PHY131H1F - Hour 33

- A wave involves a disturbance, or pattern, that moves through space.
- The disturbance carries energy, but not matter.
- Just as a wave can travel across a field of wheat without the wheat moving across the field, sound energy can move from my mouth to a listener's ear, without the air particles actually moving that distance.

Today:

11.4 Wave Intensity, 11.7 Intensity Level (Decibels)

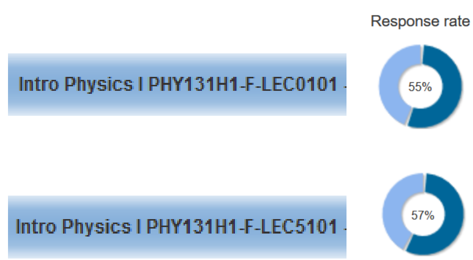
11.5 , 11.6 Superposition Principle for Waves, Wave Interference, Intro to Standing Waves

Bonus Point for Over 65% Course Evaluation Response Rate

• The end of the evaluation period for this semester next Friday December 7 at 11:59PM.

• If, by the end of the course evaluation period, at least 65% of the students enrolled in *both* sections of this course have completed the course evaluations, then **every student in the course will have 1% bonus added to their final course mark.**

•Results as of Friday Nov. 30 at 1pm:



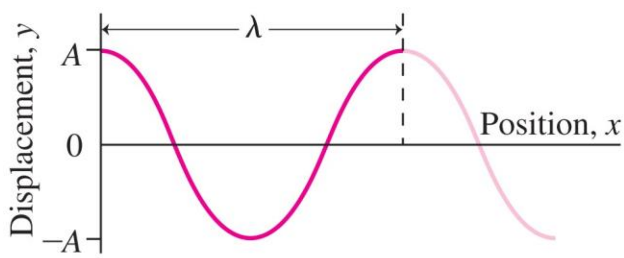
Latest Comments from Learning Catalytics: "Please enter at least one specific question or concern you would like me to address in class."

- *"How does the small angle approximation work?"*
- **Harlow answer:** when θ is measured in radians, then:
- $\sin\theta \approx \theta$
- This helps in many cases, for example whenever you have a tall skinny isosceles triangle.

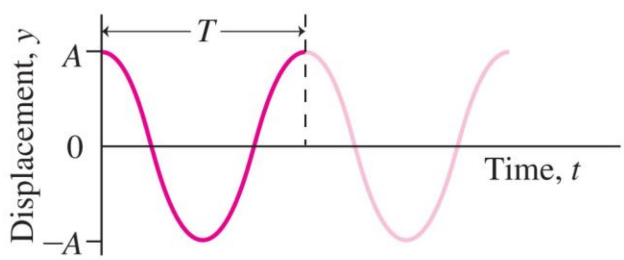
Angle [deg]	Angle [rad]	sine	% error	sig figs
0.1	0.00174533	0.00174533	0.0001%	6
1	0.01745	0.01745	0.01%	4
3	0.05236	0.05234	0.05%	3
5	0.08727	0.08716	0.13%	2
10	0.17453	0.17365	0.51%	2
15	0.26180	0.25882	1.15%	2
20	0.34907	0.34202	2.06%	1
25	0.43633	0.42262	3.25%	1

Properties of Sinsoidal Waves

- **Wavelength** λ is the distance over which a wave repeats in space.
- **Period** T is the time for a complete oscillation of the wave at a fixed position.
- **Frequency** f is the number of wave cycles per unit time: $f = 1/T$
- **Amplitude** A is the maximum value of the wave disturbance.



(a)

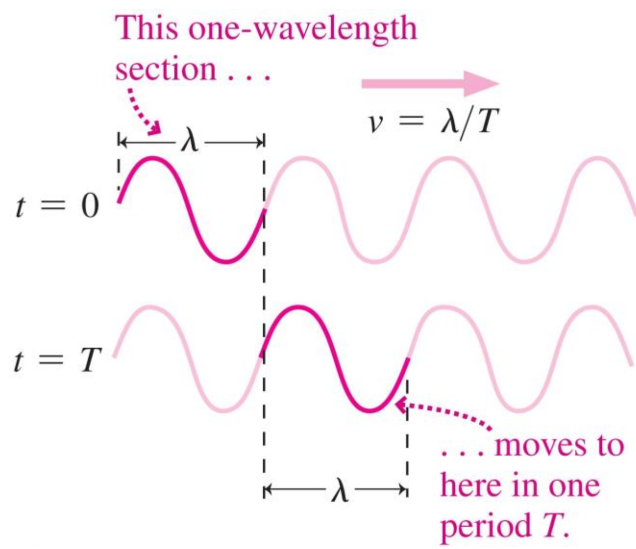


(b)

Wave Speed

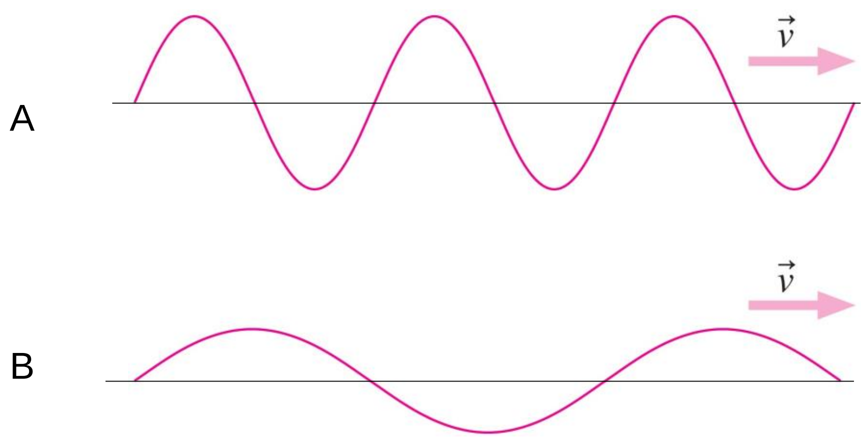
- **Wave speed** is the rate at which the wave propagates.
- Wave speed, wavelength, period, and frequency are related:

$$v = \frac{\lambda}{T} = \lambda f$$



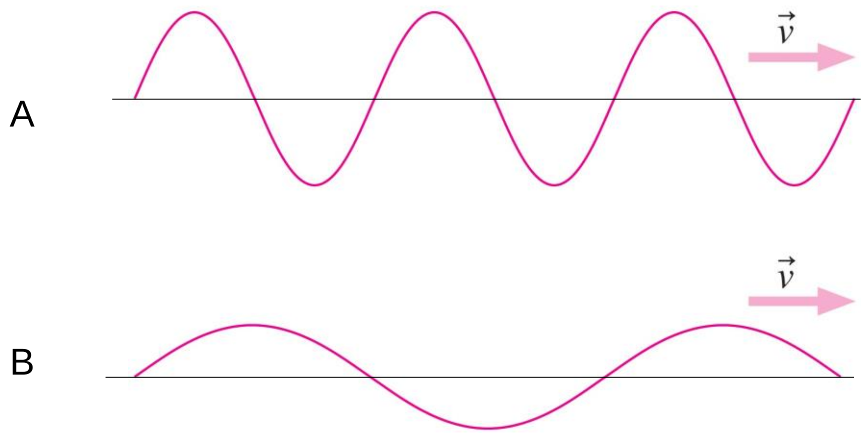
Quick Learning Catalytics Question

- Here are snapshots (y vs x) of two waves that have the same speed.
- Which has the greater **amplitude**?



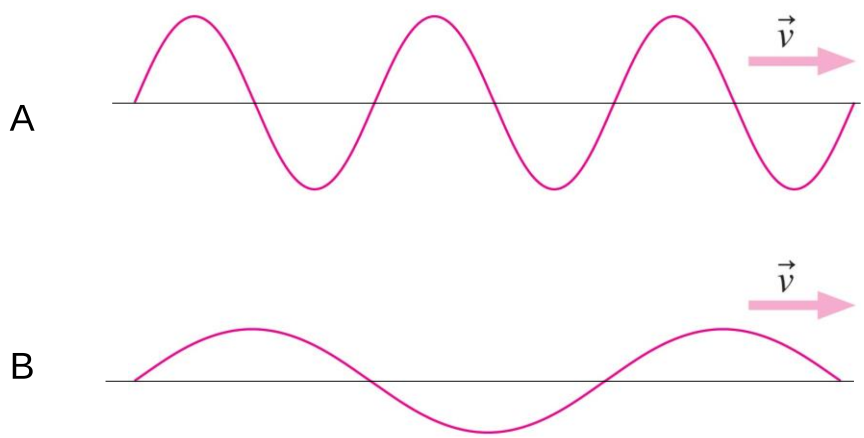
Quick Learning Catalytics Question

- Here are snapshots (y vs x) of two waves that have the same speed.
- Which has the greater **wavelength**?



Quick Learning Catalytics Question

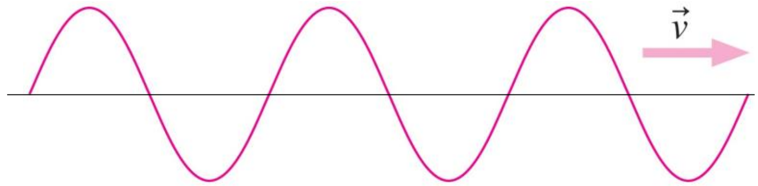
- Here are snapshots (y vs x) of two waves that have the same speed.
- Which has the greater **period**?



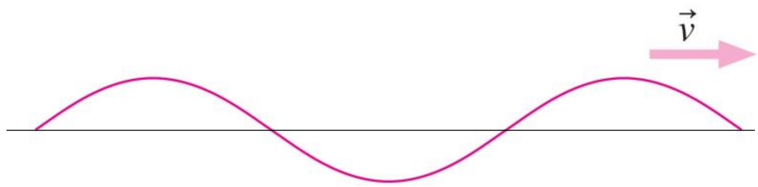
Quick Learning Catalytics Question

- Here are snapshots (y vs x) of two waves that have the same speed.
- Which has the greater **frequency**?

A

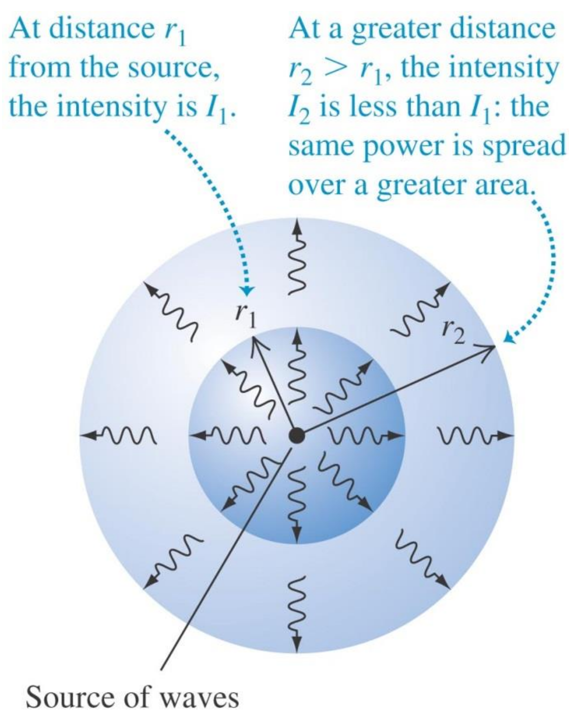


B



Wave intensity

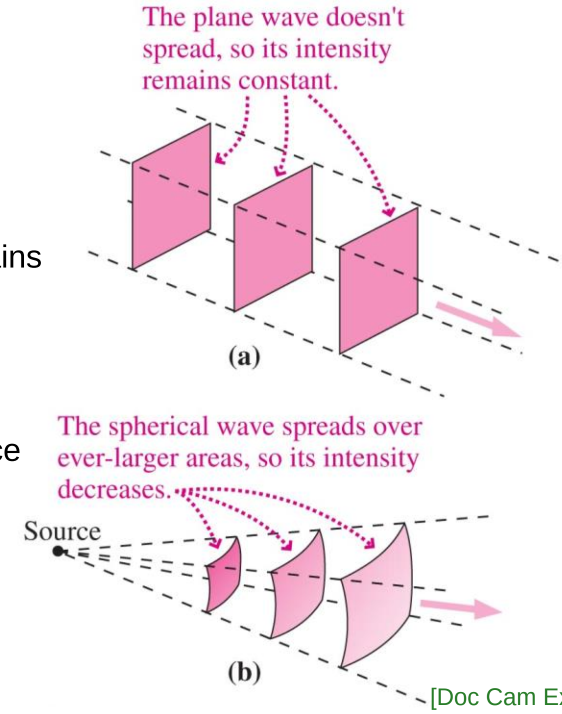
- The *intensity* of a wave is the average power it carries per unit area.
- If the waves spread out uniformly in all directions and no energy is absorbed, the intensity I at any distance r from a wave source is inversely proportional to r^2.



Wave Intensity

- Wave **intensity** is the power crossing a unit perpendicular area.
  - In a **plane wave**, the intensity remains constant.
  - A **spherical wave** spreads in three dimensions, so its intensity drops as the inverse square of the distance from its source:

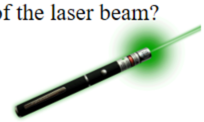
$$I = \frac{P}{A} = \frac{P}{4\pi r^2}$$



[Doc Cam Examples]

A laser pointer emits 1.0 mW of light power into a 1.0 mm diameter laser beam. What is the intensity of the laser beam?

Sketch and translate



Simplify and diagram

A 1.0 mW laser pointer has an intensity of 1273 W/m^2.
How far from a 100-Watt light bulb should your eye be in order to have the same intensity as shining this green laser directly into your eye?

Sketch and translate

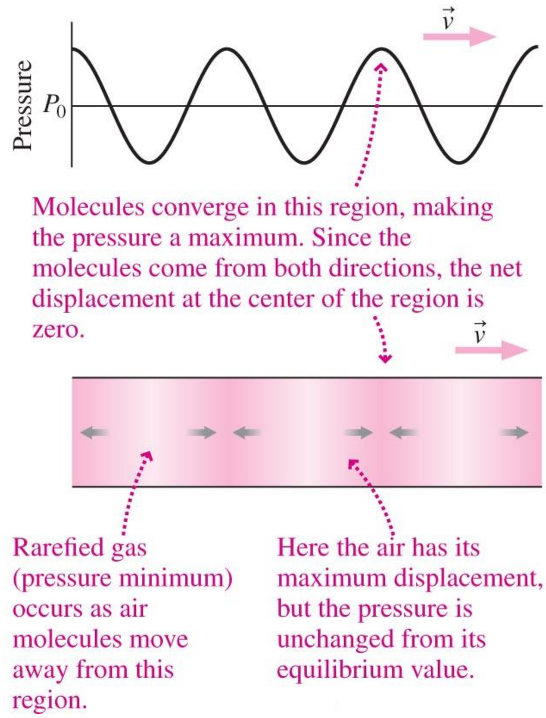
Simplify and diagram

Some Typical Wave Intensities

Wave	Intensity, W/m^2
Sound, 4 m from loud rock band	1
Sound, jet aircraft at 50 m	10
Sound, whisper at 1 m	10^{-10}
Light, sunlight at Earth's orbit	1364
Light, sunlight at Jupiter's orbit	50
Light, 1 m from typical camera flash	4000
Light, at target of laser fusion experiment	10^{18}
TV signal, 5 km from 50-kW transmitter	1.6×10^{-4}
Microwaves, inside microwave oven	6000
Earthquake wave, 5 km from Richter 7.0 quake	4×10^{4}

Sound

- Sound waves are longitudinal mechanical waves that propagate through gases, liquids, and solids.
- Sound waves in air involve small changes in air pressure and density, associated with back-and-forth motion of the air as the wave passes.



Human Hearing and the Decibel

- The human ear responds to a broad range of sound intensities and frequencies
  - The audible range extends from about 20 Hz to 20 kHz in frequency and over 12 orders of magnitude in intensity
  - The sound intensity level β is measured in **decibels:**

$$b = 10\log\left(I/I_0\right)$$

  - The decibel is a logarithmic unit based on a comparison to the nominal threshold of hearing:

$$I_0 = 10^{-12}\ \mathrm{W/m^2}$$

Sound Intensity Levels – Representative Values

Source	**Sound Intensity Level, β (dB)**	**Intensity, I (W/m^2)**
Military jet aircraft 30 m away	140	10^{2}
Threshold of pain	120	1
Elevated train	90	10^{-3}
Busy street traffic	70	10^{-5}
Quiet radio in home	40	10^{-8}
Average whisper	20	10^{-10}
Threshold of hearing at 1000 Hz	0	10^{-12}

Learning Catalytics Question

- A sound level of 10 decibels has 10 times more intensity than a sound level of zero decibels.
- A sound level of 20 decibels has ___ times more intensity than a sound level of zero decibels.

A. 10
B. 20
C. 50
D. 100
E. 200

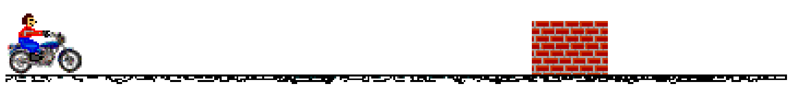
Learning Catalytics Question

- When you turn up the volume on your earbuds, the sound originally entering your ears at 50 decibels is boosted to 80 decibels. By what factor is the intensity of the sound has increased?

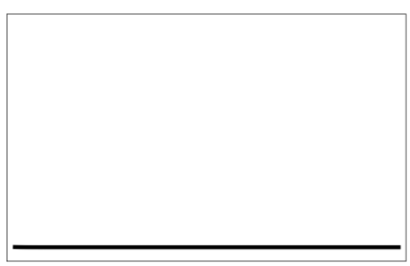
A. 1 (no increase)
B. 30
C. 100
D. 300
E. 1000

Particles and Waves

- Particles cannot occupy the same space. They **collide**.



- Waves pass right through each other. They **interfere**.



[Animations from http://www.physicsclassroom.com/mmedia/newtlaws/mb.cfm and http://www.acs.psu.edu/drussell/demos/superposition/superposition.html]

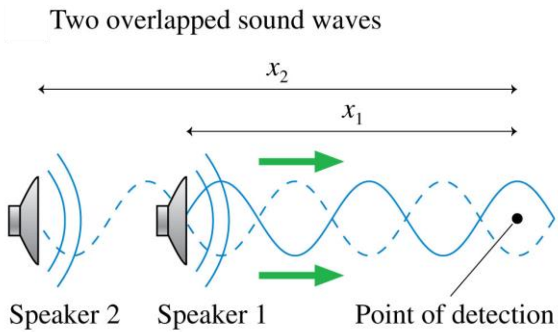
The Superposition Principle

If two or more waves combine at a given point, the resulting disturbance is the *sum* of the disturbances of the individual waves.

$$y = y_1 + y_2$$

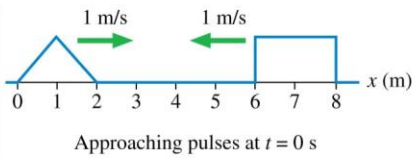
Wave Interference

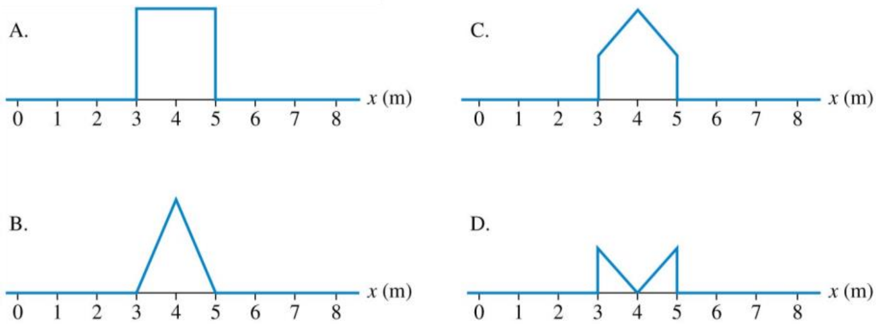
- The pattern resulting from the superposition of two waves is called interference. Interference can be
- ***constructive***, meaning the disturbances **add** to make a resultant wave of **larger** amplitude, or
- ***destructive***, meaning the disturbances **cancel**, making a resultant wave of **smaller** amplitude.



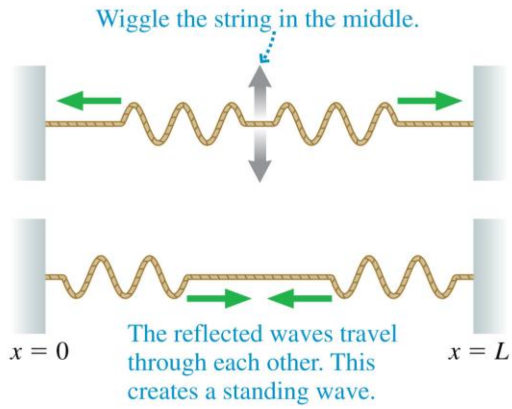
i-Clicker Discussion Question

Two wave pulses on a string approach each other at speeds of 1 m/s. How does the string look at $t = 3$ s?





Standing Waves on a String



Reflections at the ends of the string cause waves of *equal amplitude and wavelength* to travel in opposite directions along the string, which results in a standing wave.

The Mathematics of Standing Waves

According to the principle of superposition, the net displacement of a medium when waves with displacements y_R (right traveling wave) and y_L (left traveling wave) are present is

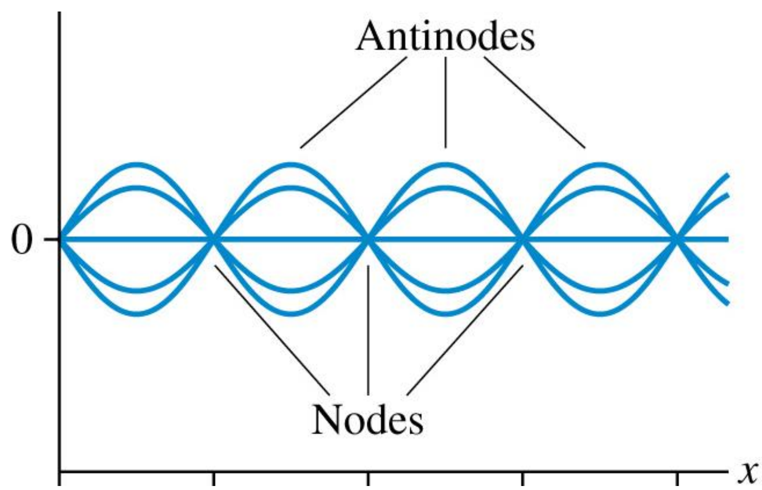
$$y = y_R + y_L = A\cos\left[2\pi\left(\frac{t}{T} - \frac{x}{\lambda}\right)\right] + A\cos\left[2\pi\left(\frac{t}{T} + \frac{x}{\lambda}\right)\right]$$

We can simplify this by using a trigonometric identity, and arrive at:

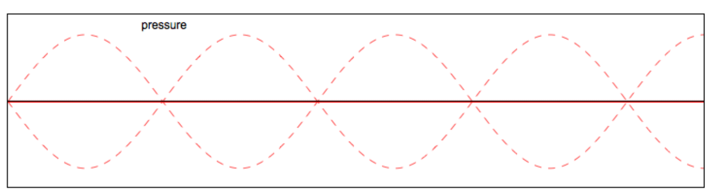
$$y = 2A\sin\left(\frac{2\pi}{\lambda}x\right)\sin\left(\frac{2\pi}{T}t\right)$$

For a standing wave, the pattern is not propagating!

Many textbooks draw this:

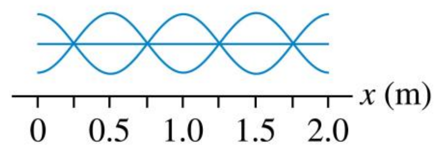


What is really happening is this:



Learning Catalytics Question

What is the wavelength of this standing wave?



A. 0.25 m.

B. 0.5 m.

C. 1.0 m.

D. 2.0 m.

E. Standing waves don't have a wavelength.