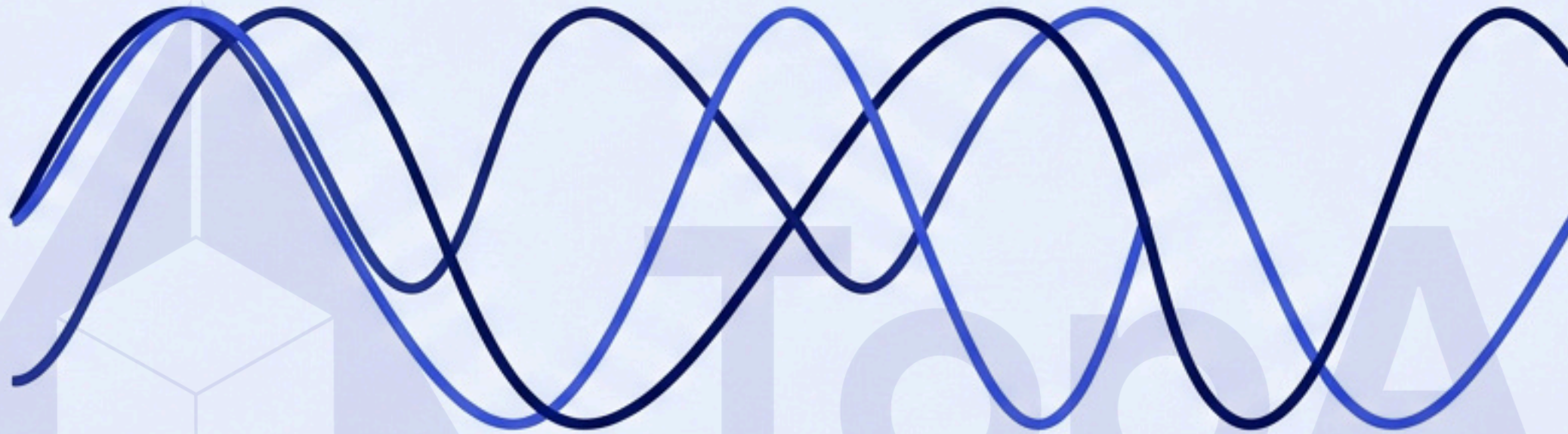


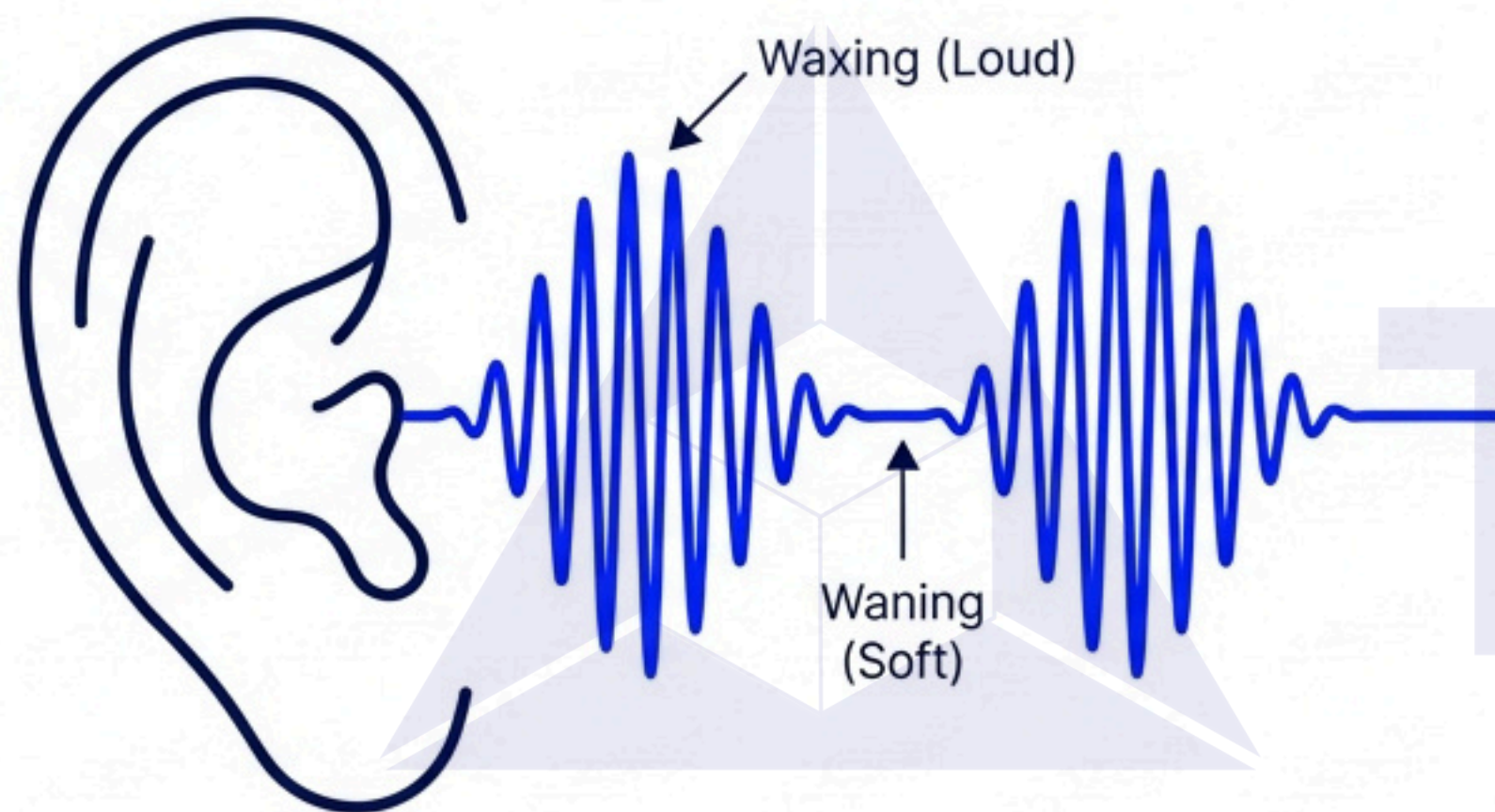
CHAPTER 14 • WAVES



14.7 Beats

The Physics of Sound Interference

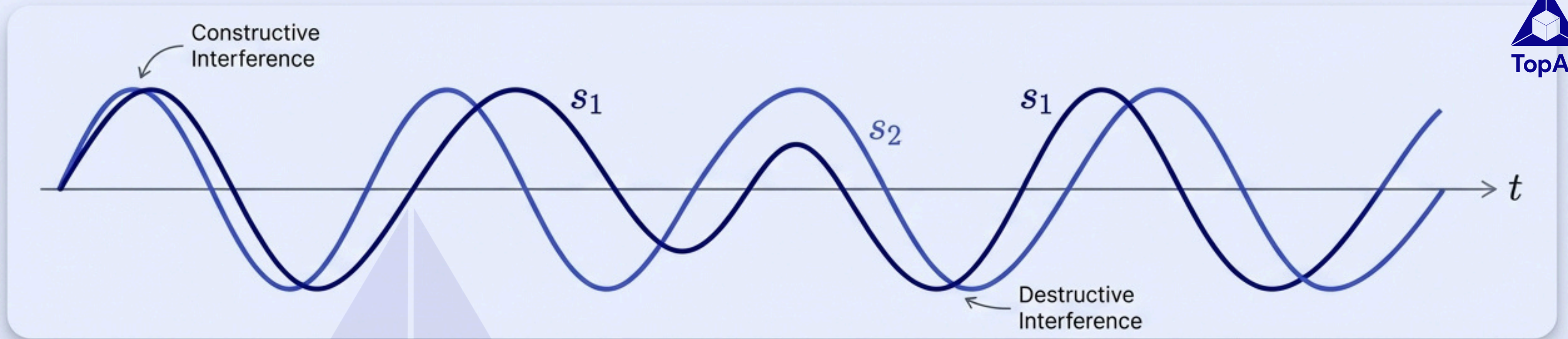
Master the mathematical and conceptual foundation of beat frequencies for NEET & JEE.



CORE CONCEPT

Waxing and Waning of Sound

- **What it is:** "Beats" arise due to the interference of two sound waves.
- **The condition:** The two waves must have close (but not equal) frequencies.
- **The result:** You hear a single sound of the average frequency, accompanied by an audibly distinct waxing and waning (loud and soft) of intensity.



INITIAL WAVES

Consider two harmonic sound waves with equal amplitudes (a) but slightly different angular frequencies (ω_1 and ω_2).

Eq. (14.45)

$$s_1 = a \cos \omega_1 t \quad \text{and} \quad s_2 = a \cos \omega_2 t$$

We assume ω_1 is slightly greater than ω_2 . Because they are close, they will periodically align and misalign.



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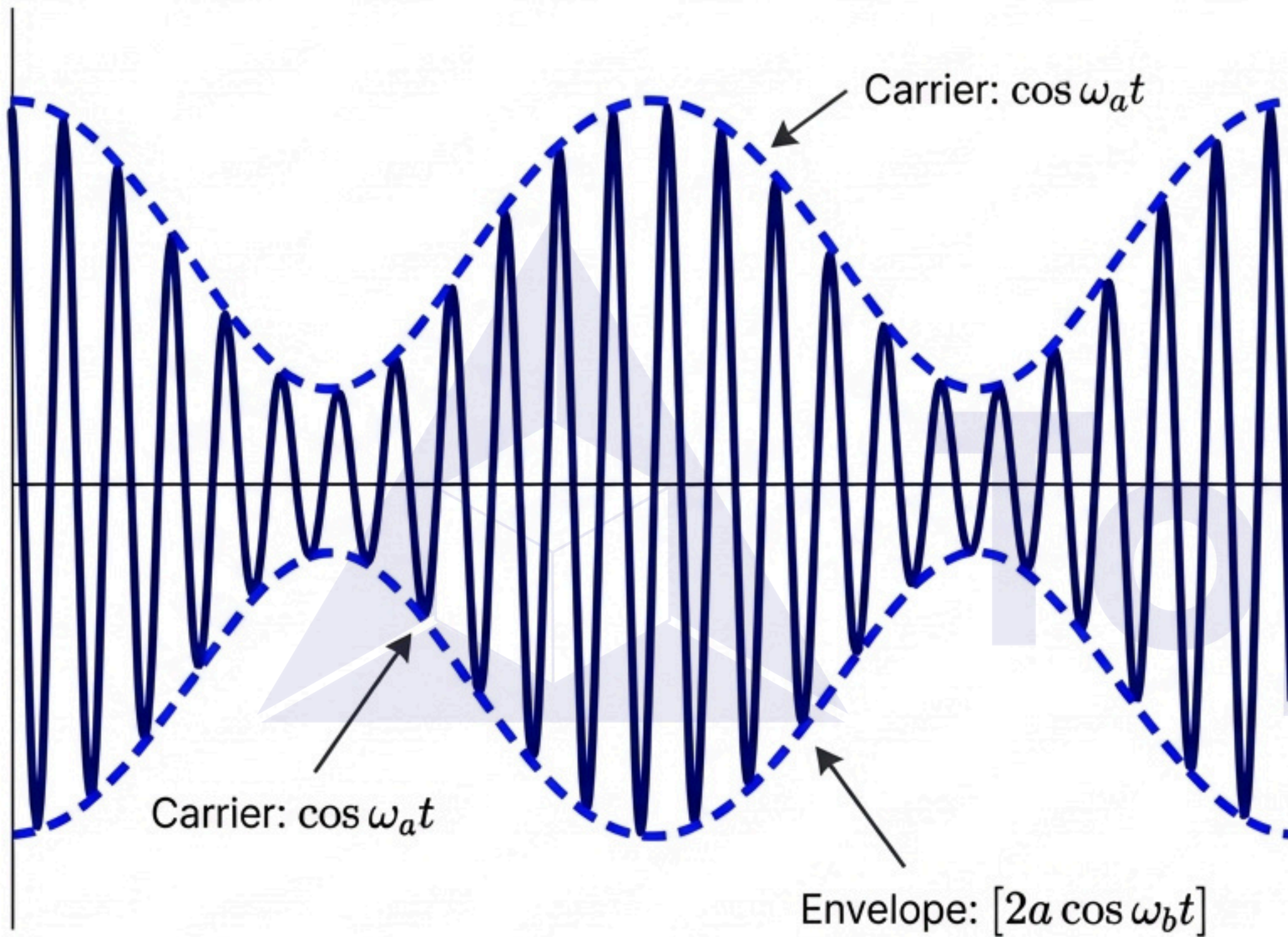


PRINCIPLE OF SUPERPOSITION

Using $s = s_1 + s_2$ and the identity for $\cos A + \cos B$:

Eq. (14.46) & (14.47)

$$s = [2a \cos \omega_b t] \cos \omega_a t$$



- **Average Frequency:** The wave oscillates at $\omega_a = \frac{\omega_1 + \omega_2}{2}$.
- **The Envelope:** The amplitude $[2a \cos \omega_b t]$ is not constant. It slowly modulates at $\omega_b = \frac{\omega_1 - \omega_2}{2}$.

Calculating Beats

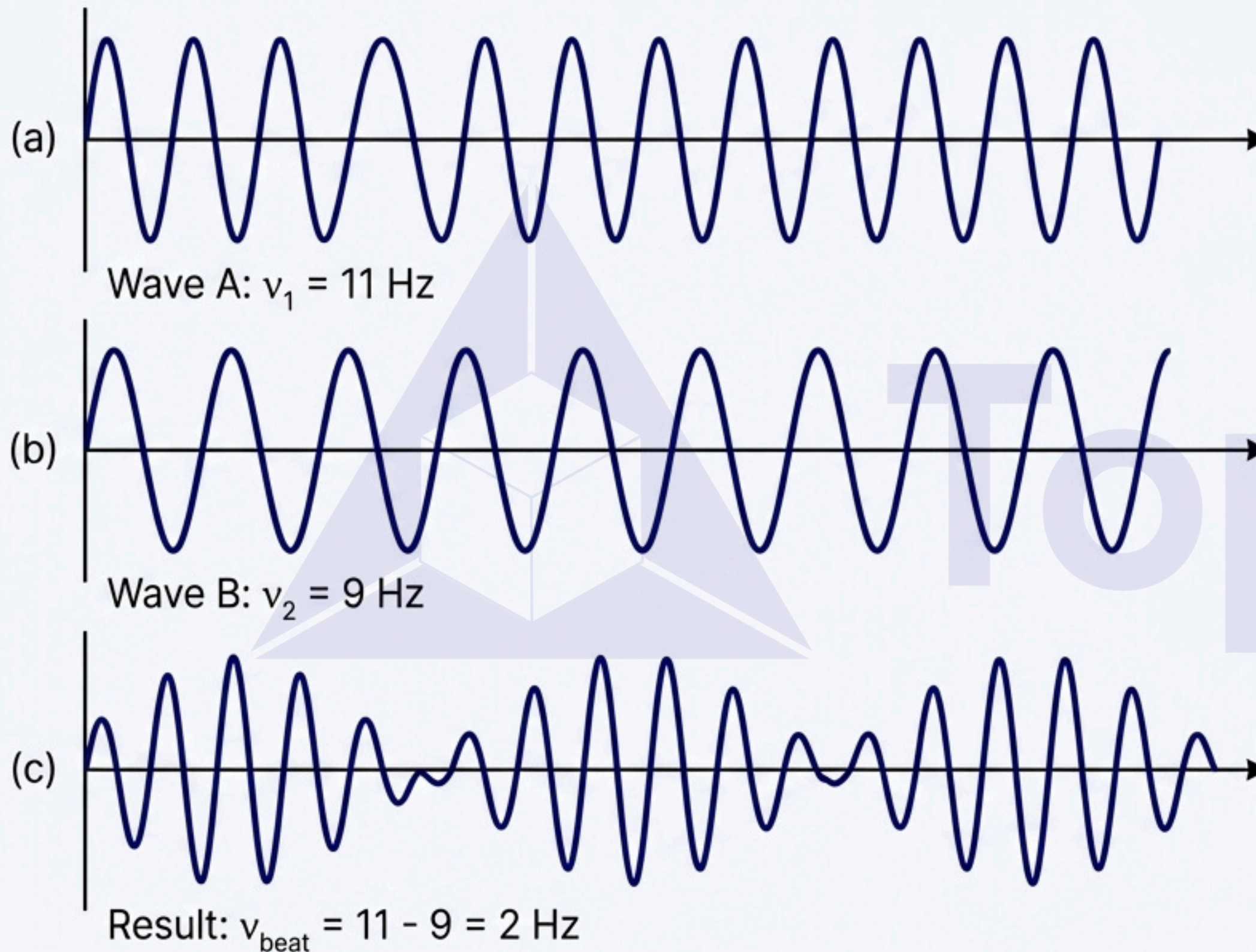
The amplitude is maximum when $\cos \omega_b t$ is +1 or -1. Therefore, the intensity waxes and wanes at twice the envelope frequency ($2\omega_b = \omega_1 - \omega_2$).

Eq. (14.48)

$$\nu_{\text{beat}} = \nu_1 - \nu_2$$

The beat frequency (ν_{beat}) is simply the difference between the two original frequencies.

FIG. 14.16 & APPLICATION



Musical Tuning



- Artists use beats to tune instruments (like a Sitar).
- They sound an out-of-tune string alongside a standard reference frequency.
- They adjust the tension until the beats slow down and disappear ($\nu_{\text{beat}} = 0$).

Key Takeaways

- Beats are regular intensity modulations caused by interference of two close frequencies.
- The resultant wave combines a fast-oscillating average frequency with a slowly varying amplitude envelope.
- Beat frequency is precisely the difference of the two source frequencies:
 $\nu_{\text{beat}} = \nu_1 - \nu_2$.
- Instruments are perfectly tuned when no beats are detected between them.

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