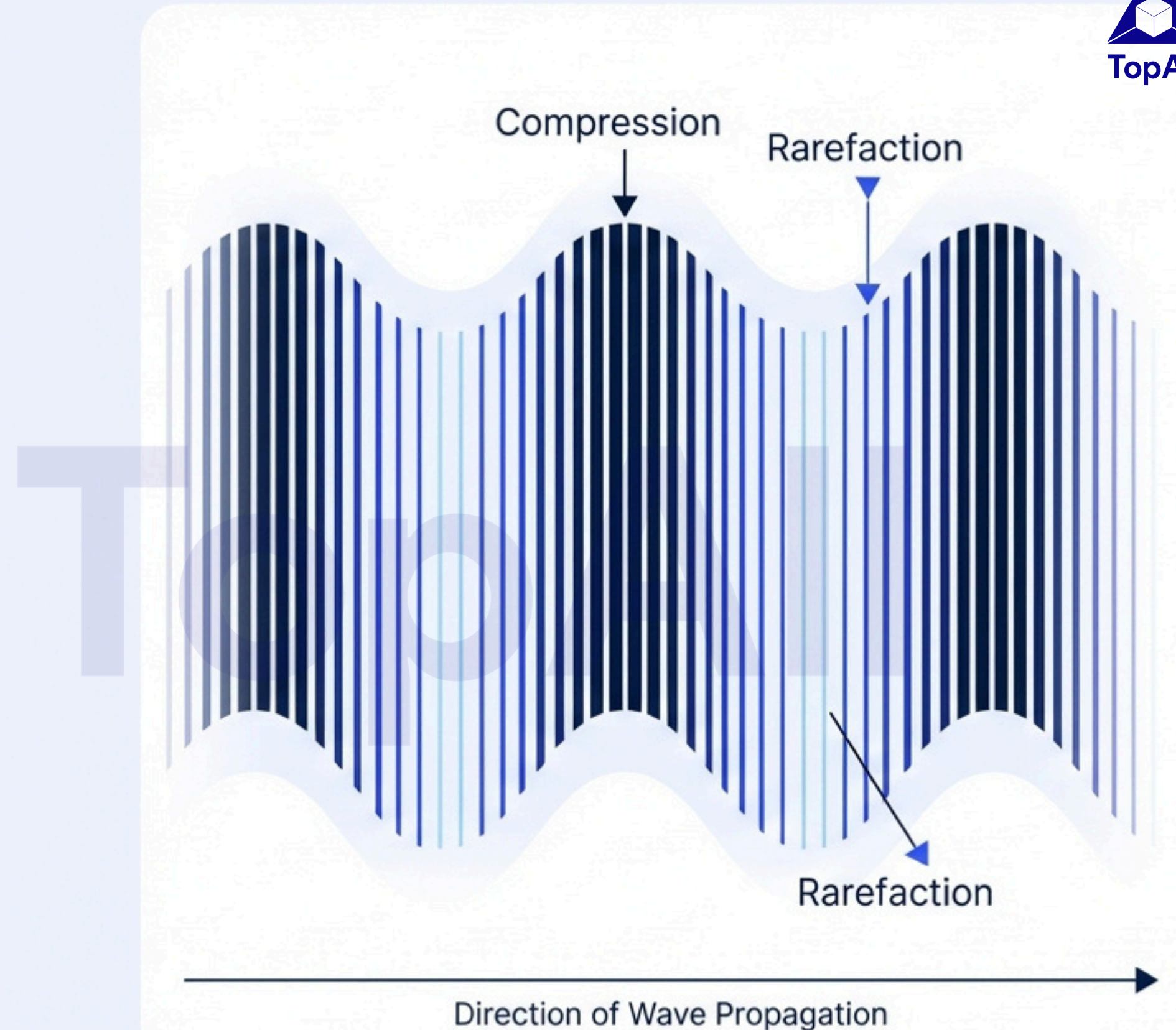


# Speed of a Longitudinal Wave

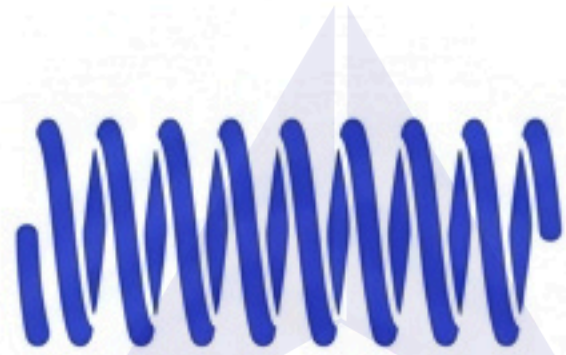
Understanding the physics of sound propagation through different media.

Master the core formulas, Newton's assumption, and the Laplace correction for your NEET/JEE prep.



# The Two Pillars of Wave Speed

The speed of any mechanical wave is determined by two opposing properties of the medium:



## Elastic Property (The 'Springiness')

- Determines the restoring force when the medium is disturbed.
- Measured by Modulus of Elasticity.

**Result: Higher elasticity = Faster wave.**



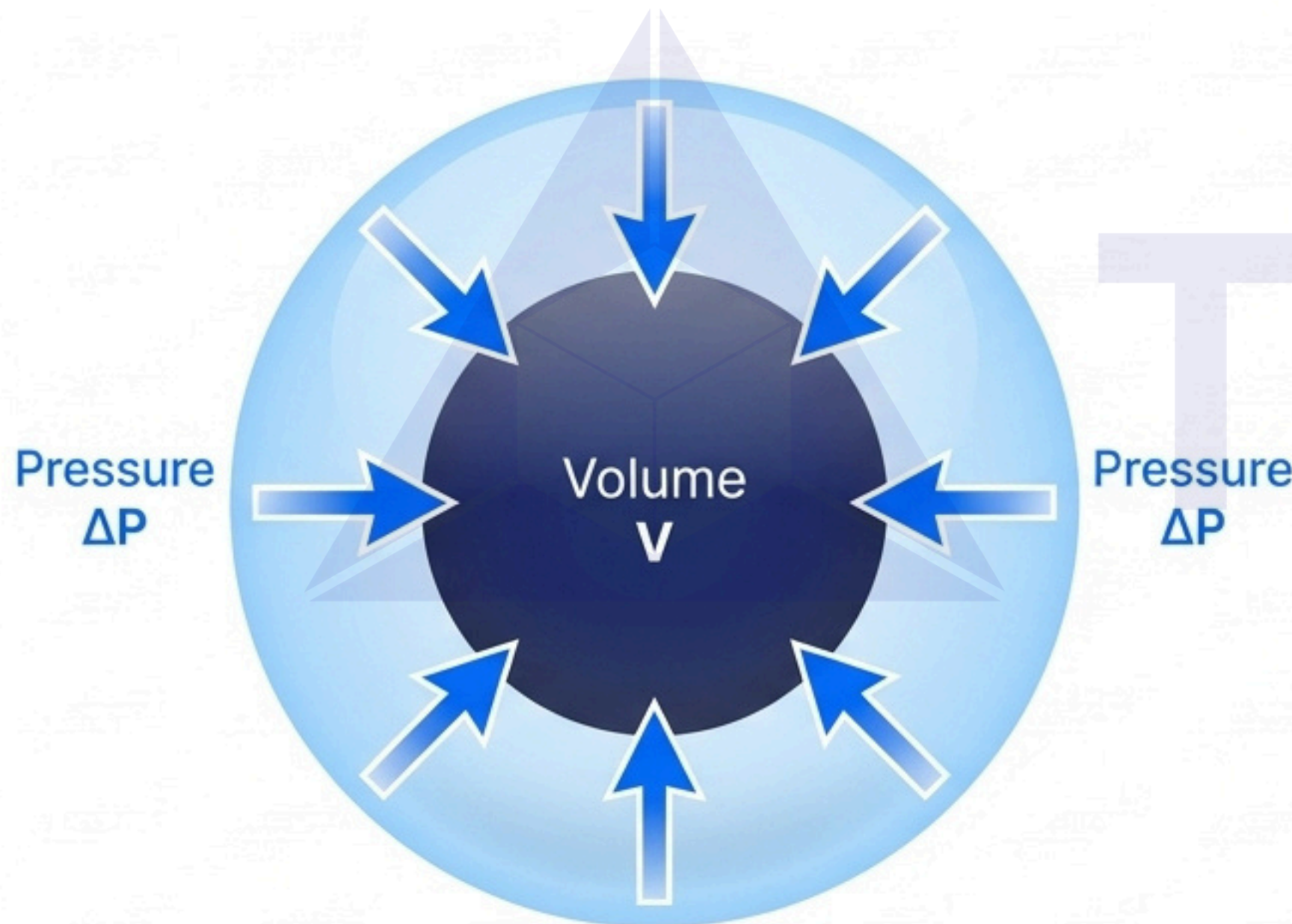
## Inertial Property (The 'Heaviness')

- Determines resistance to motion.
- Measured by Mass Density ( $\rho$ ).

**Result: Higher density = Slower wave.**

# Measuring 'Springiness' in Fluids

Sound travels via compressions and rarefactions. The elastic property governing this in fluids and gases is the Bulk Modulus (B).



EQ. 14.16

## Bulk Modulus Formula

$$B = - \frac{\Delta P}{\frac{\Delta V}{V}}$$

Change in pressure

Volumetric strain (fractional volume change)

Negative sign indicates volume decreases as pressure increases.



# You've Learned the Theory. Let's Test Them Now.

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# Calculating Longitudinal Wave Speed

EQ. 14.19

General Formula

$$v = \sqrt{\frac{B}{\rho}}$$

→ Bulk Modulus (Elasticity)

→ Mass Density (Inertia)

EQ. 14.20

For a Solid Linear Bar

$$v = \sqrt{Y / \rho}$$

*Note: Lateral expansion is negligible, so Young's Modulus (Y) replaces Bulk Modulus.*



**[EXAM TIP] Speed depends ONLY on the medium's properties, not on the frequency or wavelength of the sound!**

# Newton's Assumption (Isothermal)

## The Assumption



Newton assumed compressions and rarefactions happen slowly enough for temperature to remain constant (Isothermal process).

For an ideal gas:  $B = P$  (Pressure)

## The Math

EQ. 14.22

$$\text{Newton's Formula: } v = \sqrt{\frac{P}{\rho}}$$

## Reality Check

Predicted speed at STP:

**280 m/s**

Actual measured speed:

**~331 m/s**

**Result: A massive ~15% error!  
Where did Newton go wrong?**

# Laplace Correction & State of Matter



EQ. 14.24

## THE ADIABATIC FIX

The Fix: Pressure variations are too fast for heat to flow. The process is Adiabatic, not isothermal.

$$\text{Laplace Correction: } B_{\text{ad}} = \gamma P \text{ (where } \gamma = \frac{c_p}{c_v}\text{)}$$
$$v = \sqrt{\frac{\gamma P}{\rho}} \rightarrow \text{Yields } 331.3 \text{ m/s at STP (Perfect match!)}$$

## TABLE 14.1 SYNTHESIS



Why? Solids have higher density ( $\rho$ ), but their Bulk/Young's modulus ( $B/Y$ ) is massively higher, making velocity ( $v$ ) much greater.

# Chapter Mastery



1. The Governing Variables: Speed is directly proportional to the square root of elasticity (B or Y) and inversely proportional to the square root of density ( $\rho$ ).



2. Solids vs. Gases: Sound travels fastest in solids because their massive elasticity easily compensates for their higher density.



3. Newton vs. Laplace: Newton incorrectly assumed isothermal propagation ( $v = \sqrt{P/\rho}$ ). Laplace corrected this to adiabatic propagation ( $v = \sqrt{\gamma P/\rho}$ ).



# You've Learned the Theory.

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