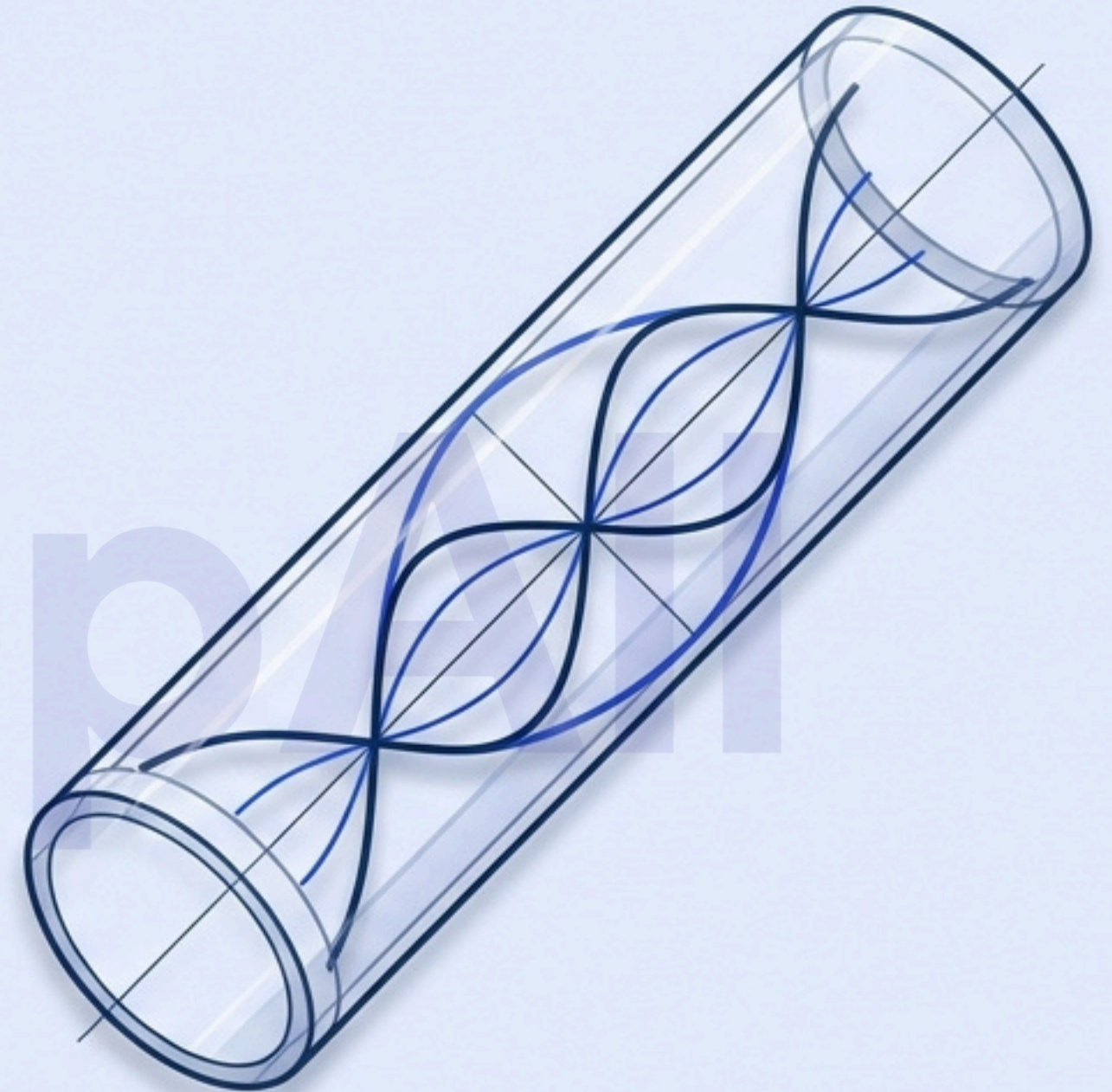


Air Columns And Resonance

Standing Waves, Normal
Modes, and Harmonics

A visual guide for competitive exam prep
(NEET/JEE)



The Physics Of The Pipe

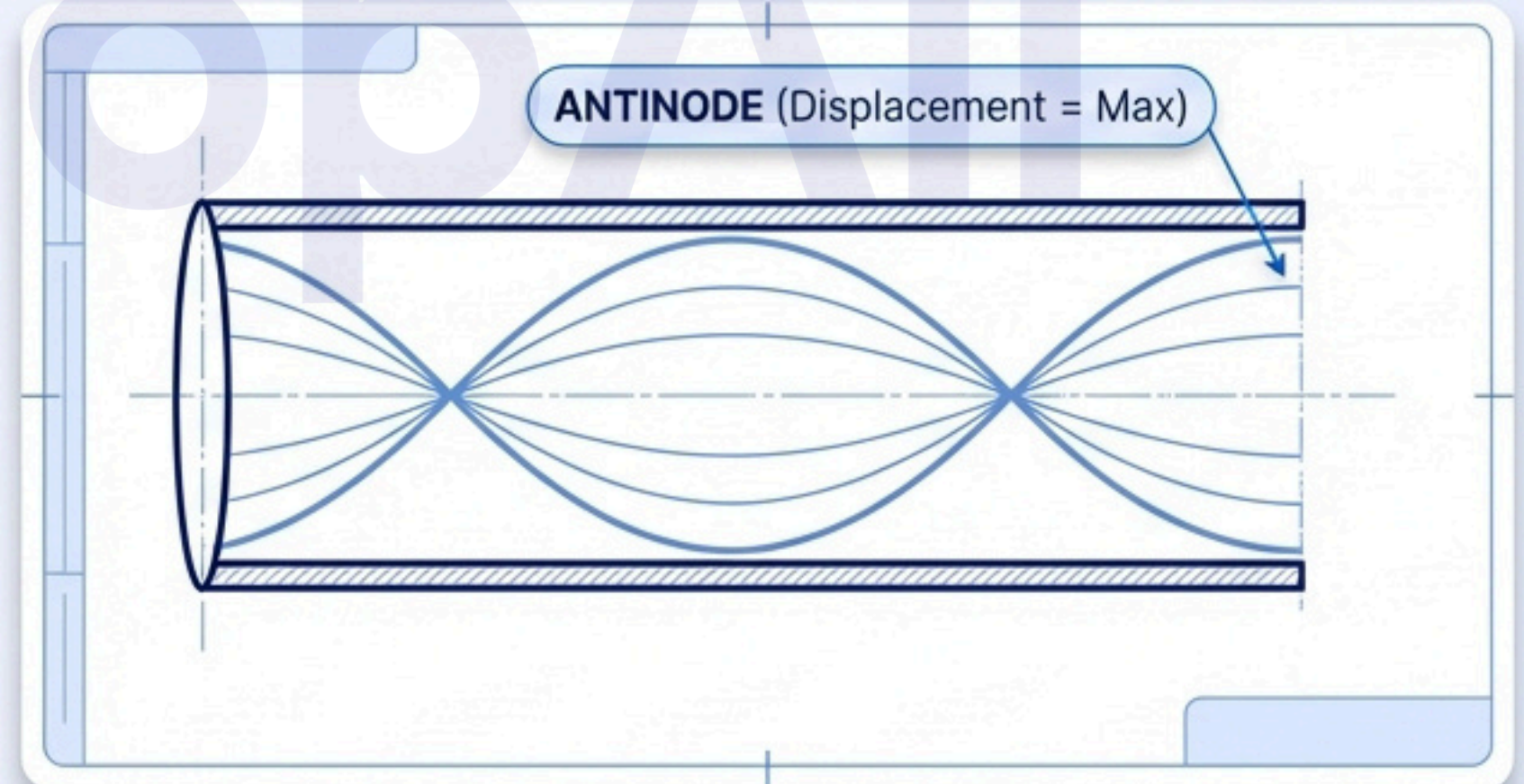
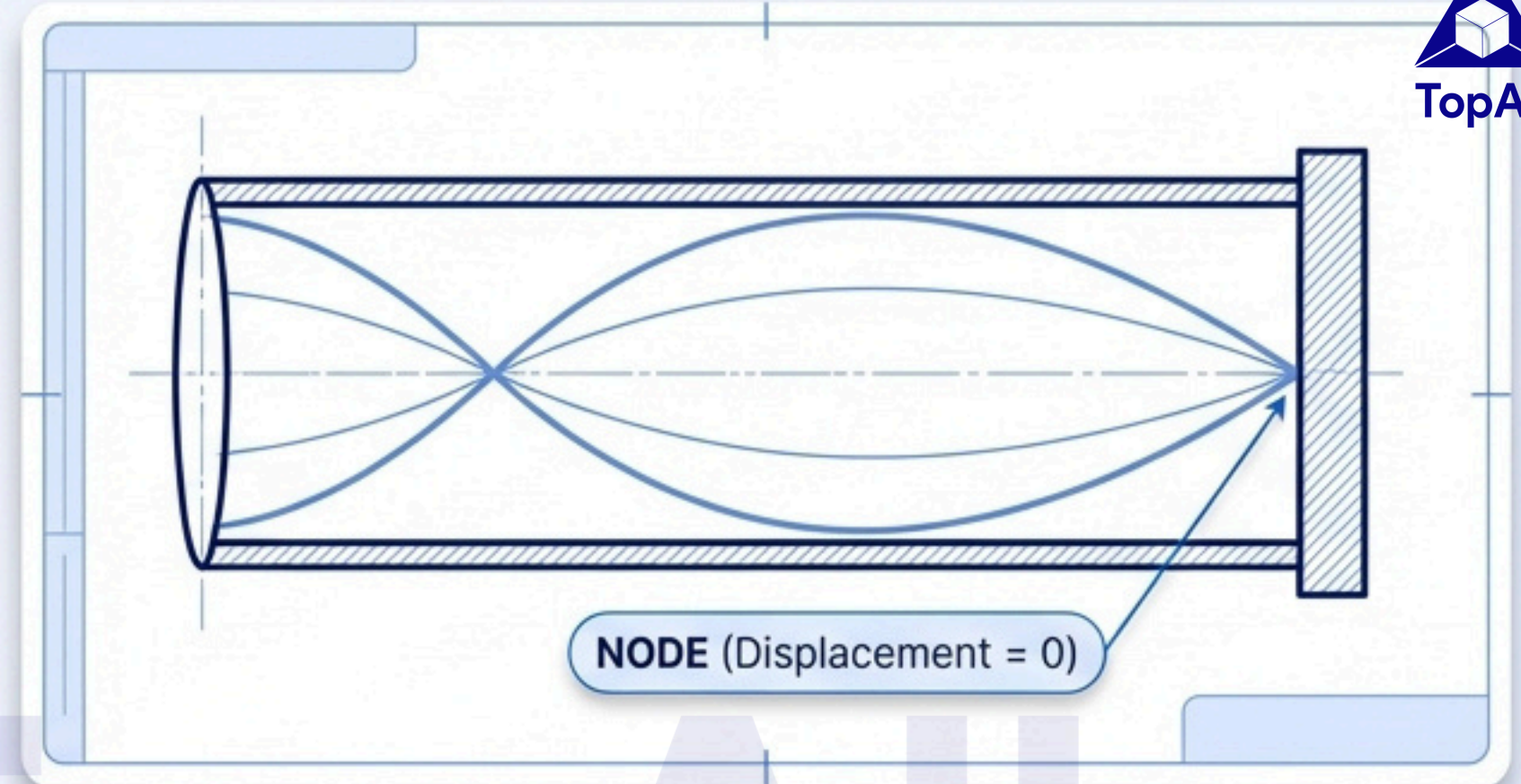
Plus Jakarta Sans

When sound travels through an enclosed air column, it reflects at the boundaries. The superposition of incident and reflected waves creates stationary (standing) waves.

Key Rules Panel

- **Node (N):** Displacement is zero. Always occurs at a **closed end** (rigid boundary).
- **Antinode (A):** Displacement is maximum. Always occurs at an **open end** (free boundary).

DISTANCE RULE: Consecutive Nodes or Antinodes = $\lambda/2$

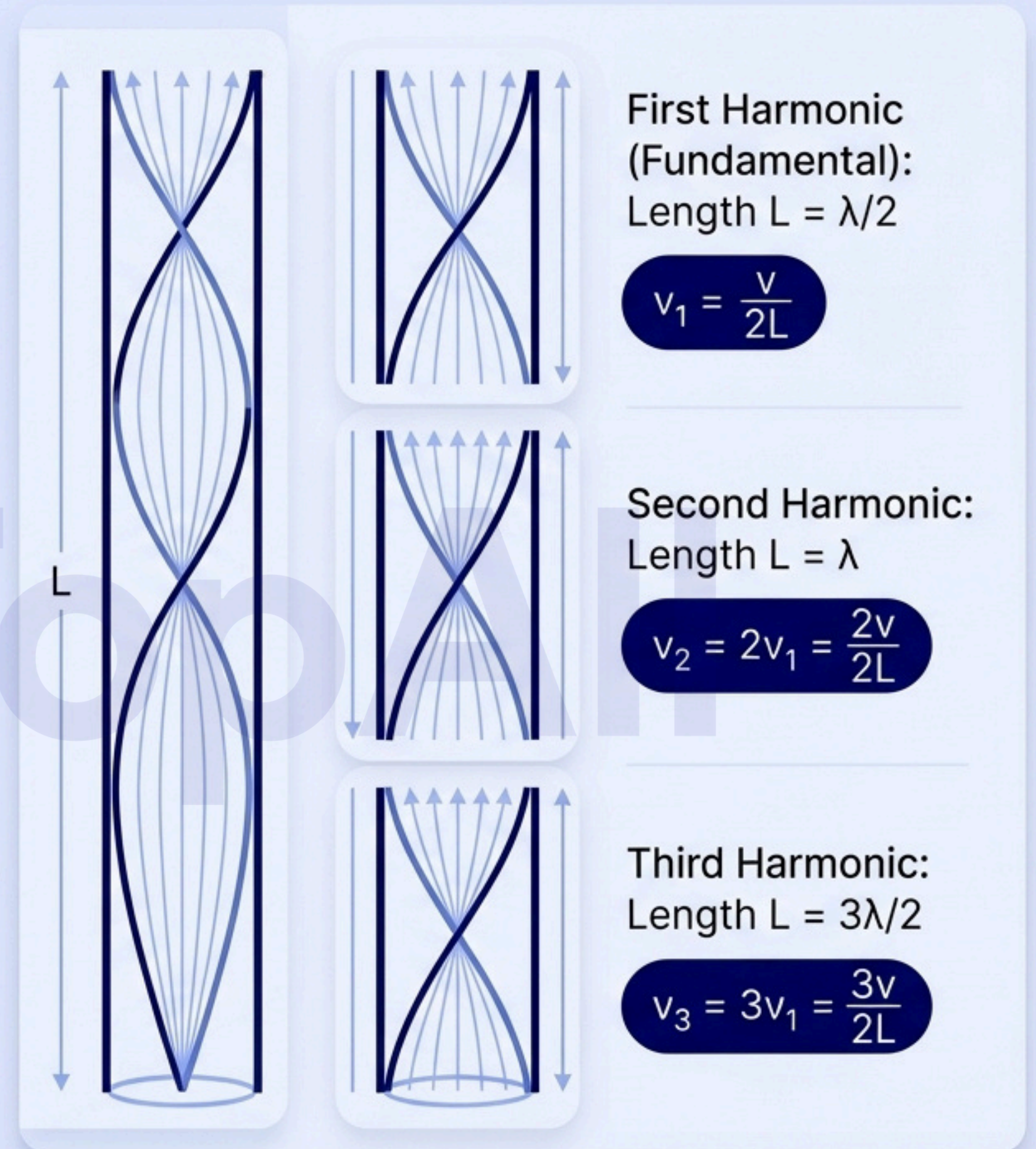


Normal Modes Of An Open Pipe

Because both ends are open to the air, both boundaries must be **Antinodes**. This symmetrical system generates all integer harmonics.

Exam Tip Badge

An open pipe produces ALL harmonics (1, 2, 3...)





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Normal Modes Of A Closed Pipe

One end is closed (Node) and the other is open (Antinode). This boundary asymmetry changes the allowed wavelengths.

Exam Tip Badge

Fundamental frequency is **HALF** that of an open pipe of the same length.



First Harmonic
(Fundamental):
Length $L = \lambda/4$

$$v_1 = \frac{v}{4L}$$



Third Harmonic:
Length $L = 3\lambda/4$

$$v_3 = 3v_1 = \frac{3v}{4L}$$



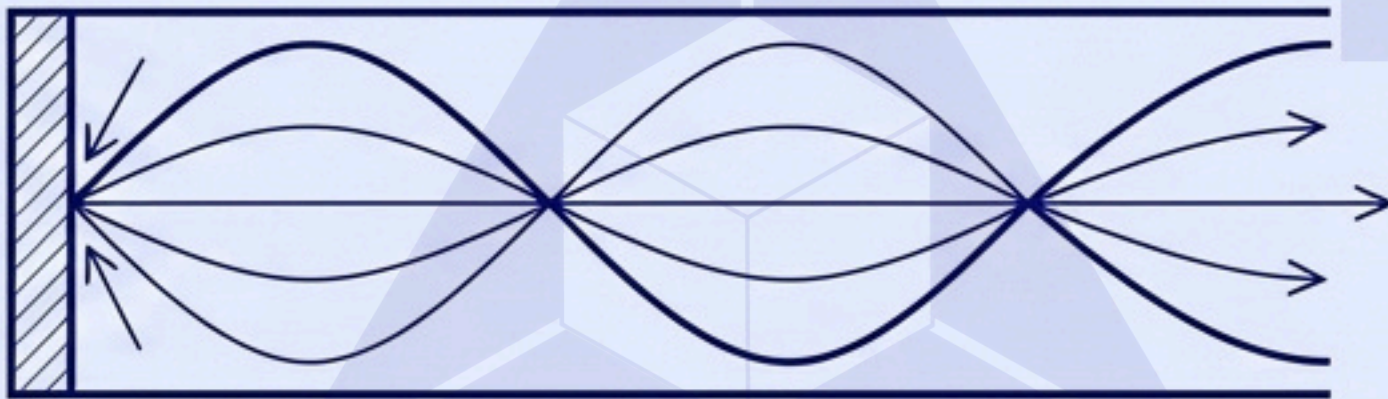
Fifth Harmonic:
Length $L = 5\lambda/4$

$$v_5 = 5v_1 = \frac{5v}{4L}$$

The “Missing” Even Harmonics

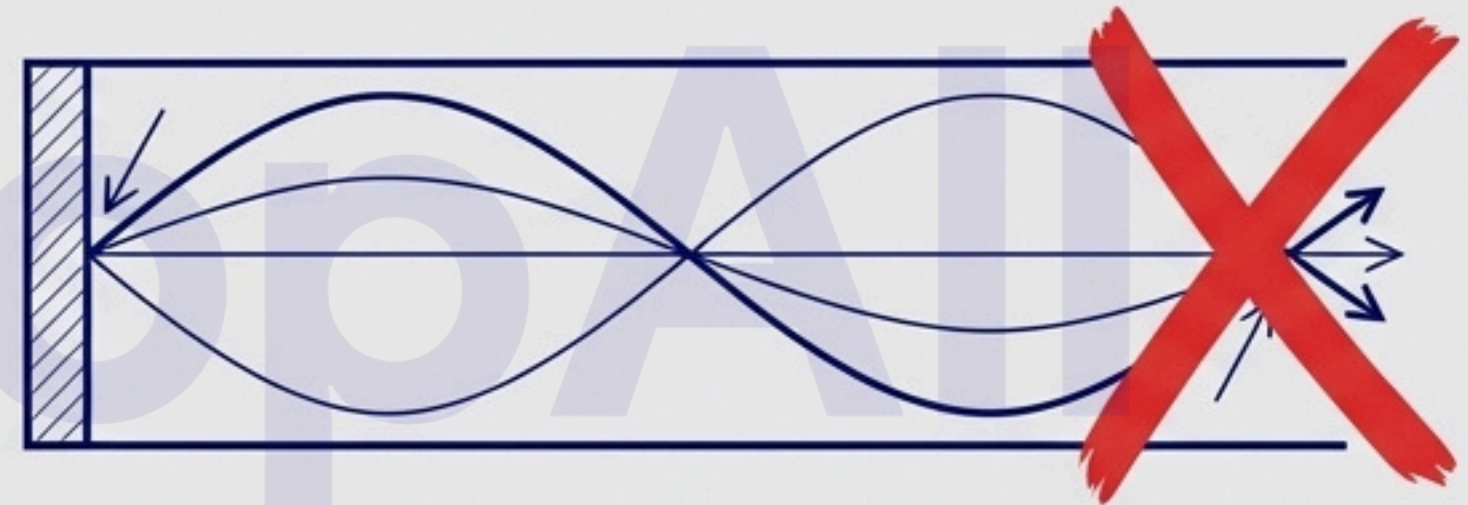
A system cannot oscillate with arbitrary frequencies. The physical ends of the pipe rigorously dictate the rules.

Allowed



VALID: Matches boundaries. Node at closed wall, Antinode at open air.

Forbidden

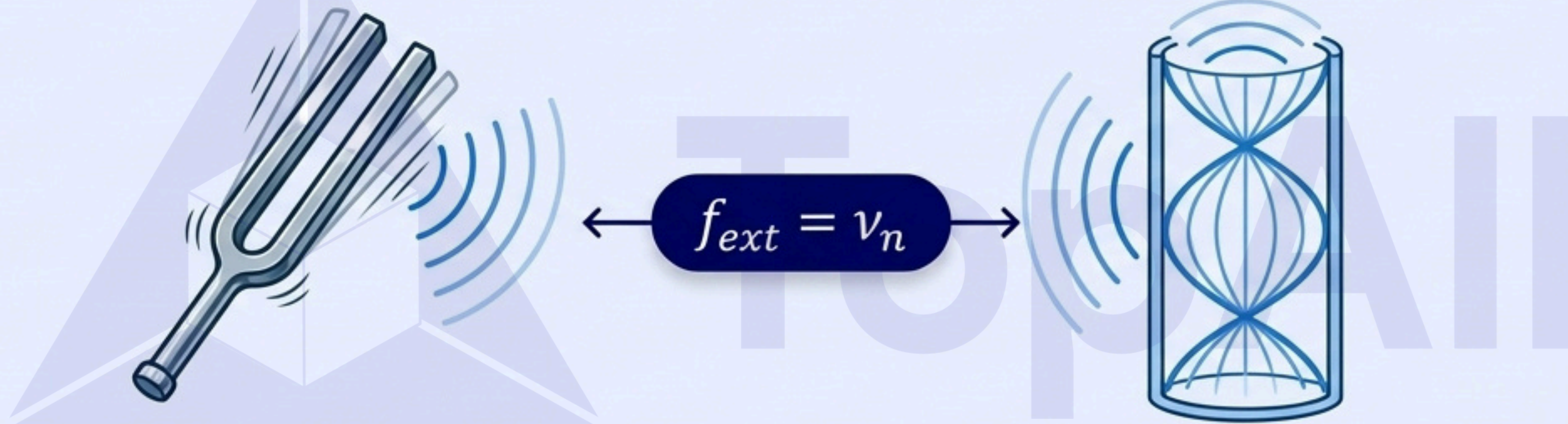


FORBIDDEN: Violates boundaries. An even multiple would require a Node at the open end, which is physically impossible.

RULE: Only odd multiples (v , $3v$, $5v$...) can exist in a one-end-closed pipe.

Resonance In Air Columns

Air columns can undergo forced oscillations. When an external source perfectly matches one of the column's natural frequencies, **resonance** occurs.



- **Condition:** External Frequency (f_{ext}) = Natural Normal Mode (v_n)
- **Result:** Maximum transfer of energy. The air column vibrates with maximum amplitude, producing a loud sound.

Exam Tip Badge If a closed pipe's fundamental frequency is $v/4L$, it will resonate with a tuning fork of $3v/4L$, but NOT with $2v/4L$.

Chapter 14 Summary



Open Pipe (Both Ends Free)

FUNDAMENTAL: $v = v / 2L$

HARMONICS: 1, 2, 3, 4, 5... (All Present)

BOUNDARIES: Antinode – Antinode

Closed Pipe (One End Rigid)

FUNDAMENTAL: $v = v / 4L$

HARMONICS: 1, 3, 5... (Odd Only)

BOUNDARIES: Node – Antinode

START PRACTICE: Try Chapter 14 Waves MCQs Next →



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