The Science of Sound

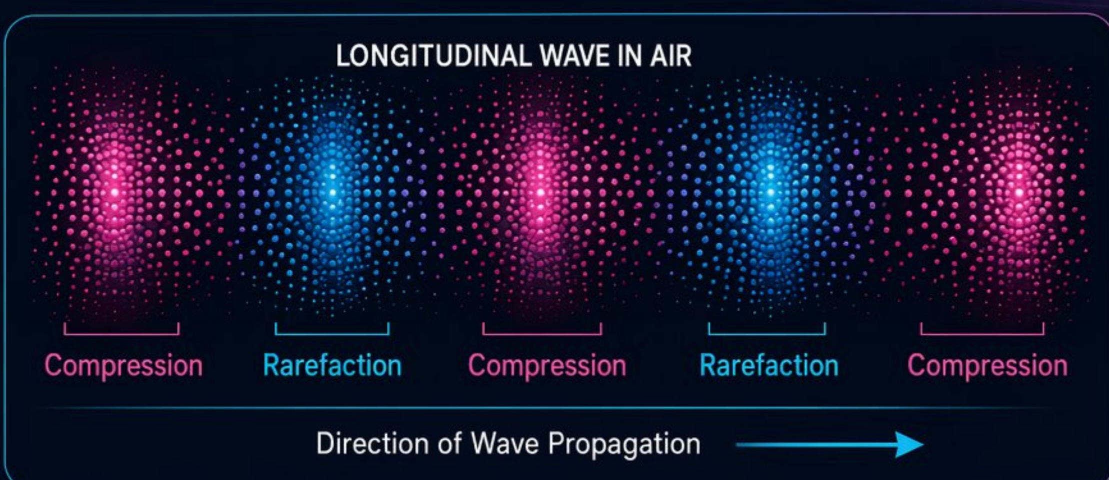
- Sound is a traveling mechanical pressure wave requiring a solid, liquid, or gas medium.
- It is essential for communication, music, warning systems, and medical diagnostics.
- Physical acoustics studies the wave itself; psychoacoustics studies how we perceive it.
- Course roadmap: from vibrations and waves to everyday phenomena like noise cancellation and the Doppler effect.

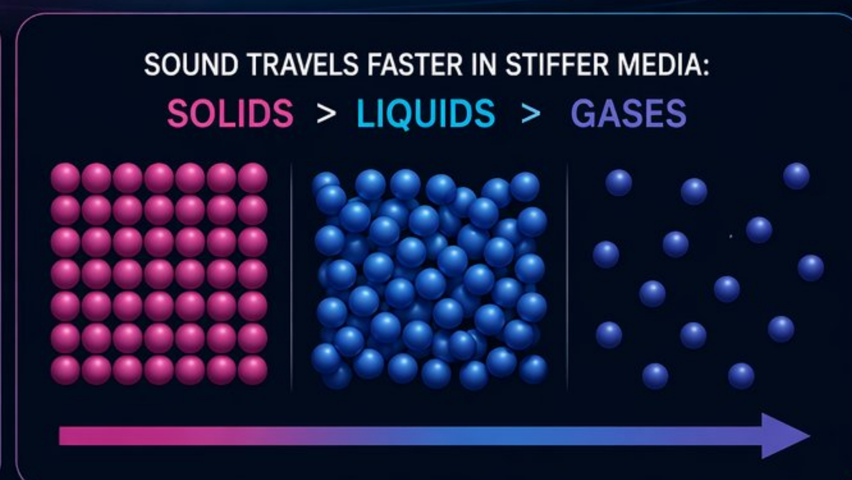
Vibrations: The Source of Sound

- Vibration is periodic back-and-forth motion around an equilibrium point
- Simple harmonic motion is the fundamental building block of all sound
- Common sources: tuning forks, vocal cords, and loudspeaker cones
- Vibration amplitude directly determines the resulting sound intensity

How Sound Travels: The Role of a Medium

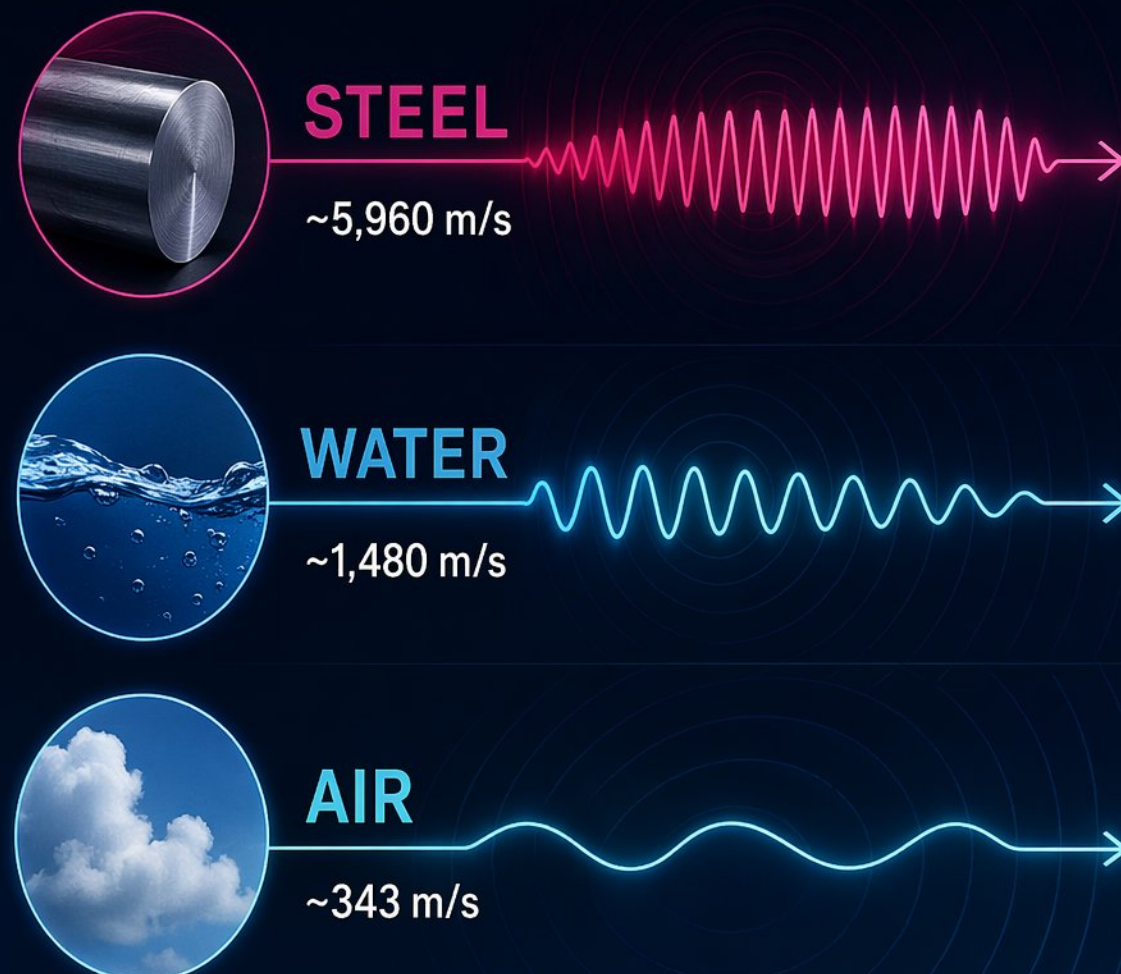
- Sound is a mechanical wave requiring a medium; cannot travel in a vacuum
- In air, sound travels as a longitudinal wave of compressions and rarefactions
- The bell jar vacuum experiment proves sound needs a medium to propagate
- Speed depends on the medium's density and elastic properties, not constant
- Sound travels faster in stiffer media: solids > liquids > gases





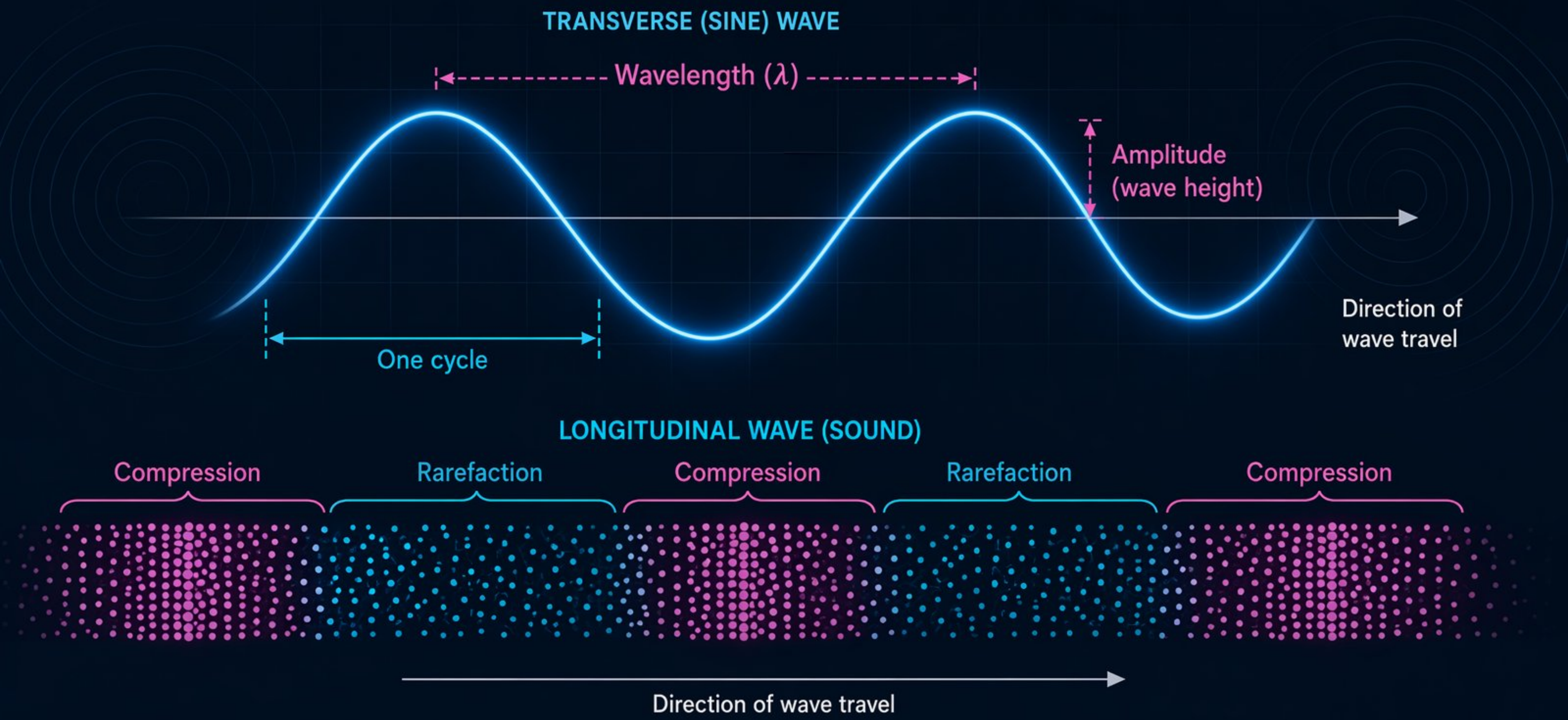
The Speed of Sound in Different Media

- Sound travels fastest in solids, slower in liquids, and slowest in gases.
- Typical speeds: ~343 m/s in air, ~1,480 m/s in water, ~5,960 m/s in steel.
- In air, speed increases with temperature: $v \approx 331 + 0.6T$ m/s.
- The general principle: v = sqrt(elastic property / inertial property).



Wave Properties: Frequency, Wavelength, and Amplitude

- **Frequency (Hz):** cycles per second; correlates with perceived pitch
- **Wavelength:** distance between successive compressions or crests
- **Wave equation:** $v = f \times \lambda$ (speed = frequency × wavelength)
- **Amplitude:** wave height corresponds to loudness; measured in decibels (dB)



The Frequency Spectrum: Infrasound to Ultrasound

- Nominal human hearing range spans 20 Hz to 20,000 Hz (20 kHz)
- Peak auditory sensitivity lies between 2,000 and 5,000 Hz
- Aging and noise exposure reduce the upper frequency limit, especially in men
- Infrasound (<20 Hz): produced by earthquakes, elephants, and industrial machinery
- Ultrasound (>20 kHz): used in medical imaging, cleaning, and bat echolocation

Reflection, Refraction, and Diffraction

- **Reflection:** sound bounces off surfaces, causing echoes and reverberation.

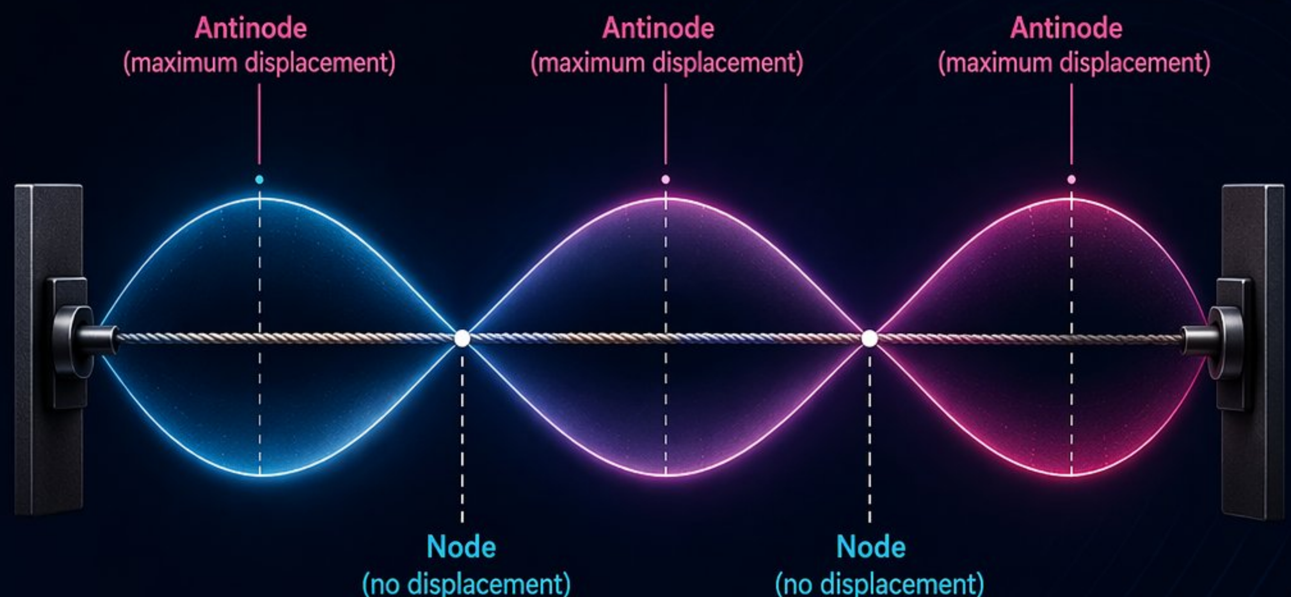
- **Refraction:** sound bends due to speed changes from temperature gradients.

- **Diffraction:** sound spreads around obstacles; lower frequencies diffract more.

- **Daytime:** sound refracts upward; nighttime inversion bends it downward.

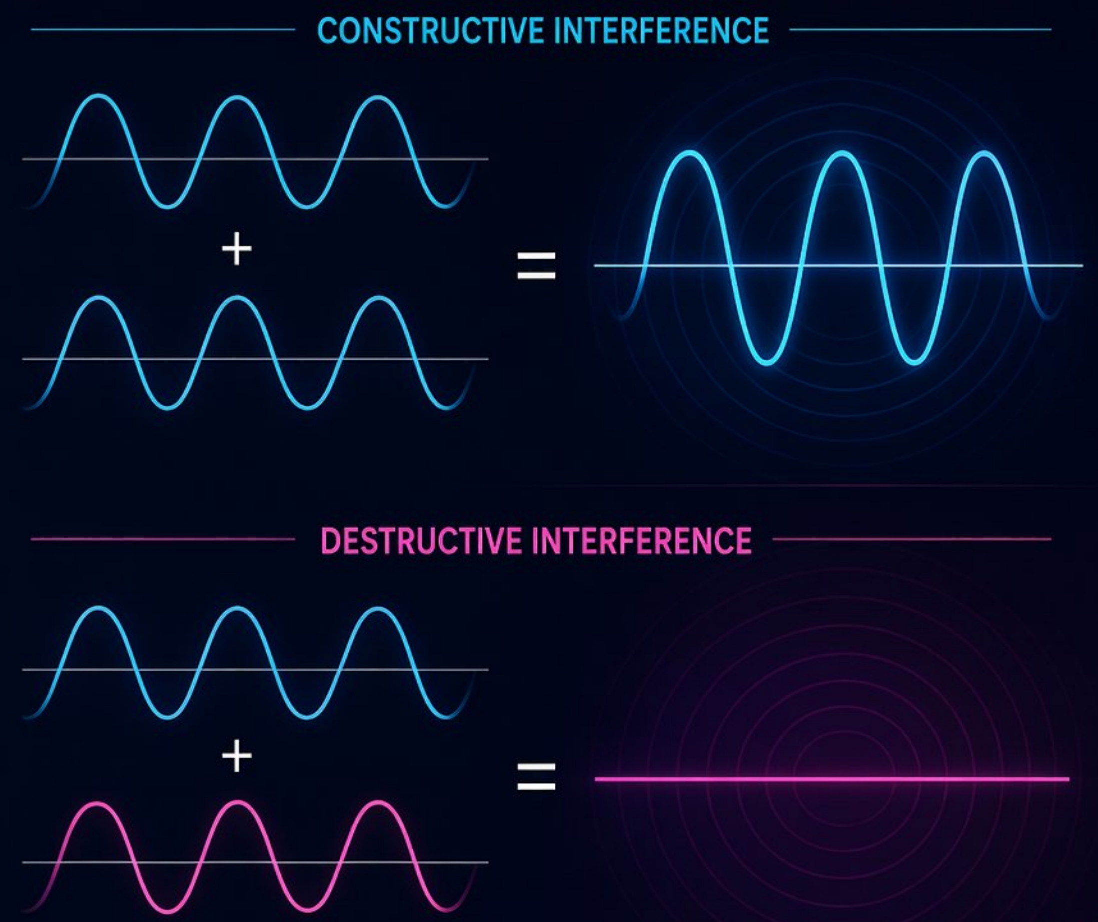
Resonance and Standing Waves

- Every object has a natural frequency where it vibrates most efficiently
- Resonance occurs when a driving force matches this natural frequency, amplifying amplitude
- Standing waves create nodes (no displacement) and antinodes (maximum displacement)
- The Tacoma Narrows Bridge failed from torsional flutter, not simple resonance



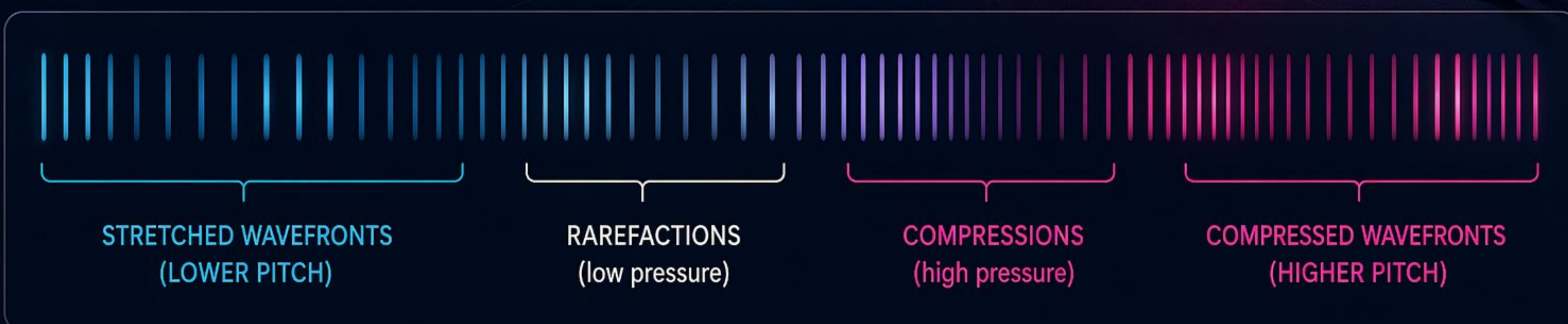
Interference: Constructive and Destructive

- Superposition principle: when waves meet, their displacements add together
- Constructive interference: in-phase waves combine to create a louder sound
- Destructive interference: out-of-phase waves cancel, reducing or silencing sound
- Beat frequencies arise from two slightly detuned waves interfering
- Musicians use beat frequencies to tune instruments precisely



The Doppler Effect: Moving Sources and Observers

- The Doppler effect is a change in observed frequency due to relative motion
- A source moving toward you compresses wavefronts, raising the perceived pitch
- A source moving away stretches wavefronts, lowering the perceived pitch
- The classic example: a siren or train horn shifts pitch as it passes by

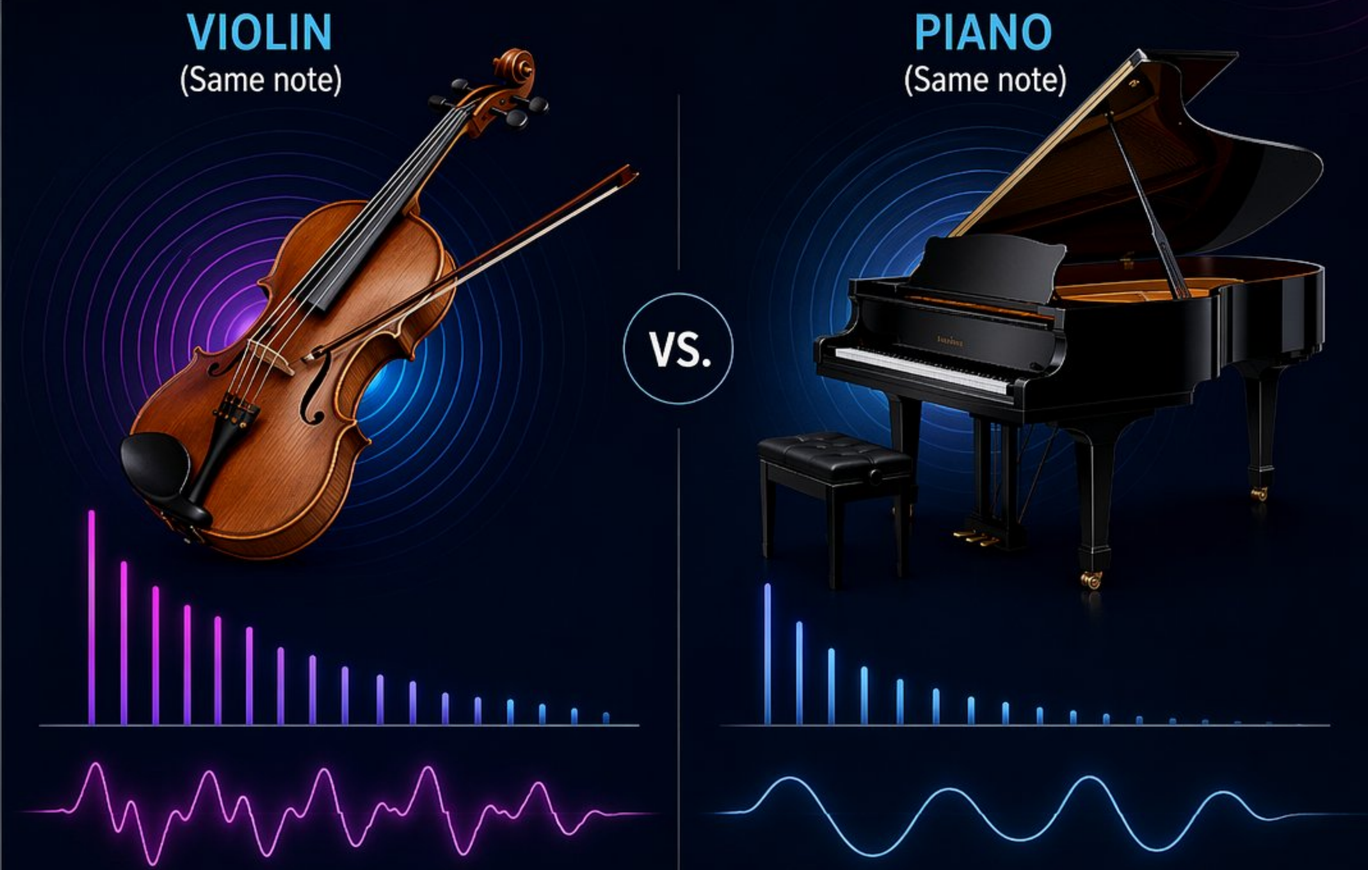


Sonic Booms and Shock Waves

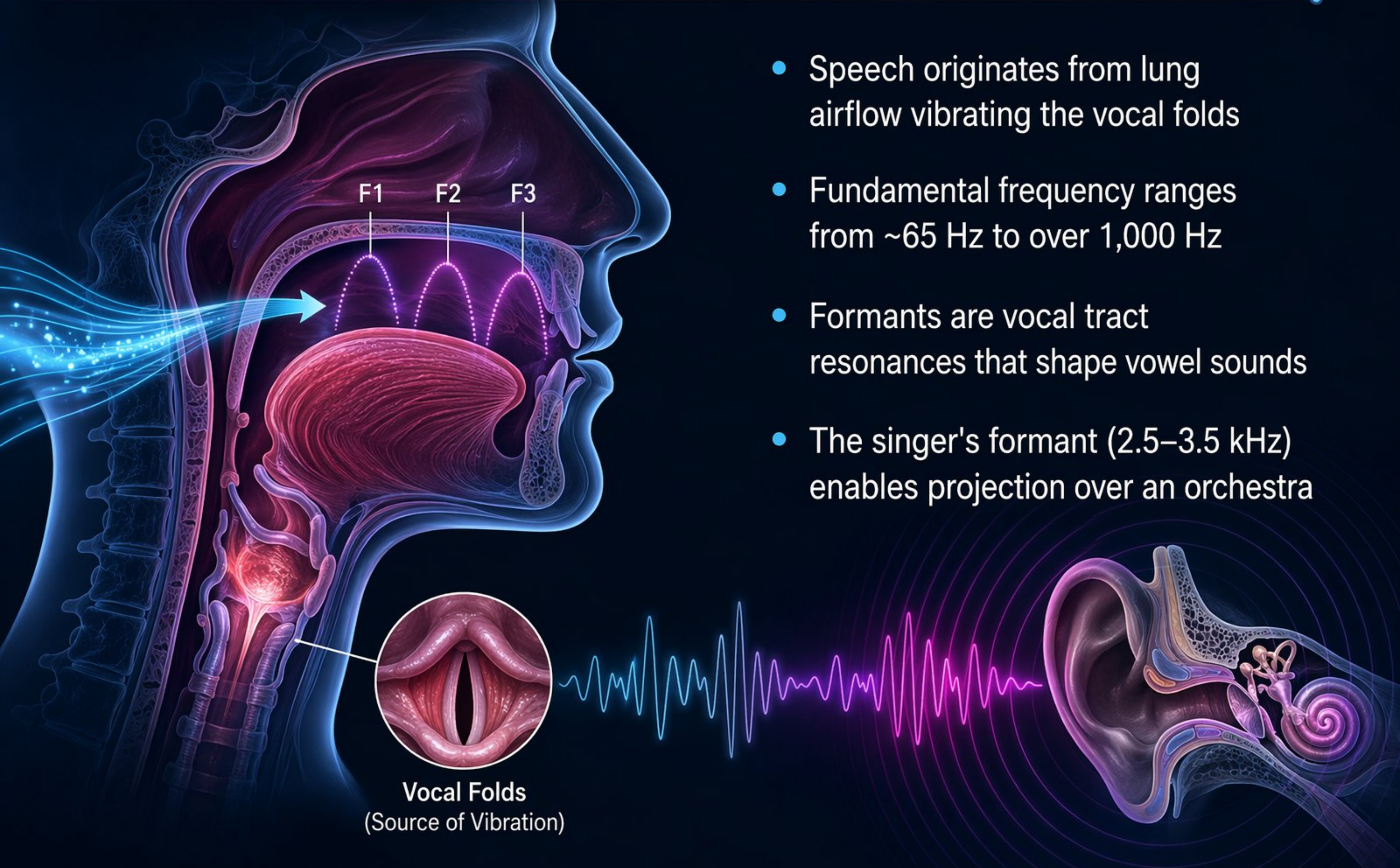
- A source moving faster than sound outruns its own wavefronts.
- Wavefronts pile up, constructively interfering into a high-pressure shock wave.
- A sonic boom is a continuous effect, heard as a loud double boom.
- Supersonic flight over populated areas is banned due to destructive potential.

The Physics of Music and Timbre

- Musical sounds are typically periodic; noise is aperiodic and random.
- The fundamental frequency determines pitch; harmonics determine timbre.
- Timbre distinguishes a violin from a piano playing the same note.
- The human voice uses vocal folds and resonant cavities for its unique harmonic spectrum.



Speech Production and Vocal Acoustics



- Speech originates from lung airflow vibrating the vocal folds
- Fundamental frequency ranges from ~65 Hz to over 1,000 Hz
- Formants are vocal tract resonances that shape vowel sounds
- The singer's formant (2.5–3.5 kHz) enables projection over an orchestra

Sound Level Safety and Hearing Protection

- NIOSH limit: 85 dBA averaged over an 8-hour work shift
- 3 dB increase halves safe exposure time; 10 dB sounds twice as loud
- Noise above 85 dBA can cause permanent, preventable hearing loss
- Fit testing ensures hearing protection delivers the right attenuation
- Reduce exposure time, use quieter equipment, and wear protectors

How Noise-Canceling Headphones Work

- Active Noise Cancellation uses destructive interference to reduce unwanted sound.
- A microphone captures ambient noise; a DSP chip generates an inverted 'anti-noise' signal.
- The anti-noise wave is played through the speakers, canceling the original sound at the ear.
- ANC is most effective for low-frequency, steady sounds like airplane engine hum.

Putting It All Together: Sound Phenomena Explained

- Your voice on a recording lacks bone conduction's lower frequencies
- Thunder rumbles because lightning channel sound arrives at different times
- Sound speed is constant; behavior depends on frequency, medium, boundaries
- A wave-based understanding clarifies everyday experiences
- Protecting hearing is a lifelong practice

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