Waves, Introduction

Knight Ch. 16

Physics 2C, Spring 2025

Agenda Today (April 7, 2025)

- Waves: Introduction, Categorization
  - Transverse vs Longitudinal
- Wavelength and Period and related quantities
- Snapshot vs. History graphs

sli.do #401391

Waves, Introduction

Waves: A disturbance that propagates through space, transferring energy but not matter.

Waves, Mathematical Form, Parameters

Waves are described mathematically via functions $f(x,t) = f(kx - \omega t)$.

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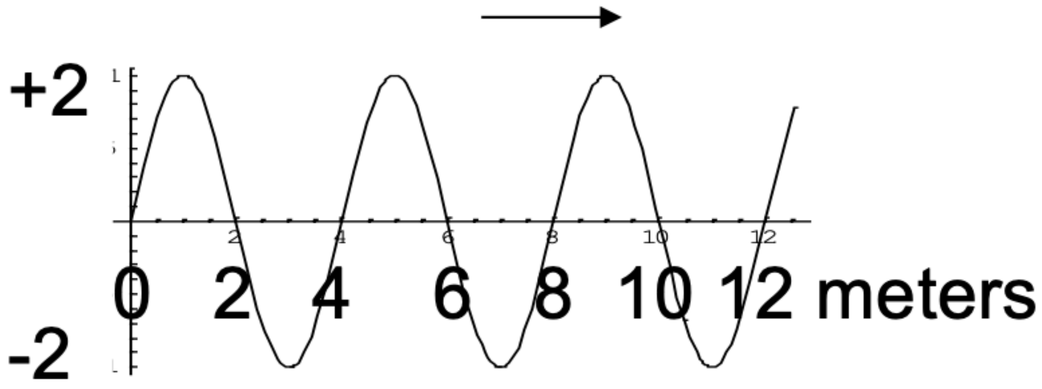
Clicker/Poll Question

The following is a snapshot at t=0 for a transverse wave traveling to the right with velocity 2 m/s. Which of the following equations is correct for this wave?



A. $y(x,t) = 2\sin\left[\left(\frac{\pi}{2}\right)x - (\pi)t\right]$

B. $y(x,t) = 2\sin\left[(\pi)x - \left(\frac{\pi}{2}\right)t\right]$

C. $y(x,t) = 2\sin\left[\left(\frac{\pi}{2}\right)x - \left(\frac{\pi}{2}\right)t\right]$

D. $y(x,t) = 2\sin\left[(\pi)x - (\pi)t\right]$

E. None of these

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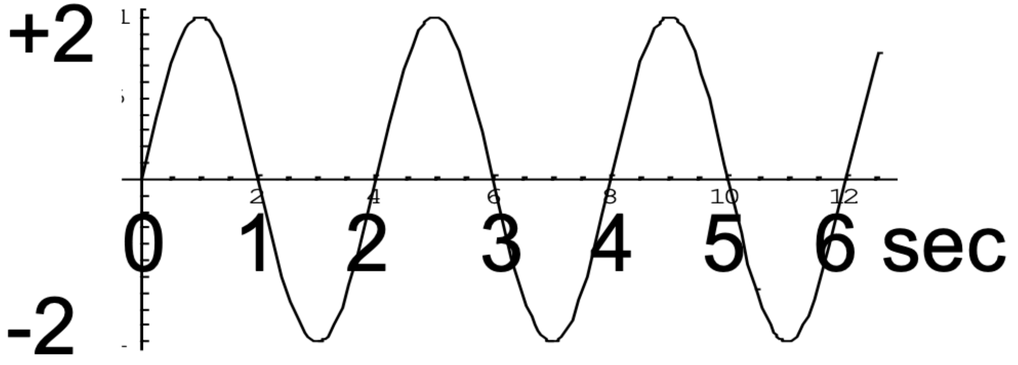
Clicker/Poll Question

The following is a history at x=0m of a transverse wave traveling to the left with velocity 2m/s. Which of the following equations is correct?



A. $y(x,t) = 2\sin\left[\left(\frac{\pi}{2}\right)x + (\pi)t\right]$

B. $y(x,t) = 2\sin\left[(\pi)x + \left(\frac{\pi}{2}\right)t\right]$

C. $y(x,t) = 2\sin\left[\left(\frac{\pi}{2}\right)x + \left(\frac{\pi}{2}\right)t\right]$

D. $y(x,t) = 2\sin\left[(\pi)x + (\pi)t\right]$

E. None of these

Snapshot Graphs vs History Graphs

Snapshot: f(x) at constant t (picture!) ; History: f(t) at constant x (story!)

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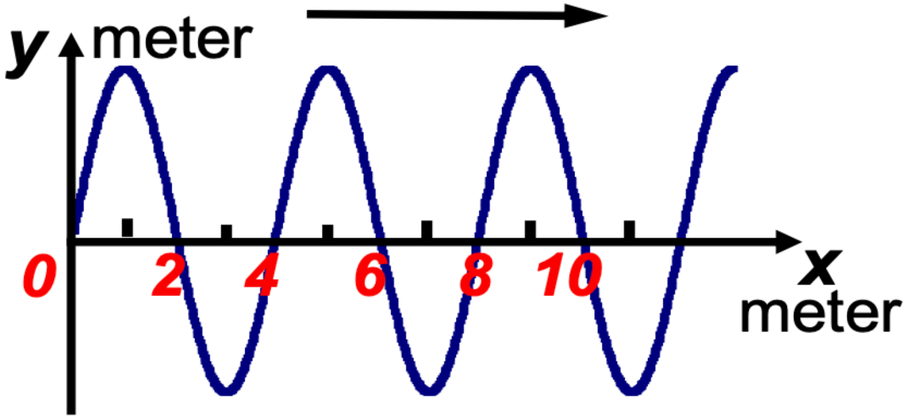
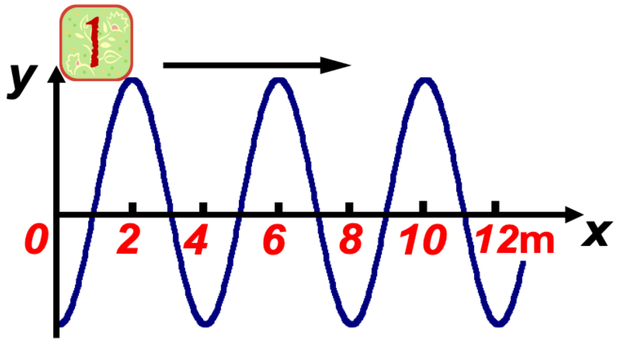
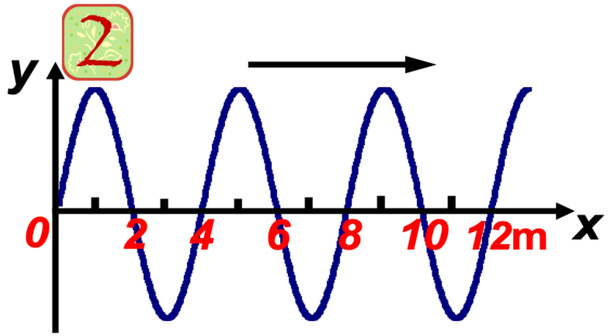
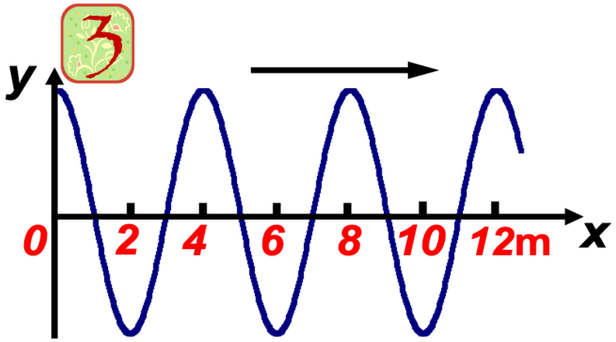
Clicker/Poll Question

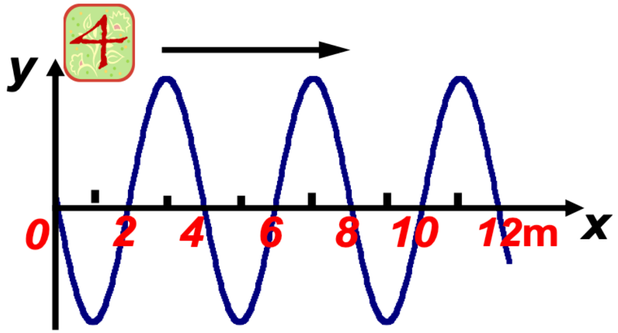
A transverse wave is traveling to the right with velocity 2m/s and wavelength 4m. What will the wave (shown on the right, at t = 0 sec.) look like at t =1.5 seconds?











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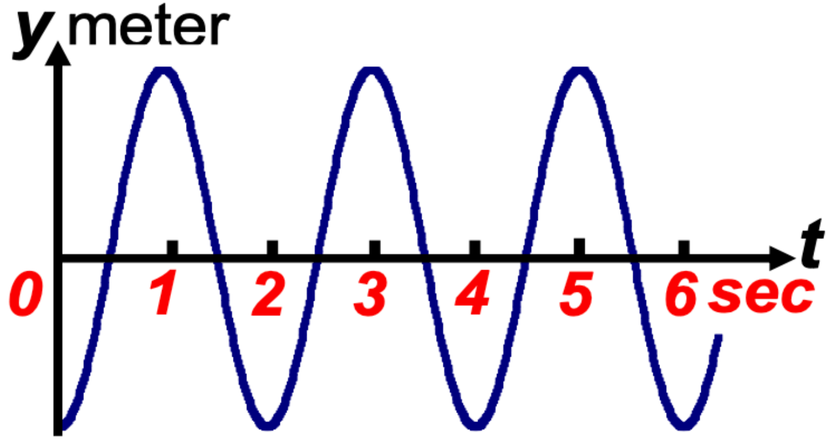
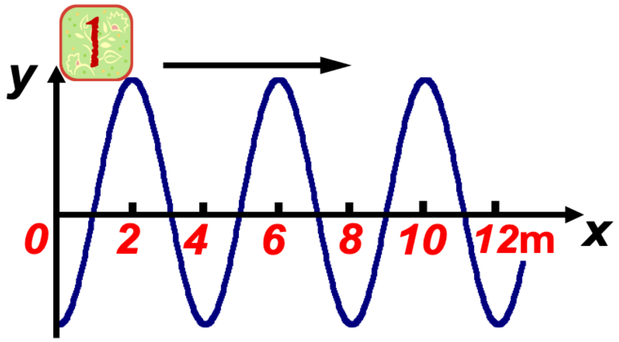
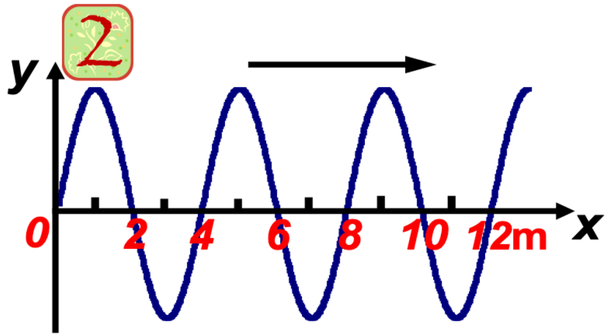
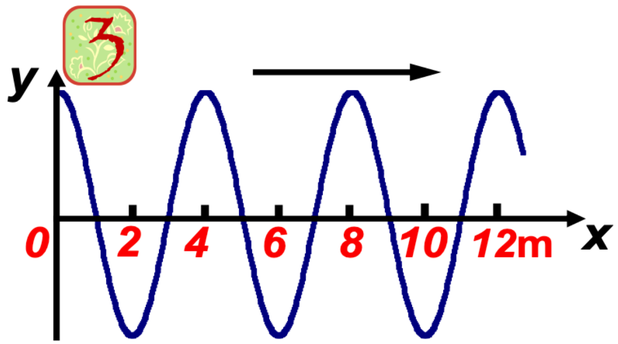
Clicker/Poll Question

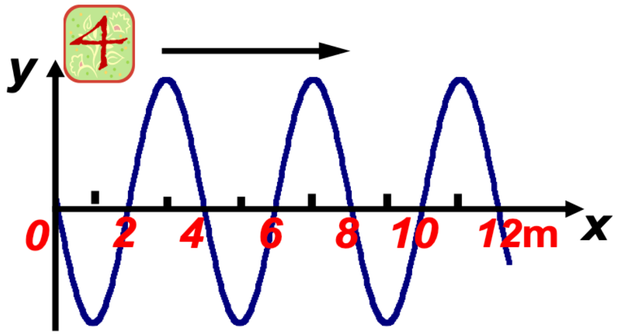
A transverse wave is traveling to the right with velocity 2m/s and wavelength 4m. The following graph describes how the particle at x=3m vibrates. Draw a snapshot of the wave at t=1s.











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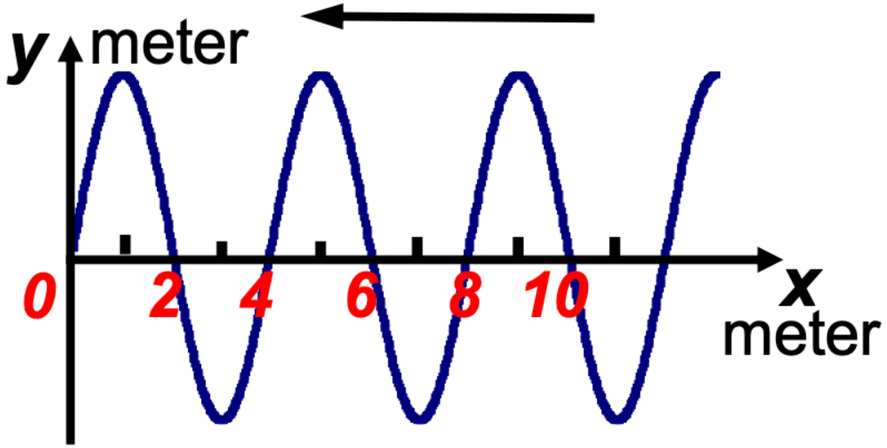
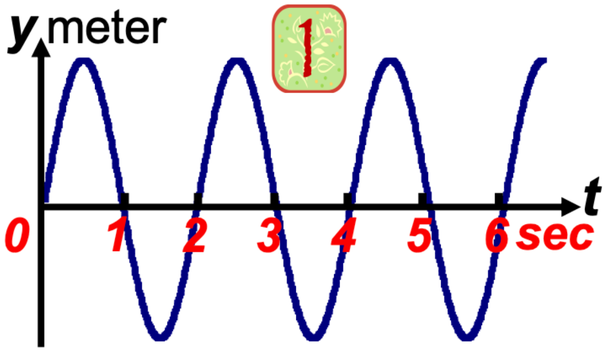
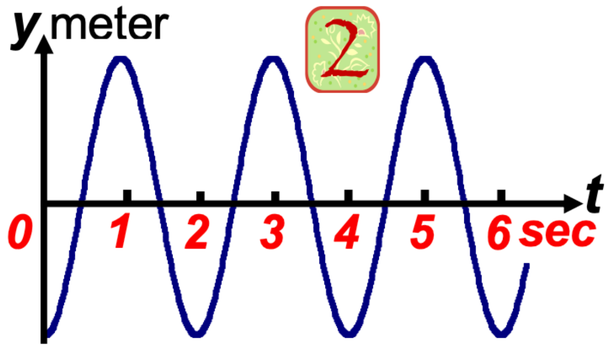
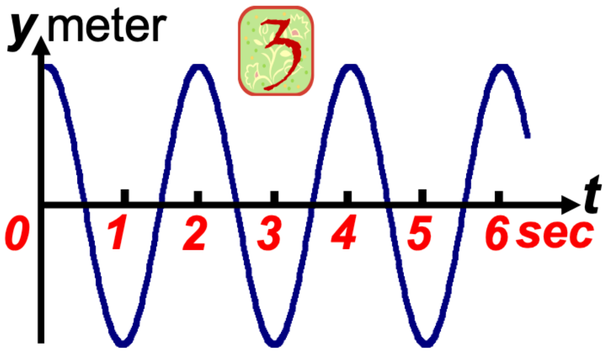
Clicker/Poll Question

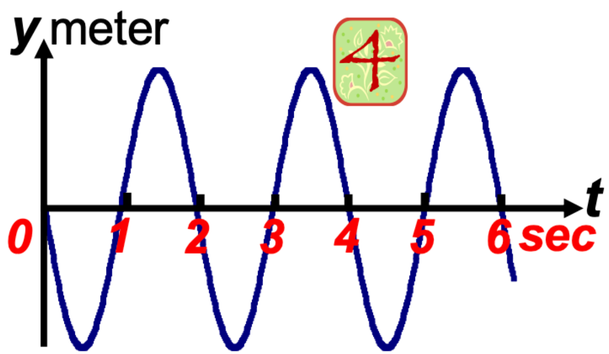
A transverse wave is traveling to left with velocity 2m/s and wave length 4m. The following is a snap shot at t=0 seconds. Which of the following graphs best describes the vibration at *x* = 2m?











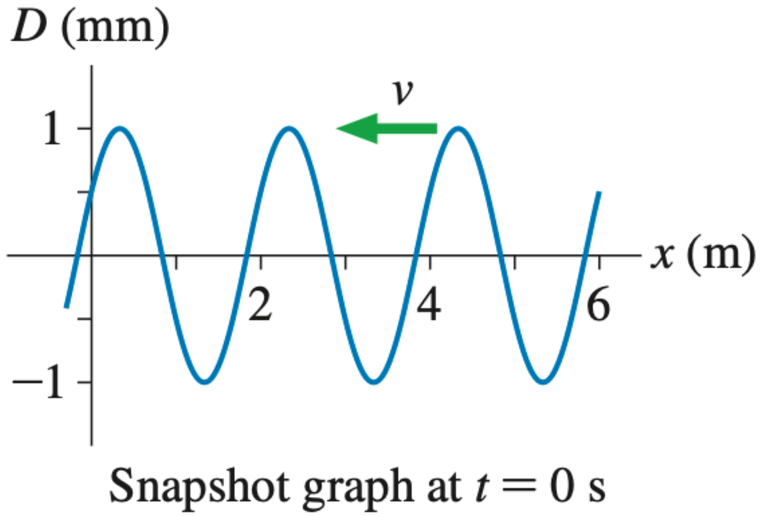
Phase constant ϕ_0

How do we find the phase constant ϕ_0 in $D(x,t) = A\cos(kx - \omega t + \phi_0)$?

Example

The figure to the right is a snapshot graph at $t = 0$ of a 5.0 Hz wave traveling to the left.

a. What is the wave speed?
b. What is the phase constant of the wave?
c. Write the displacement equation for this wave.



Snapshot graph at $t = 0$ s

FIGURE P16.46

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Clicker/Poll Question

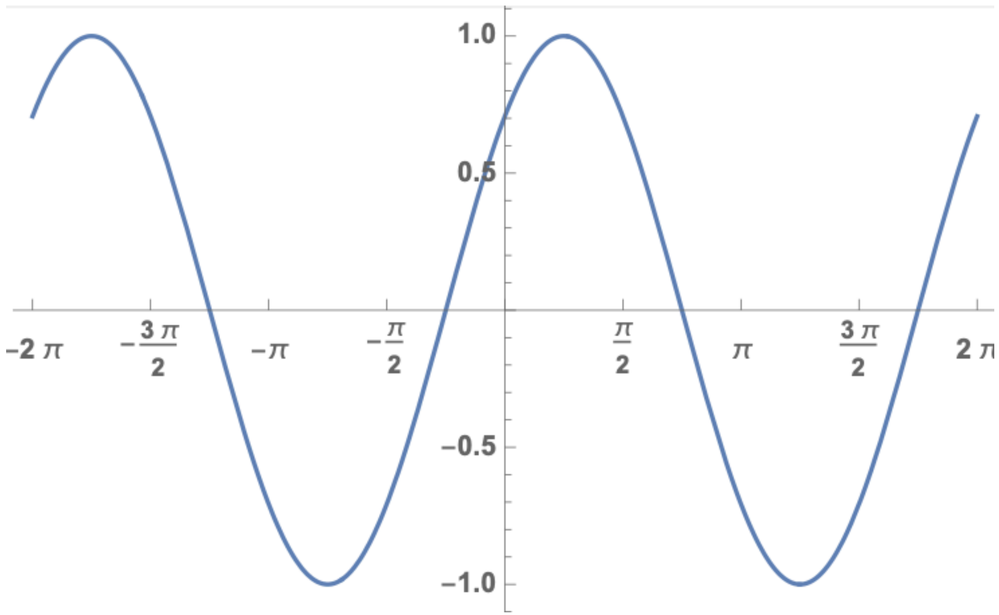
Which of the following best describes $f(\theta)$ (plotted below)?

A. $\sin\left(\theta + \frac{\pi}{4}\right)$

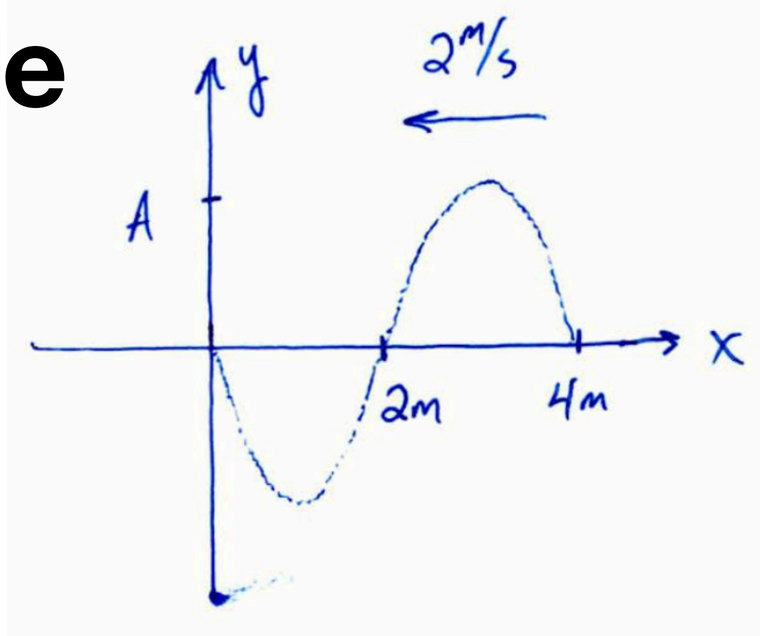
B. $\sin\left(\theta - \frac{\pi}{4}\right)$

C. $\sin\left(\theta + \frac{3\pi}{4}\right)$

D. $\sin\left(\theta - \frac{3\pi}{4}\right)$



Example



To the left is a snapshot of a wave @ $t = \frac{1}{2}T$, where T is the period.

Find an equation for $y(x, t)$ of the form $y = A \sin\left[kx \pm \omega t + \phi_0\right]$, with $\phi_0 \in [0, 2\pi)$

Agenda Today (April 10, 2025)

- Snapshot and History graphs, more examples
- Wave speed / the wave equation
  - Wave speed for waves on strings
- EM Waves and Index of Refraction
- Power and Intensity
- Sound Waves
  - Intensity for Sound Waves
  - Doppler Effect

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Wave Equation, Wave Speed on String

A function $f(kx - \omega t)$ satisfies the wave equation, $\frac{\partial^2 D}{\partial t^2} = v^2 \frac{\partial^2 D}{\partial x^2}$

Analyzing waves on strings, you can show $v = \sqrt{\frac{T}{\mu}}$

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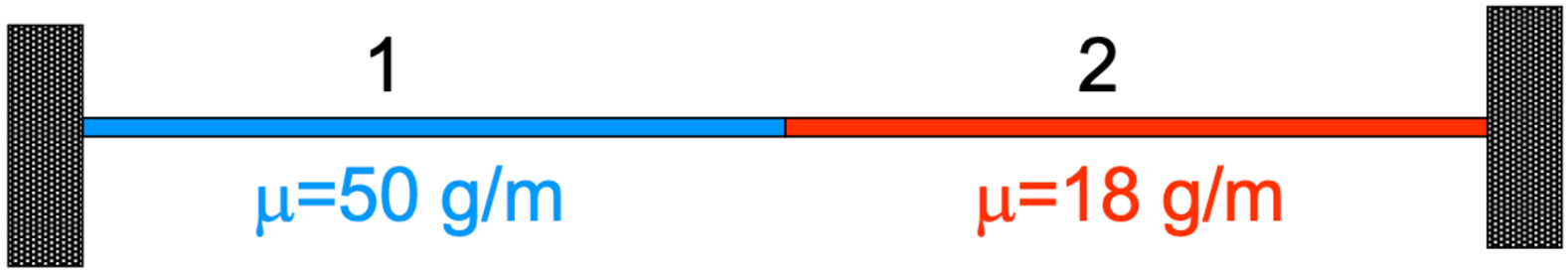
Clicker/Poll Question

Two strings with different unit mass are tied in the center and attached with a tension of 1000N to two walls as shown.

What is the ratio of the wave's speed in the two strings?



A. $v_1/v_2 = 9/25$

B. $v_1/v_2 = 3/5$

C. $v_1/v_2 = 25/9$

D. $v_1/v_2 = 5/3$

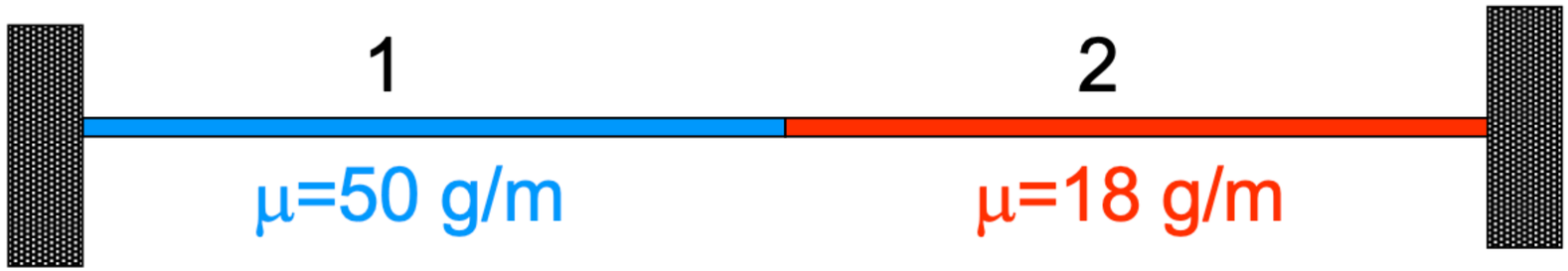
E. $v_1/v_2 = 1$

sli.do #401391

Clicker/Poll Question

Two strings with different unit mass are tied in the center and attached with a tension of 1000N to two walls as shown.

What is the ratio of the wave's frequencies in the two strings?



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C. $f_1/f_2 = 25/9$

D. $f_1/f_2 = 5/3$

E. $f_1/f_2 = 1$

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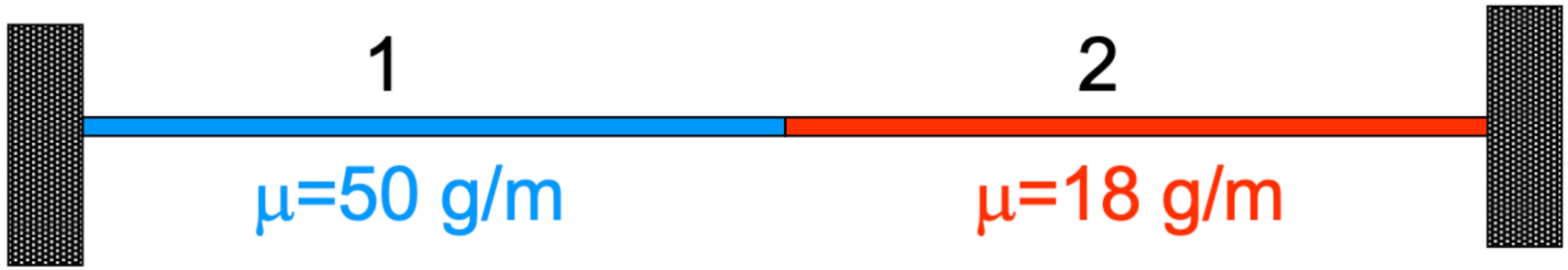
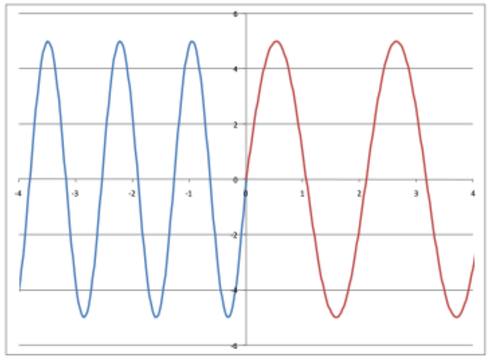
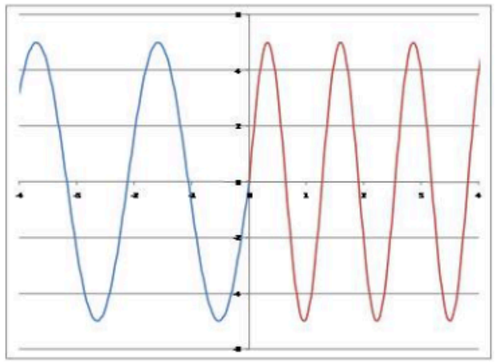
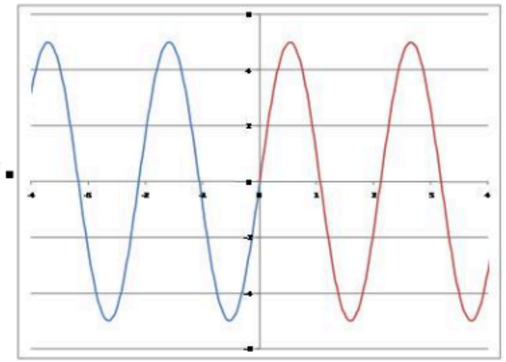
Clicker/Poll Question

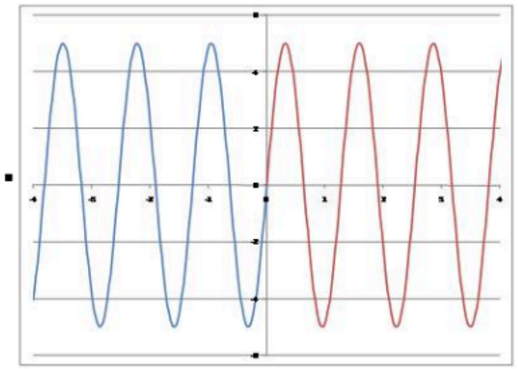
Two strings with different unit mass are tied in the center as shown. What will the waves look like in the two strings? Ignore reflections that might occur at the knot.



A. 

B. 

C. 

D. 

Example

A wave on a string is described by $D(x,t) = (0.020)\sin(12.57x - 638t)$, where {x,D} are in meters and t is in seconds. The linear mass density of the string is 5.00g/m. What are (a) the string tension, (b) v_{max} of a point on the string?

EM Waves and the Index of Refraction n

EM Waves: transverse, $\vec{E}$ & $\vec{B}$ fields are disturbances. $v = \frac{c}{n}$.

sli.do #401391

Clicker/Poll Question

The index of refraction of water is 1.33.
What is the speed of light in water?

A. 1.7×10^8 m/s

B. 2.3×10^8 m/s

C. 3.0×10^8 m/s

D. 4.0×10^8 m/s

sli.do #401391

Clicker/Poll Question

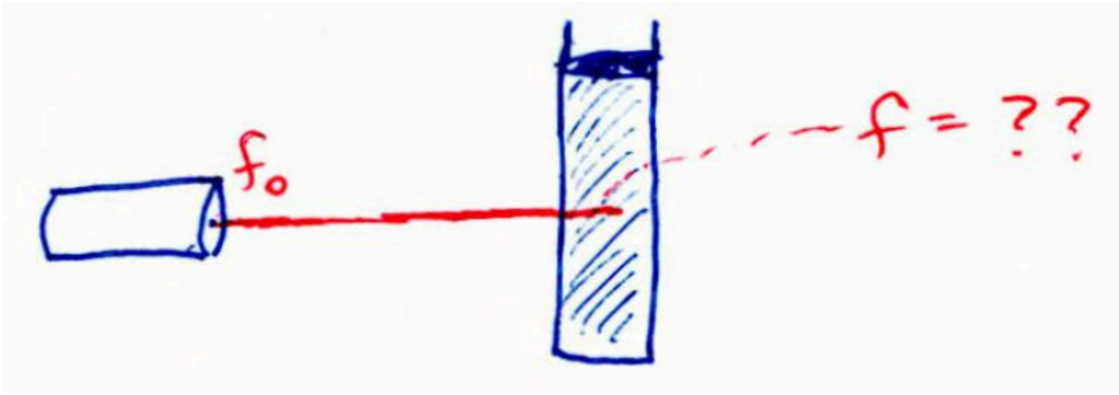
The index of refraction of water is 1.33. A red laser pointer with frequency f_0 in air is shining on a glass of water. What is the frequency of the light when it is inside the water?

A. $f = 1.33 f_0$

B. $f = f_0$

C. $f = f_0 / 1.33$

D. None of these



Power and Intensity

$$\text{Power} = \frac{\text{Energy}}{\text{Time}} \text{ in [W] = [watts]; } \quad \text{Intensity} = \frac{\text{Power}}{\text{Area}} \text{ in [W/m}^2\text{]}$$

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Clicker/Poll Question

A satellite radio station puts out 10 kW of cool jazz for an hour at 99.3 MHZ on your radio dial. How much energy per unit time goes through a sphere 50 kilometers in diameter that is centered on the satellite? The drawing below is not to scale.

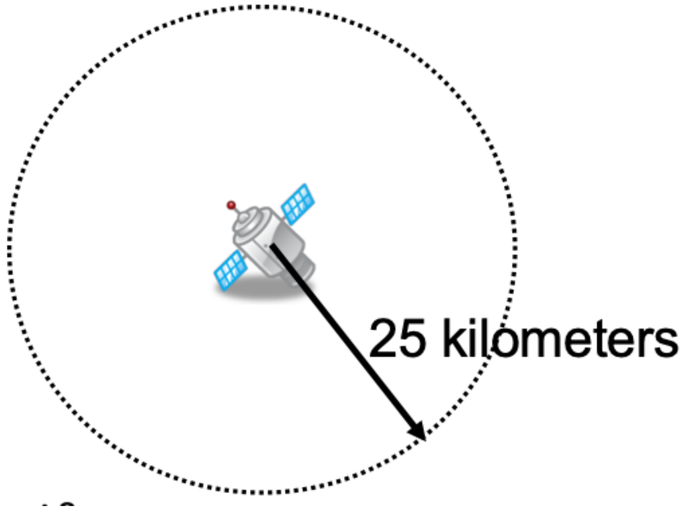
A. $(10\,\text{kW})\,/\,(25\,\text{km})^2$

B. $10\,\text{kW}$

C. $(10\,\text{kW})(4\pi)(25\,\text{km})^2$

D. $(10\,\text{kW})(4\pi)(25\,\text{km})^2(\text{time})$

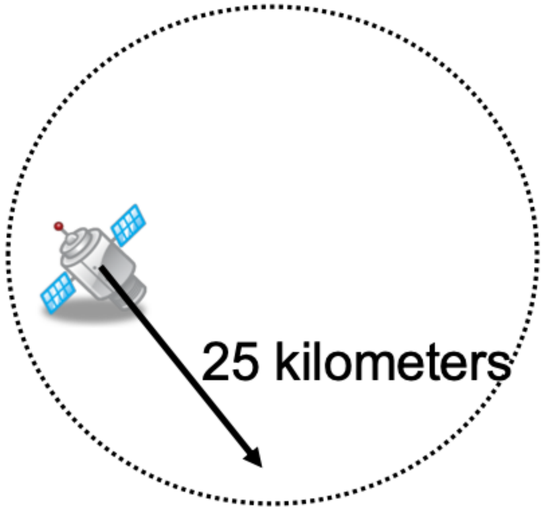
E. None of the above



sli.do #401391

Clicker/Poll Question

Now the sphere enclosing the satellite that is broadcasting at 10 kW for an hour is way off center as shown. The total power going through the sphere is now:



A. $(10\,\text{kW})\,/\,(25\,\text{km})^2$

B. $10\,\text{kW}$

C. $(10\,\text{kW})(4\pi)(25\,\text{km})^2$

D. $(10\,\text{kW})(4\pi)(25\,\text{km})^2(1\,\text{hr})$

E. None of the above

sli.do #401391

Clicker/Poll Question

A ground-based radio station puts out 50 kW and your radio needs to receive at least $1 \times 10^{-6}\,\mathrm{W/m^2}$ of power per unit area in order to faithfully reproduce the sound of cool jazz. What is the maximum distance that you can be from the broadcast antenna?

A. 1000 km

B. 630 km

C. 316 km

D. 63 km

E. 32 km

Power and Intensity of Sound Waves (dB)

SI units of intensity are [W/m^2], but for sound we like to use [dB].

Example

A 20-W loudspeaker emits sound waves isotropically. What is the intensity a distance 30m from the loudspeaker? Give your answer both in SI units as well as in dB.

sli.do #401391

Clicker/Poll Question

At a distance of 50m from a loudspeaker, the sound intensity level is 70dB. Which of the following is closest to the sound intensity level a distance 100m from the loudspeaker?

A. 50 dB
B. 56 dB
C. 60 dB
D. 64 dB
E. 66 dB

Doppler Effect

If either the source or the receiver are moving, the detected frequency is modified when compared to the emitted frequency.

Example

A killer phone is attacking you. If the phone emits its ring at 500Hz, what is the frequency detected by you if…

a) …the phone is chasing you at 100m/s?
b) …you're running away from the phone at 100m/s?

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Clicker/Poll Question

A speaker broadcasting at a frequency of 2 MHz is moving with a velocity of 200 m/s toward a stationary detector. What is the frequency that the detector will hear? Speed of sound: 343m/s.

A. 0.83 MHz
B. 1.3 MHz
C. 2.0 MHz
D. 3.2 MHz
E. 4.8 MHz

sli.do #401391

Clicker/Poll Question

A speaker is moving with a velocity of 200 m/s toward a detector and the detector is moving with a velocity of 100m/s away from the speaker. The speaker's frequency is 2 MHz what is the frequency that the detector will hear? (The speed of sound is 343 m/s, and all speeds are relative to the ground.)

A. Both methods are right
B. Both methods are wrong
C. Only method 1 is right
D. Only method 2 is right

Method 1: According to the detector, the speaker is approaching at 200-100=100 m/s, so the frequency is

$$2 \times \frac{1}{1-100/343} = 2.82 \text{ MHz}$$

Method 2: the speaker is moving 200 m/s towards the detector, and the detector is moving 100m/s away. So the frequency is

$$2 \times \frac{1-100/343}{1-200/343} = 3.40 \text{ MHz}$$

sli.do #401391

Clicker/Poll Question

A combined speaker and detector system is moving at 100 m/s toward a wall. The speaker's frequency is 2 MHZ and the detector will hear the wave reflected by the wall. What frequency will the detector hear?

A. 1.10 MHZ
B. 2.00 MHZ
C. 2.58 MHZ
D. 2.82 MHZ
E. 3.65 MHZ

Interference / Standing Waves

Knight Ch. 17

Physics 2C, Spring 2025

Agenda Today (April 14-15, 2025)

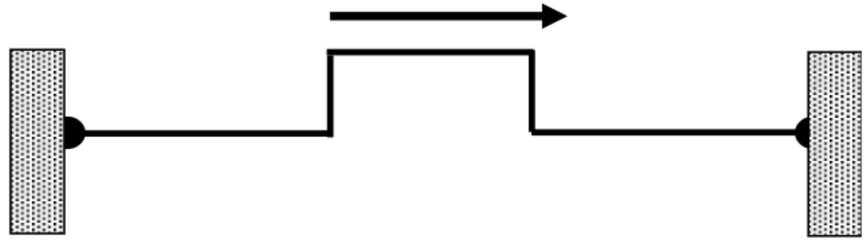
- Superposition and Interference
- Standing Waves
  - Waves on Strings
  - Sound waves (standing waves in pipes)
- Beats

sli.do #401391

Superposition

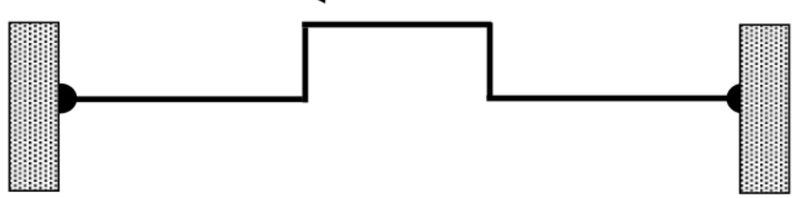
Two waves pass through each other undisturbed. The displacement at any point is the sum of the two contributions.

Clicker/Poll Question

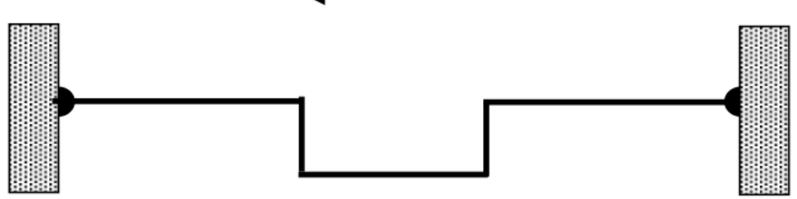


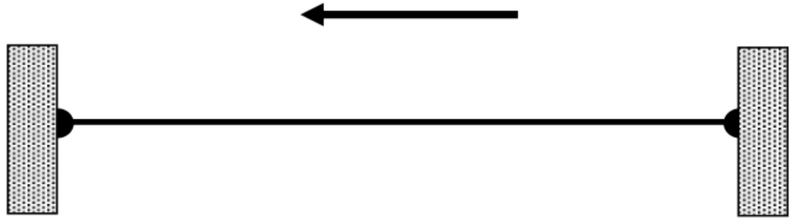
A symmetric pulse is approaching the right end of a string tied to two walls as shown above. Which of the following best represents the shape of the string after it has completely reflected off the wall on the right?

1.



2.

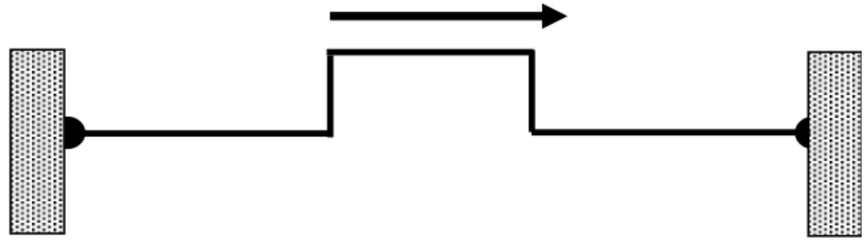




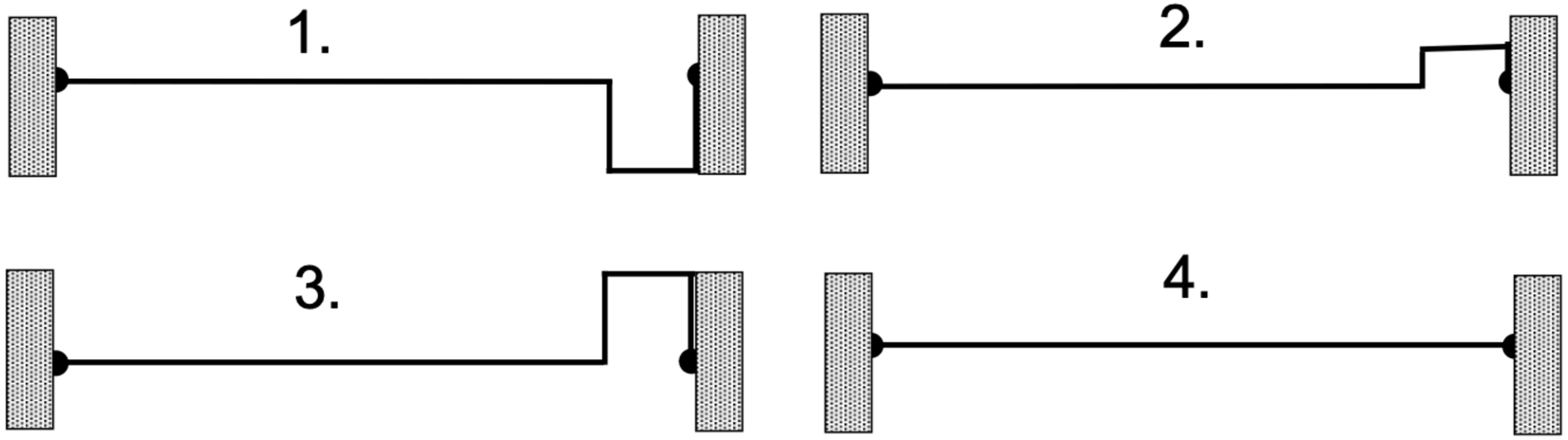
3.

4. None of the above.

Clicker/Poll Question

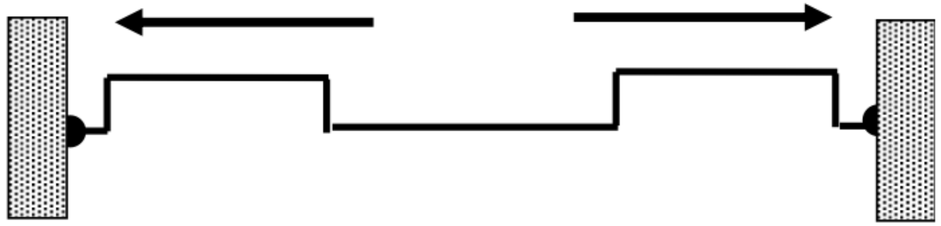


A symmetric pulse is approaching the right end of a string tied to two walls as shown below on the right. At the precise moment when half of the wave has hit the wall which of the following best represents the shape of the string?

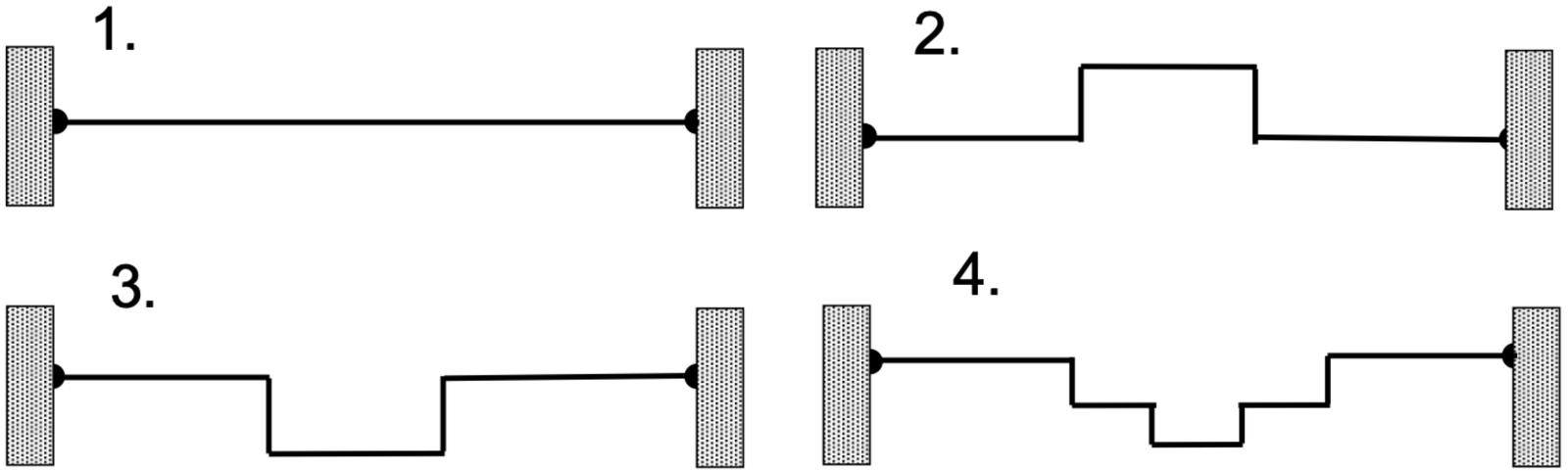


5. None of the above.

Clicker/Poll Question



Two identical pulses move in opposite directions toward opposite ends of a string tied to two walls as shown on the right. Which of the following represents possible shape(s) for the string after both pulses have undergone reflections and meet somewhere in the middle.



5. 3 AND 4.

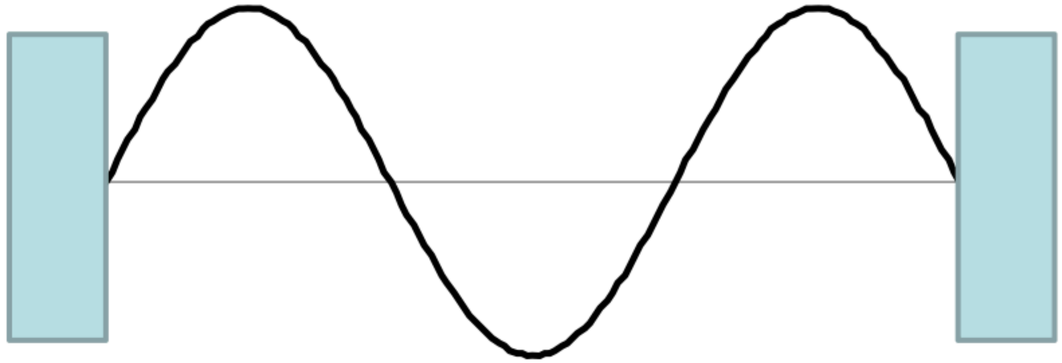
Standing Waves, nodes/antinodes

A combination of waves left and right can produce a standing wave (seemingly stationary). Displacement nodes at ends.

sli.do #401391

Clicker/Poll Question

A string is vibrating at 300 Hz. Using a strobe light and an ultra fast camera you get a picture of the string as sketched below. The blue walls are separated by 1 meter. What is the speed of the wave?



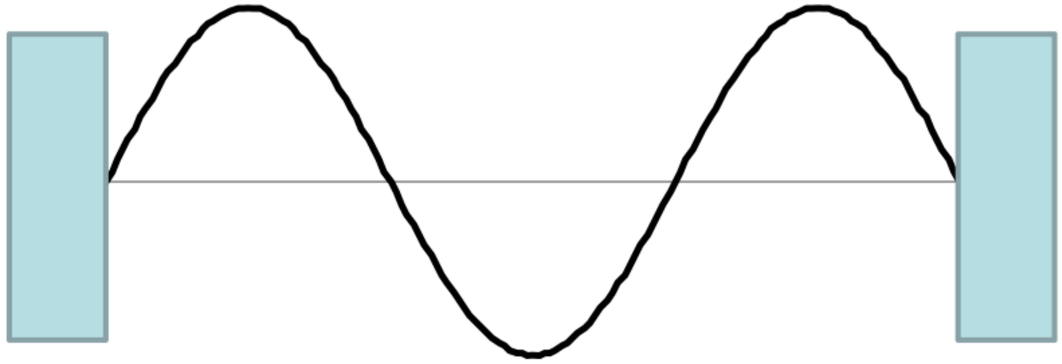
A. 50 m/s
B. 100 m/s
C. 150 m/s
D. 200 m/s
E. 300 m/s

sli.do #401391

Clicker/Poll Question

A string is vibrating at 300 Hz. Using a strobe light and an ultra fast camera you get a picture of the string as sketched below. The blue walls are separated by 1 meter. As determined in the previous question the speed of the wave vibrating as shown is 200 m/s. what would its speed be if it were vibrating in the lowest possible frequency?

A. 50 m/s
B. 100 m/s
C. 150 m/s
D. 200 m/s
E. 300 m/s



Standing Sound Waves

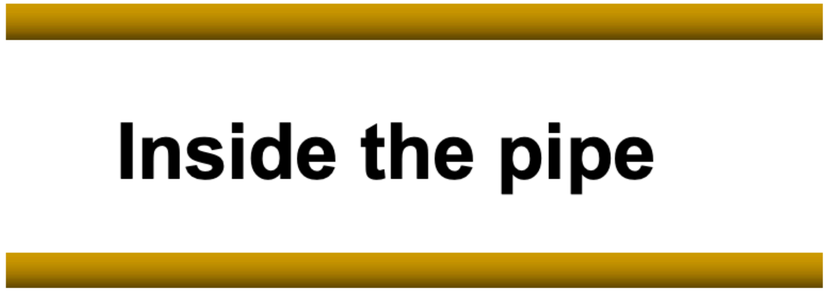
For sound waves, the standing waves have either nodes or antinodes at the ends, depending on whether the tube/pipe is open or closed.

sli.do #401391

Clicker/Poll Question

A pipe with two open ends is shown below. The length of the pipe is 1m and the speed of sound is 343 m/s. What is the first harmonic frequency of the sound wave created in this pipe?

A. 172 Hz
B. 343 Hz
C. 686 Hz
D. 1029 Hz
E. None of the above.

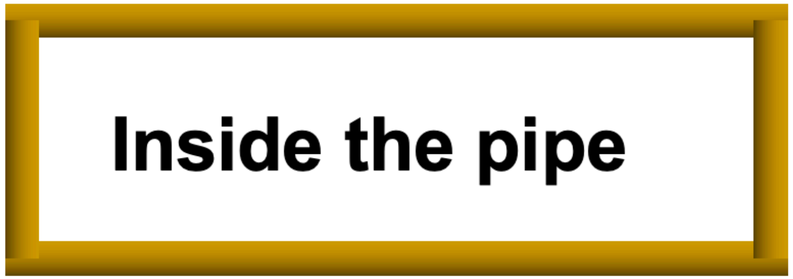


sli.do #401391

Clicker/Poll Question

A pipe with two closed ends is shown below. The length of the pipe is 1m and the speed of sound is 343 m/s. What is the first harmonic frequency of the sound wave created in this pipe?

A. 172 Hz
B. 343 Hz
C. 686 Hz
D. 1029 Hz
E. None of the above.



sli.do #401391

Clicker/Poll Question

A pipe with one closed end is shown below. 428.75 Hz 600.25 Hz and 771.75 Hz are three adjacent harmonic frequencies of sound waves created in this pipe. What is the pipe's first harmonic (lowest) frequency?

A. 86 Hz
B. 172 Hz
C. 343 Hz
D. 257 Hz
E. None of the above.

Beats

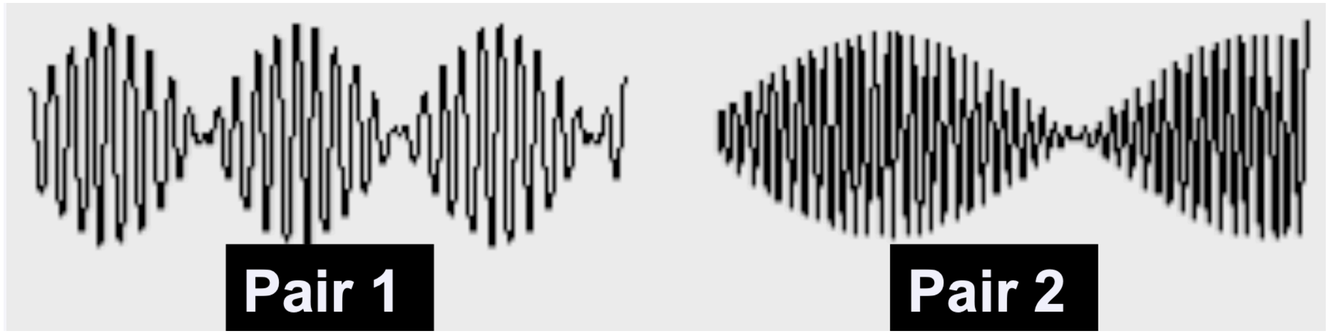
Two waves of almost the same frequency $f_1 \approx f_2$ add together to make a wave that has small wiggles and and overall long-period wave envelope. The long-period envelope has a “beat frequency” $f_{\text{beat}} = |f_1 - f_2|$.

Clicker/Poll Question

sli.do #401391

The traces below show beats that occur when two different pairs of waves interfere. For which case is the difference in frequency of the original waves greater?

A. Pair 1
B. Pair 2
C. Same for both pairs
D. Impossible to tell
E. ???



Example

An open-closed pipe is exactly 1.00m long. A second pipe, almost identical, is a little bit longer. What's the length of the second pipe if the beat frequency between the two is 2 Hz ? (Assume Fundamental Freq.). Take v=343m/s.