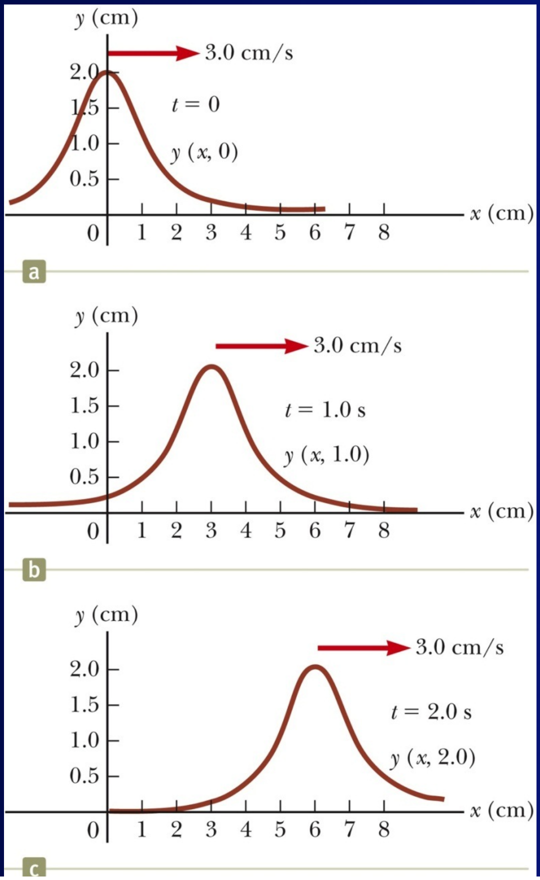
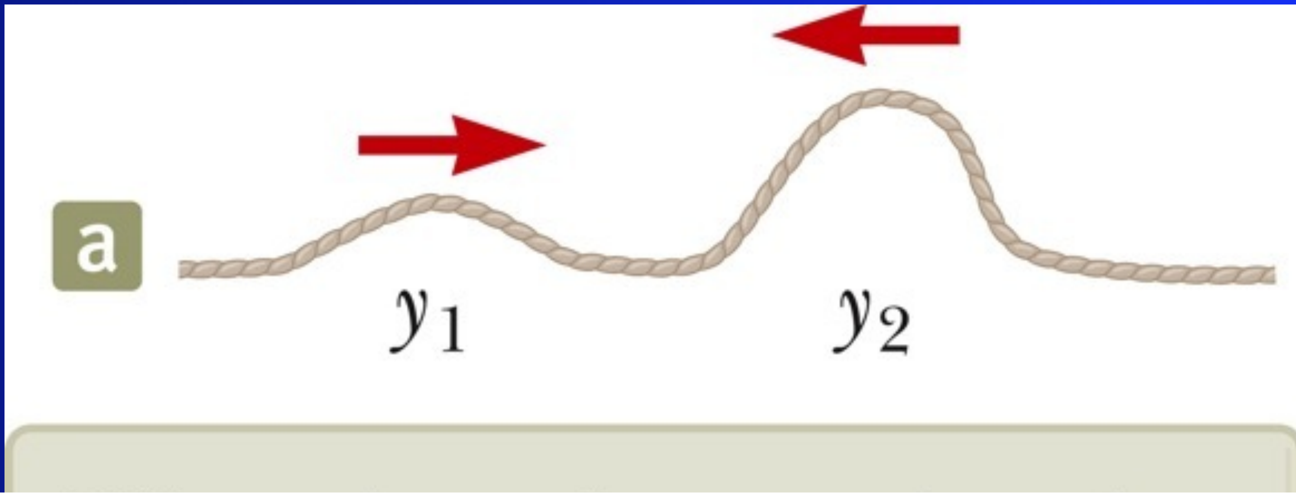
Physics 1C: Mechanical Waves

Wednesday, 1 July 2015



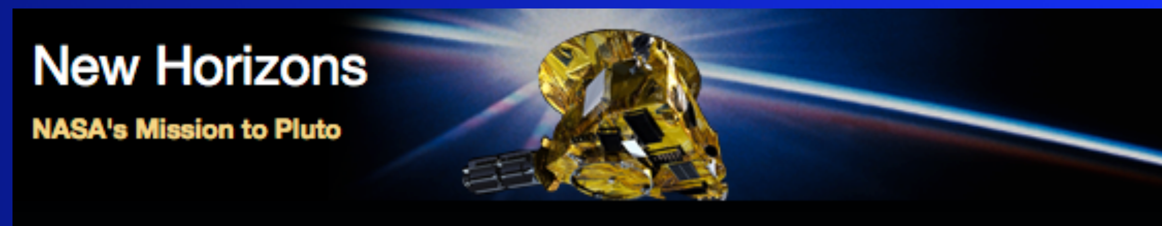


Reminders

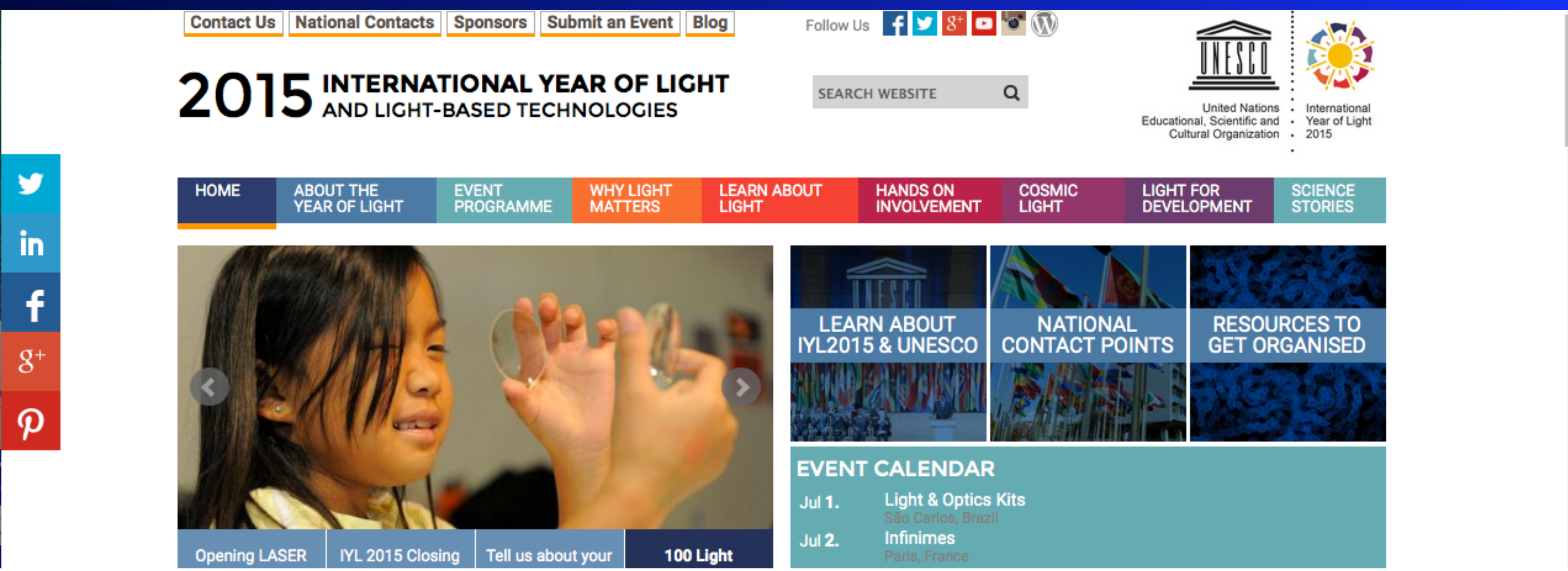
- our Ted course website is now up! look there for the syllabus, lecture slides, announcements, and other info
- register your clicker on the Ted site if you haven't already
- self-enroll on `webassign.net` (class key: ucsd 1146 4985), and don't worry, "trial period" will be extended for course duration
- start working on chapter 13 homework problems & questions, which are due on Friday at 5pm
- the first quiz will be on Monday, and you'll be given the equations

Physics News

- physics researchers recently figured out how to use low-frequency sound waves to put out fires
- NASA's *New Horizons* will reach Pluto within two weeks to get the best observations of it yet



- International Year of Light (www.light2015.org)



Oscillatory Motion (chapter 12)

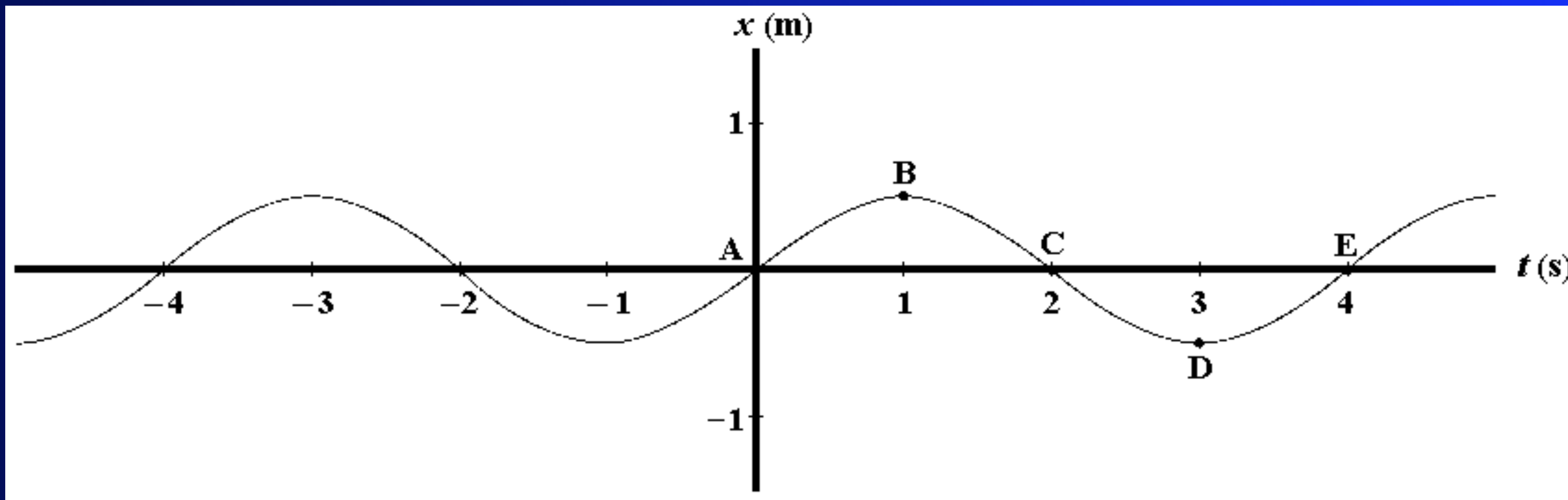
- review chapter 12 (mainly sections 1-4) and chapter 12 homework problems and questions on WebAssign
- ask about concepts or problems that you're not sure about or have trouble with
- and go to the problem sessions on Wednesdays (today) right after class

Oscillatory Motion

- position (x or y), velocity (v), acceleration (a), and force (F)
- frequency (ω or f) and period (T)
- energy: kinetic (K) and potential (U), energy conservation
- simple pendulum (but not physical pendulum)
- it's good to know about damped oscillations too
- make sure to understand what the equations mean and how they describe relationships between physical quantities
- be familiar with the graphs too, including sines & cosines

Oscillatory Motion: example

A graph of position versus time for an object oscillating at the end of a horizontal spring is shown below. A point (or points) at which the object has positive velocity and zero acceleration is (are)



a. B
b. C
c. D
d. B and D
e. A and E

[Hint: think of $x(t) = A\cos(\omega t+\phi_0)$ and its derivatives. Or think of energy conservation.]

Oscillatory Motion: example

The amplitude of a system moving with simple harmonic motion is doubled. The total energy will then be

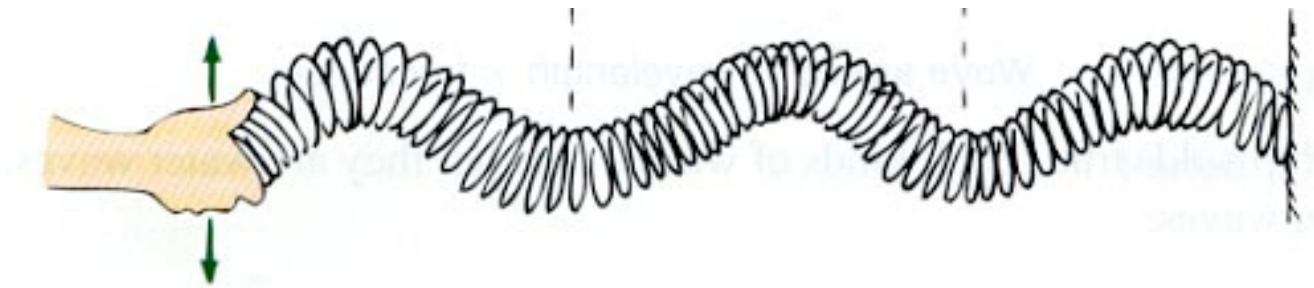
a. 4 times as large
b. 3 times as large
c. 2 times as large
d. the same as it was
e. half as much

Mechanical Waves: What is a Wave?

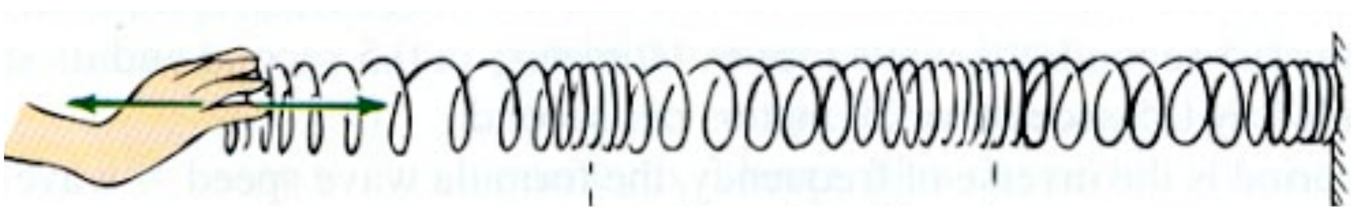
- a disturbance that carries *energy and momentum* from one location to another *without a transfer of matter*
- a wave is created by a source and typically needs a medium to travel through
- examples: ripples in water and sound waves
- waves of light and radiation are *not* mechanical waves

What is a wave?

- Transverse wave: motion of medium is perpendicular to direction of motion



- Longitudinal wave: motion of medium is parallel to direction of motion



Mechanical Waves: transverse waves

A transverse wave travels to the left through a medium. The individual particles in the medium move:

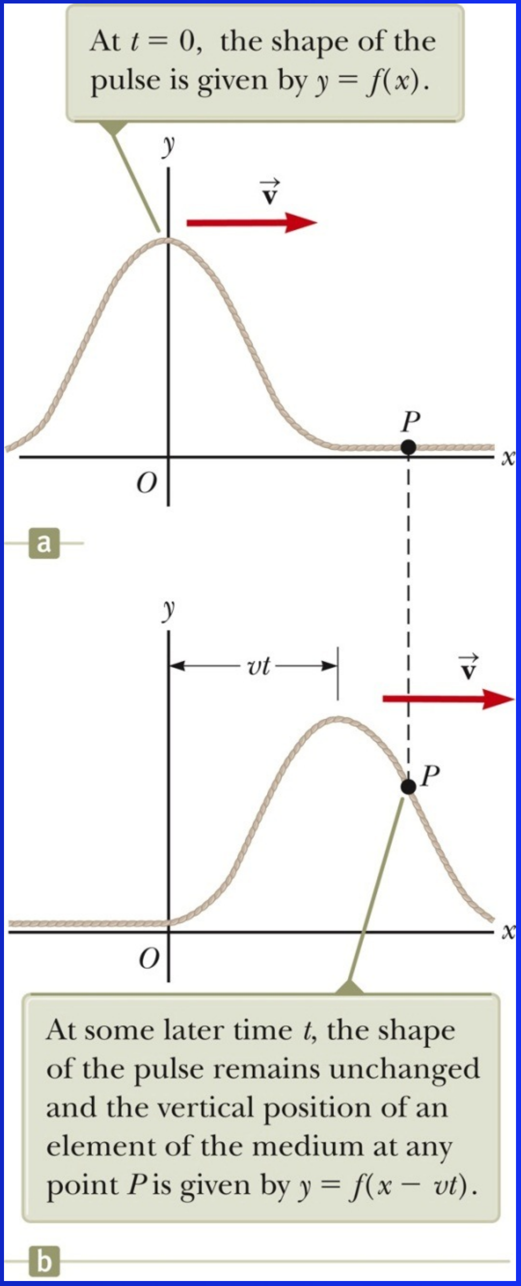
A. to the right
B. to the left
C. up/down
D. the particles in the medium do not move

Propagation of a Disturbance

At t=0, we can describe the shape of a pulse of rope with $y(x,0) = f(x)$

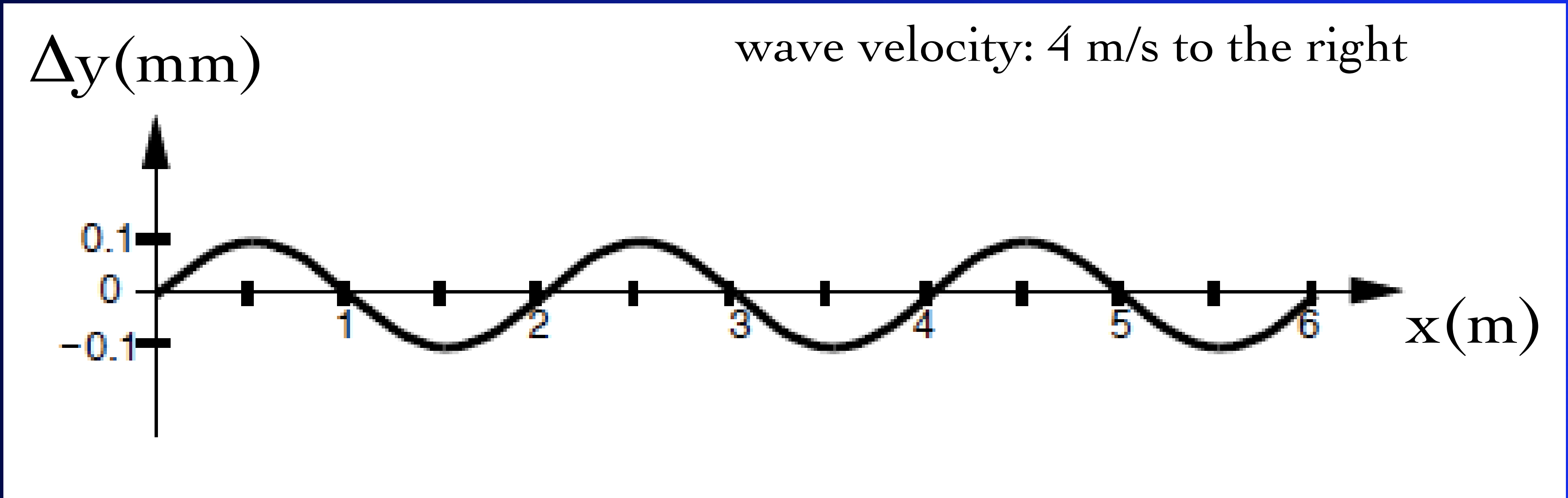
At a later time, its position is:
$y(x,t) = y(x-vt,0)$ to the right

This is the *wave function*, which could be sinusoidal, parabolical, or something else



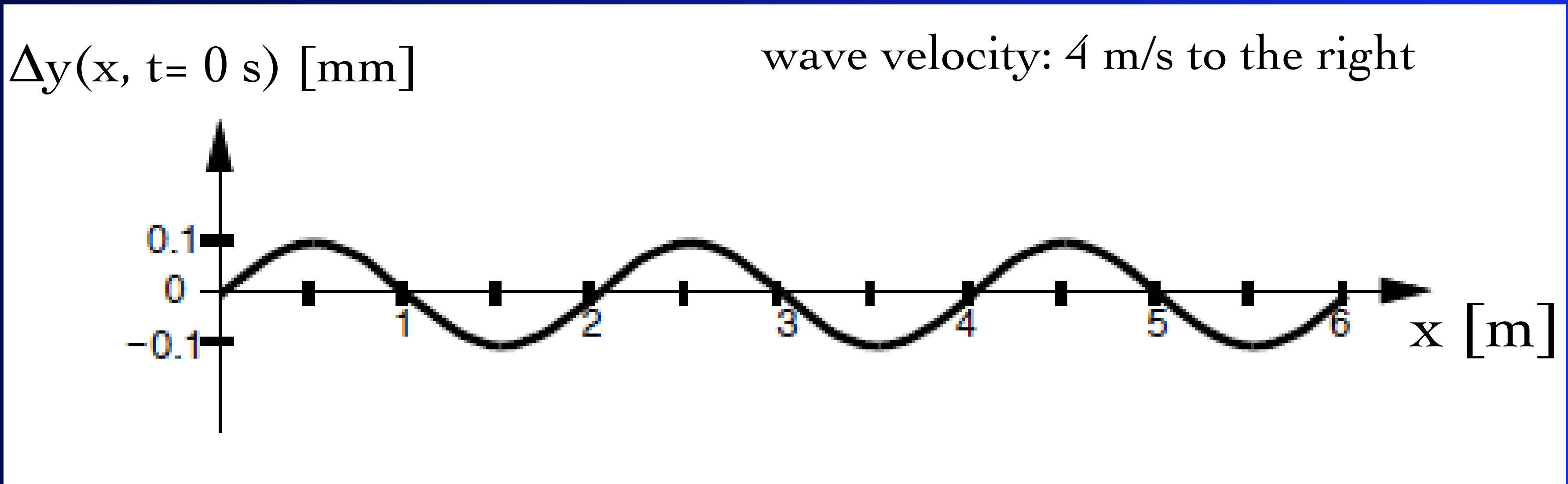
Properties of Sinusoidal Waves

- wavelength: the distance between two corresponding points on a wave
- frequency: the number of cycles a wave undergoes in a given amount of time
- wave speed: $v = \lambda f$



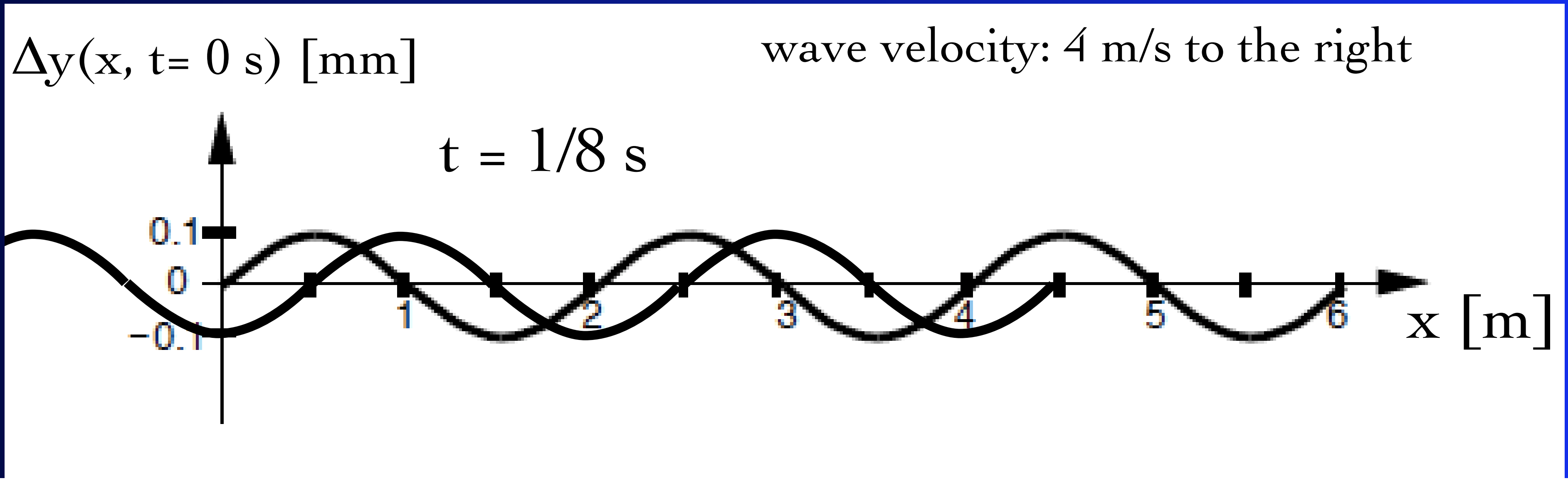
Sinusoidal Waves

- From the figure, we can find the amplitude (0.1 mm) and wavelength (λ=2 m).
- How do we determine the period of a wave? It's the length of time needed to cycle through the wave (and it's inversely related to frequency).



Sinusoidal Waves

- How do we determine the period of a wave? It's the length of time needed to cycle through the wave…



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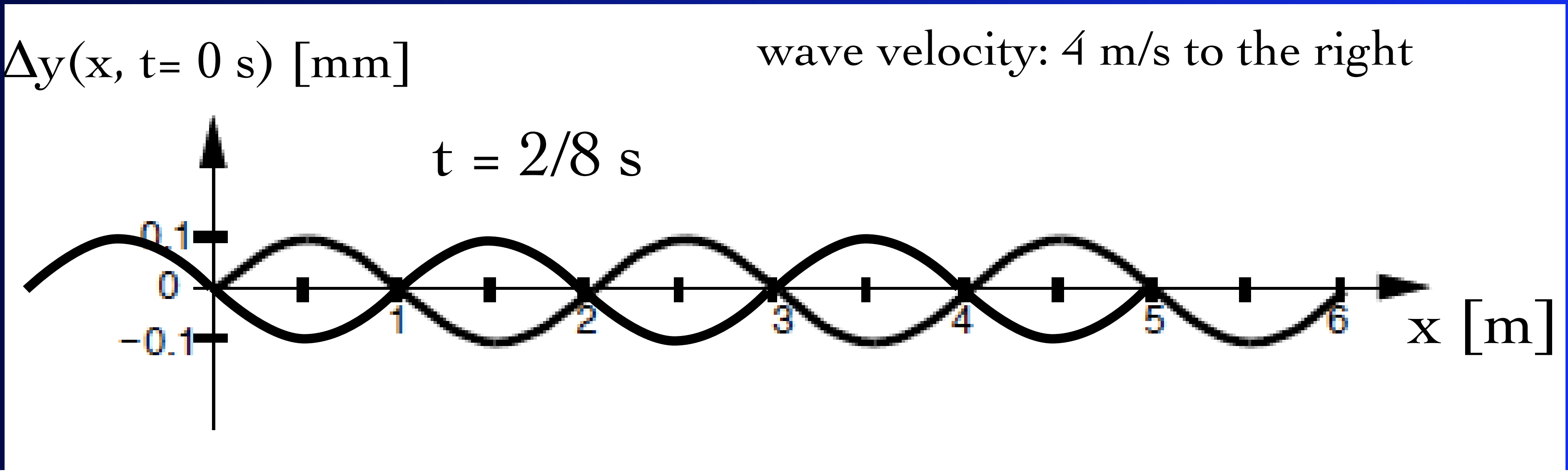

Sinusoidal Waves

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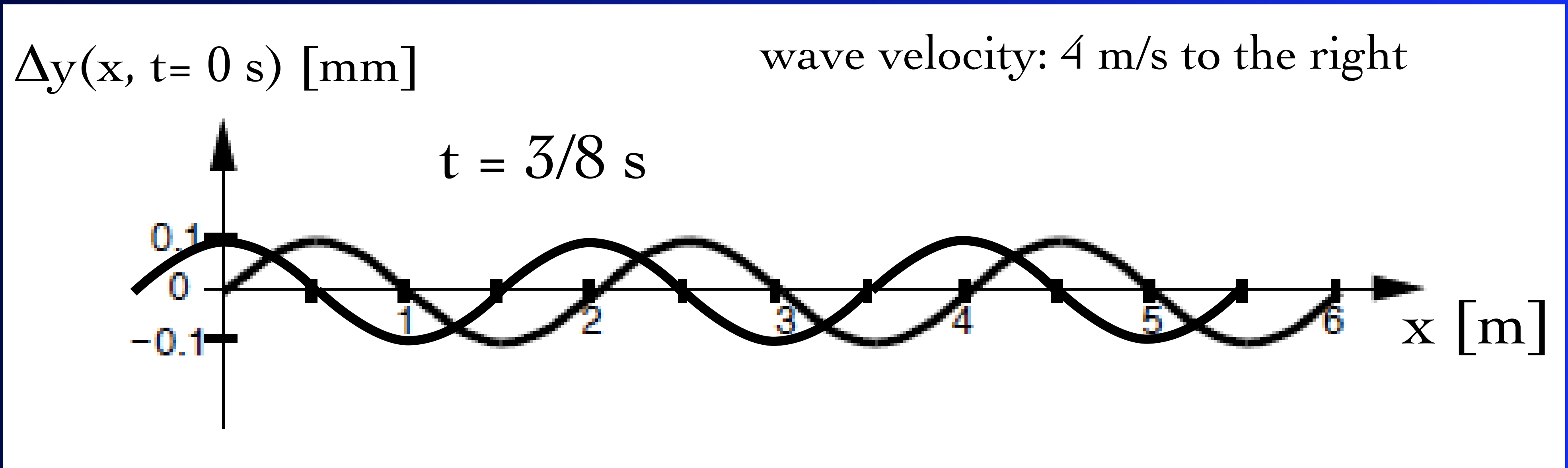
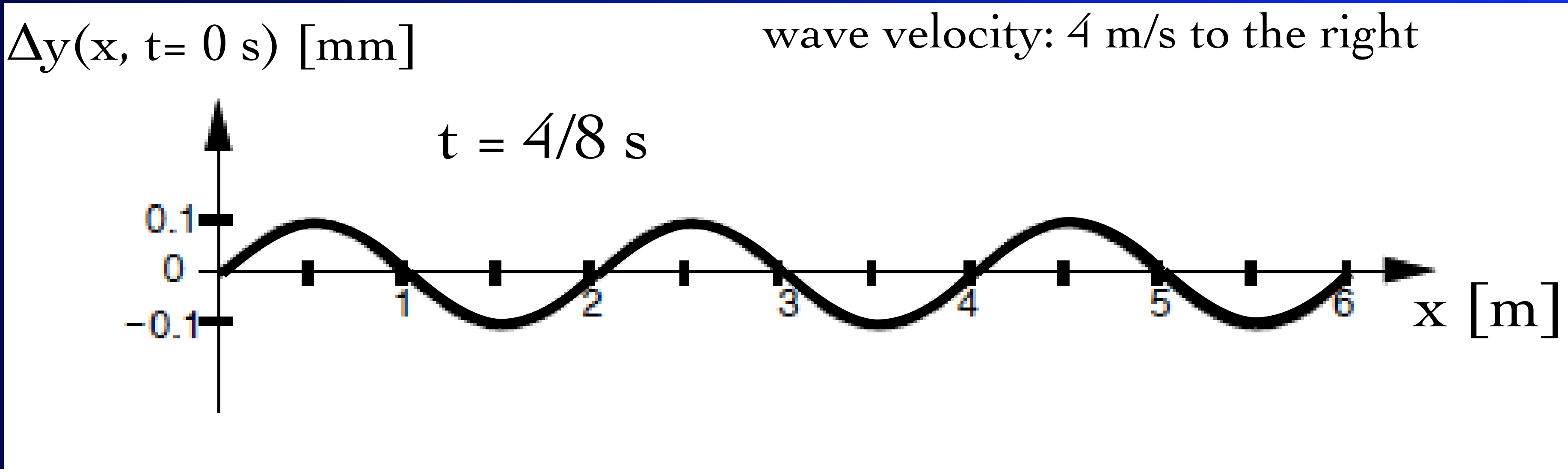


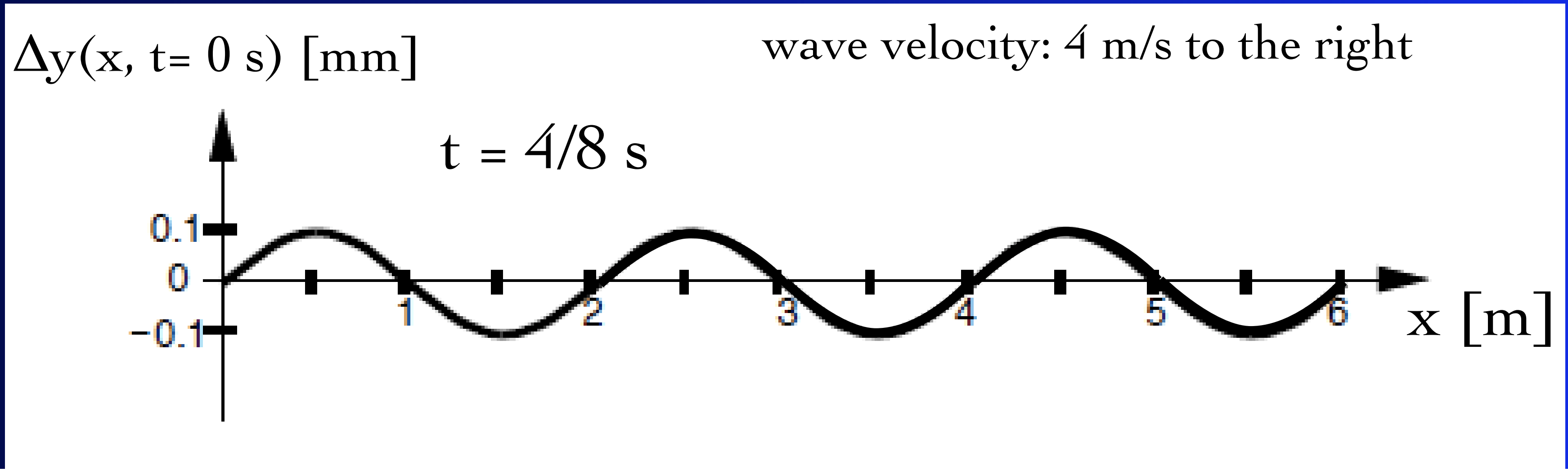
Sinusoidal Waves

- How do we determine the period of a wave? It's the length of time needed to cycle through the wave, so $T = 1/2$ s
- How do we determine the frequency of the wave? $f = 1/T = 2$ Hz
- angular frequency $\omega = 2\pi f = 12.57$ rad/s



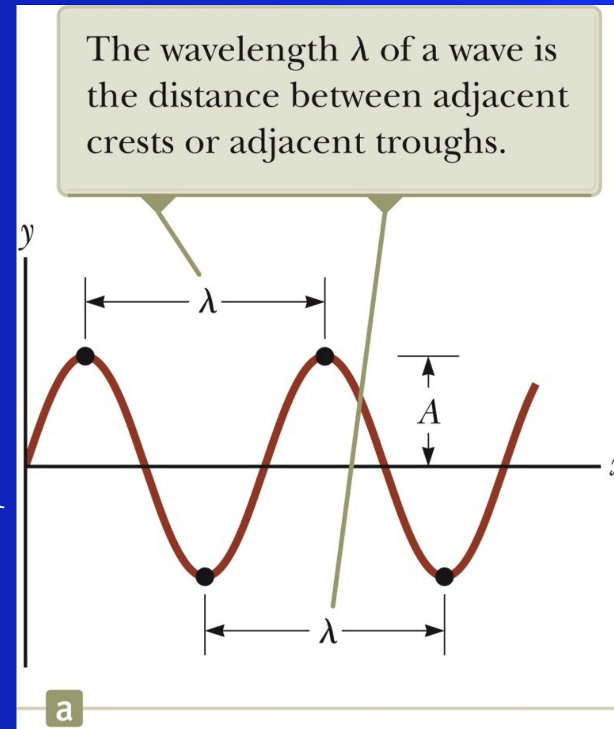
Sinusoidal Waves

- The period (T) is the amount of time necessary for the wave to travel by one wavelength (λ)
- speed=wavelength/period, which is equivalent to $v = \lambda f$
- v = (2 m) (2 Hz) = 4 m/s

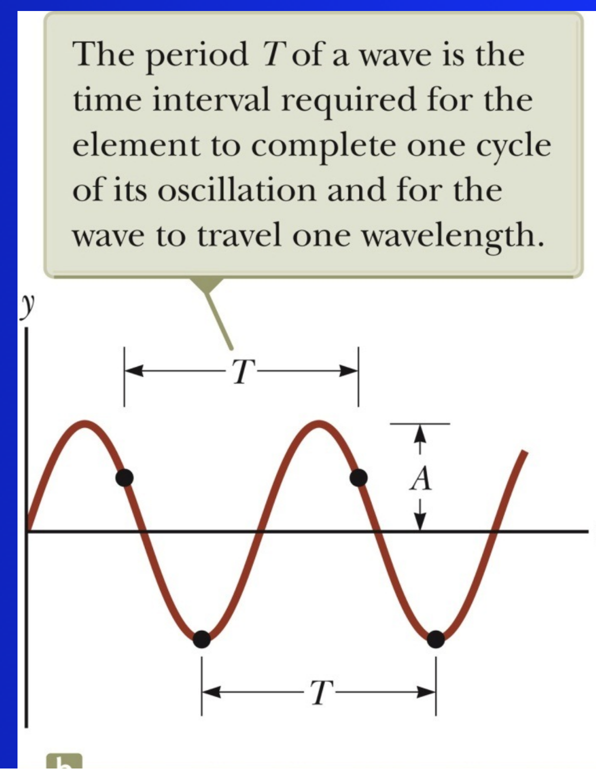


Traveling Wave: More Definitions

- **wavelength** λ (inversely related to *k*) and **amplitude** *A*



- **period** *T* and **frequency** (number of crests that pass a given point in a unit time interval: $f=1/T$)



generalized **wave function** (for a wave moving to the right):

$$y = A \sin\,(kx - \omega t + \phi)$$

Traveling Wave: water ripples

think of water ripples $y(x)$ at a given snapshot in time t. or think of $y(t)$ at a given x.

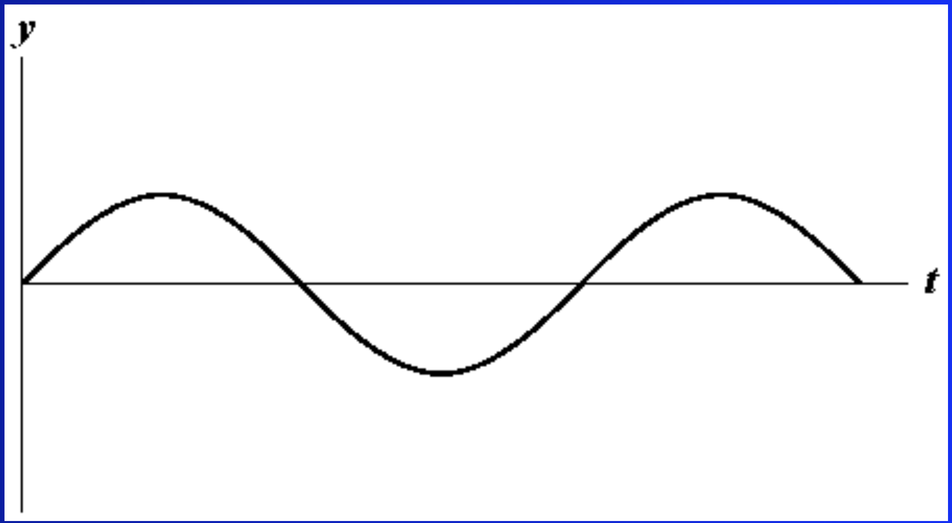
model of a wave function (for wave moving to the right): *y is a function of both* ***x*** *and* ***t***

$$y = A \sin\,(kx - \omega t + \phi)$$

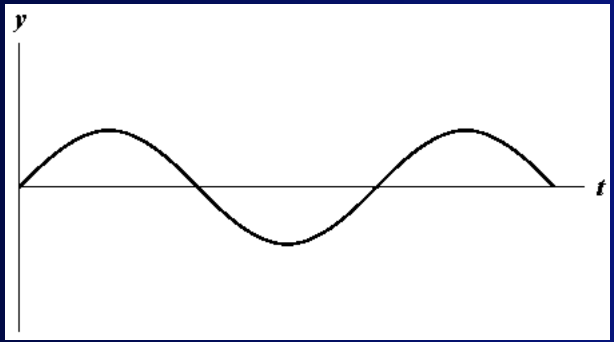
$$y(x,\, t) \; = A \sin \left[\frac{2\pi}{\lambda}(x - vt) \right]$$

Traveling Wave: example

The figure on the right shows a sine wave at one point of a string as a function of time. Which of the lower graphs shows a wave where the amplitude and frequency are doubled?



A.



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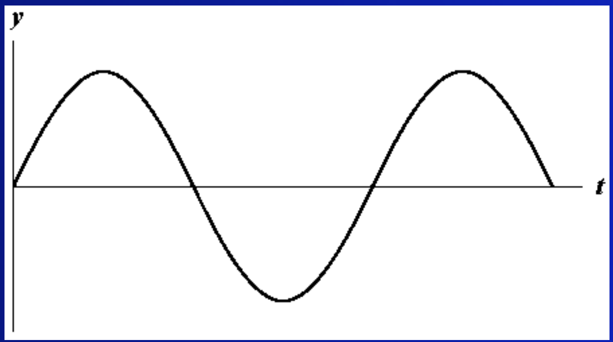

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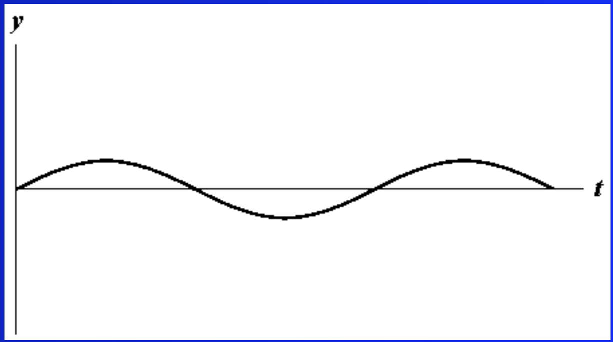
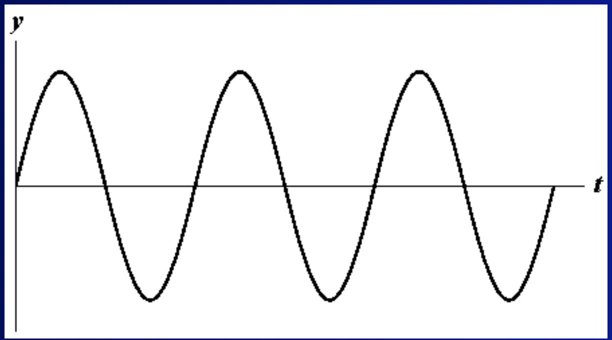
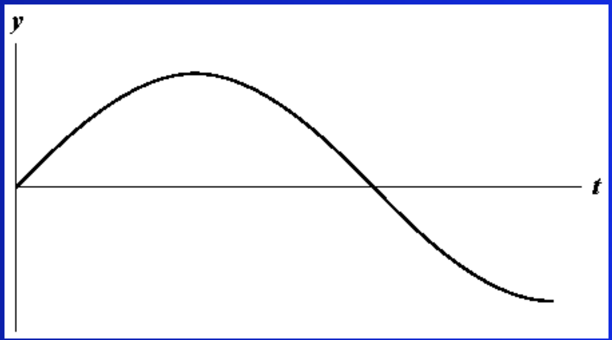


D.



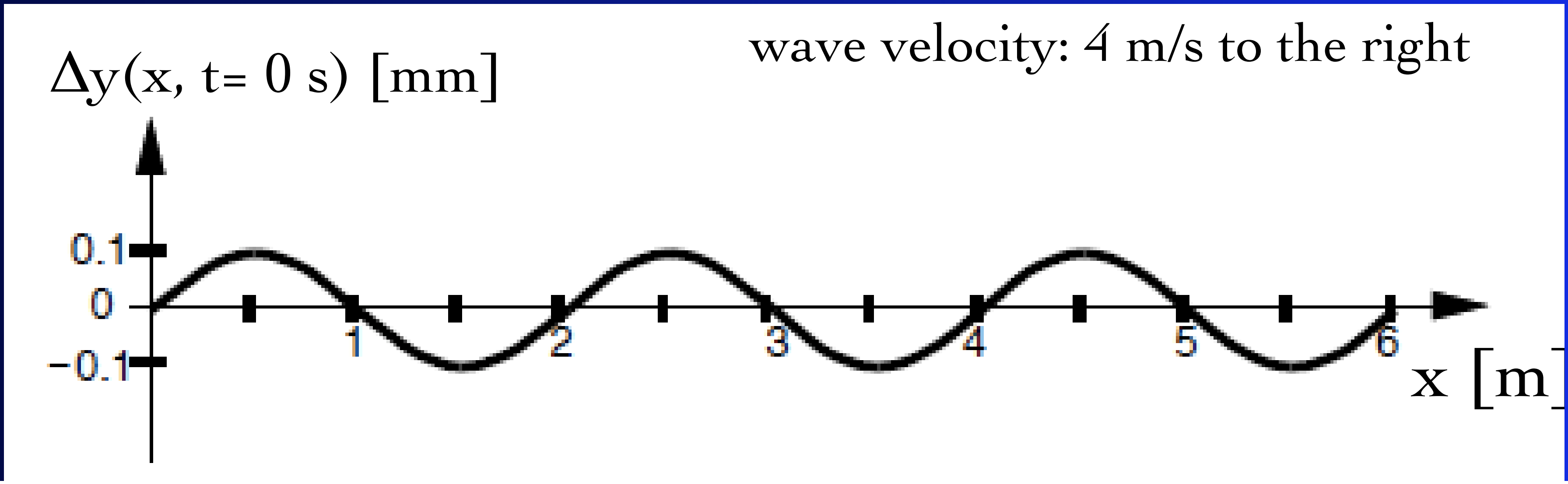
E.



another example

If we alter the medium so that the speed is halved but we keep the frequency the same, what happens to this graph?

A. nothing
B. stretched in the horizontal direction
C. compressed in the horizontal direction
D. stretched in the vertical direction
E. compressed in the vertical direction

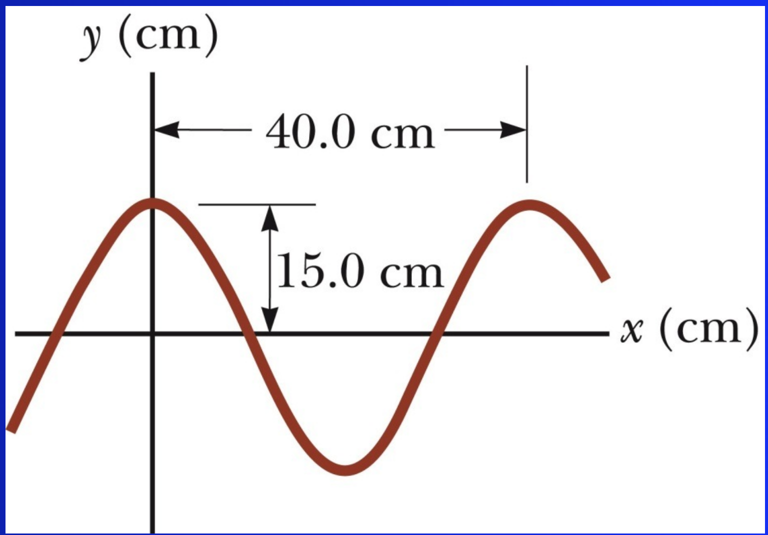


Example: Traveling Sinusoidal Wave

A sinusoidal wave traveling in the positive x direction has an amplitude of 15.0 cm, a wavelength of 40.0 cm, and a frequency of 8.00 Hz.

The vertical position of an element of the medium at t=0 and x=0 is also 15.0 cm.

a) Find the wave number k, period T, angular frequency ω, and speed v of the wave.



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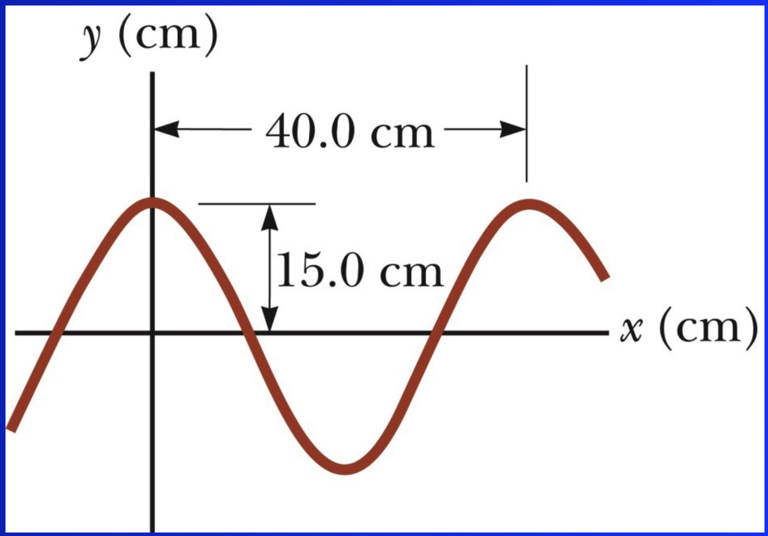
b) Determine the phase constant and write a general expression for the wave function.



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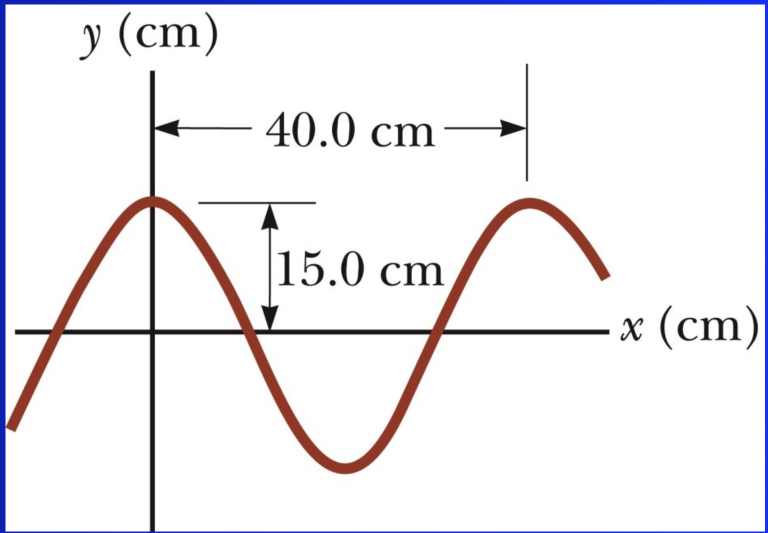


b) Determine the phase constant and write a general expression for the wave function.

(15.0 cm)=(15.0 cm) sin ϕ, so $\phi=\pi/2$ rad

$$y = A \sin\left(kx - \omega t + \frac{\pi}{2}\right) = A \cos\,(kx - \omega t)$$

$$y = 0.150 \cos\,(15.7x - 50.3t)$$

Linear Wave Equation

- The functions $y(x,t) = A \sin(kx - \omega t)$ represent solutions to the ***linear wave equation***
- The transverse speed & acceleration are the derivatives with respect to time t, and the derivatives with respect to x are similar (but factors of k rather than ω come out)
- since $v = \lambda f = (2\pi/k)(\omega/2\pi)$, this means…

$$\frac{\partial^2 y}{\partial x^2} = \frac{1}{v^2}\frac{\partial^2 y}{\partial t^2}$$

Speed of Transverse Wave

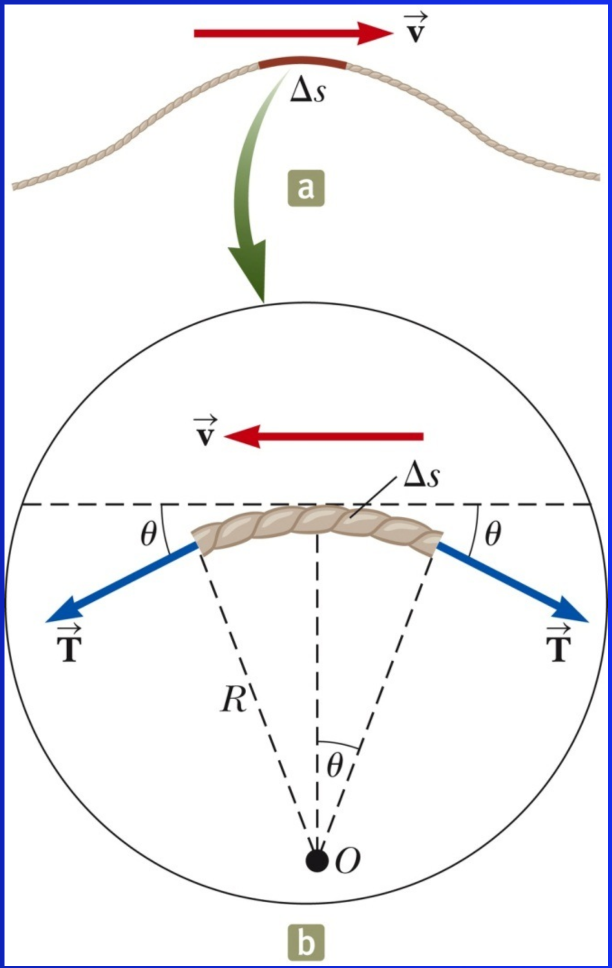
net force acting on piece (or "element") of string under tension *T*:

$$F_r = 2T\sin\theta \approx 2T\theta$$

applying the sinusoidal wave function to the linear wave equation gives us the speed of the wave on a string

$$v = \sqrt{\frac{T}{\mu}}$$

(μ is the string's mass per unit length)



transverse wave on a string: example

A student attaches a length of nylon fishing line to a fence post. She stretches it out and shakes the end of the rope in her hand back and forth to produce waves on the line. The most efficient way for her to increase the wavelength is to

A. increase the tension and shake the end more times per second

B. decrease the tension and shake the end more times per second

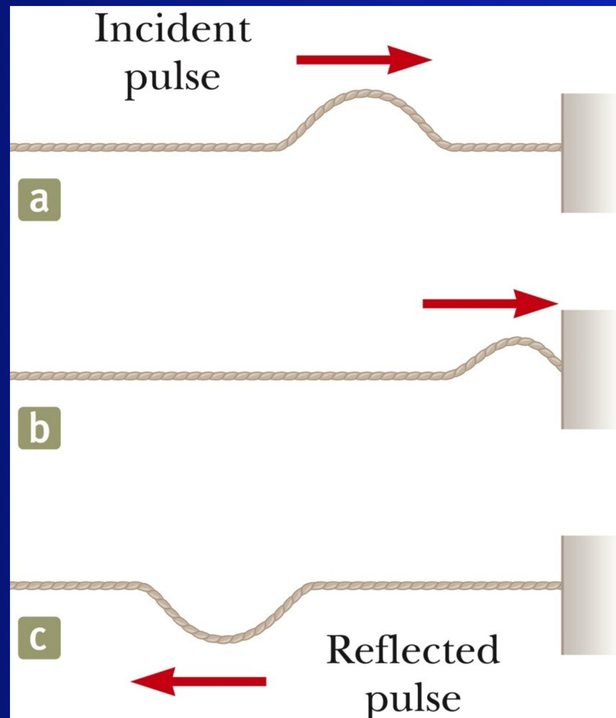
C. increase the tension and shake the end fewer times per second

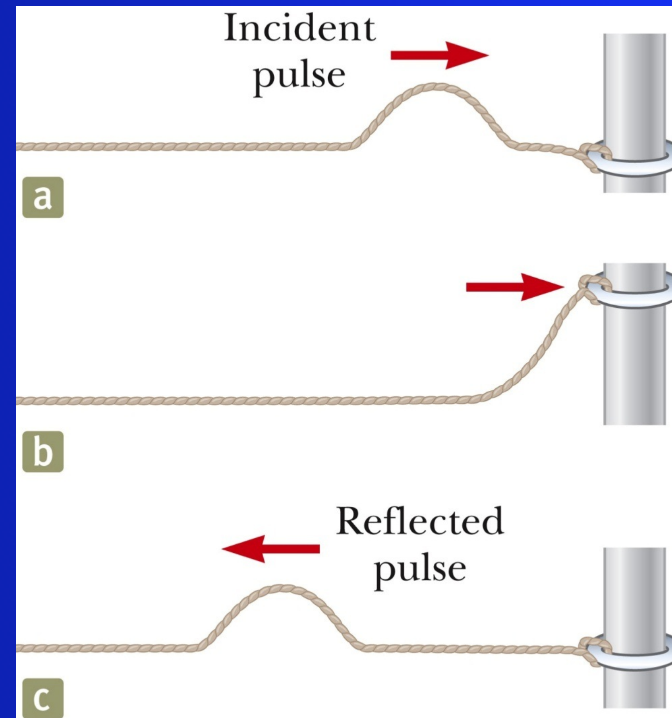
D. decrease the tension and shake the end fewer times per second

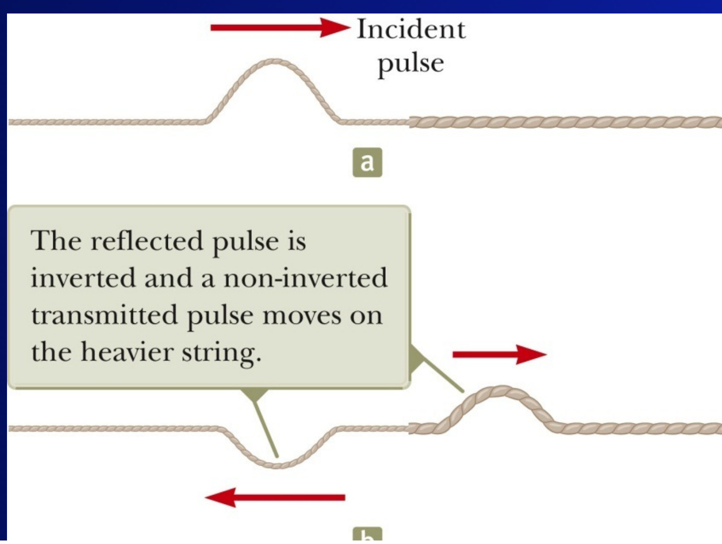
E. keep the tension and frequency the same but increase the length

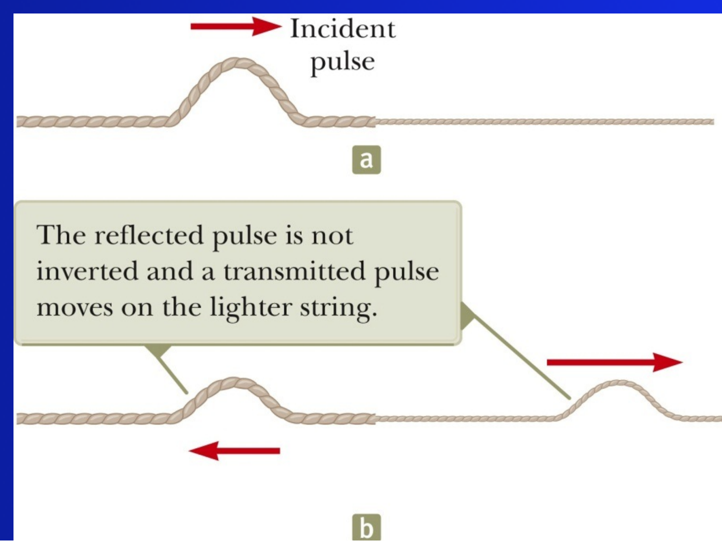
reflection and transmission of wave pulses

Note that the traveling pulse is inverted only when the point on the wall is fixed:









Rate of Energy Transfer

Waves transport energy (and momentum) when they propagate through a medium

We model *each* piece of string as a simple harmonic oscillator; each element has the same total energy

Kinetic energy: $dK = (1/2)\, dm\, v^2$

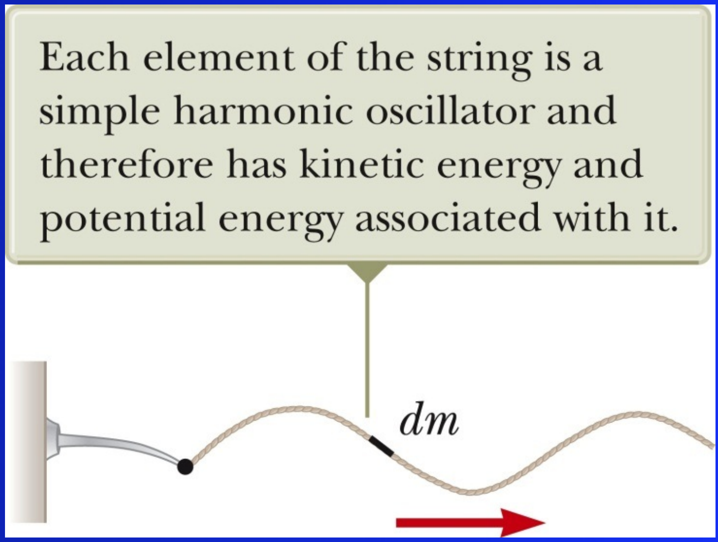
using $A\cos(kx-\omega t)$, then we get:

$K = (1/4)\, \mu\, \omega^2 A^2 \lambda$

Potential energy: $U_\lambda = \frac{1}{4}\mu\omega^2 A^2\lambda$

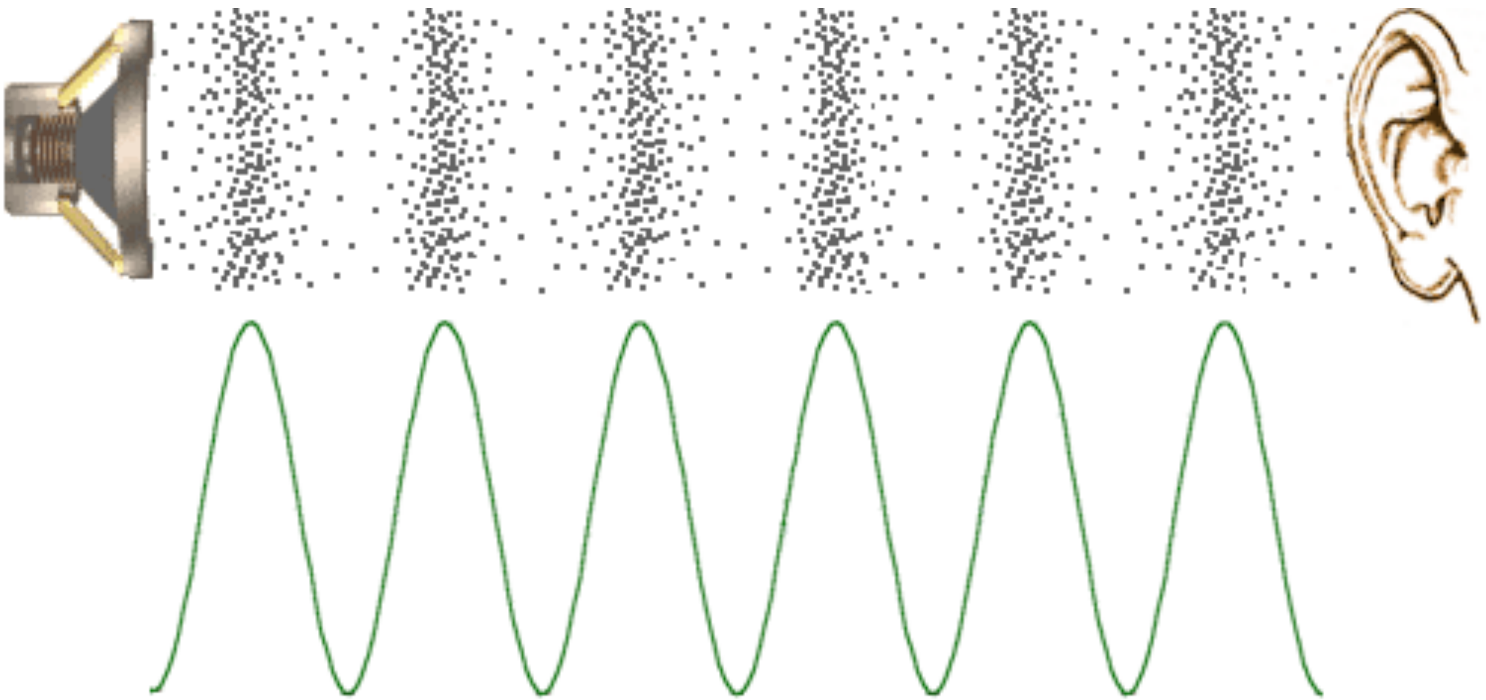
Total Energy: $E_\lambda = U_\lambda + K_\lambda = \frac{1}{2}\mu\omega^2 A^2\lambda$

Power: rate of energy transfer (E_λ / T)

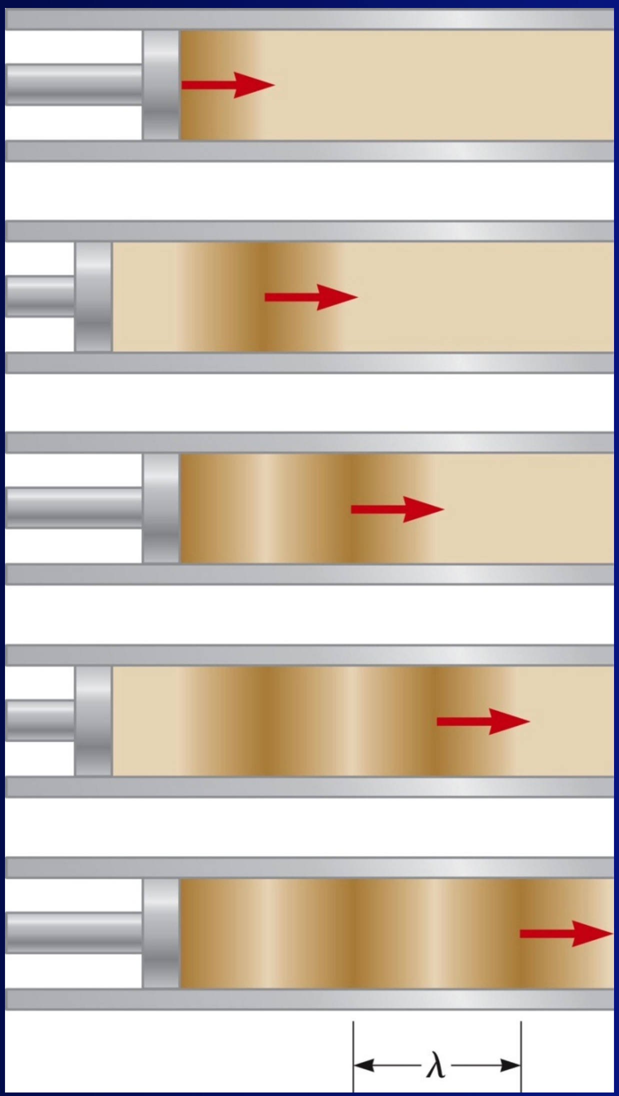


Sound Waves

- Longitudinal Wave traveling through the air
- speed of sound at room temperature ~ 340 m/s
- audio frequency range: 20-20,000 Hz



Sound Waves



- sound waves are longitudinal waves, such as the simple case of an oscillating piston producing a wave in a gas-filled tube
- low pressure areas are “rarefactions” and high pressure ones are “compressions”
- like waves on a string, sound waves have velocities, frequencies, periods, etc., and they can be reflected and transmitted through media

Sound Waves

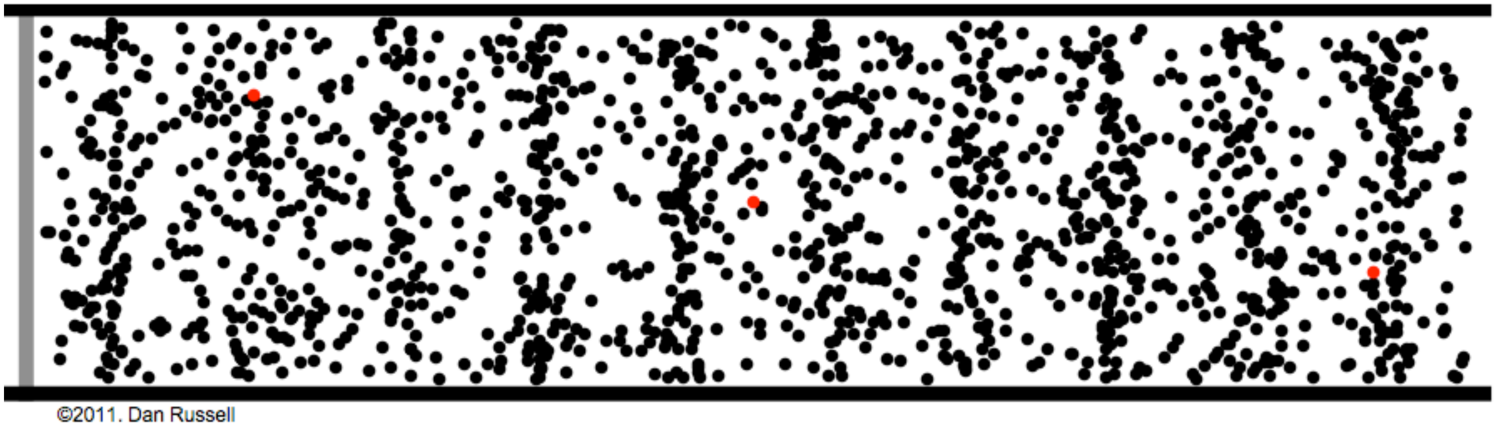
- note that the speed of sound depends on the temperature of the medium:

$$v = 331\sqrt{1 + \frac{T_{\mathrm{C}}}{273}}$$

- the speed of sound in room temperature air (20 C) is about 343 m/s. (That's about 767 mph. Think of planes going Mach 1, named after Austrian physicist Ernst Mach.)

- the speed of sound in room temperature water—which is more dense—is even faster (about 1500 m/s)

Sound Waves



The red dot represents an air molecule that oscillates in simple harmonic motion with a period, T. What physical factors determine the period of its oscillations?

frequency of the vibrator on the left? speed of sound in air? distance between the vibrator and the red dot?

Sound Wave question

Two sirens *A* and *B* are sounding so that the frequency from *A* is twice the frequency from *B*. Compared with the speed of sound from *A*, which of the following statements is true?

A. The speed of sound from *B* is the same.

B. The speed of sound from *B* is half as fast.

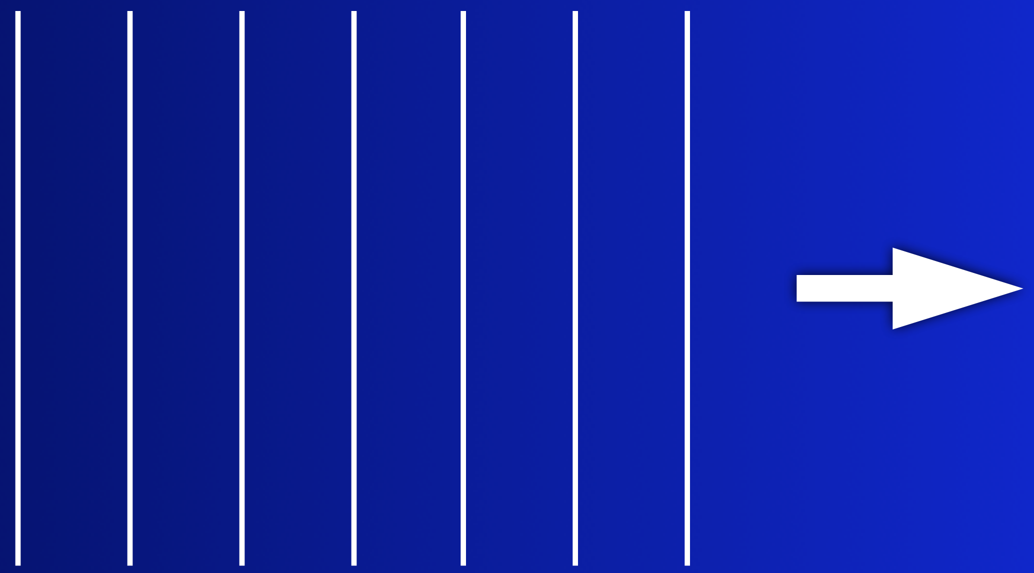
C. The speed of sound from *B* is one-fourth as fast.

D. The speed of sound from *B* is twice as fast.

E. The speed of sound from *B* is four times as fast.

Reflection & Transmission, Wavefronts

- Wavefronts: a way to draw a "snapshot graph," but in multiple dimensions
- lines represent the peaks of the waves
- as the wave propagates, the wavefronts move

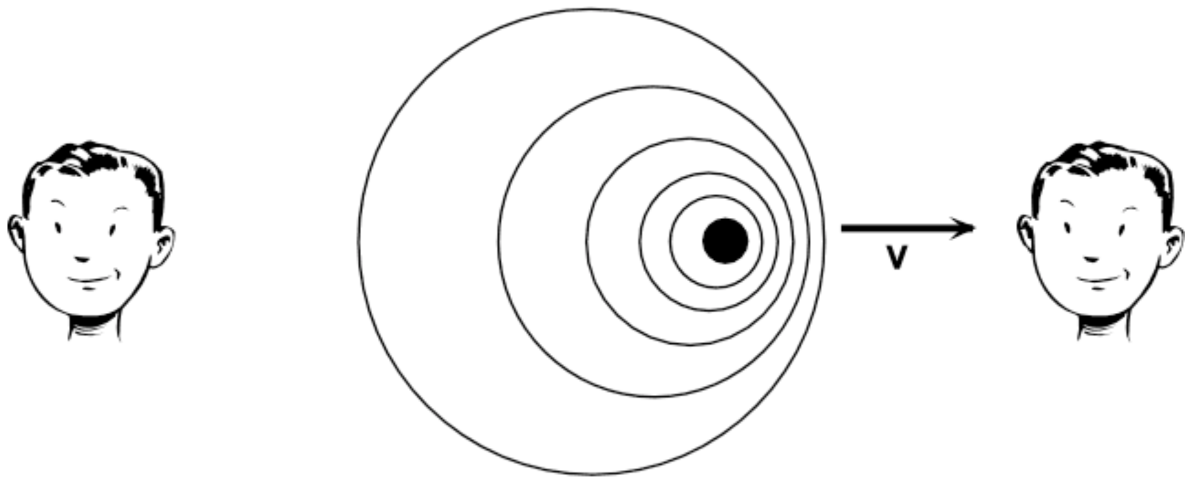


next time: Doppler Effect

- Observer moves toward Source:
  observes crests to occur *more* often ⇒ *higher* pitch
  (higher frequency *f*)

- Observer moves away from Source:
  observes crests to occur *less* often ⇒ *lower* pitch

Source moving:



for Thursday:

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- finish reading chapter 13
- look at the Ted course website and make sure that you've registered your clicker, if you haven't done so already