

CLASS 11 PHYSICS • CHAPTER 14

Standing Waves And Normal Modes

Mastering superposition, wave equations,
and harmonics for NEET & JEE.

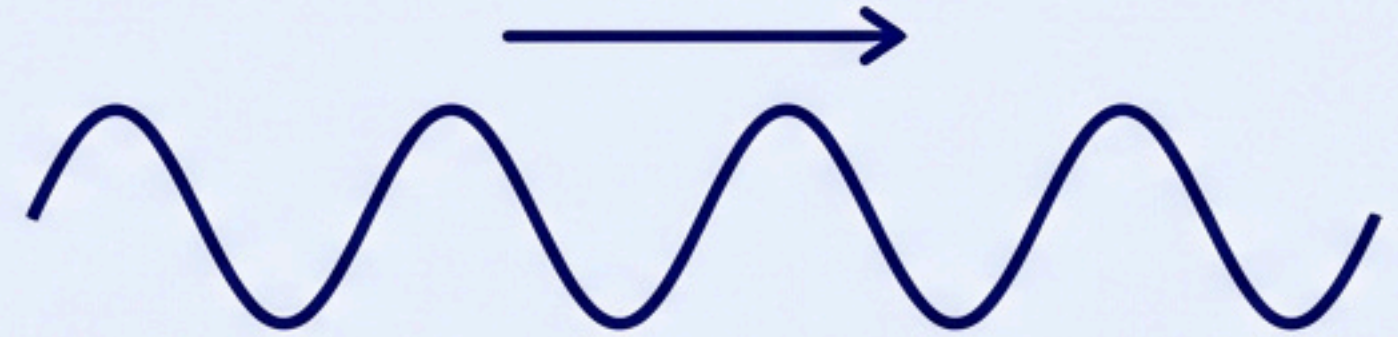
Visual Study Deck

How Standing Waves Form

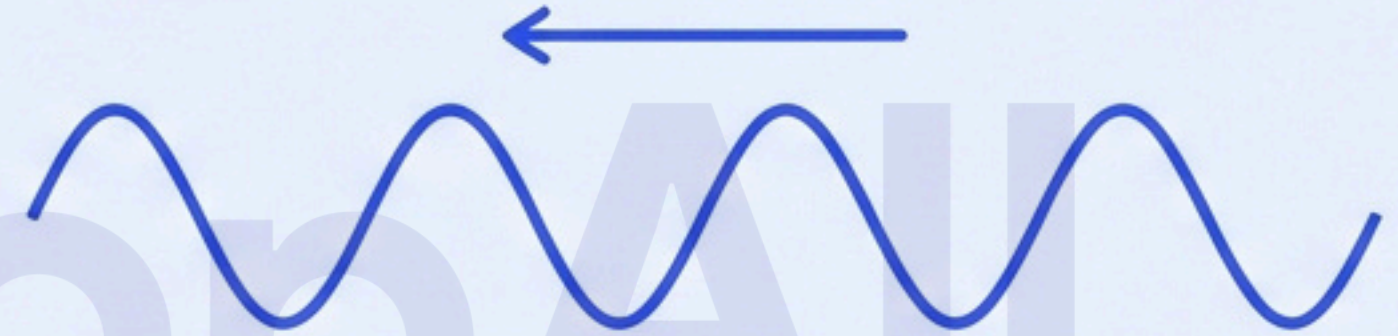
When two identical travelling waves move in opposite directions, they interfere to create a steady wave pattern.

CONCEPT FOCUS

- **Same amplitude & wavelength:** The constituent waves must be identical.
- **Opposite directions:** One travels $+x$, the other $-x$.
- **No energy transfer:** The resulting wave pattern does not move to the right or left.



Wave 1 ($+x$ direction)



Wave 2 ($-x$ direction)



Standing Wave

The Mathematical Model

FORMULA

By adding $y_1 = a \sin(kx - \omega t)$ and $y_2 = a \sin(kx + \omega t)$, we get a wave where spatial amplitude and time are separated.

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

Amplitude: Fixed at any given location x .

Time Oscillation: Every element oscillates with the same angular frequency.



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$$E=mc^2$$



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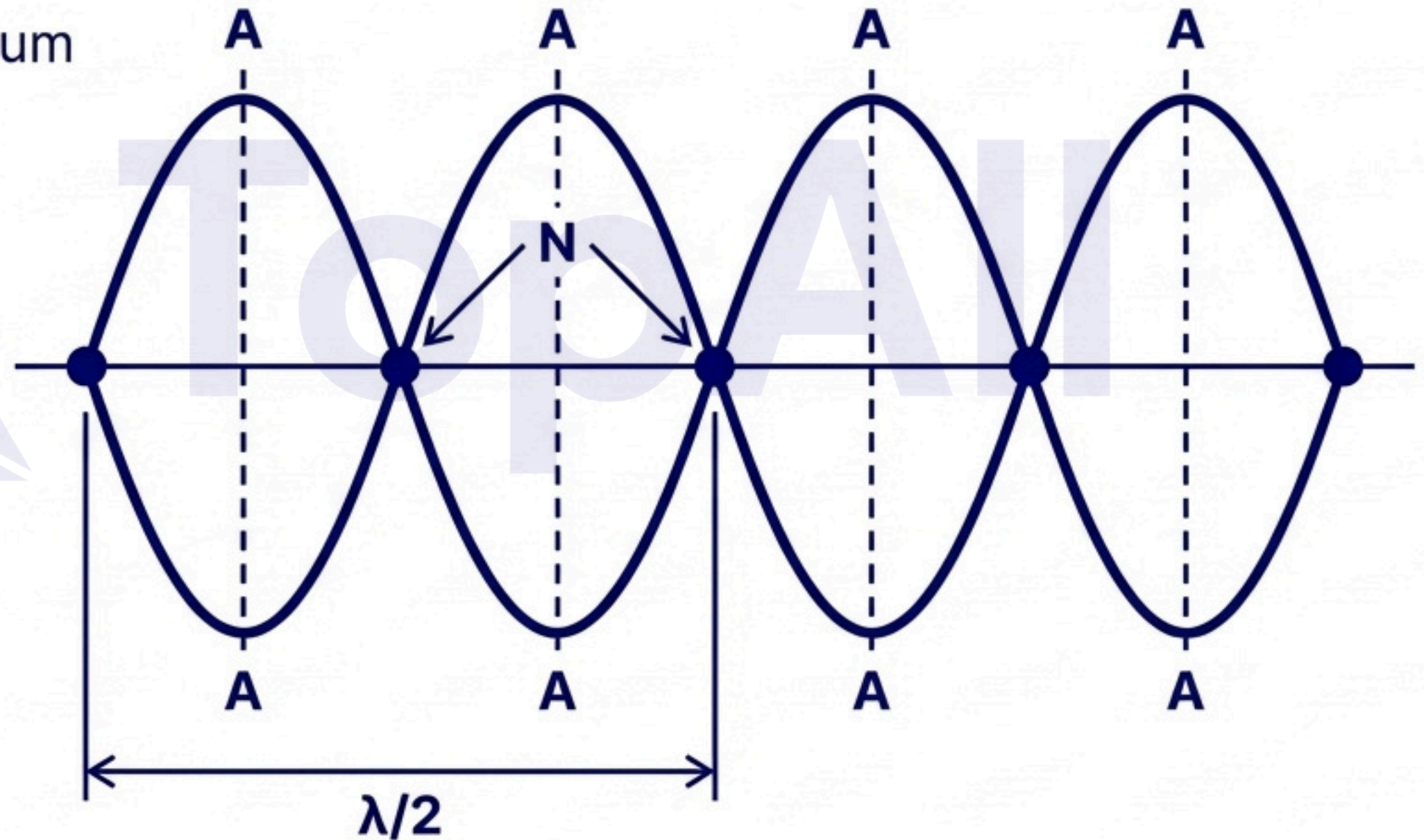


H2: The Anatomy of a Stationary Wave

- **Nodes (N):** Points of zero amplitude / zero displacement ($\sin kx = 0$).
- **Antinodes (A):** Points of maximum amplitude ($\sin kx = \pm 1$).

Exam Tip

- Separation between consecutive nodes = $\lambda/2$
- Separation between consecutive antinodes = $\lambda/2$



H2: The Rules of a Fixed String

A system cannot oscillate with just any arbitrary frequency. The physical boundaries constrain the possible waves.

- Strings fixed at both ends must have Nodes at $x=0$ and $x=L$.
- This means the length L must be an integer multiple of $\lambda/2$.

$$L = n(\lambda/2) \quad (n = 1, 2, 3...)$$

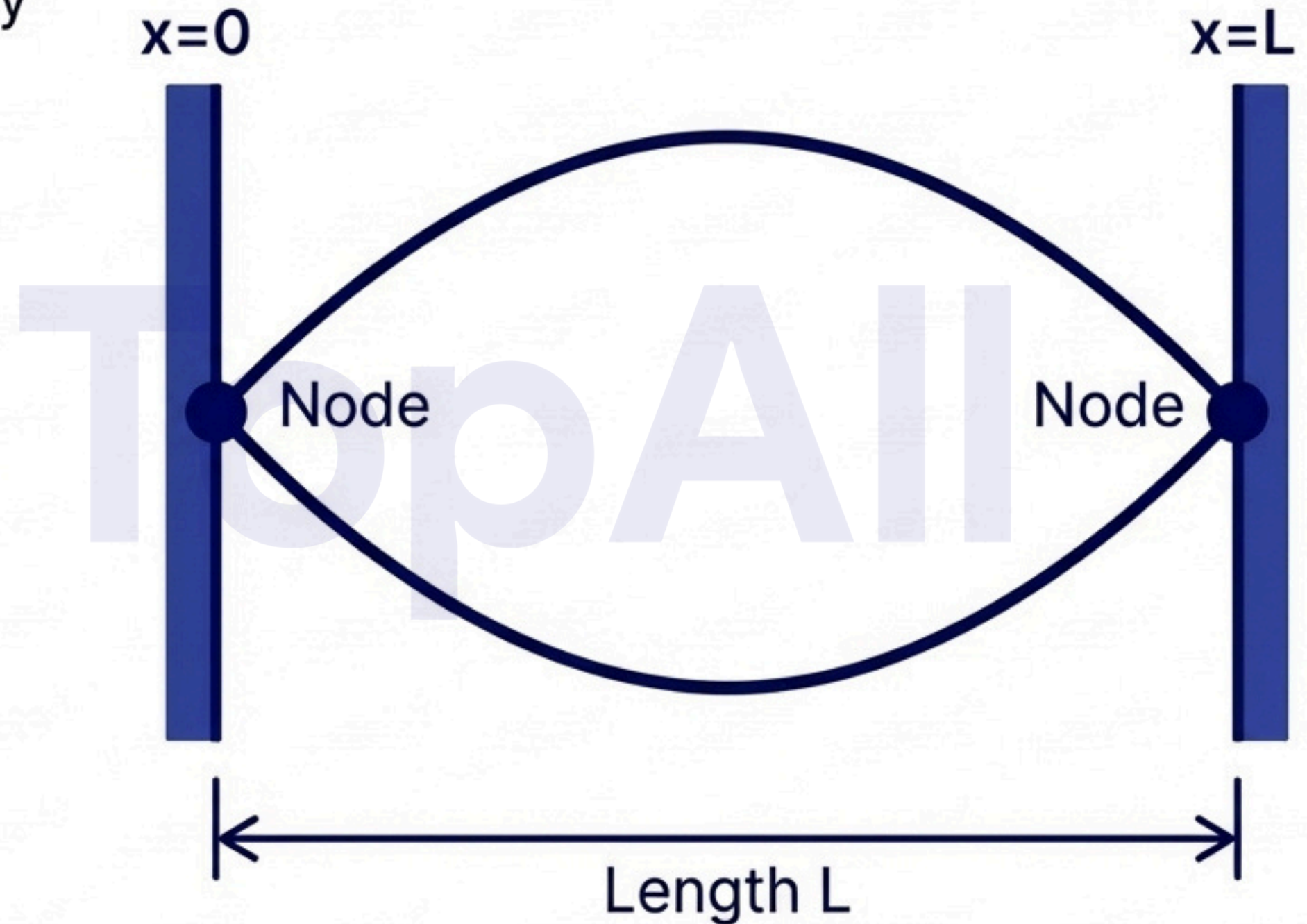


Fig 14.13: The First Three Harmonics

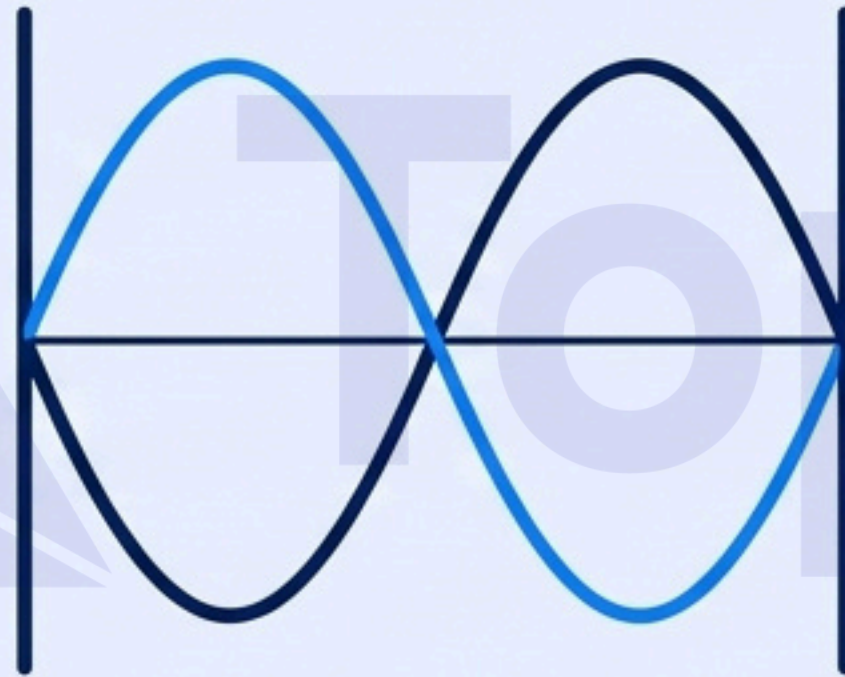
Fundamental (1st Harmonic)



$$L = \lambda_1/2$$

$$v_1 = v/(2L)$$

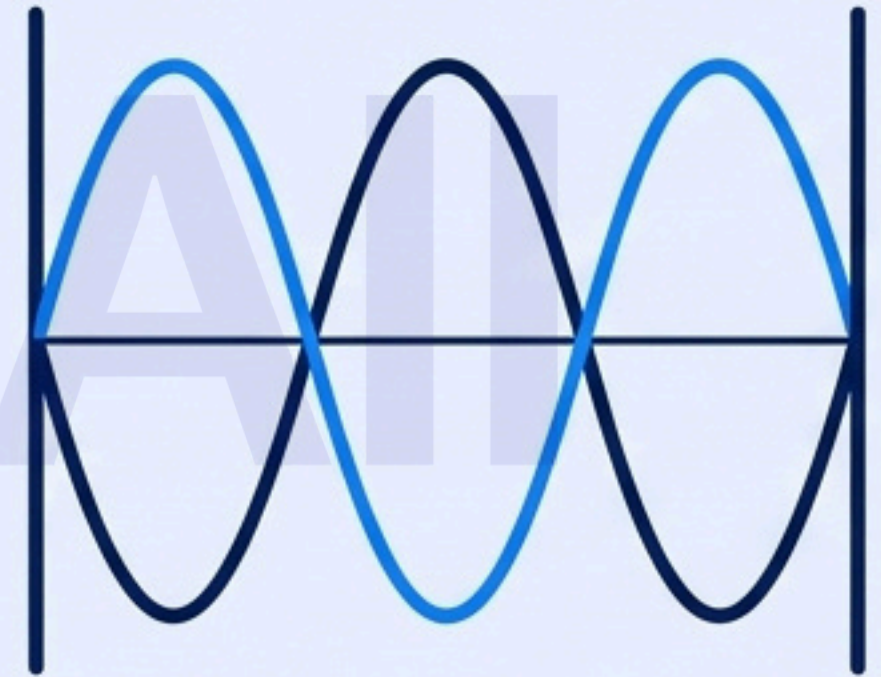
Second Harmonic



$$L = \lambda_2$$

$$v_2 = 2v_1$$

Third Harmonic



$$L = 3\lambda_3/2$$

$$v_3 = 3v_1$$

Summary & Next Steps

- **Superposition:** Standing waves form from two identical, opposite-traveling waves.
- **Equation:** $y(x,t) = [2a \sin kx] \cos \omega t$ isolates amplitude from time.
- **Geometry:** Nodes ($\lambda/2$ apart) never move; Antinodes oscillate at max amplitude.
- **Harmonics:** Fixed strings vibrate only at natural frequencies: $v_n = n(\frac{v}{2L})$.

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