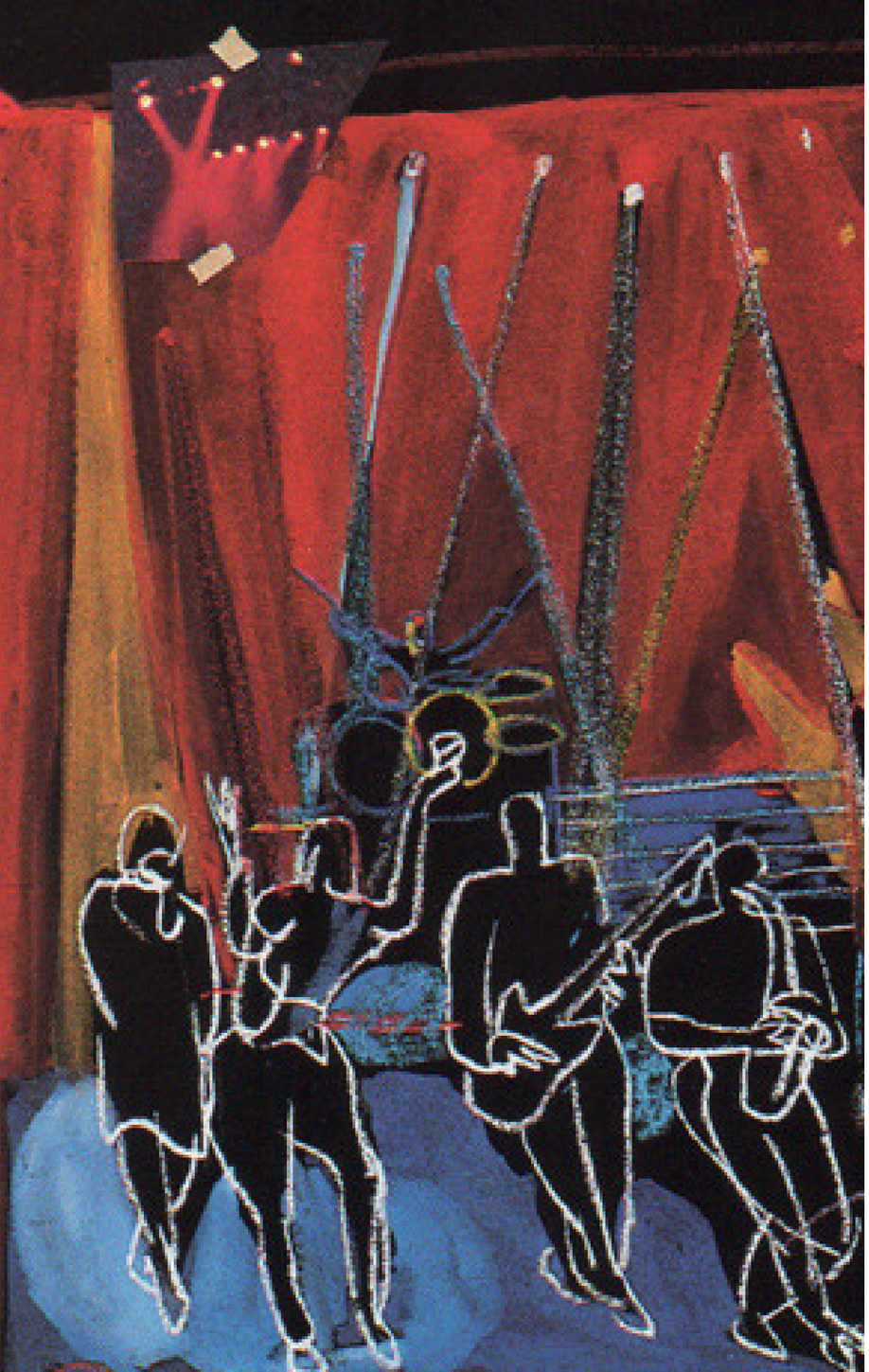


PHY-141

Craftting Sound Anatomy

Luis Anchordoqui

Outline

- Sound is generated when an object vibrates, forcing surrounding particles to move and create pressure waves

- It travels fastest through solids, then liquids, and slowest through gases

- In today's class we examine the fundamentals of sound waves

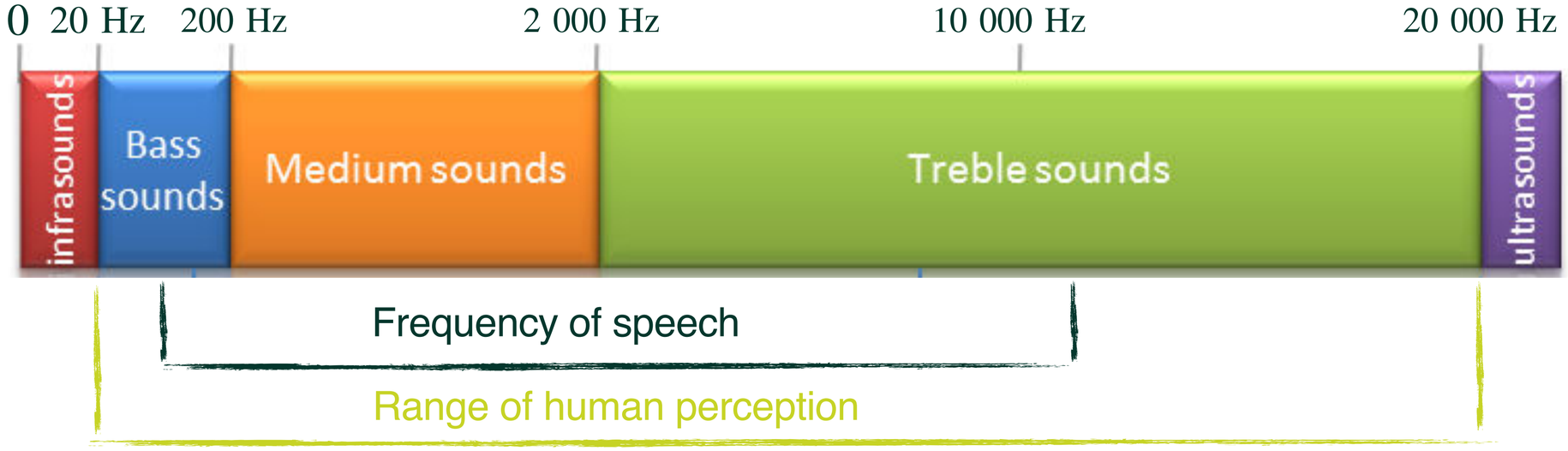
Sound Energy

- Sound energy is essentially mechanical energy created by vibrating objects
- These vibrations travel through air, water, or solids as waves that we can hear
- Defined by their pitch, volume, and length, these waves consist of both moving particles and the pressure they create
- Beyond just being what we hear, this energy is a fundamental tool for communication, music, and technology

Sound Energy Scales

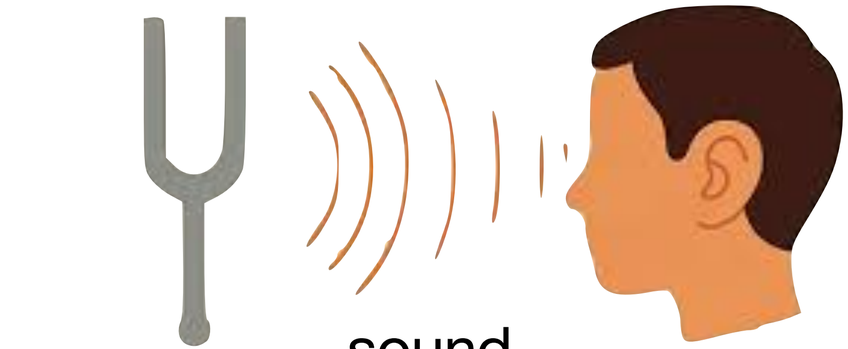
- Sound energy is classified by frequency into three distinct ranges: infrasound (under $20\ \mathrm{Hz}$), audible sound ($20\ \mathrm{Hz}$ to $20\ \mathrm{kHz}$), and ultrasound (over $20\ \mathrm{kHz}$)

- Each category serves specific roles, with audible sound enabling human communication, infrasound facilitating geological and environmental studies, and ultrasound providing vital tools for medical and industrial imaging

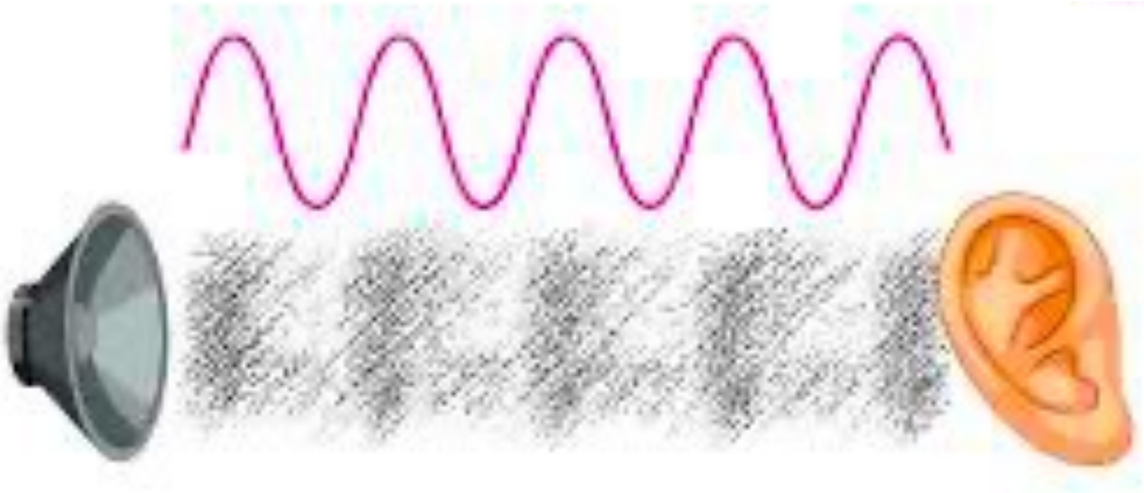


The Mechanics of Hearing

- Our ears turn sound waves into electrical signals for the brain
- Sound vibrates the eardrum and middle ear bones, sending energy to the inner ear
- There, cells convert these vibrations into signals that travel along the auditory nerve, allowing us to hear the world around us



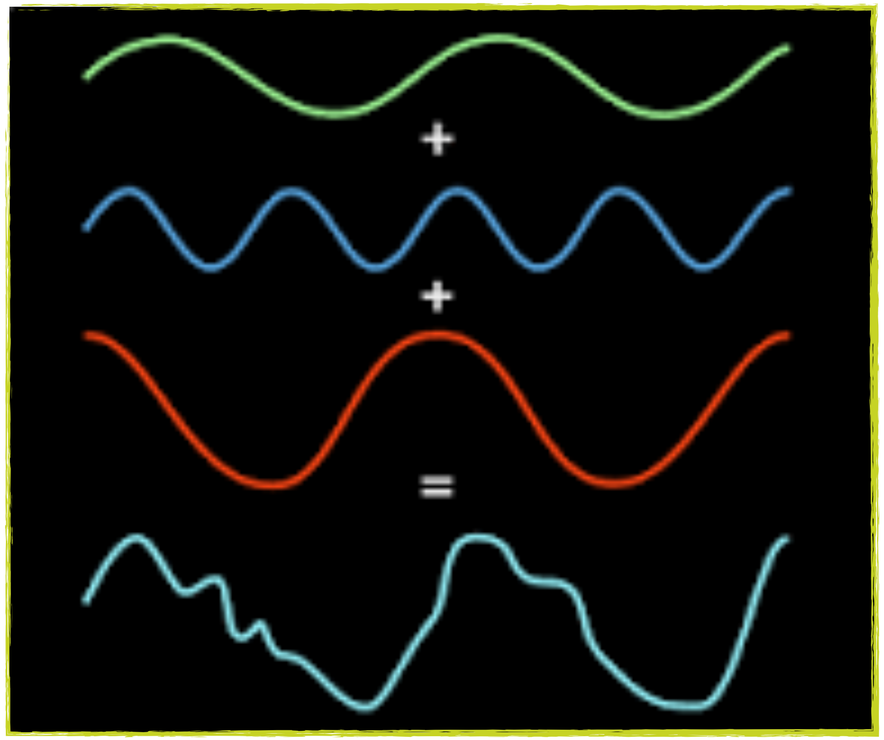
sound energy at a glance



Wave Spectrum

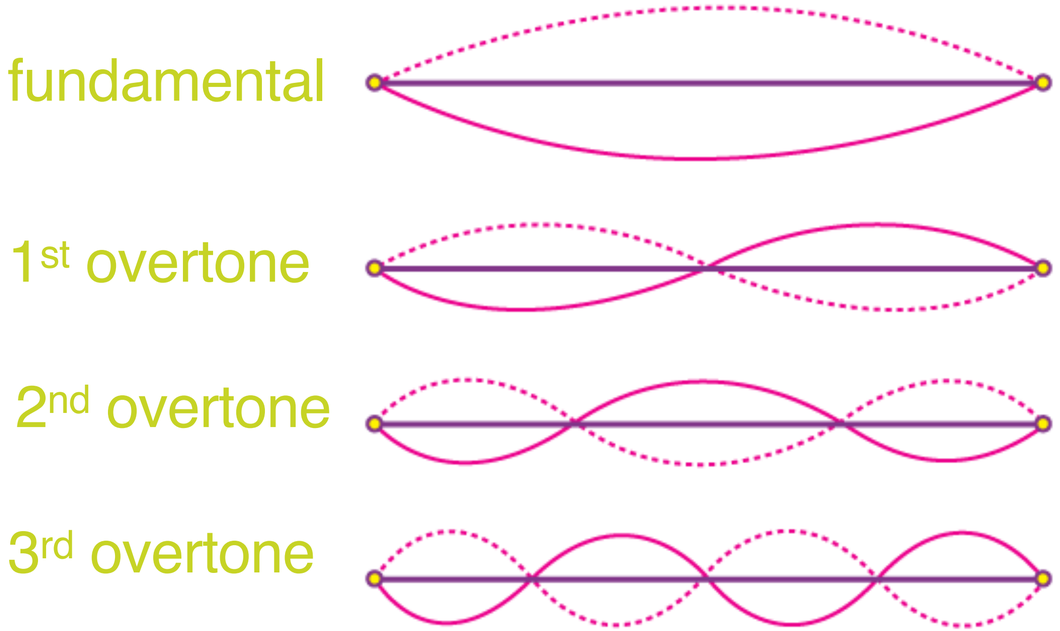
- Complex sounds (like human voices, musical instruments, or rushing water) are actually blends of multiple sine waves

- This specific mix of waves at any moment is called a spectrum, and each individual wave within it is a partial



Overtone Series

- The lowest frequency is the fundamental, while the higher waves are labeled overtones and numbered in order
- For instance, in a sound made of $100\ \text{Hz}$, 260Hz, and $400\ \text{Hz}$ waves, the fundamental is $100\ \text{Hz}$ and the overtones are $260\ \text{Hz}$ and $400\ \text{Hz}$
- More concretely, $260\ \text{Hz}$ is called the first overtone while $400\ \text{Hz}$ is called the second overtone

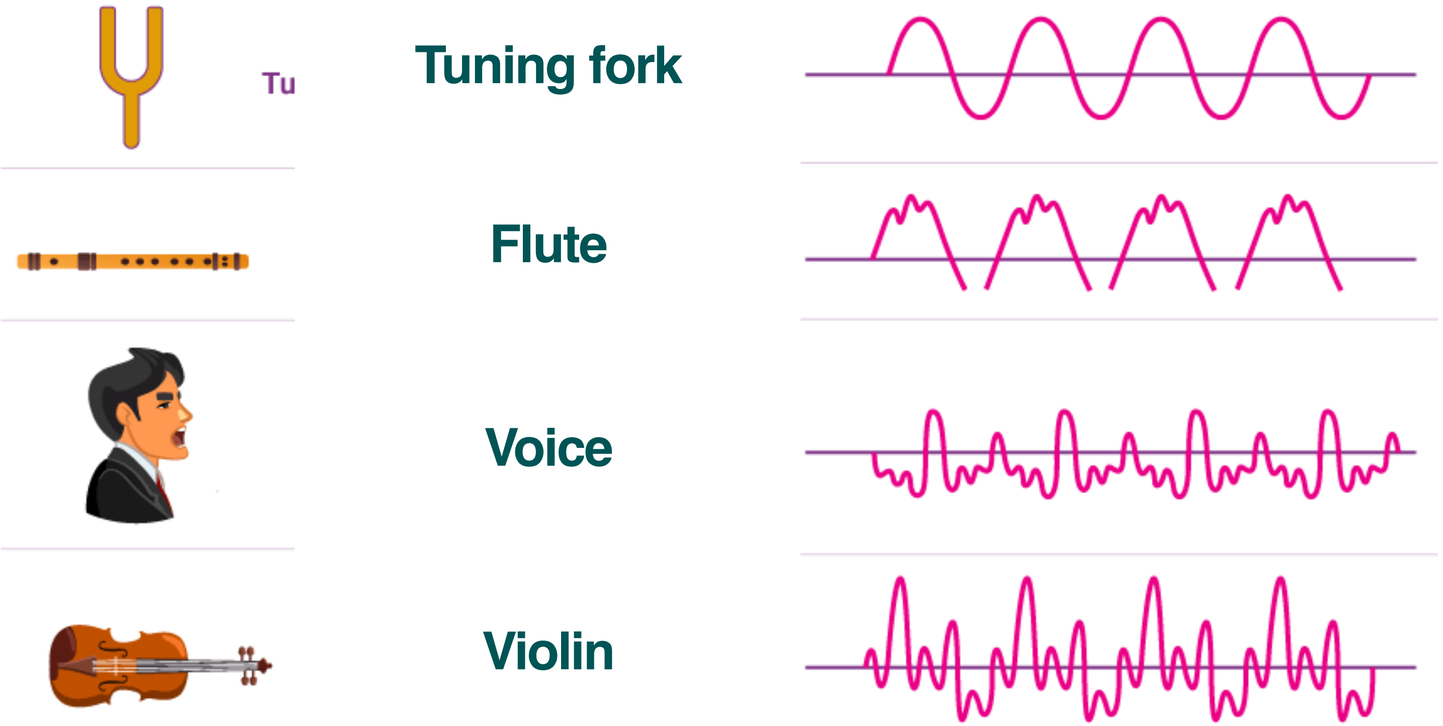


Sound's Timbre

- In music theory, the set of overtones is a key component that defines a sound's timbre,

  which is why different instruments sound unique even when playing the same pitch Importantly, this harmonic structure is not fixed; individual partials can change over time

- In fact, some overtones may fade away entirely while new ones emerge as the sound evolves



Overtones: Harmonic vs. Inharmonic

- Overtones are categorized as harmonic if they are integer multiples of the fundamental frequency and inharmonic if they are not
- While natural environmental sounds like rain or thunder are typically inharmonic, musical instruments -- especially those utilizing vibrating strings (e.g., guitar, violin) or air columns (e.g., trumpet, saxophone, flute) -- produce harmonic overtones because the physical length of the instrument constrains the waveforms to whole-number ratios

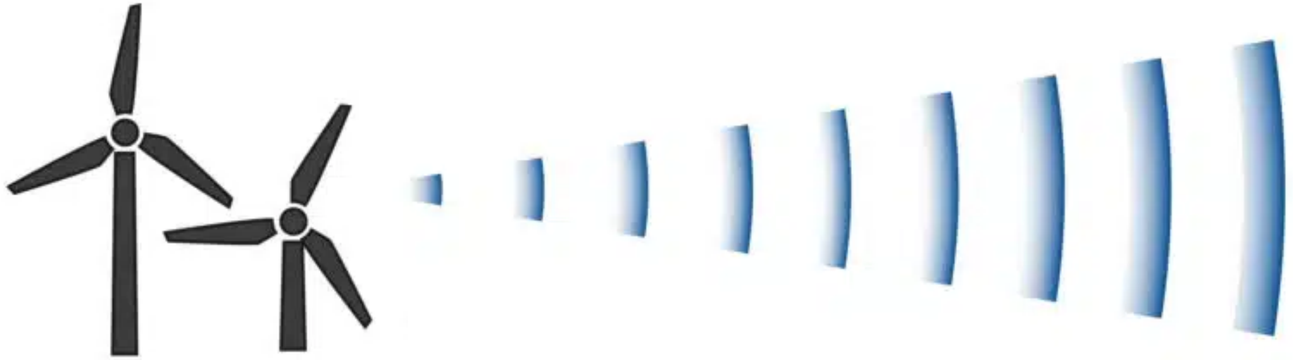
Propagation of Pressure Waves

- Pressure waves propagate through space at a finite speed determined by intermolecular collisions within a gas, representing an intrinsic property of the gas rather than a factor of the source's velocity
- As molecular interaction times limit propagation speed, pressure waves produced by moving sources (such as a speaker on a vehicle) travel at the same speed through the medium as waves produced by stationary sources

Speed of Pressure Waves

- We have seen that the speed of pressure waves in a gas depends on the frequency of molecular collisions

- When molecules collide more often, compression pulses can more effectively shift them into adjacent areas



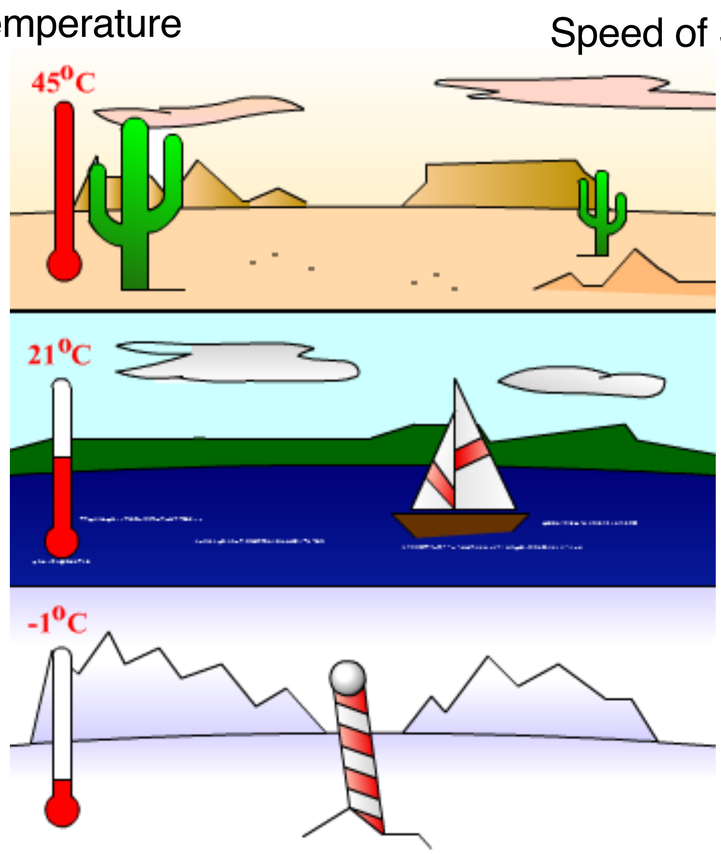
- Since collision rates are driven by molecular velocity, which is itself a function of temperature, a direct link exists between a gas's temperature and its ability to propagate pressure waves

Speed of Pressure Waves

- Specifically, the speed of pressure waves in an ideal gas, expressed in terms of the Boltzmann constant k_B is given by

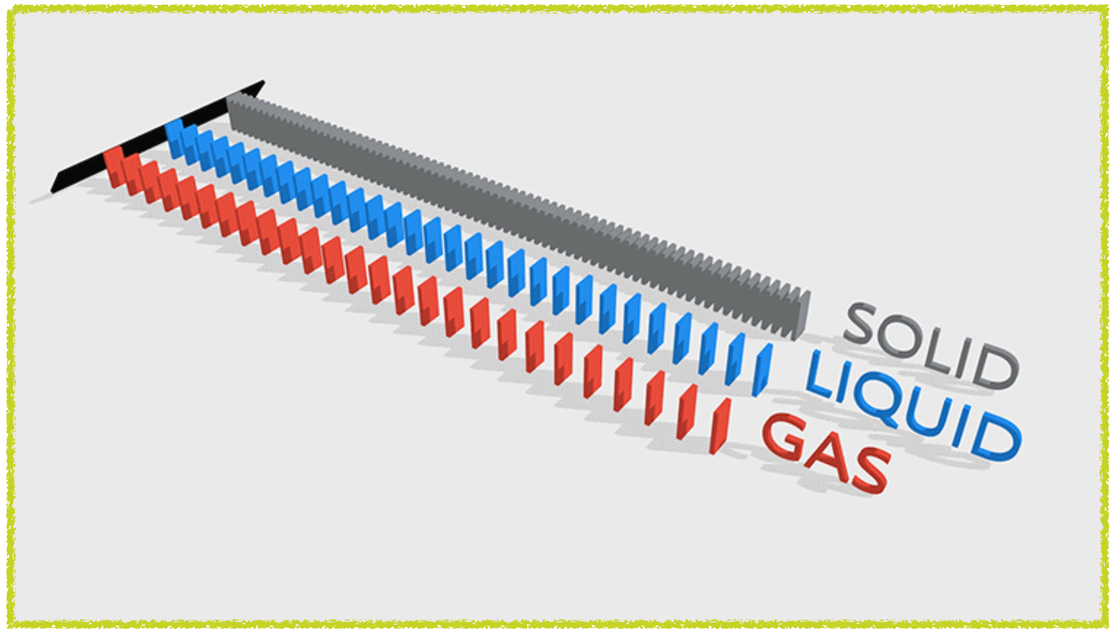
$$\text{speed of pressure waves} \equiv u = \sqrt{\frac{\gamma\ k_B T}{m}}$$

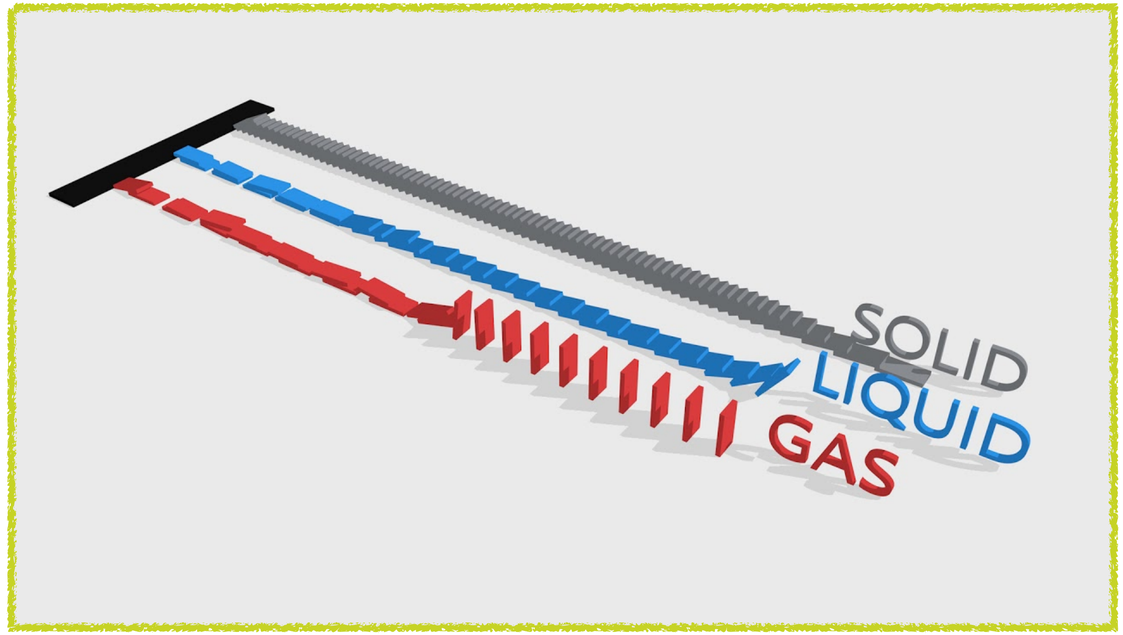
where T is the absolute temperature (measured in K), m is the mass of one molecule (measured in kg), and γ is the *adibatic gas index* a dimensionless parameter (always > 1; e.g., 1.4 for air) that characterizes the behavior of an ideal gas during an adiabatic process, where no heat is transferred



Why Sounds Travels Faster in Solids than in Air

- Sound waves travel faster in solids than in liquids or gases primarily because the particles in a solid are tightly packed together and strongly bonded, allowing vibrational energy to transfer rapidly

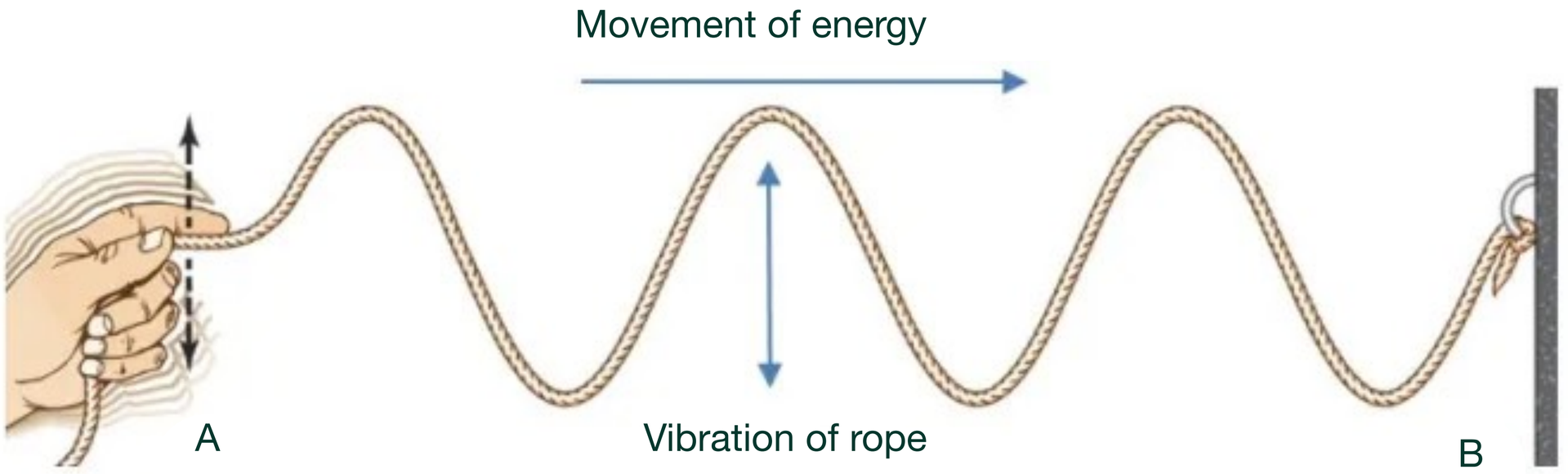




Transverse Waves on a String

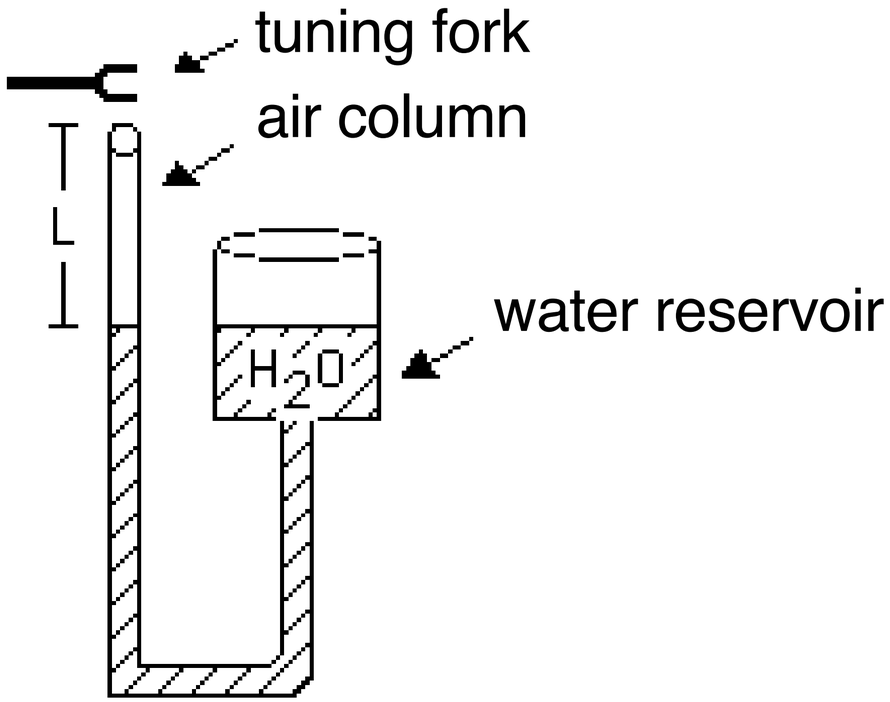
- Transverse waves on a string are caused by a perpendicular vibration and depend on different properties of the string itself, rather than the bulk material properties of the medium
- Indeed the speed of a transverse wave on a string is $u = \sqrt{T/\mu}$ where T is the string tension

  (i.e. force applied to stretch it) and μ the linear mass density (or mass per unit length) of the string



Measuring the Speed of Sound with Standing Waves

- Measuring the speed of sound in air using harmonics is typically done with a resonance tube (an open-closed cavity) and a tuning fork of known frequency f
- By finding the lengths of air column where resonance occurs we can calculate the wavelength and subsequently the speed of sound



Measuring the Speed of Sound with Standing Waves (cont'd)

- The first harmonic occurs when the column air is 1/4 of the wavelength of the sound

$$L_1 = \frac{1}{4}\lambda$$

- The next point of maximum loudness (first overtone) occurs when the air column is 3/4 of the wave of sound,

$$L_2 = \frac{3}{4}\lambda$$

- This implies that ☛ $\Delta L = L_2 - L_1 = \lambda/2$

- The speed of sound in air is ☛ $u = \lambda f = 2\Delta L\, f$

Measuring the Speed of Sound with Standing Waves (cont'd)

- Using two harmonics eliminates the need to calculate the border effects at the top of the tube

- For example, a sound wave of $512\ \text{Hz}$ propagating inside the resonant tube at $284.31\ \text{K}$ leads to $L_1 \simeq 16\ \text{cm}$ and $L_2 \simeq 49\ \text{cm}$, yielding $u \simeq 338\ \text{m/s}$

- The speed of sound in air, as a function of temperature, is measured to be

$$u \approx 331.3\sqrt{\frac{T}{273.15\ \text{K}}}\ \text{m/s}$$

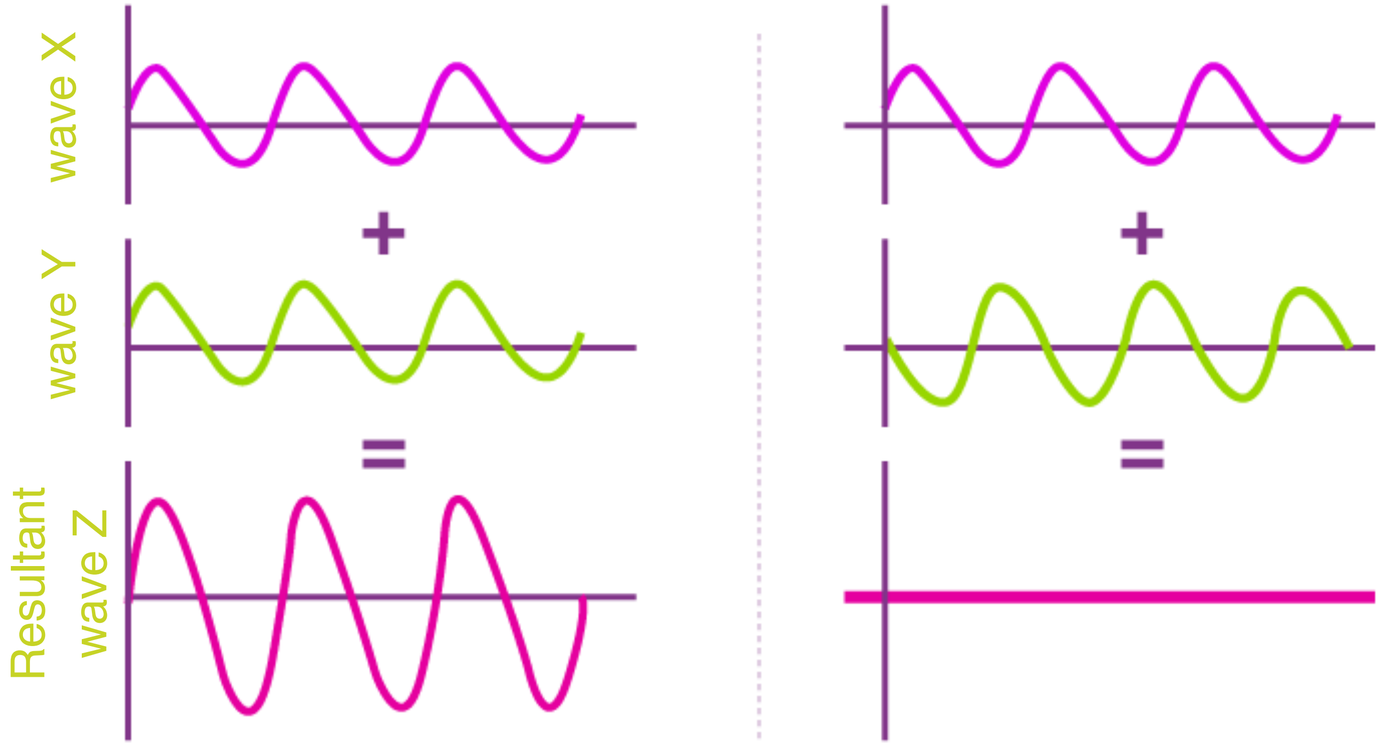
Measuring the Speed of Sound with Destructive Interference

- Measuring the speed of sound with toilet rolls is an alternative hands-on experiment that uses the principle of destructive interference to determine the sound's wavelength

- In this setup, you typically use a pair of wired earbuds (two coherent sources) inside a tube (made of toilet rolls), looking for the *quiet spots* where the sound almost disappears
- When the two earbuds are separated by exactly half a wavelength $(\lambda/2)$, the peak of the wave from one earbud meets the trough of the wave from the other
- They cancel each other out, creating a {\it node} of silence
- By measuring the distance between two consecutive quiet spots we can find the wavelength, and then use it to calculate the speed u

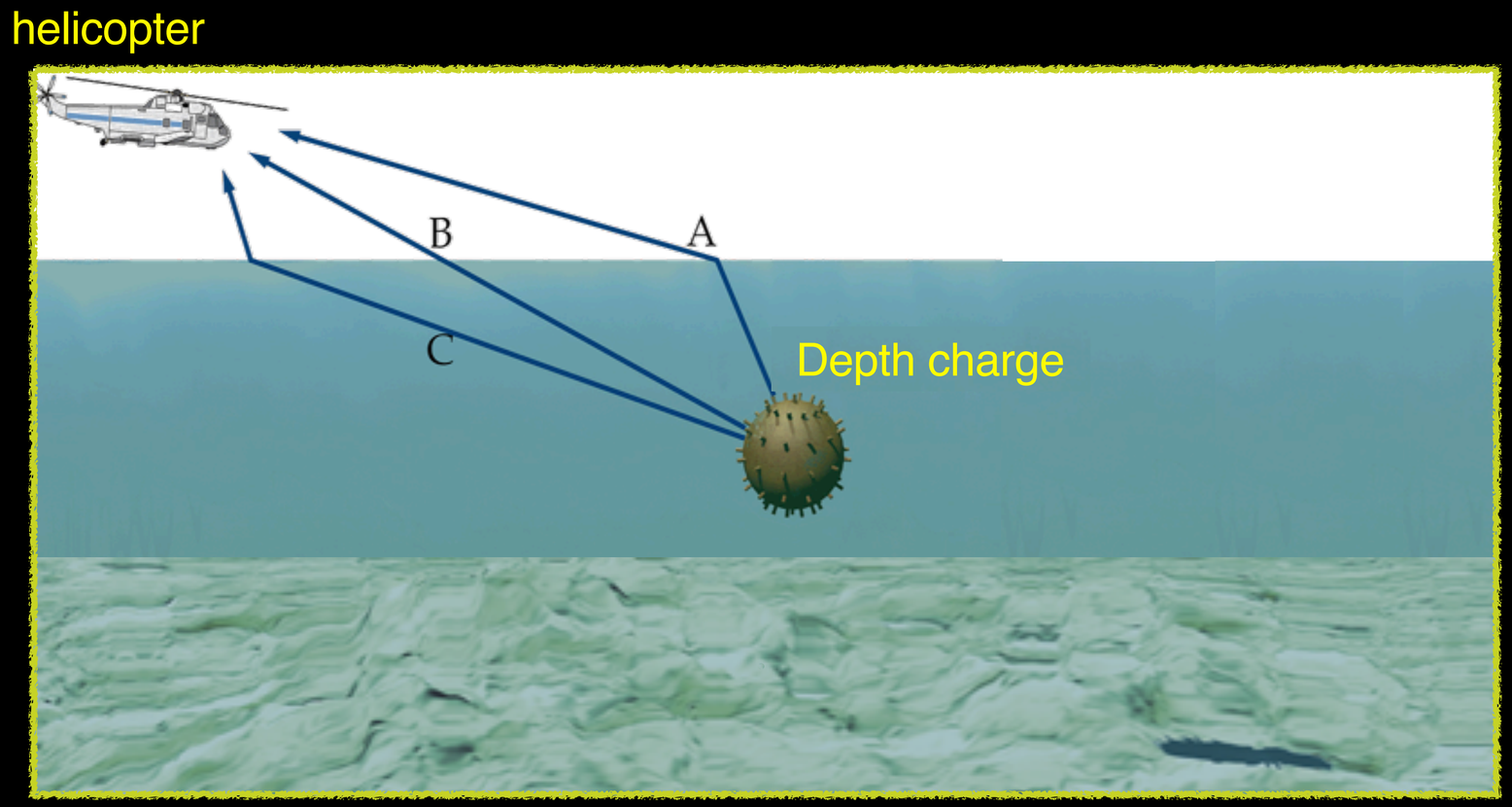
Differences is Sound Speed Experiments

- In sound speed experiments, the difference between *destructive* and *constructive* interference depends on whether you are measuring phase cancellation between two sources (the toilet roll method) or resonance in a standing wave (the water tube method)



Explosion of a depth charge beneath surface of a body of water is recrded by an helicopter hovering above water's surface as shown in figure

Along which path (A, B or C) will sound wave take least time to reach helicopter?



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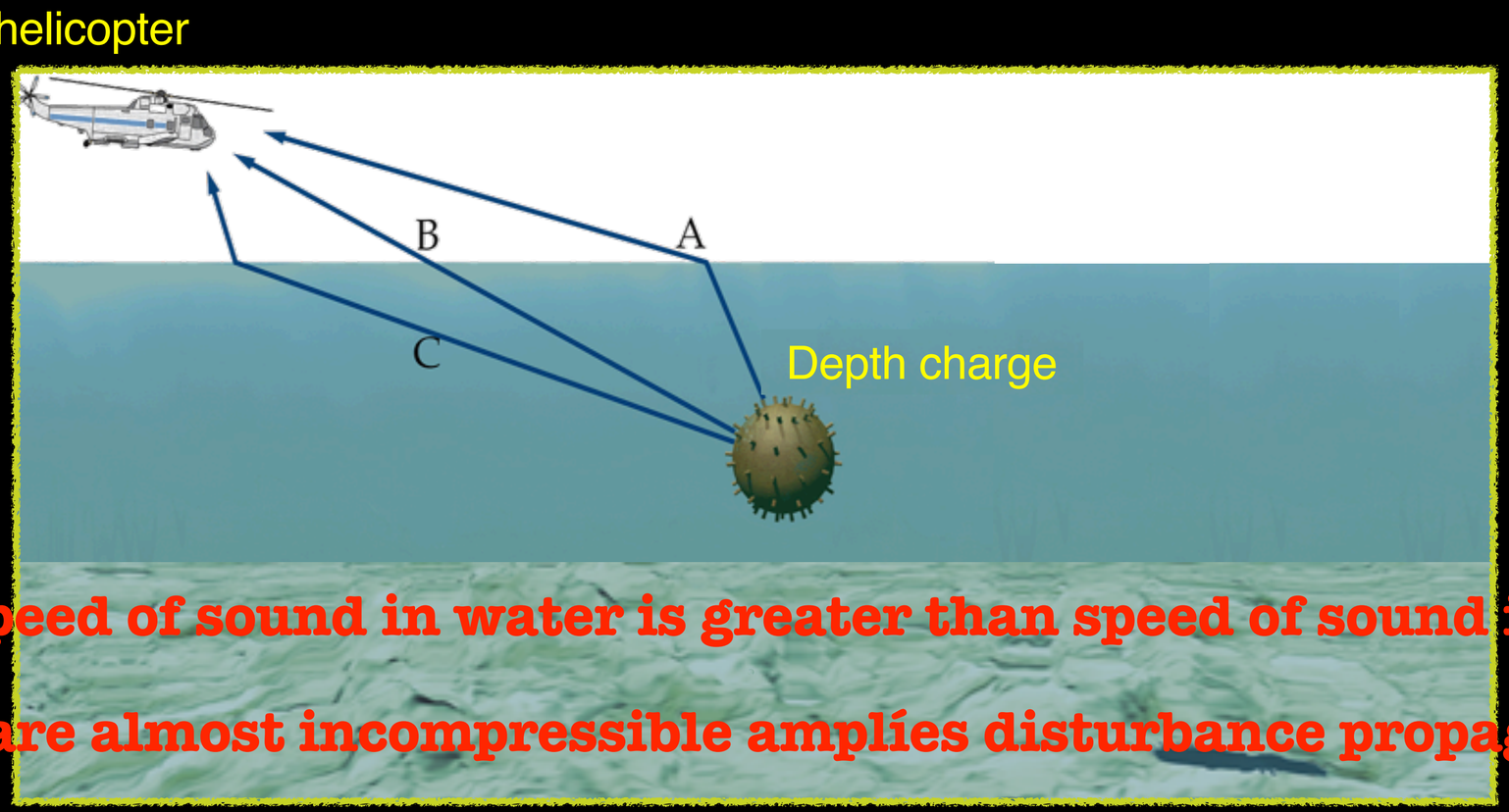
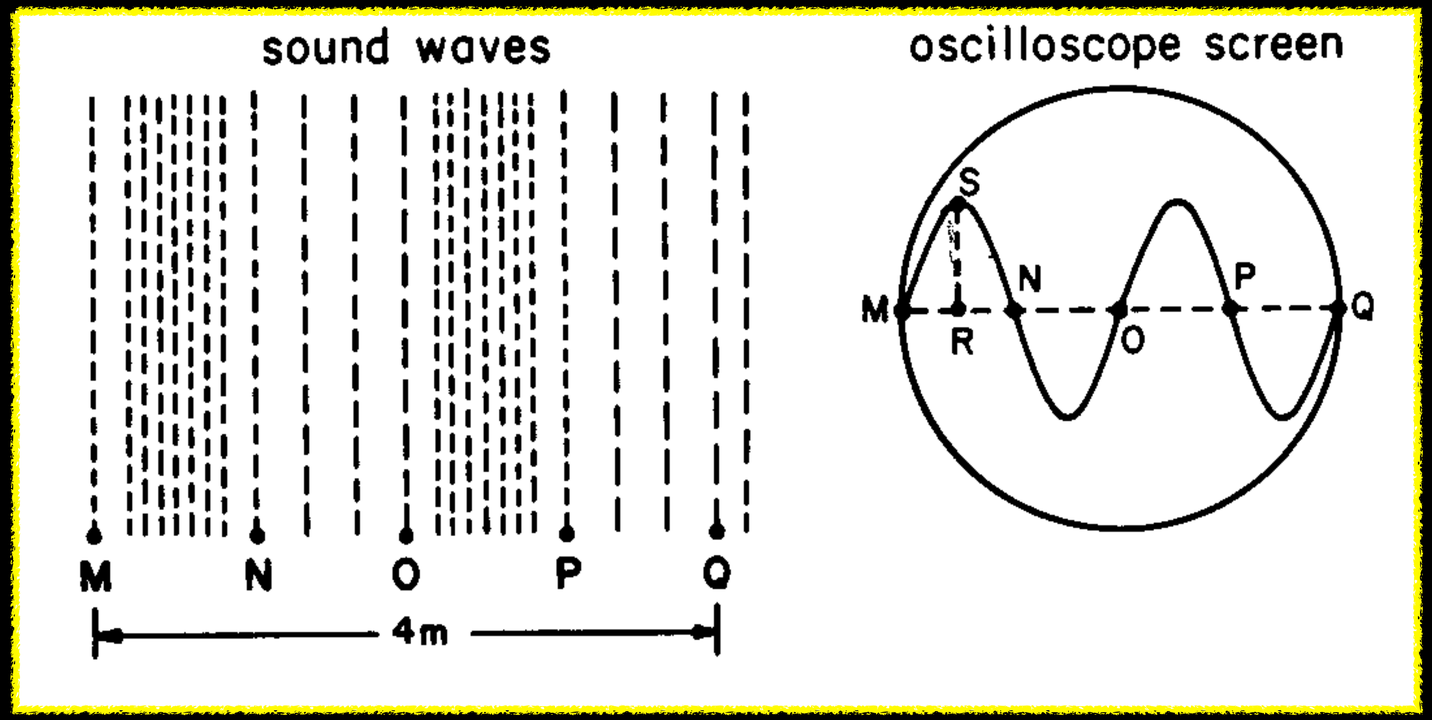


Speed of sound in water is greater than speed of sound in air

☛ path C fluis are almost incompressible amplíes disturbance propagates very quickly

Base your answer to the following question on the accompanying diagram which represents a sound wave and its corresponding pattern on an oscilloscope screen



What type of wave is the sound wave?

A. elliptical

B. transverse

C. torsional

D. longitudinal

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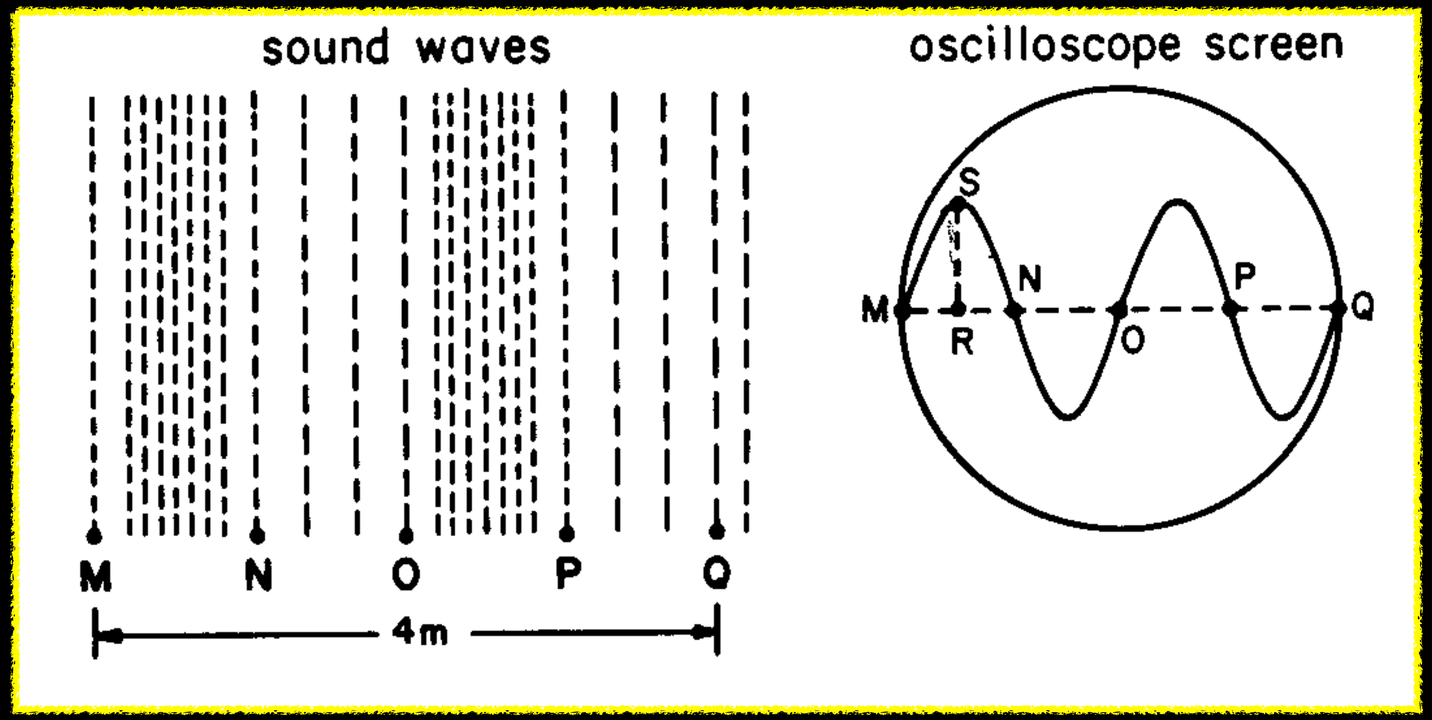

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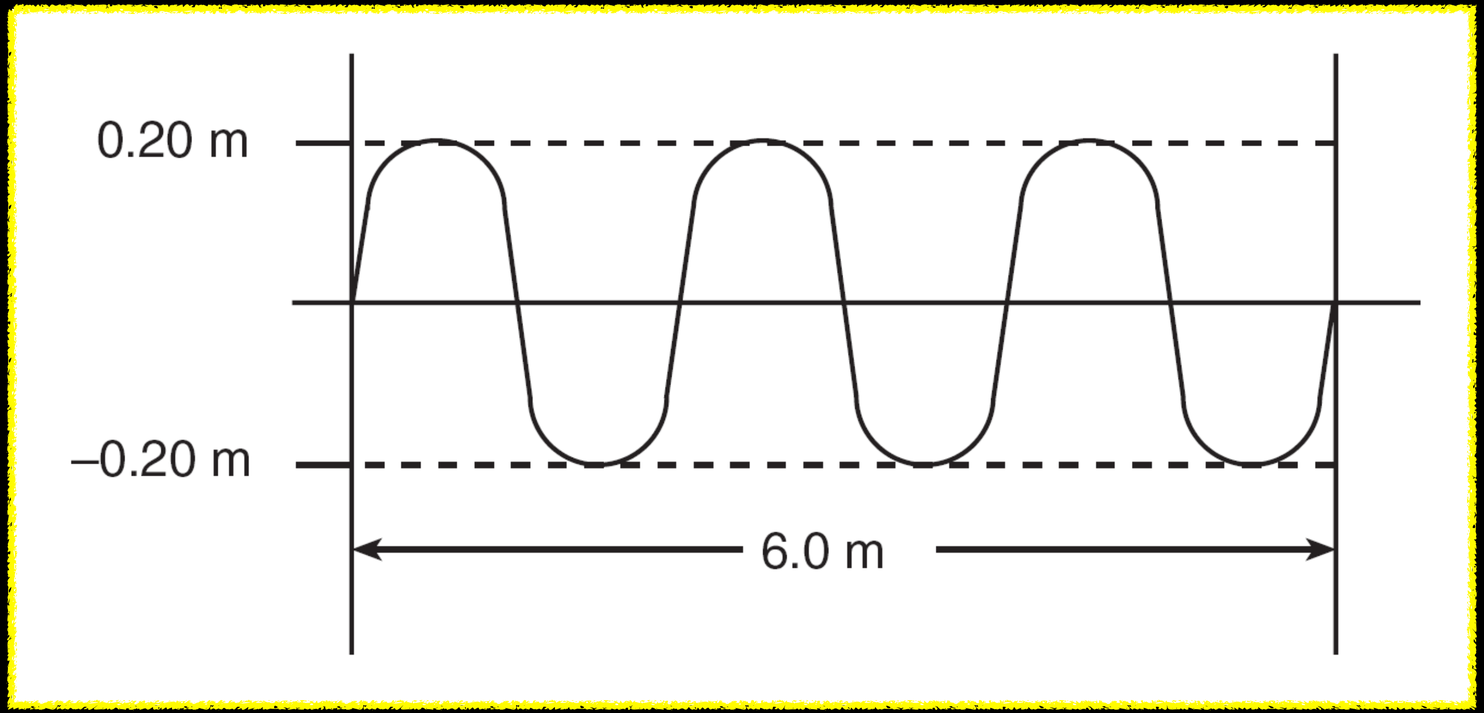

What is the speed of the wave if its frequency is 8.0 hertz?

A. 48 m/s

B. 16 m/s

C. 3.2 m/s

D. 1.6 m/s

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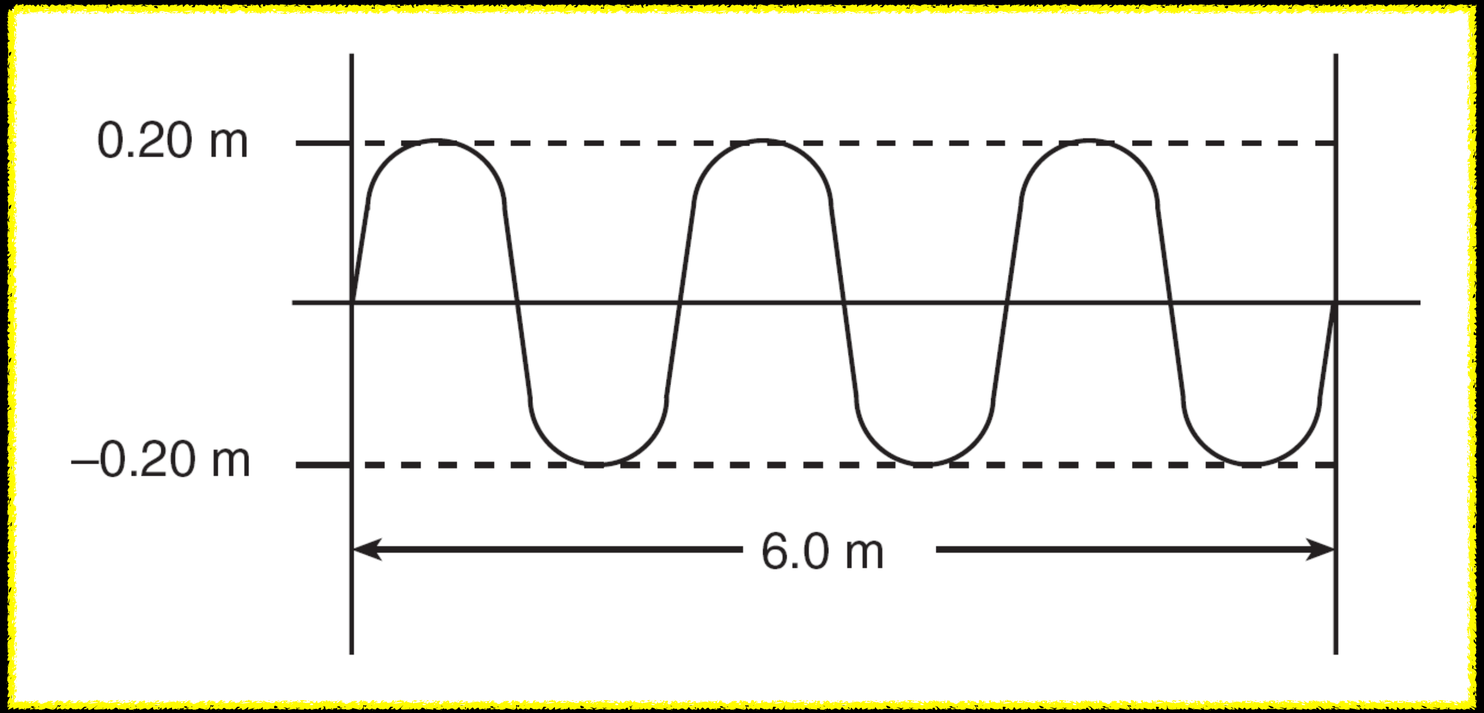

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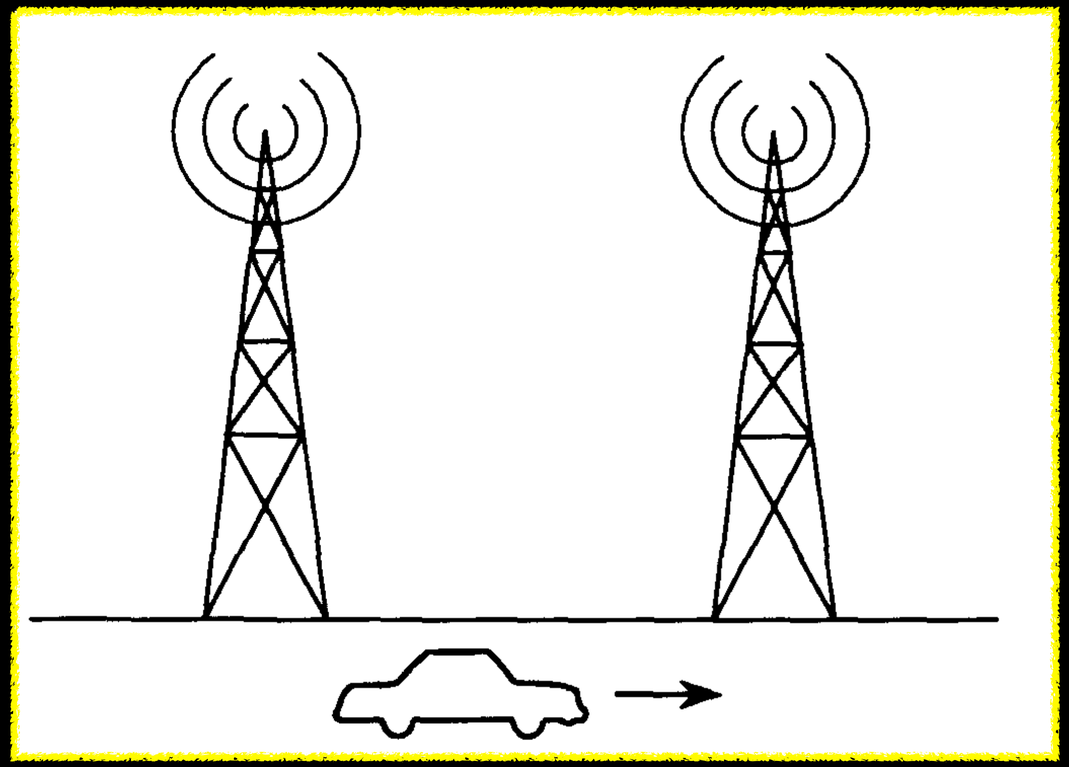

This phenomenon can best be explained by

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B. interference

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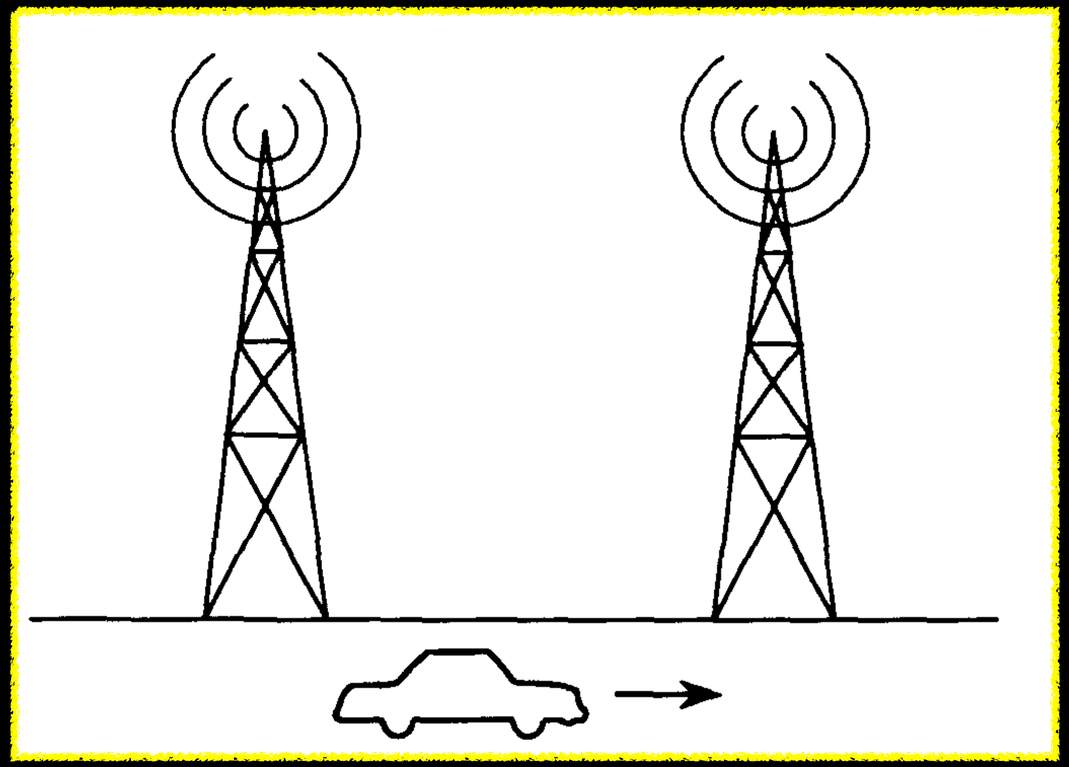

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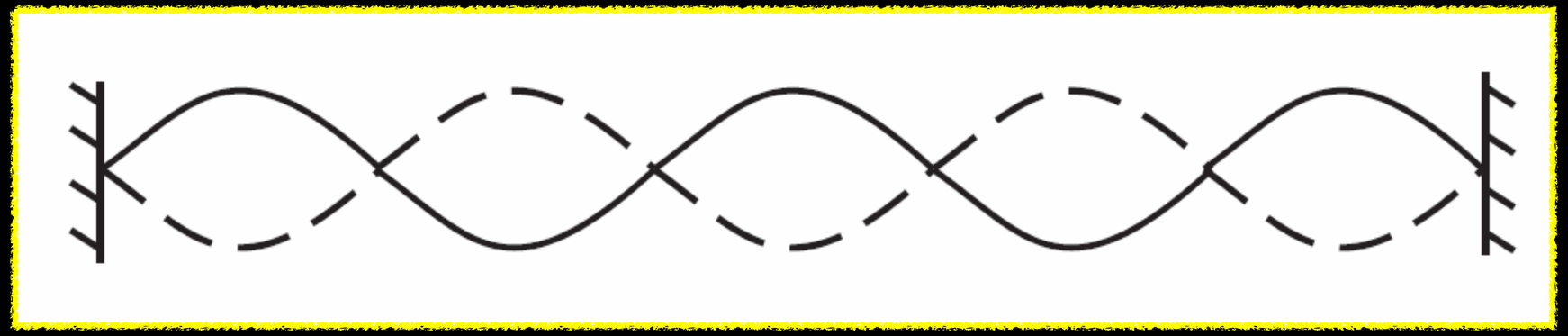

The number of nodes and antinodes shown in the diagram is

A. 4 nodes and 5 antinodes

B. 5 nodes and 6 antinodes

C. 6 nodes and 5 antinodes

D. 6 nodes and 10 antinodes

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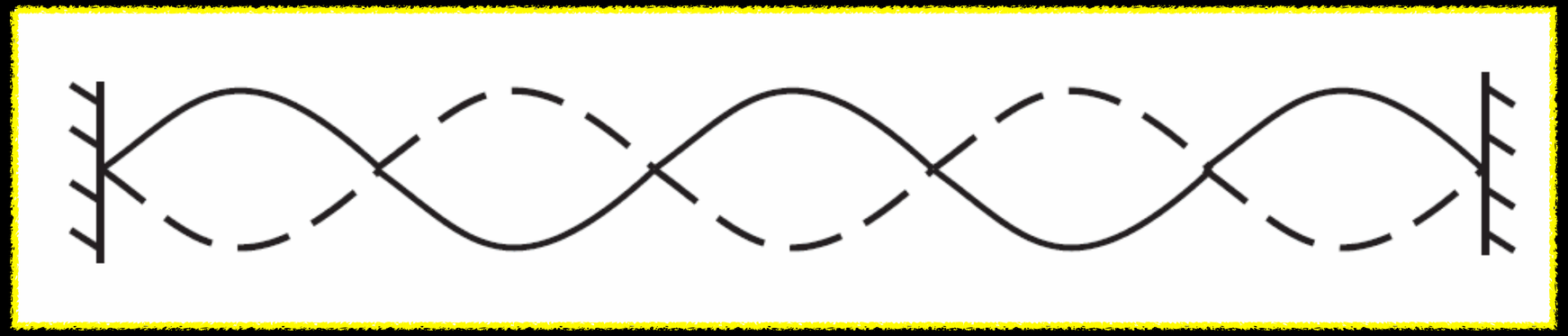

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Wave X travels eastward with frequency f and amplitude A

Wave Y, traveling in the same medium, interacts with wave X and produces a standing wave

Which statement about wave Y is correct?

A. Wave Y must have a frequency of f, an amplitude of A, and be traveling eastward

B. Wave Y must have a frequency of 2f, an amplitude of 3A, and be traveling eastward

C. Wave Y must have a frequency of 3f, an amplitude of 2A, and be traveling westward

D. Wave Y must have a frequency of f, an amplitude of A, and be traveling westward

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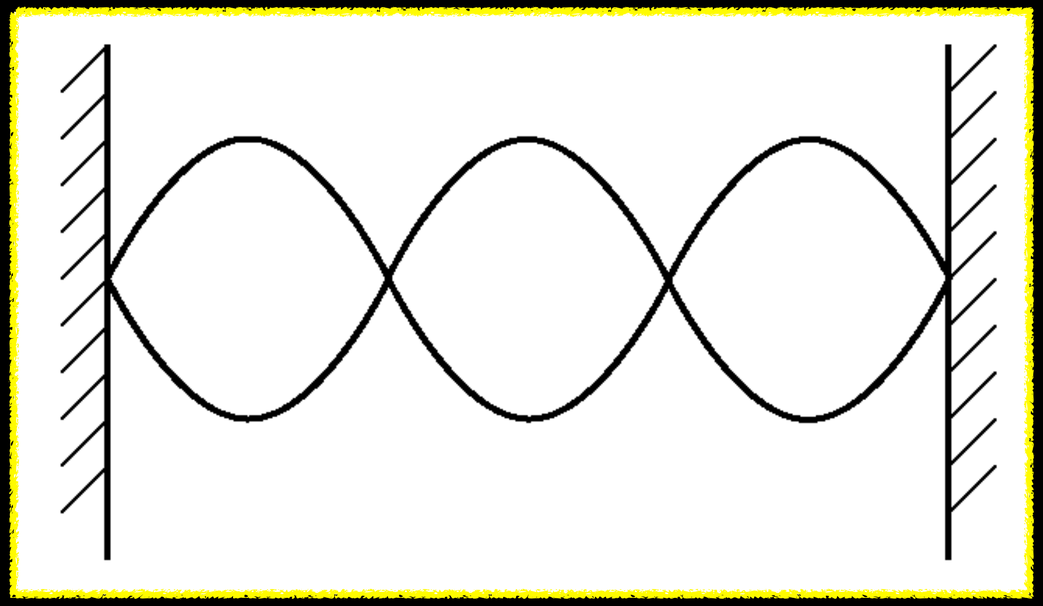

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B. 6

C. 3

D. 4

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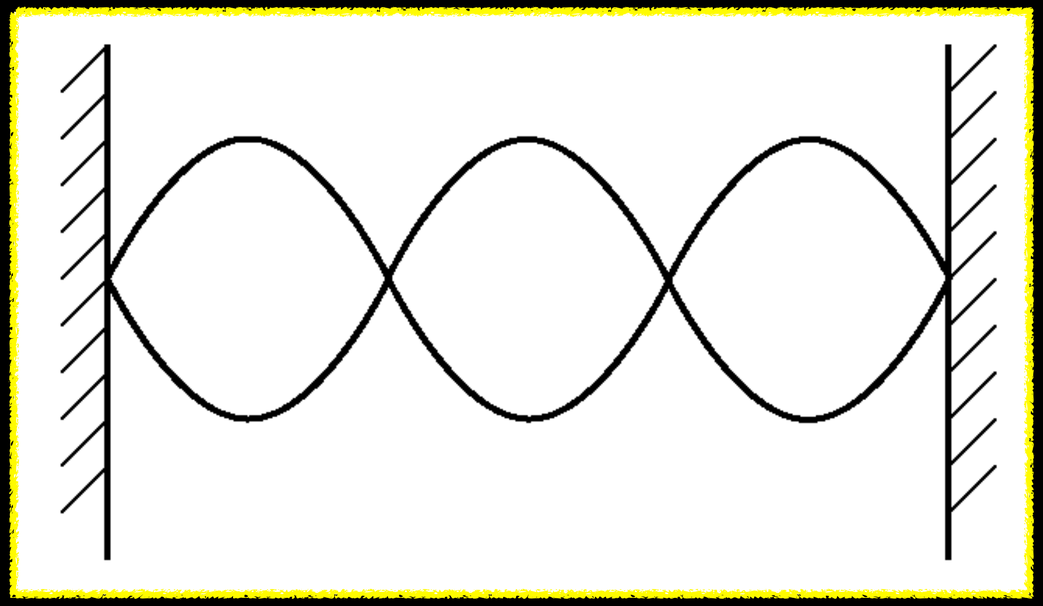

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Standing waves in water are produced most often by periodic water waves

A. being absorbed at the boundary with a new medium

B. refracting at a boundary with a new medium

C. diffracting around a barrier

D. reflecting from a barrier

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Standing waves are produced by the interference of two waves with the same

A. frequency and amplitude, but opposite directions

B. frequency and direction, but different amplitudes

C. amplitude and direction, but different frequencies

D. frequency, amplitude, and direction

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An opera singer's voice is able to break a thin crystal glass if the singer's voice and the glass have the same natural

A. frequency

B. speed

C. amplitude

D. wavelength

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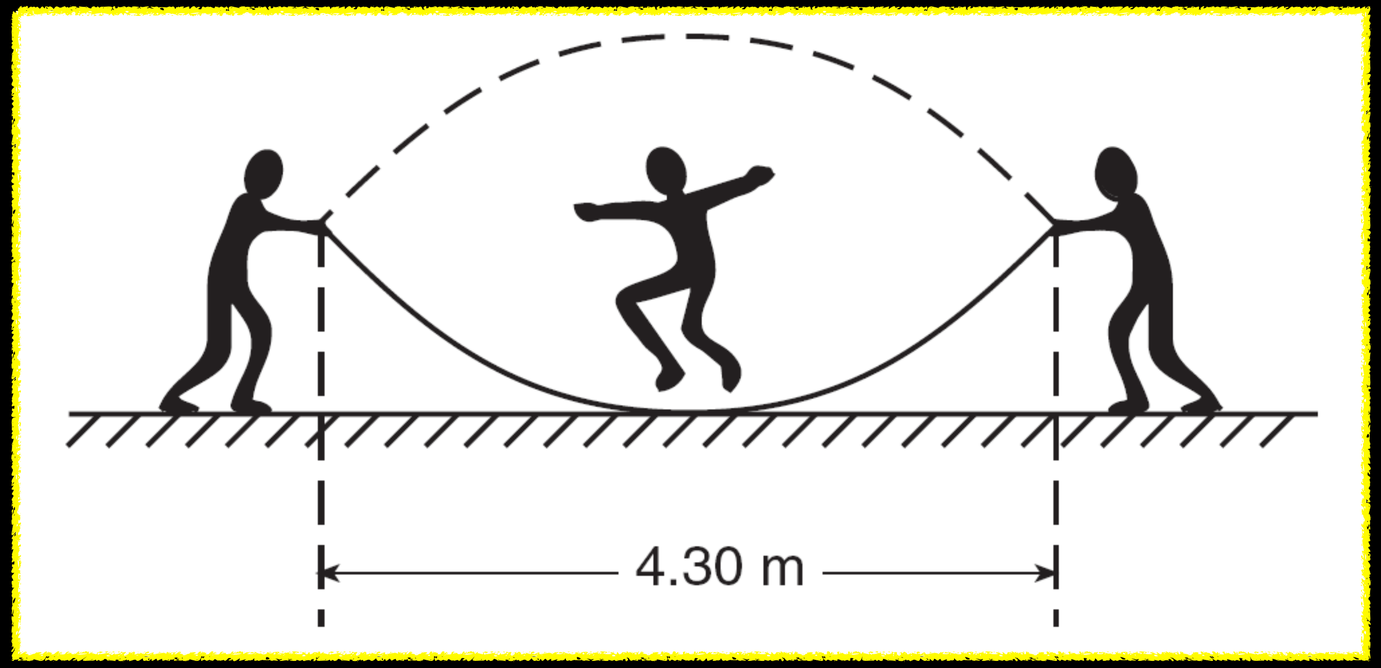
While playing, two children create a standing wave in a rope, as shown in the diagram below

A third child participates by jumping the rope



What is the wavelength of this standing wave?

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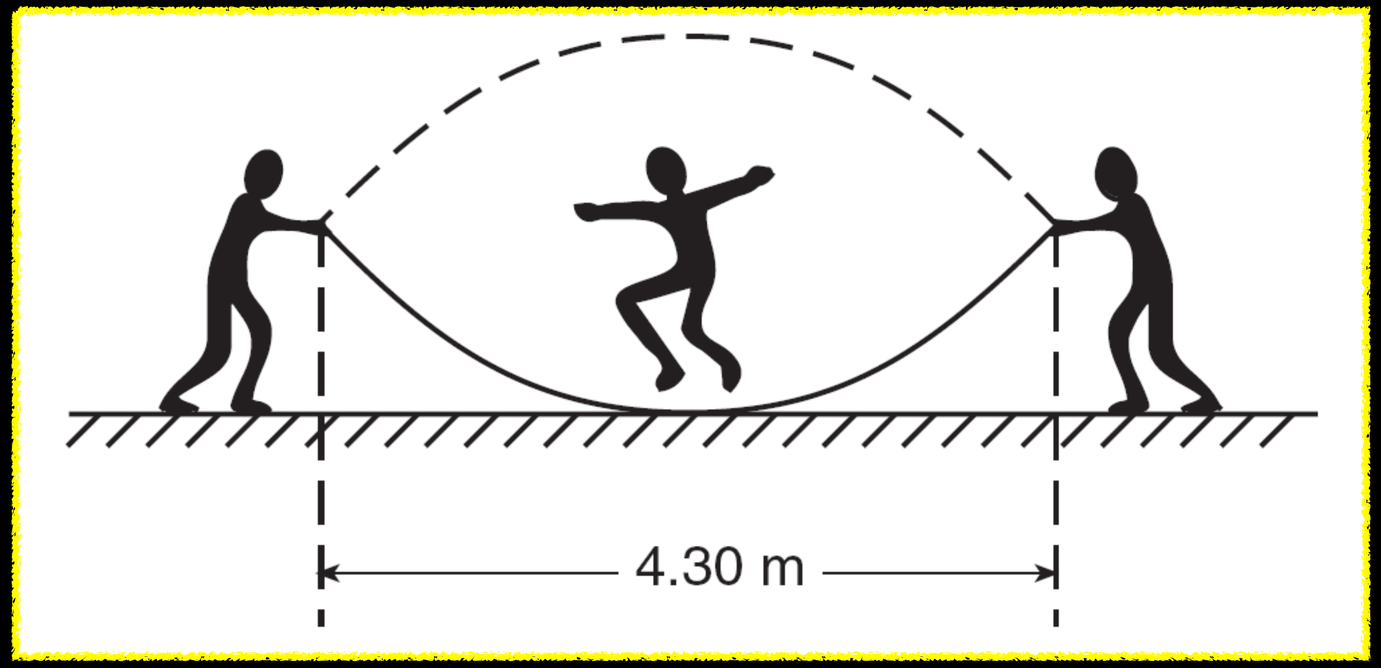

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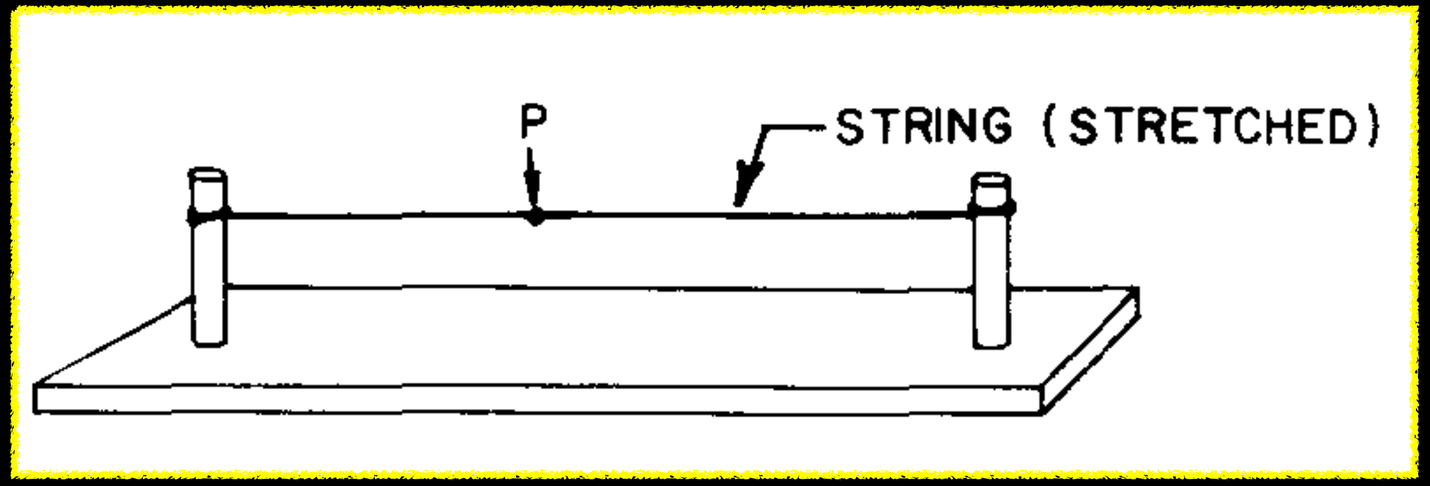
When the stretched string of the apparatus represented below is made to vibrate, point P does not move



point P is most probably at the location of

A. a node

B. an antinode

C. maximum amplitude

D. maximum pulse

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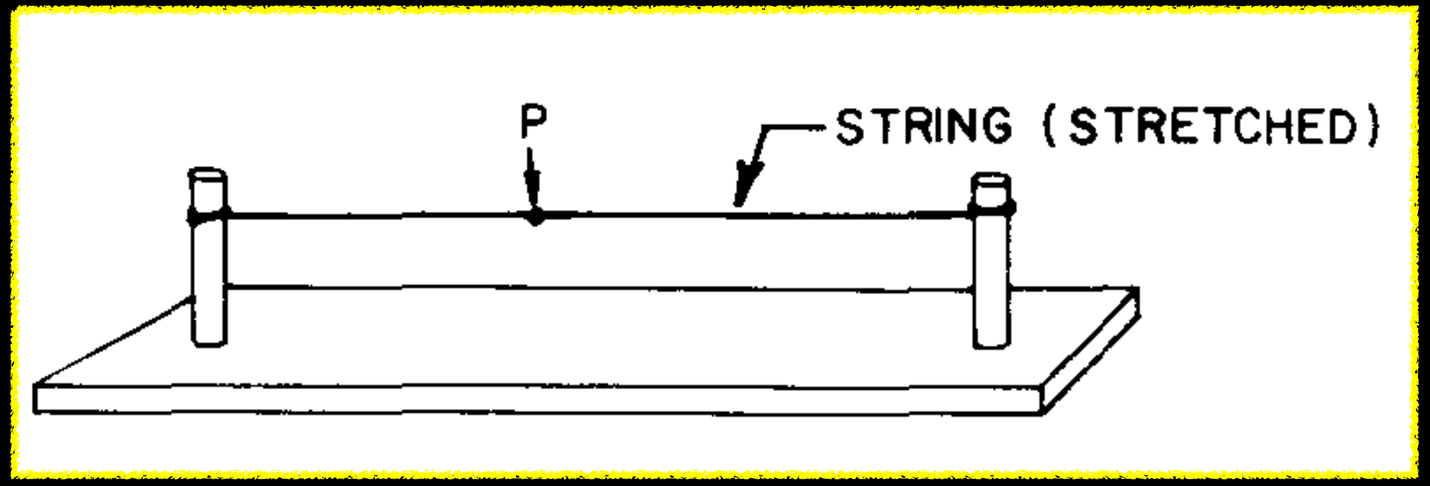

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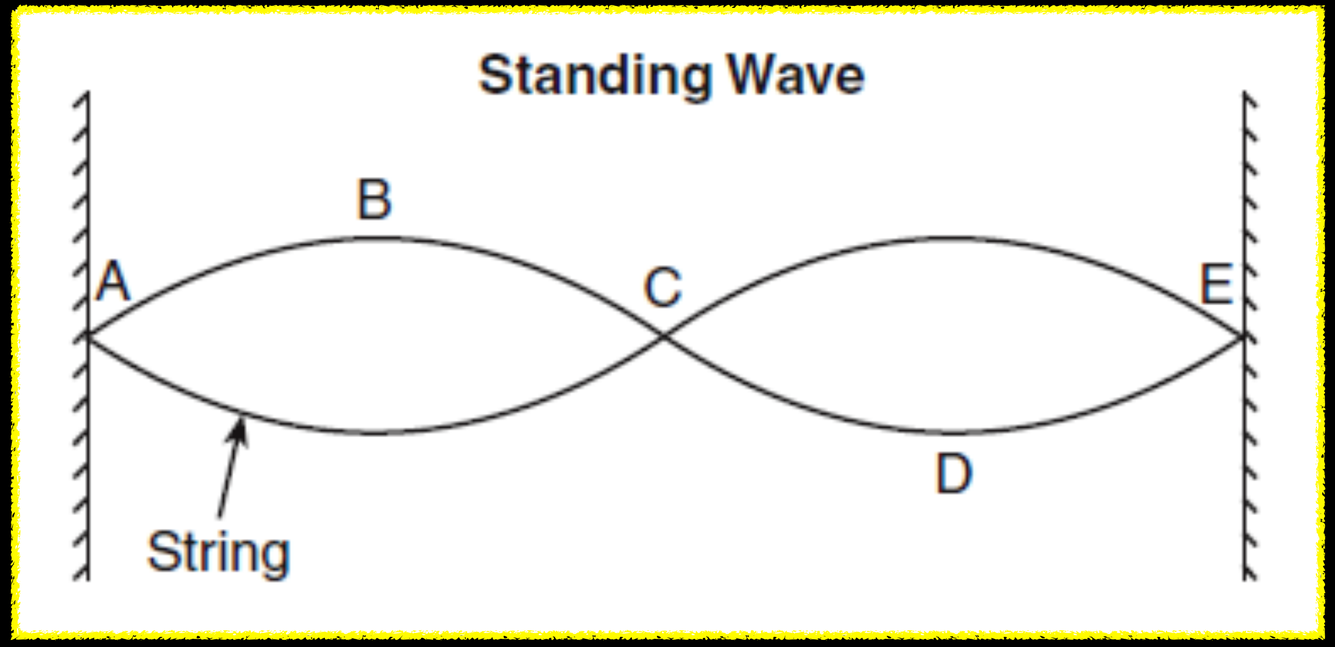

Maximum constructive interference occurs at the

A. antinodes A, C, and E

B. nodes A, C, and E

C. antinodes B and D

D. nodes B and D

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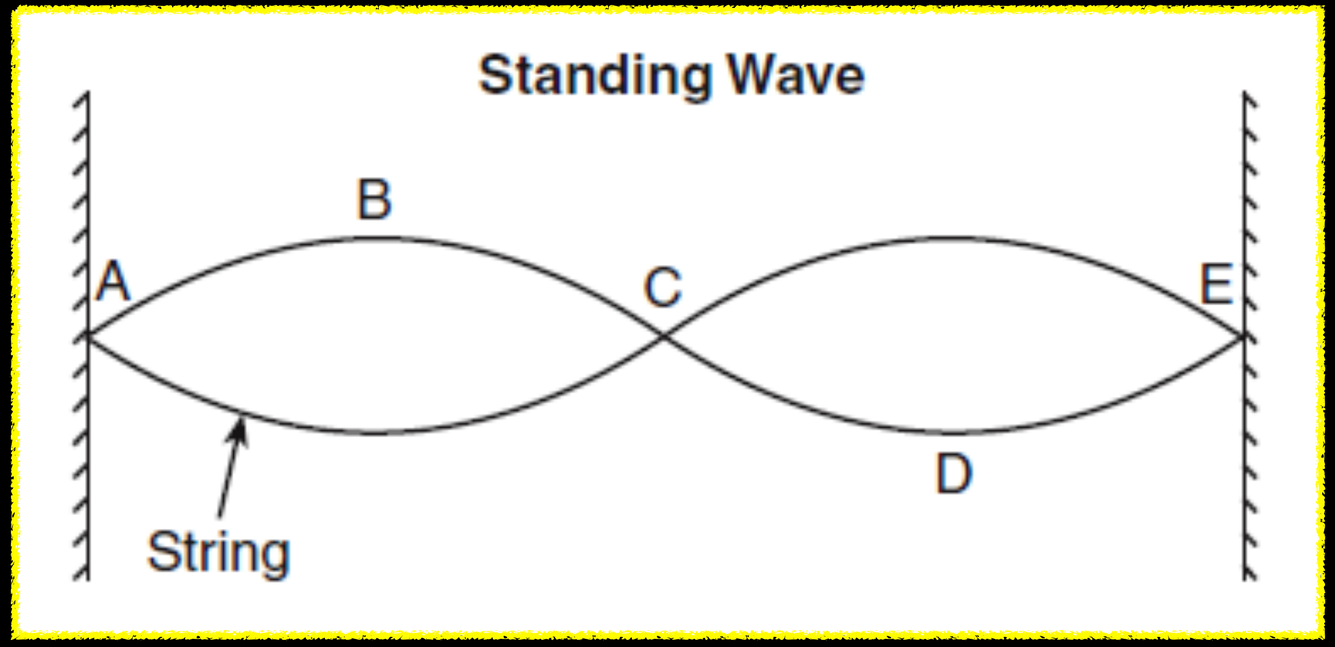

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Two waves traveling in the same medium interfere to produce a standing wave
What is the phase difference between the two waves at a node?

A. 0°

B. 90°

C. 180°

D. 360°

Two waves traveling in the same medium interfere to produce a standing wave
What is the phase difference between the two waves at a node?

A. 0°

B. 90°

C. 180°

D. 360°