: (1) 252 Hz

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20. Velocity of sound in air at NTP is $350 ms^{-1}$. If the pressure is increased four times and temperature is tripled, the velocity of sound will be nearly

1) $1050\ ms^{-1}$
2) $605\ ms^{-1}$
3) $4200\ ms^{-1}$
4) $525\ ms^{-1}$

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Solution:

$$v \propto \sqrt{T} \quad \text{and} \quad v' \propto \sqrt{3T}$$

$$v' = \sqrt{3}\, v$$

$$= 1.73 \times 350$$

$$\approx 605\ ms^{-1}$$

Answer: (2)

21. If 80dB sound is 'x' times more intense than 50dB sound, then x =

1) 3
2) 30
3) 300
4) 1000

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Solution:

$$I_L = \log_{10}\left(\frac{I}{I_o}\right) \Rightarrow \frac{I}{I_o} = 10^{I_L}, \quad I_L \text{ in bel}$$

$$\Rightarrow \quad I = I_o\, 10^{I_L}$$

$$\therefore x = \frac{I_2}{I_1} = 10^{I_{L2} - I_{L1}}$$

$$= 10^{8-5} = 10^3 = 1000$$

Answer: (3)

22. Waves produced in an organ pipe are

1) Longitudinal stationary polarized

2) Transverse stationary polarized

3) Longitudinal stationary unpolarised

4) Transverse stationary unpolarised.

23. When the length of a vibrating segment of a sonometer is increased by 2%, the percentage change in its frequency is

1) 2% decrease

2) 2% increase

3) 4% increase

4) 6% increase.

Solution:

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

$$\Rightarrow f \propto \frac{1}{L}$$

$$f' \propto \frac{1}{1.02\,L} \qquad \frac{1}{1.02} \approx 0.98$$

$$= 0.98\,f = 98\%\,f$$

Percentage change is 2% decrease.

24. The ratio of velocity of sound in hydrogen ($\gamma = \frac{7}{5}$) to that in helium ($\gamma = \frac{5}{3}$) at the same temperature is

1) $\sqrt{\frac{5}{21}}$ 2) $\sqrt{\frac{5}{42}}$

3) $\frac{\sqrt{42}}{5}$ 4) $\frac{\sqrt{21}}{5}$

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Solution:

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

$$\frac{v_H}{v_{He}} = \sqrt{\frac{\gamma_H}{\gamma_{He}} \frac{M_{He}}{M_H}}$$

$$= \sqrt{\left(\frac{7/5}{5/3}\right) \frac{4}{2}} = \frac{\sqrt{42}}{5}$$

Answer: (3)

25. A particle on the crest of a wave at any instant will come to mean position after a time

1) T/4 s
2) T/2 s
3) T s
4) 2T s

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Answer:

Answer: 1) T/4 s

26. A person standing between two cliffs produces a sound. Two echoes are heard after 2s and 3s respectively.

If the velocity of sound is 350m/s, then the separation between the cliffs is

1) 1750 m   2) 175m

3) 875 m   4) 3500 m

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Solution:

Distance travelled by the sound when it reflects from the first cliff is $2s_1 = vt_1$

Distance travelled by the sound when it reflects from the second cliff is $2s_2 = vt_2$

Distance between the cliffs

$$= s_1 + s_2 = \frac{1}{2}(vt_1 + vt_2)$$

$$= \frac{1}{2}(350)(2+3) = 175 \times 5 = 875\text{m.}$$

Answer: 3)

27. The disk of siren has n holes and frequency of its rotation is 300 rpm. It produces a note of wavelength 2.4m, when the velocity of sound in air is 360 ms^{-1}. The value of n is

1) 5 2) 24 3) 30 4) 36

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Solution:

Frequency of rotation f = 300rpm

$$= \frac{300}{60} = 5\text{ Hz}$$

Frequency of sound produced

$$f' = nf = 5n$$

$$\Rightarrow \frac{v}{\lambda} = \frac{360}{2.4} = 5n$$

$$\Rightarrow n = \frac{150}{5} = 30$$

Answer: 3)

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