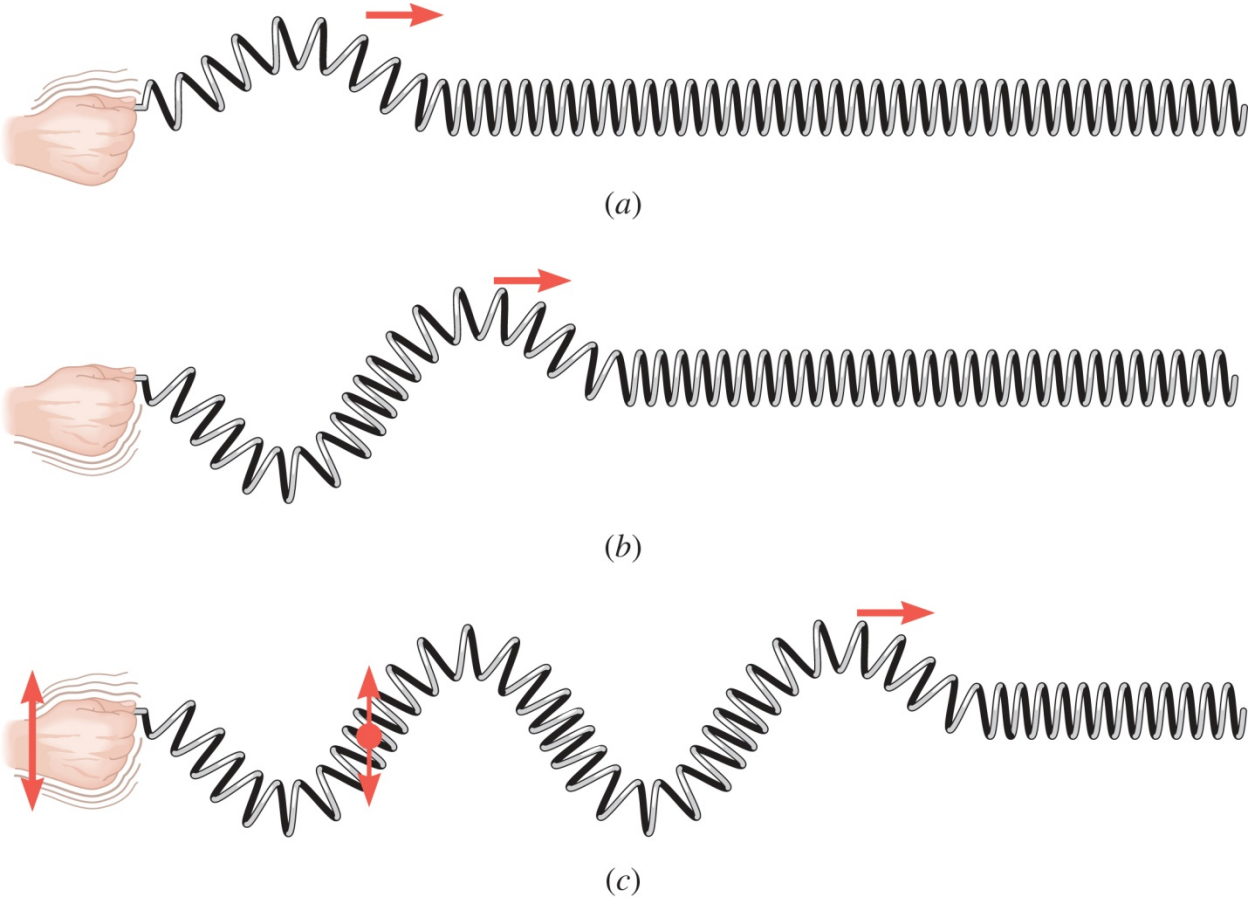
Chapter 16

Waves and Sound

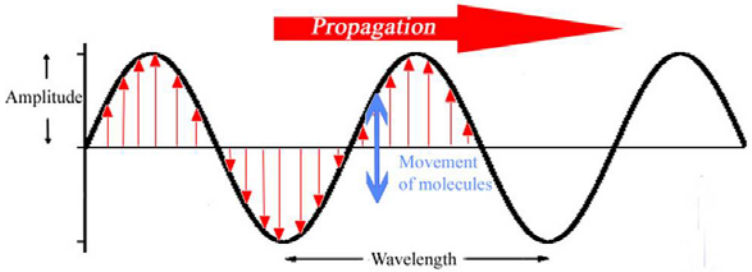
Waves:

1. A wave is a traveling disturbance.
2. A wave carries energy from place to place.



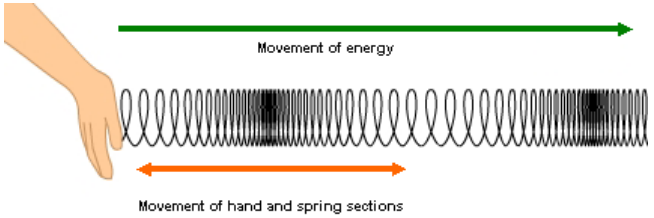
Two types

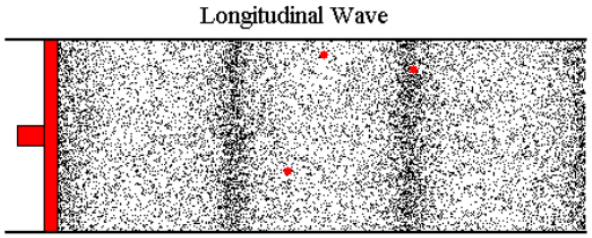
Transverse Wave

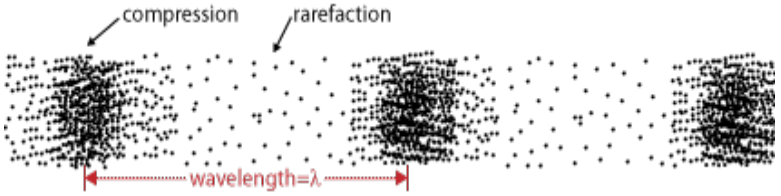


Vibration of particles is perpendicular to the direction of wave's speed

Longitudinal Wave

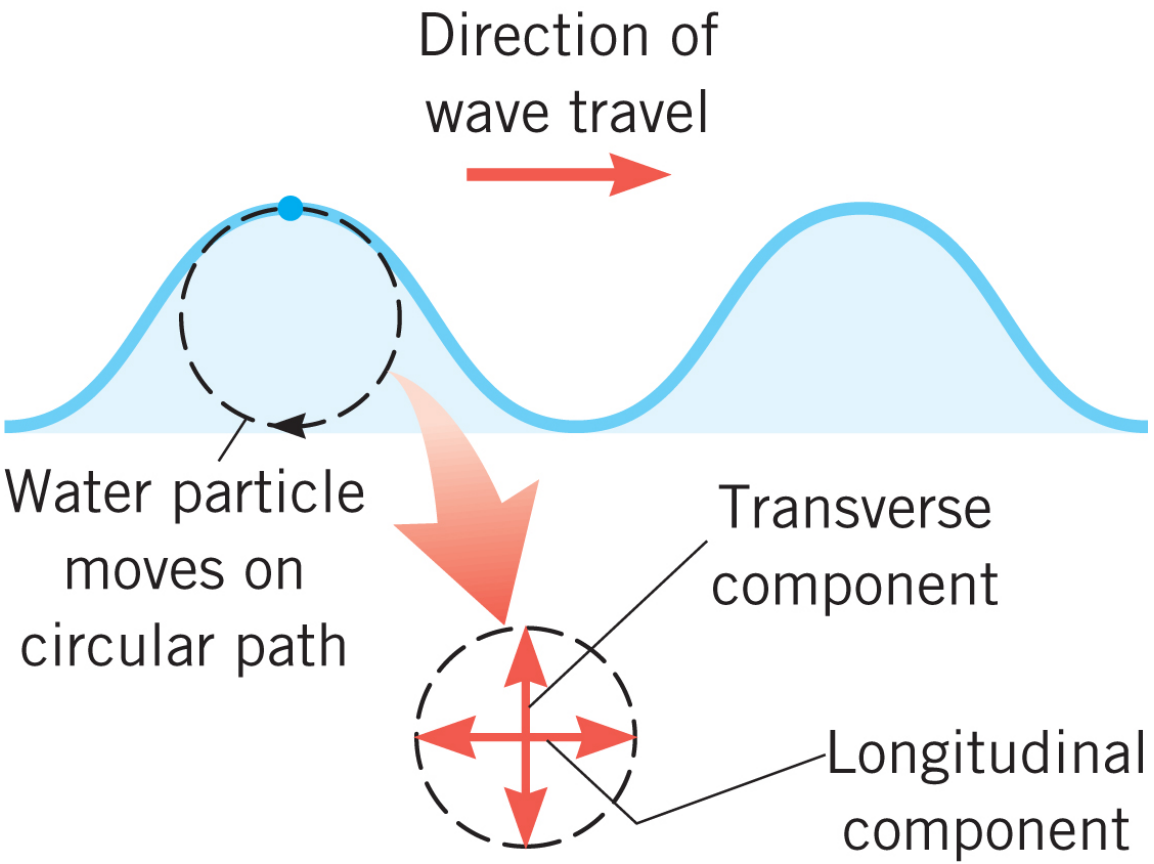




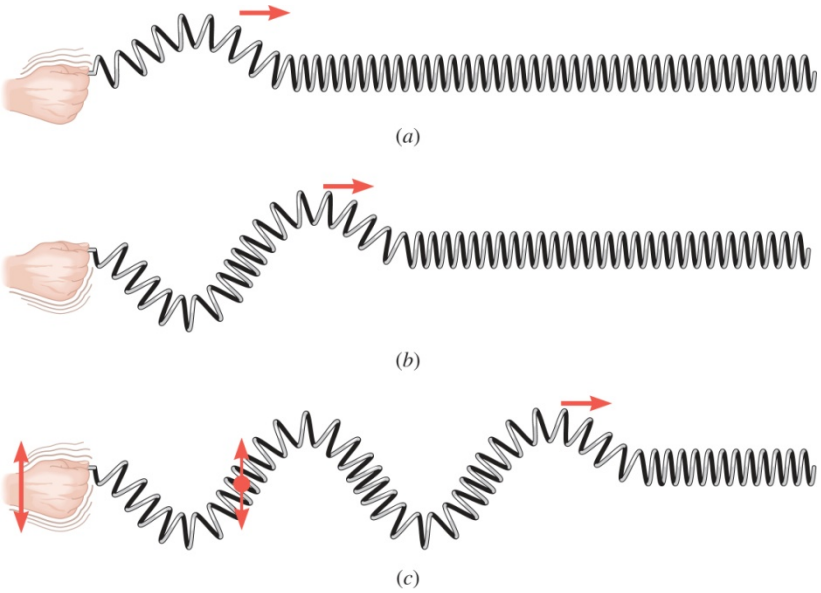


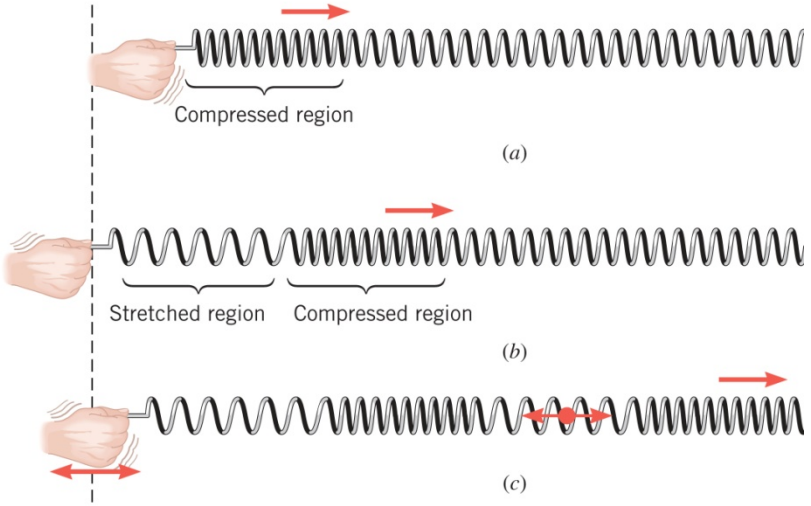
Vibration of particles is parallel to the direction of wave's speed

Water waves are partially transverse and partially longitudinal.

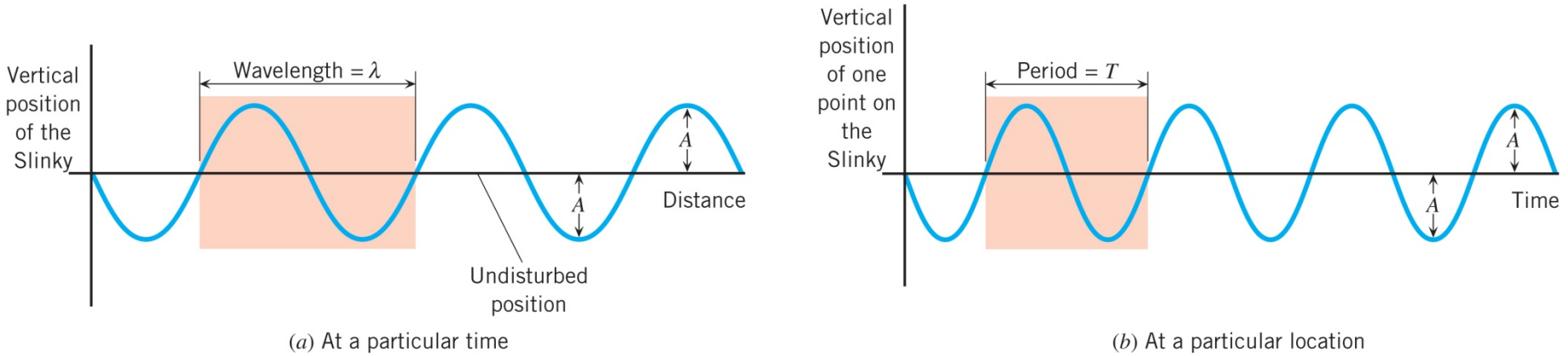


Periodic waves consist of cycles or patterns that are produced over and over again by the source.





In both cases, every segment of the slinky vibrates in simple harmonic motion, provided the end of the slinky is moved in simple harmonic motion.



(a) At a particular time (b) At a particular location

The ***amplitude,*** A is the maximum excursion of a particle of the medium from the particles undisturbed position (equilibrium position).

The ***period***, T is the time required for one complete cycle.

The ***frequency***, f is related to the period and has units of Hz, or s^{-1}. $f = \frac{1}{T}$

The ***wavelength,*** λ is the horizontal length of one cycle of the wave.

SI Units? m

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

***Example:* The Wavelengths of Radio Waves**

AM and FM radio waves are transverse waves consisting of electric and magnetic field disturbances traveling at a speed of $3.00\text{x}10^8$ m/s. A station broadcasts AM radio waves whose frequency is $1230\text{x}10^3$ Hz and an FM radio wave whose frequency is $91.9\text{x}10^6$ Hz. Find the distance between adjacent crests in each wave.

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

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

AM Radio Waves

$$\lambda = \frac{v}{f} = \frac{3.00\times10^8\ \text{m/s}}{1230\times10^3\ \text{Hz}}$$

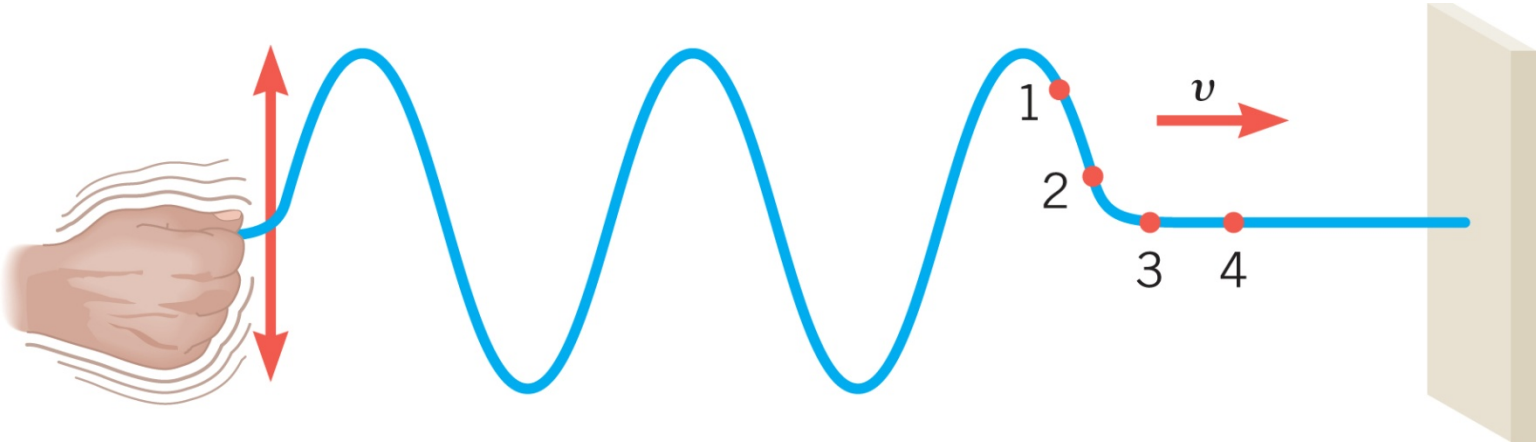
244 m

FM Radio Waves

$$\lambda = \frac{3.00\times10^8\ \text{m/s}}{91.9\times10^6\ \text{Hz}}$$

3.26 m

The speed at which the wave moves to the right depends on how quickly one particle of the string is accelerated upward in response to the net pulling force.



- Speed will be large if Force on each particle is large
- Speed will be small if mass of each particle is large

$$v = \sqrt{\frac{F}{m/L}}$$

tension

linear density

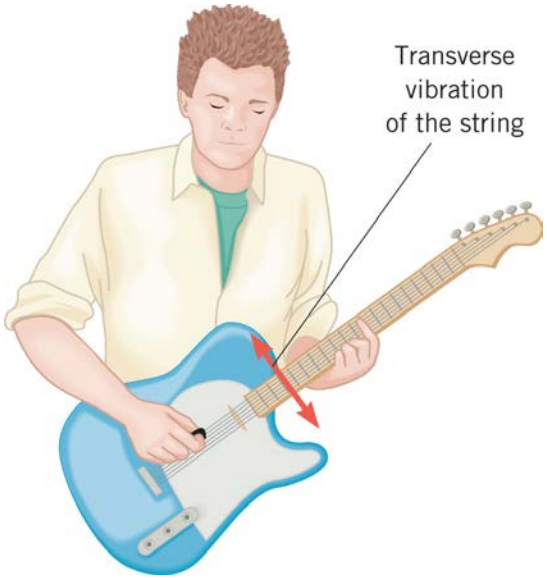
Example: **Waves Traveling on Guitar Strings**

Transverse waves travel on each string of an electric guitar after the string is plucked. The length of each string between its two fixed ends is 0.628 m, and the mass is 0.208 g for the highest pitched E string and 3.32 g for the lowest pitched E string. Each string is under a tension of 226 N. Find the speeds of the waves on the two strings.

High E

$$v = \sqrt{\frac{F}{m/L}} = \sqrt{\frac{226\ \text{N}}{(0.208\times10^{-3}\ \text{kg})/(0.628\ \text{m})}}$$

826 m/s



Low E

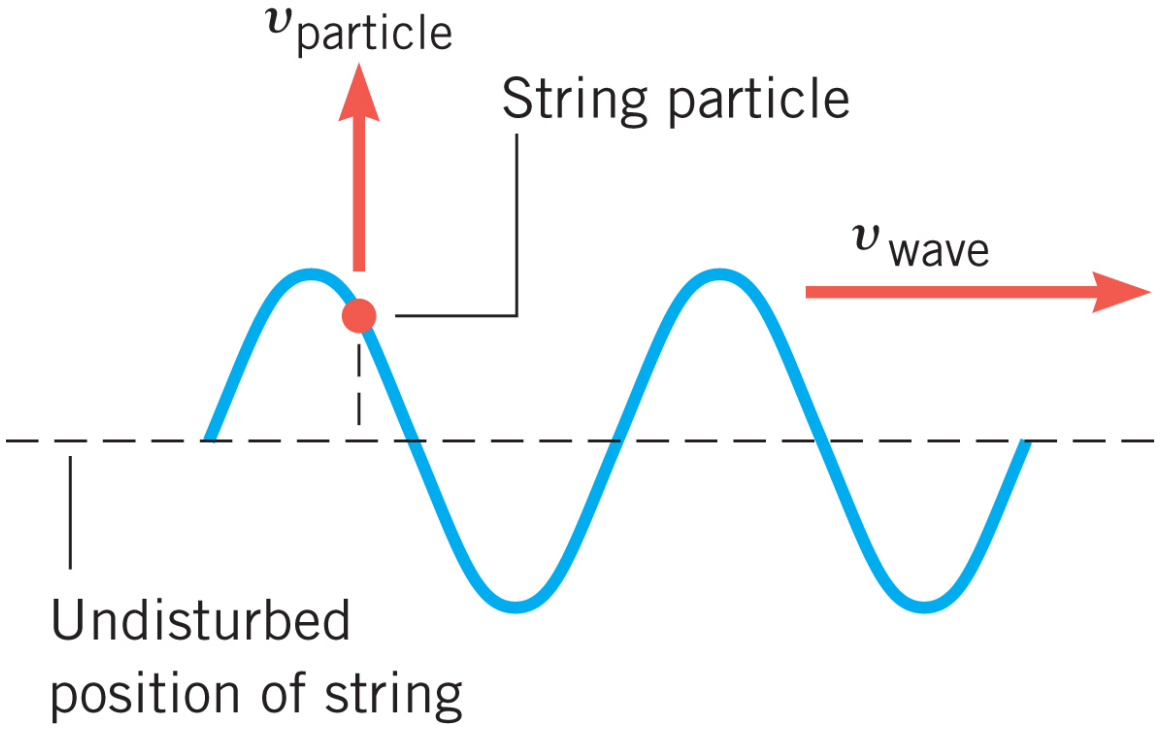
$$v = \sqrt{\frac{F}{m/L}} = \sqrt{\frac{226\ \text{N}}{(3.32\times10^{-3}\ \text{kg})/(0.628\ \text{m})}}$$

207 m/s

***Conceptual Example:* Wave Speed Versus Particle Speed**

Is the speed of a transverse wave on a string the same as the speed at which a particle on the string moves?

NO



Problem: 3 A woman is standing in the ocean, and she notices that after a wave crest passes by, five more crests pass in a time of 50.0 s. The distance between two successive crests is 32.0 m. What is the wave's (a) period, (b) frequency, (c) wavelength, (d) speed, and (e) amplitude?

a. After the initial crest passes, 5 additional crests pass in a time of 50.0 s. The period T of the wave is

$$T = \frac{50.0\ \text{s}}{5} = \boxed{10.0\ \text{s}}$$

b. Since the frequency f and period T are related by $f = 1/T$, we have

$$f = \frac{1}{T} = \frac{1}{10.0\ \text{s}} = \boxed{0.100\ \text{Hz}}$$

c. The horizontal distance between two successive crests is given as 32 m. This is also the wavelength l of the wave, so

$$\lambda = \boxed{32\ \text{m}}$$

d. According to Equation 16.1, the speed v of the wave is

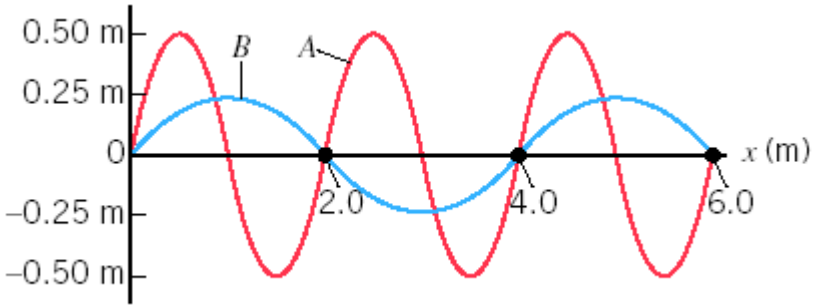
$$v = f\lambda = (0.100\ \text{Hz})(32\ \text{m}) = \boxed{3.2\ \text{m/s}}$$

e. There is no information given, either directly or indirectly, about the amplitude of the wave. Therefore,

It is not possible to determine the amplitude

Problem: 19

The drawing shows a graph of two waves traveling to the right at the same speed. **(a)** Using the data in the drawing, determine the wavelength of each wave. **(b)** The speed of the waves is 12 m/s; calculate the frequency of each one. **(c)** What is the maximum speed for a particle attached to each wave?



a. From the drawing, we determine the wavelength of each wave to be

$\lambda_A =$ 2.0 m $\quad \lambda_B =$ 4.0 m

b. The frequency of each wave is given by:

$f_A = \dfrac{v}{\lambda_A}$ 6.0 Hz $\quad f_B = \dfrac{v}{\lambda_B}$ 3.0 Hz

c. The maximum speed for a particle moving in simple harmonic motion is given by: $v_{max} = A\omega$

$v_{max} = A_A\omega_A = A_A(2\pi f_A) = (0.5\ m)(2\pi f_A)$ 19 m/s

$v_{max} = A_B\omega_B = A_B\, 2\pi\, f_B = (0.25\ \text{m})\,2\pi\,(3.0\ \text{Hz}) =$ 4.7 m/s

Problem: 10

A jet skier is moving at 8.4 m/s in the direction in which the waves on a lake are moving. Each time he passes over a crest, he feels a bump. The bumping frequency is 1.20 Hz, and the crests are separated by 5.8 m. What is the wave speed?

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

$$v_{JW} = v_{JS} - v_{WS} = f\lambda$$

$$\Downarrow$$

$$v_{WS} = v_{JS} - f\lambda$$

5.8 m

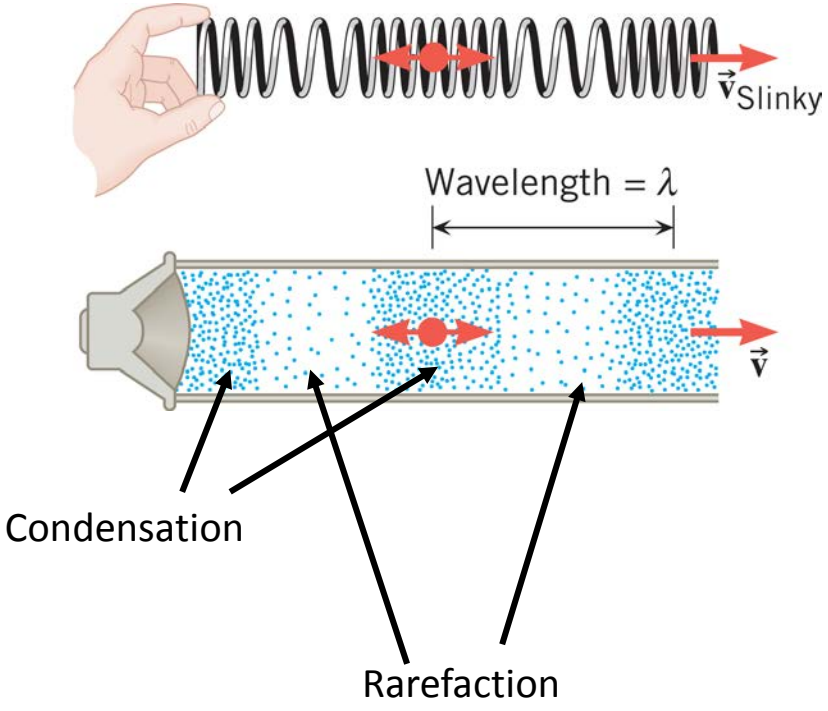
8.4 m

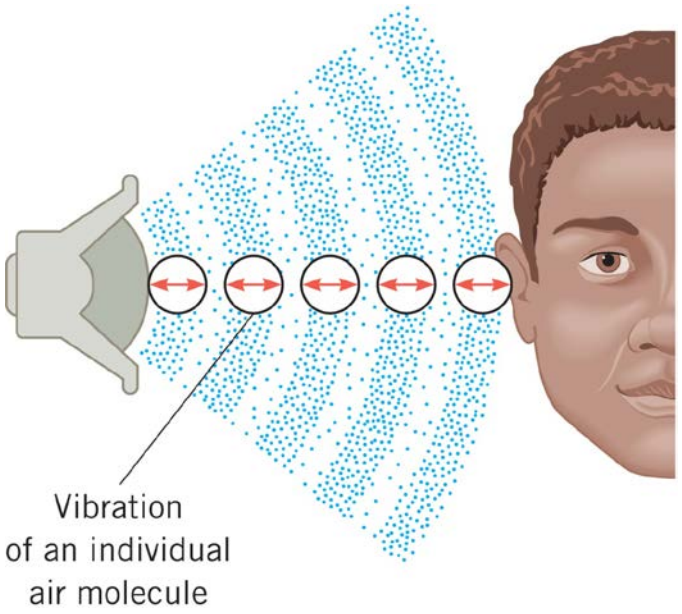
1.2 Hz

$$v_{WS} = v_{JS} - f\lambda = 8.4 \text{ m/s} - (1.2 \text{ Hz})(5.8 \text{ m}) = \boxed{1.4 \text{ m/s}}$$

LONGITUDINAL SOUND WAVES

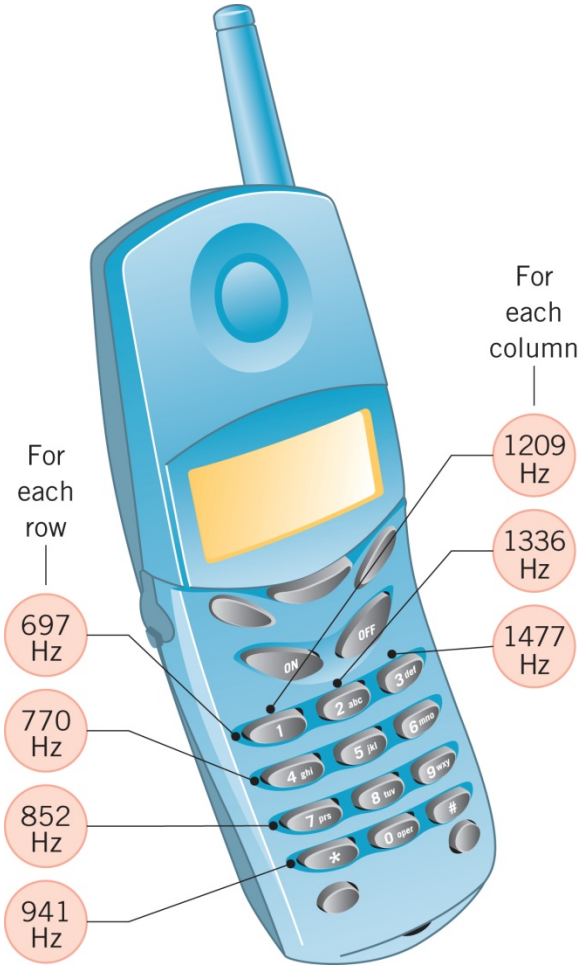
The distance between adjacent condensations is equal to the wavelength of the sound wave.





Individual air molecules are not carried along with the wave.

THE FREQUENCY OF A SOUND WAVE

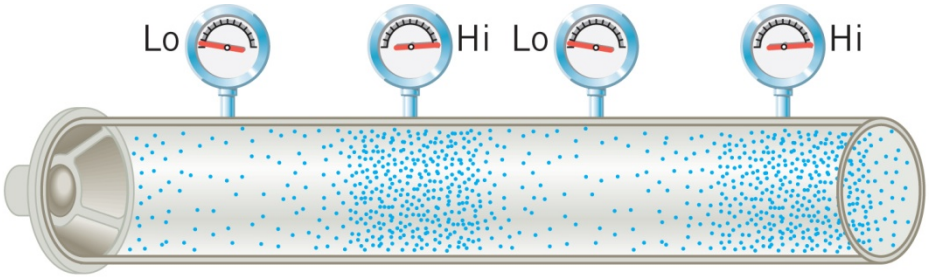


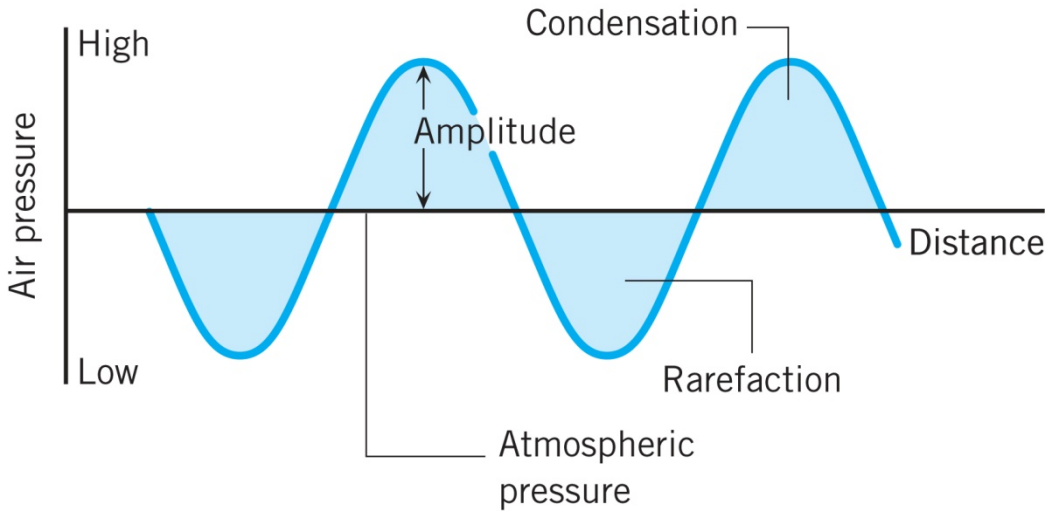
The ***frequency*** is the number of cycles per second.

A sound with a single frequency is called a ***pure tone***.

The brain interprets the frequency in terms of the subjective quality called ***pitch***.

THE PRESSURE AMPLITUDE OF A SOUND WAVE





Loudness is an attribute of a sound that depends primarily on the pressure amplitude of the wave.

Sound travels through gases, liquids, and solids at considerably different speeds.

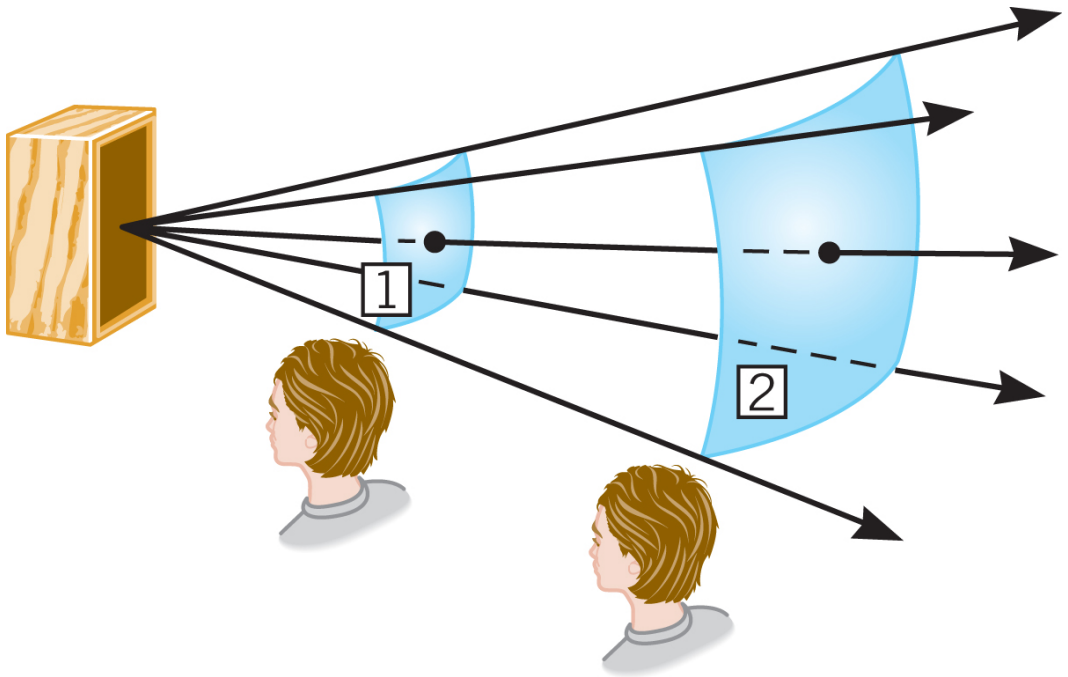
Table 16.1 Speed of Sound in Gases, Liquids, and Solids

Substance	Speed (m/s)
Gases	
Air (0 °C)	331
Air (20 °C)	343
Carbon dioxide (0 °C)	259
Oxygen (0 °C)	316
Helium (0 °C)	965
Liquids	
Chloroform (20 °C)	1004
Ethyl alcohol (20 °C)	1162
Mercury (20 °C)	1450
Fresh water (20 °C)	1482
Seawater (20 °C)	1522
Solids	
Copper	5010
Glass (Pyrex)	5640
Lead	1960
Steel	5960

Sound waves carry energy that can be used to do work.

The amount of energy transported per second is called the ***power*** of the wave.

The ***sound intensity*** is defined as the power that passes perpendicularly through a surface divided by the area of that surface.



$$I = \frac{P}{A}$$

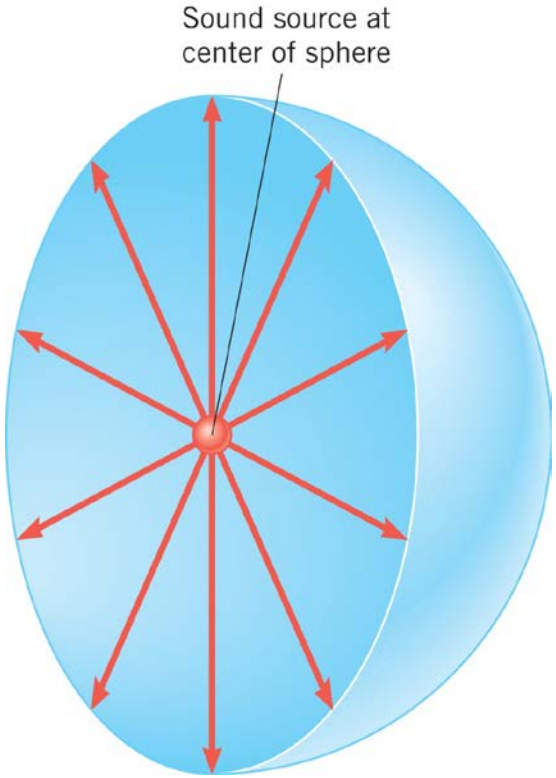
Units of Intensity?

Watts/m^2

For a 1000 Hz tone, the smallest sound intensity that the human ear can detect is about $1 \times 10^{-12} W/m^2$. This intensity is called the ***threshold of hearing***.

On the other extreme, continuous exposure to intensities greater than $1 W/m^2$ can be painful.

If the source emits sound *uniformly in all directions*, the intensity depends on the distance from the source in a simple way.



Power of sound source

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

area of sphere

Q: A source is emitting sound waves uniformly in all directions. A student measures Intensity I_1 at a distance r from the source and measures the intensity I_2 again at a distance double than the previous distance (that is 2r). The Intensity ratio (I_2/I_1) he found was

a) 0.25
b) 1
c) 2
d) 4

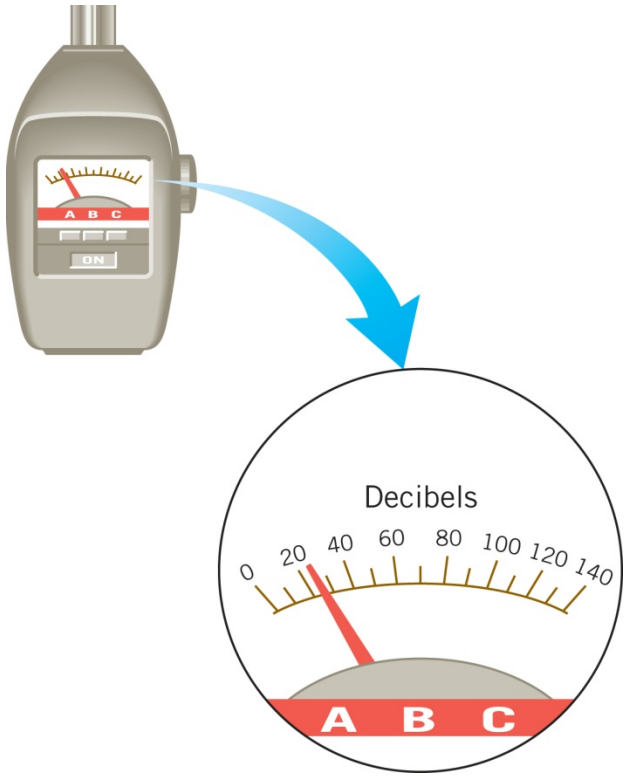
$$I = \frac{P}{4\pi r^2}$$

The ***decibel*** (dB) is a measurement unit used when comparing two sound intensities.

Because of the way in which the human hearing mechanism responds to intensity, it is appropriate to use a logarithmic scale called the ***intensity level:***

$$\beta = (10\ \text{dB})\log\left(\frac{I}{I_o}\right)$$

$$I_o = 1.00\times10^{-12}\ \text{W/m}^2$$



Note that log(1)=0, so when the intensity of the sound is equal to the threshold of hearing, the intensity level is zero.

$$\beta = (10\ \text{dB})\log\left(\frac{I}{I_o}\right)$$

$$I_o = 1.00\times10^{-12}\ \text{W/m}^2$$

Q: An intensity level of 0 dB means that the sound intensity is

a) 0 N/m^2

b) Equal to hearing threshold frequency.

c) Equal to 1 N/m^2.

d) No way to tell

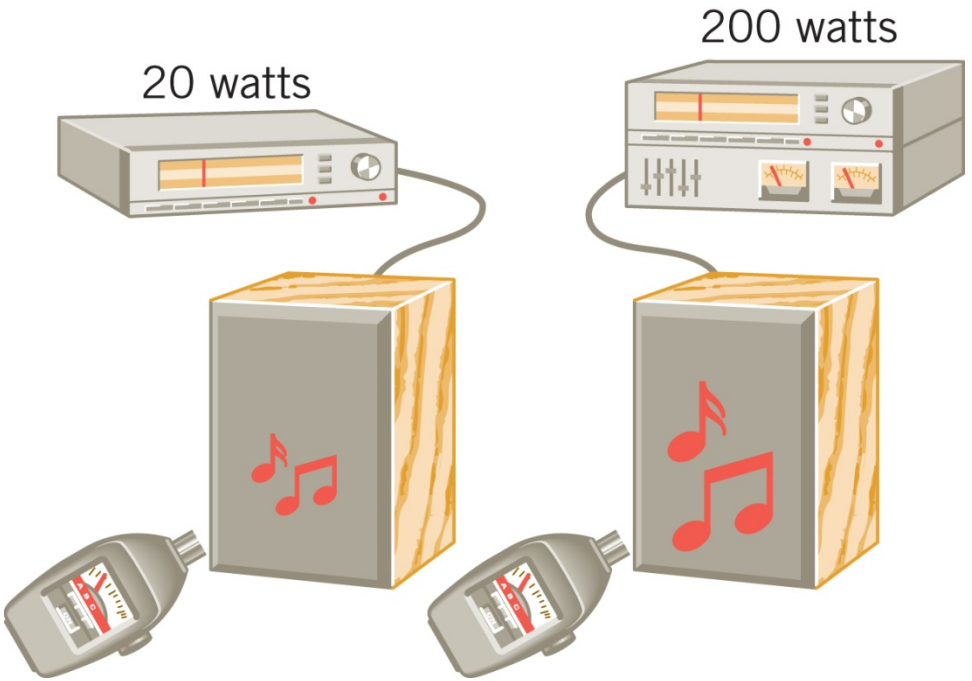
Table 16.2 Typical Sound Intensities and Intensity Levels Relative to the Threshold of Hearing

	Intensity I (W/m^2)	Intensity Level β (dB)
Threshold of hearing	1.0×10^{-12}	0
Rustling leaves	1.0×10^{-11}	10
Whisper	1.0×10^{-10}	20
Normal conversation (1 meter)	3.2×10^{-6}	65
Inside car in city traffic	1.0×10^{-4}	80
Car without muffler	1.0×10^{-2}	100
Live rock concert	1.0	120
Threshold of pain	10	130

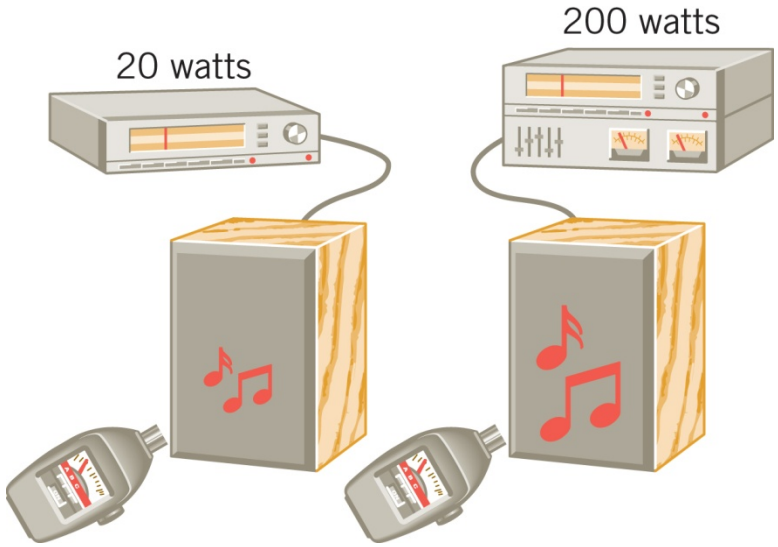
Example 9 Comparing Sound Intensities

Audio system 1 produces a sound intensity level of 90.0 dB, and system 2 produces an intensity level of 93.0 dB. Determine the ratio of intensities.

$$\beta = (10\ \text{dB})\log\left(\frac{I}{I_o}\right)$$



$$\beta = (10\ \text{dB})\log\left(\frac{I}{I_o}\right)$$



$$\beta_1 = (10\ \text{dB})\log\left(\frac{I_1}{I_o}\right) \qquad \beta_2 = (10\ \text{dB})\log\left(\frac{I_2}{I_o}\right)$$

$$\beta_2 - \beta_1 = (10\ \text{dB})\log\left(\frac{I_2}{I_o}\right) - (10\ \text{dB})\log\left(\frac{I_1}{I_o}\right) = (10\ \text{dB})\log\left(\frac{I_2/I_o}{I_1/I_o}\right) = (10\ \text{dB})\log\left(\frac{I_2}{I_1}\right)$$

93-90 dB
(given)

$$3.0\ \text{dB} = (10\ \text{dB})\log\left(\frac{I_2}{I_1}\right)$$

$$0.30 = \log\left(\frac{I_2}{I_1}\right) \qquad \frac{I_2}{I_1} = 10^{0.30} = 2.0$$

For Recitation

Ch. 16

FOC: 3, 7, & 15.

Problems 3, 10, 53 &101

Reading For Next Class

Ch. 17