Purdue University Department of Physics

Physics 22000

General Physics

Lecture 25 – Waves

Fall 2016 Semester

Prof. Matthew Jones

Final Exam

UniTime

Examination Schedule

Fall 2016 (PWL)
Click here to change the session / role.

Filter

Term: Fall 2016 (PWL), Exams: Final, Subject: PHYS Apply

Fall 2016 (PWL) final examinations (PHYS)

↑Subject	Course	CRN	Section	Date	Time	Room
PHYS	17200			Wed 12/14	1:00p - 3:00p	LAMB F101
PHYS	17200H	26979	26979-H01	Mon 12/12	8:00a - 10:00a	PHYS 114
PHYS	21400	26984	26984-001	Tue 12/13	10:30a - 12:30p	PHYS 114
PHYS	21500	26987	26987-001	Fri 12/16	1:00p - 3:00p	PHYS 112
PHYS	21800	16840	16840-014	Mon 12/12	7:00p - 9:00p	HIKS B848
PHYS	21800	26997	26997-001	Fri 12/16	1:00p - 3:00p	PHYS 114
PHYS	21900	27009	27009-001	Wed 12/14	1:00p - 3:00p	PHYS 112
PHYS	22000			Fri 12/16	1:00p - 3:00p	LAMB F101
PHYS	22100			Wed 12/14	1:00p - 3:00p	LILY 1105
PHYS	23300	67161	67161-001	Fri 12/16	8:00a - 10:00a	EE 129
PHYS	23400	10833	10833-001	Fri 12/16	8:00a - 10:00a	PHYS 111

SUPPLEMENTAL INSTRUCTION

Free Study Sessions!

Rachel Hoagburg

Come to SI for more help in **PHYS 220**

Tuesday and Thursday	7:30-8:30PM Shreve C113

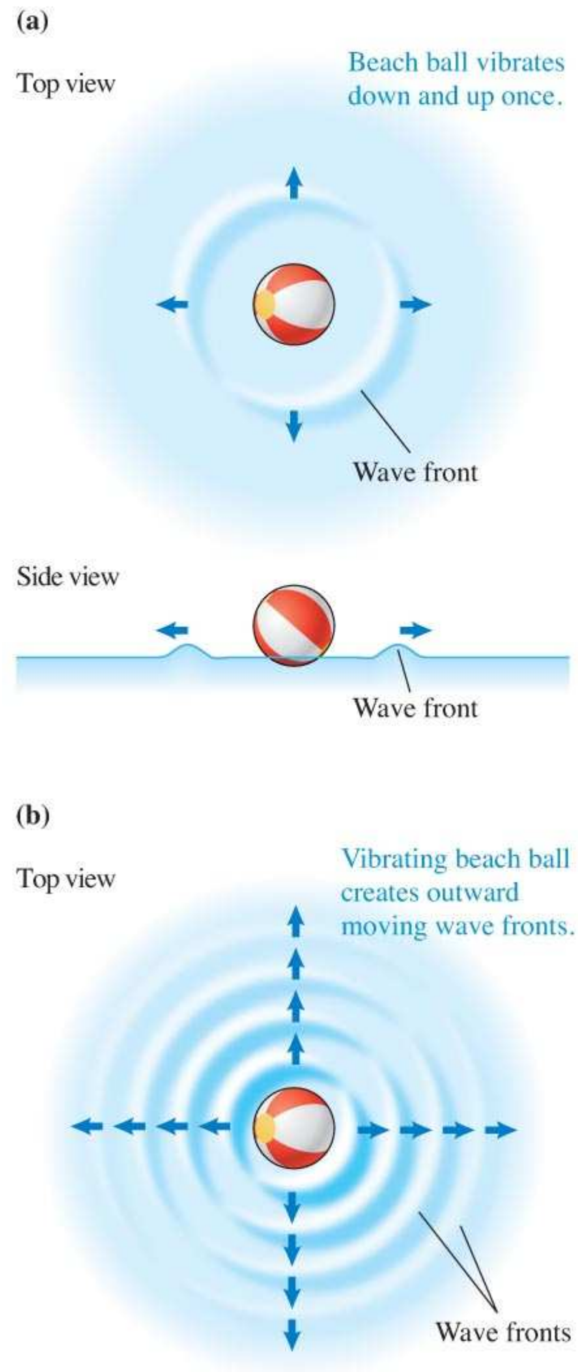
Office Hour

Tuesday 1:30-2:30 4th floor of Krach

For other SI-linked courses and schedules, visit purdue.edu/si or purdue.edu/boilerguide

Mechanical Waves

- Waves and wave fronts:

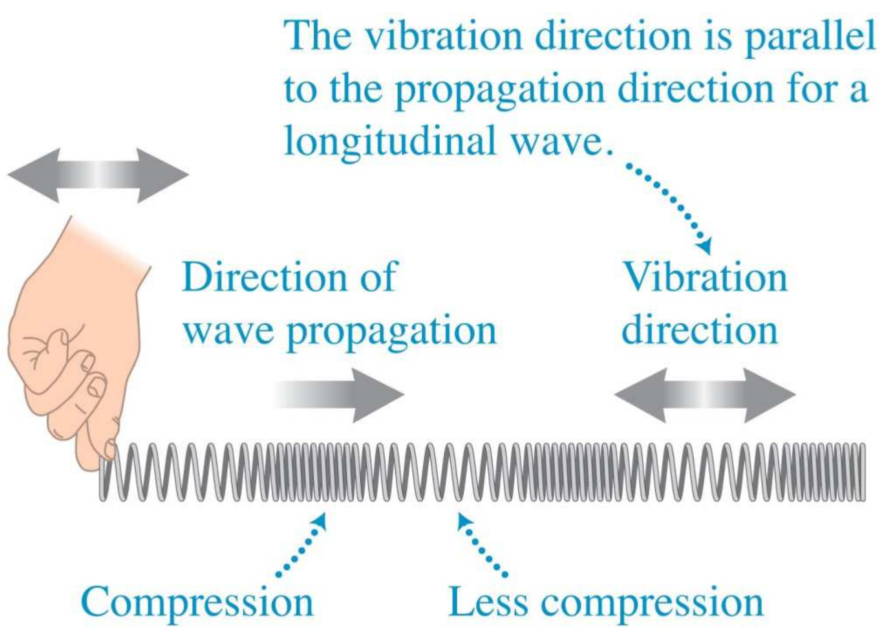


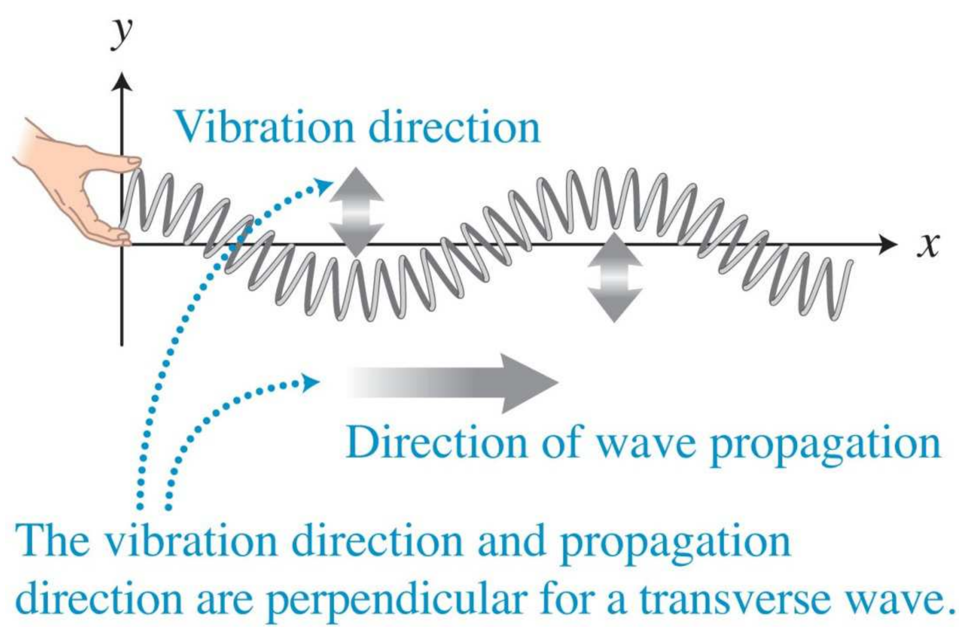
Wave Motion

Wave motion involves a disturbance produced by a vibrating object (a source). The disturbance moves, or propagates, through a medium and causes points in the medium to vibrate. When the disturbed medium is physical matter (solid, liquid, or gas), the wave is called a **mechanical wave.**

Two Kinds of Waves

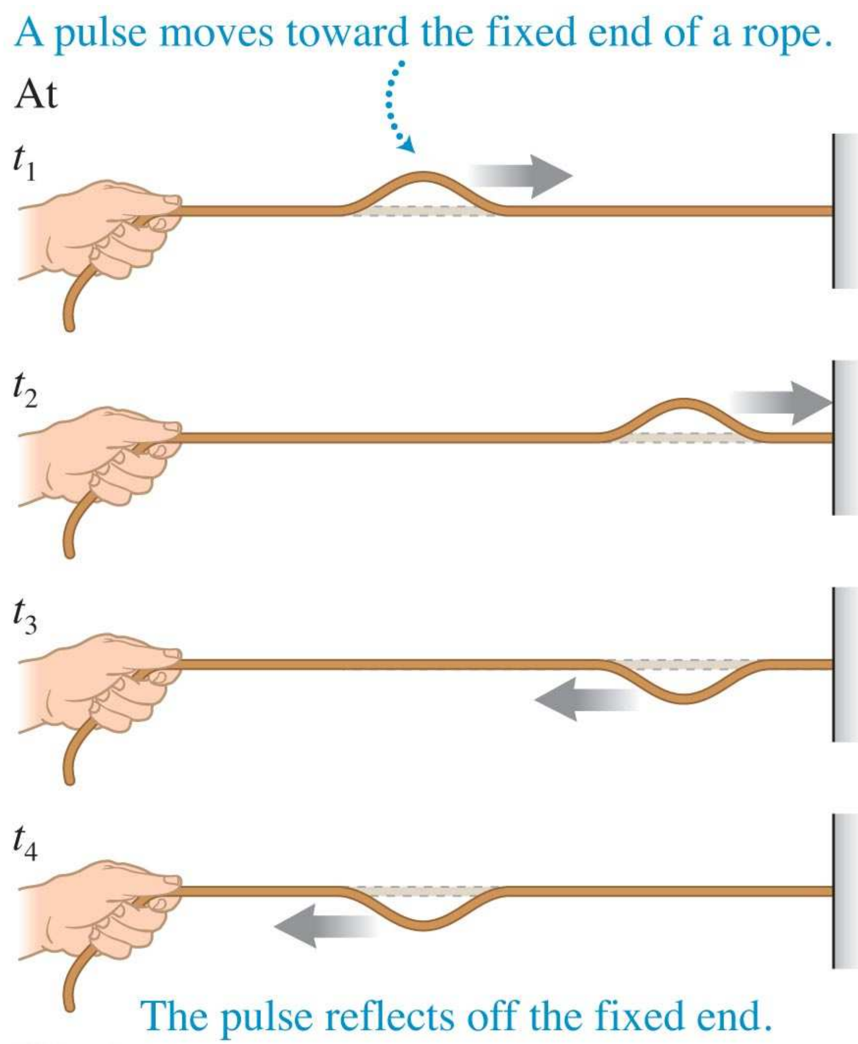
Longitudinal and transverse waves In a *longitudinal wave* the vibrational motion of the particles or layers of the medium is parallel to the direction of propagation of the disturbance. In a *transverse wave* the vibrational motion of the particles or layers of the medium is perpendicular to the direction of propagation of the disturbance.





Reflection of Waves

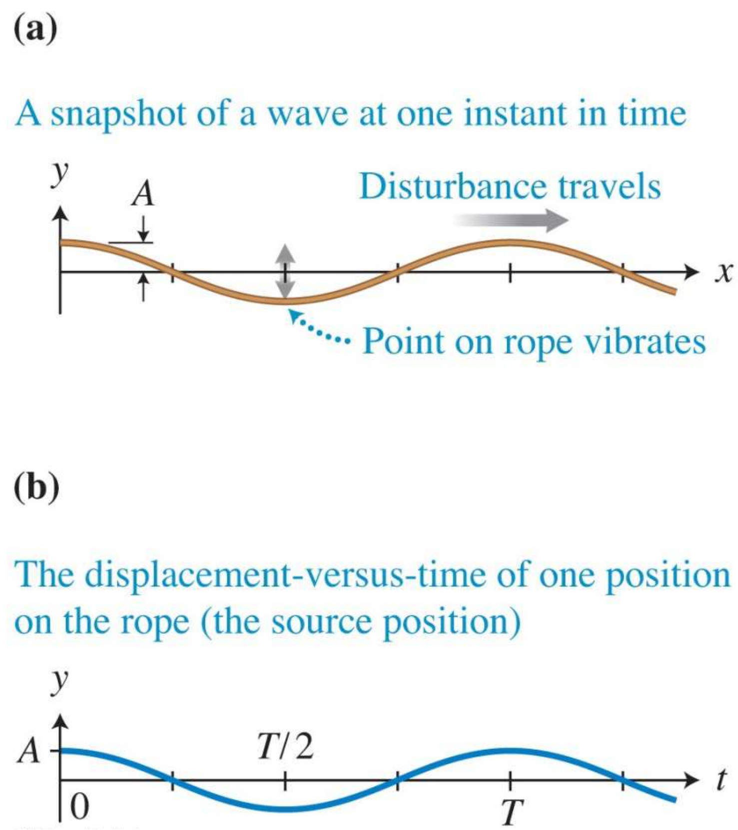
- When a wave reaches the wall of the container or the end of the Slinky or rope, it reflects off the end and moves in the opposite direction.
  - When a wave encounters any boundary between different media, some of the wave is reflected back.



Mathematical Description of Waves

- A wave can be created in a rope by a motor that vibrates the end of a rope up and down, producing a transverse wave.
- The displacement is described by a sinusoidal function of time:

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



Mathematical Description of Waves

Period T in seconds is the time interval for one complete vibration of a point in the medium anywhere along the wave's path.

Frequency f in Hz (s^{-1}) is the number of vibrations per second of a point in the medium as the wave passes.

Amplitude A is the maximum displacement of a point of the medium from its equilibrium position as the wave passes.

Speed v in m/s is the distance a disturbance travels during a time interval, divided by that time interval.

Mathematical Description of a Traveling Sinusoidal Wave

- We know the source oscillates up and down with a vertical displacement given by:

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

- We can mathematically describe the disturbance *y*(*x*, *t*) of a point of the rope at some positive position *x* to the right of the source (at *x* = 0) by:

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

Wavelength

Wavelength λ equals the distance between two nearest points on a wave that at any clock reading have exactly the same displacement and shape (slope). It is also the distance between two consecutive wave fronts:

$$\lambda = Tv = \frac{v}{f} \tag{20.3}$$

Mathematical Description of a Traveling Sinusoidal Wave

Mathematical description of a traveling sinusoidal wave The displacement from equilibrium y of a point at location x at time t when a wave of period T travels at speed v in the positive x-direction through a medium is described by the function

$$y = A\cos\left[2\pi\left(\frac{t}{T} - \frac{x}{\lambda}\right)\right] \tag{20.4}$$

The wavelength λ of this wave equals $\lambda = Tv$.

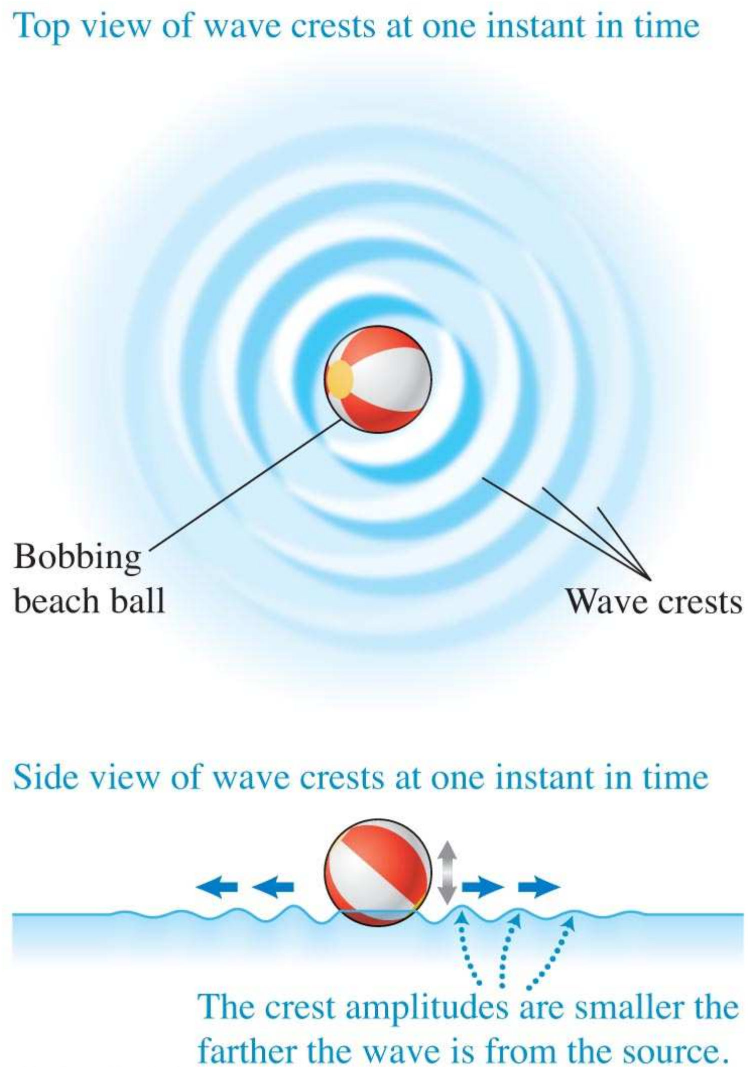
Wave Speed

- The speed of a wave on a string depends on
  - The mass per unit length (μ): waves propagate more quickly on a light string
  - The tension (T): waves propagate more quickly when the string is tight

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

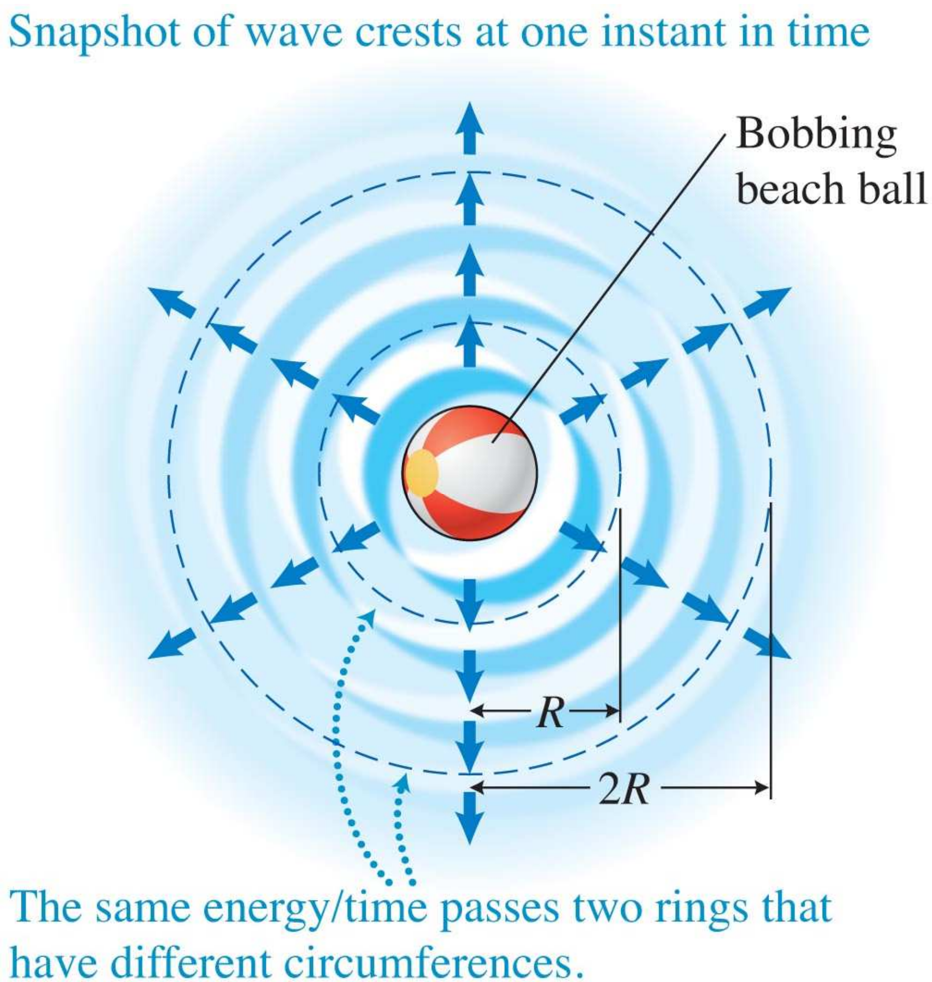
Amplitude and Energy in a Two Dimensional Medium

- A beach ball bobs up and down in water in simple harmonic motion, producing circular waves that travel outward across the water surface in all directions.
  - The amplitudes of the crests decrease as the waves move farther from the source.



Amplitude and Energy in a Two Dimensional Medium

- The circumference of the second ring is two times greater than the first, but the same energy per unit time moves through it.
  - The energy per unit circumference length passing through the second ring is one-half that passing through the first ring.

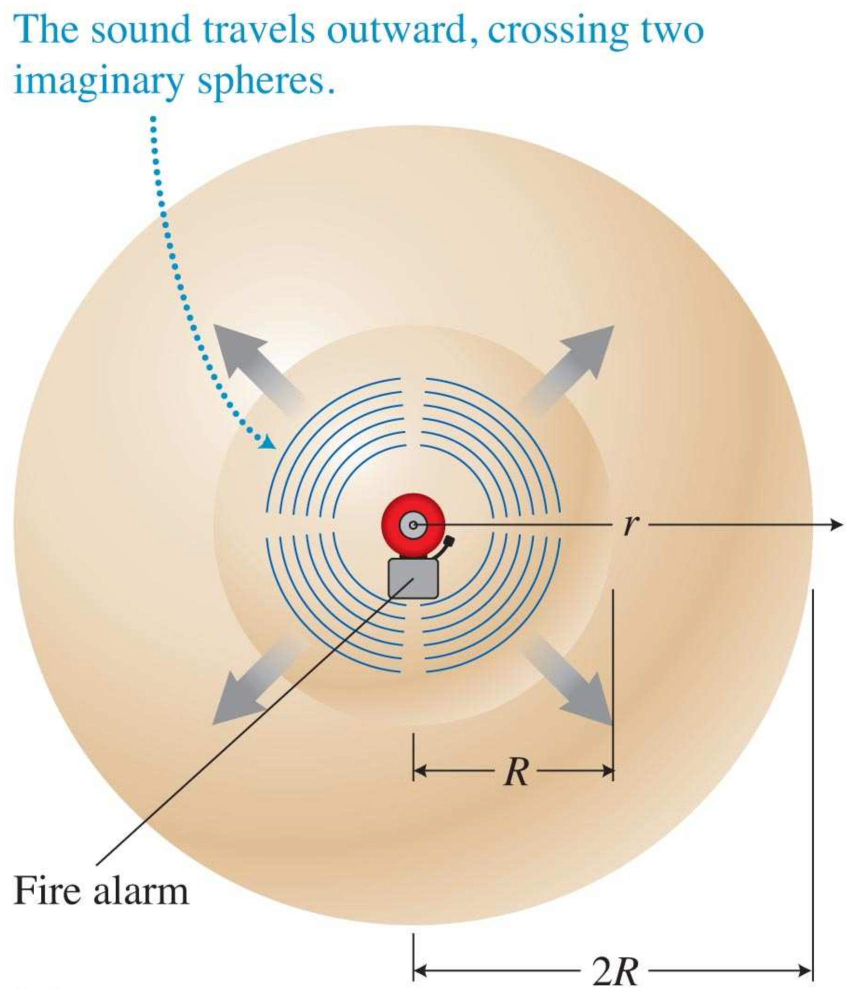


Two-dimensional waves produced by a point source

Two-dimensional waves produced by a point source The energy per unit circumference length and per unit time crossing a line perpendicular to the direction that the wave travels decreases as $1/r$, where r is the distance from the point source of the wave.

Three-Dimensional waves produced by a point source

- The area of the second sphere is four times the area of the first sphere, but the same energy per unit time moves through it.
  - The energy per unit area through the second sphere is one-fourth that through the first sphere.



Three-dimensional waves produced by a point source

Three-dimensional waves produced by a point source The energy per unit area per unit time passing across a surface perpendicular to the direction that the wave travels decreases as $1/r^2$, where r is the distance from the point source of the wave.

Wave Power and Wave Intensity

- The intensity of a wave is defined as the energy per unit area per unit time interval that crosses perpendicular to an area in the medium through which it travels:

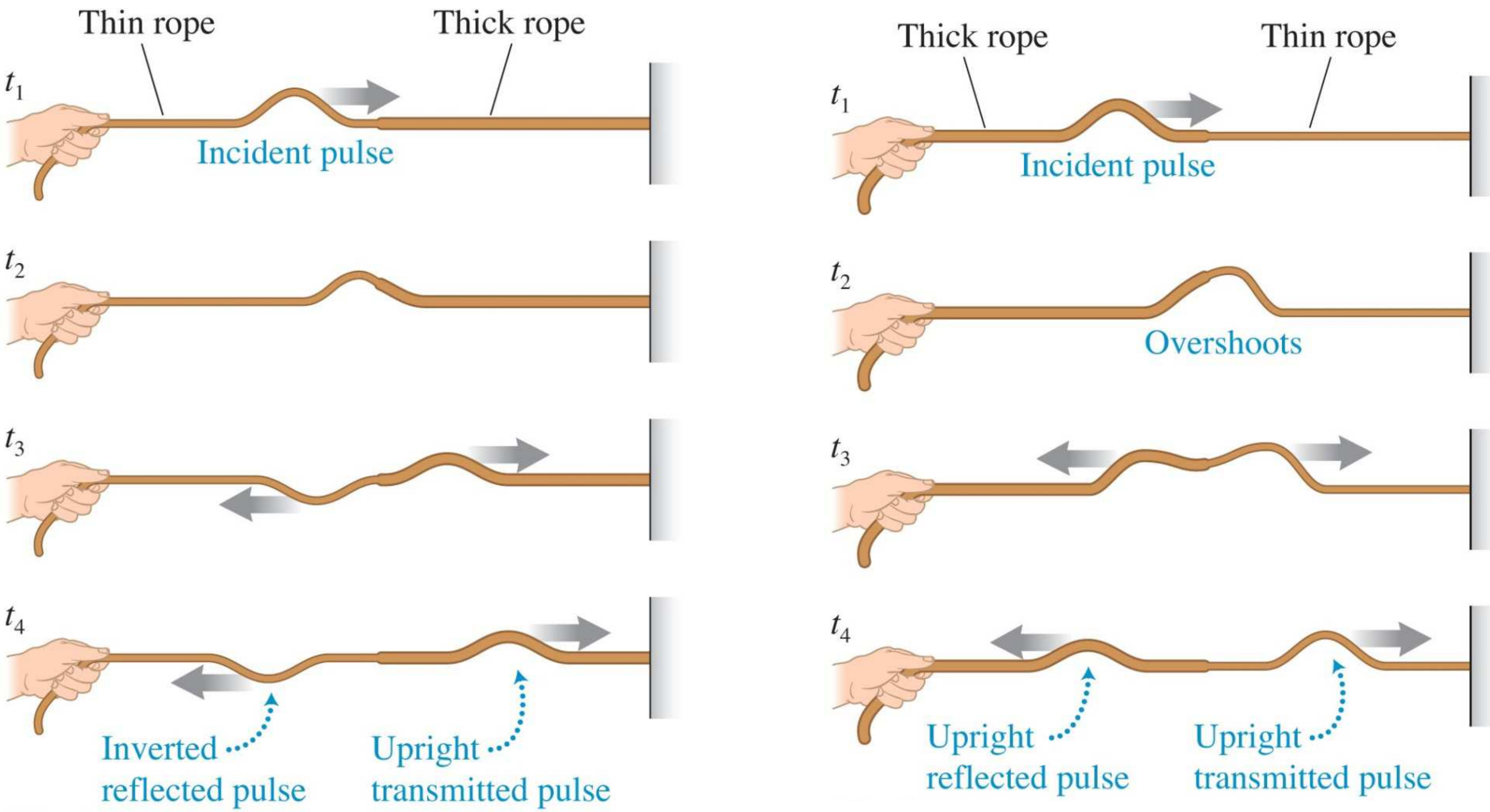
$$\text{Intensity} = \frac{\text{Energy}}{\text{Time} \cdot \text{Area}} = I = \frac{\Delta U}{\Delta t \cdot A} = \frac{P}{A}$$

- The unit of intensity *I* is equivalent to joules per second per square meter or watts per square meter.

Reflection and Impedance

- If you hold one end of a rope whose other end is fixed and shake it once, you create a transverse traveling incident pulse.
  - When the pulse reaches the fixed end, the reflected pulse bounces back in the opposite direction.
  - The reflected pulse is inverted—oriented downward as opposed to upward.
- What happens to a wave when there is an abrupt change from one medium to another?

Reflection and Impedance



Impedance

- Impedance characterizes the degree to which waves are reflected and transmitted at the boundary between different media.
- Impedance is defined as the square root of the product of the elastic and inertial properties of the medium:

$$\text{Impedance} = Z = \sqrt{(\text{Elastic property})(\text{Inertial property})}$$

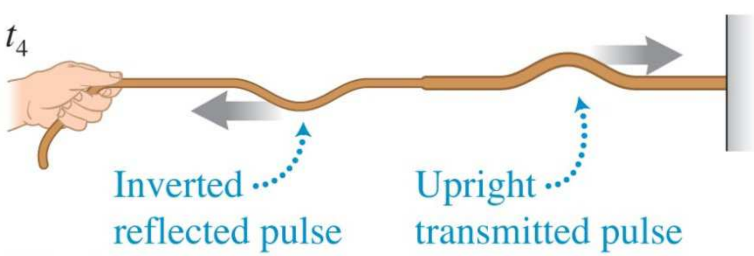
Amplitude of Reflected Waves

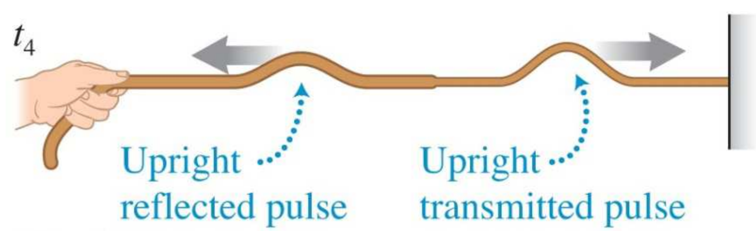
- The amplitude of the reflected pulse depends on the impedance of the two media:

$$A_r = R\, A_i$$

$$R = \frac{Z_2 - Z_1}{Z_2 + Z_1}$$

(when incident from medium 1 into medium 2)





Ultrasound

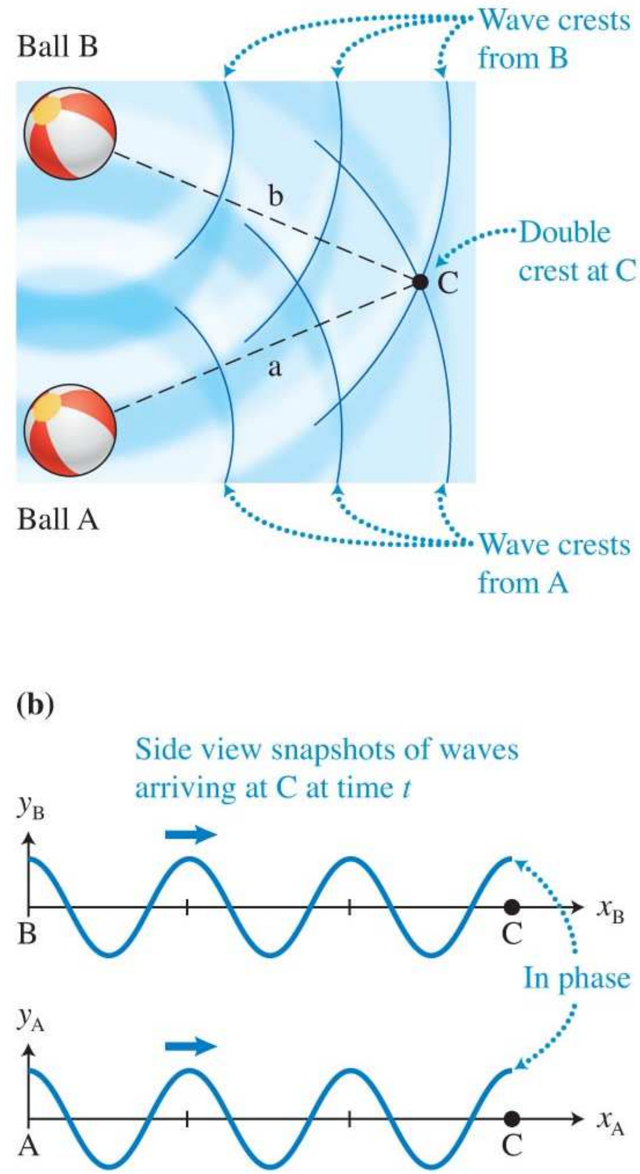
- Ultrasound takes advantage of the differing densities of internal structures to "see" inside the body.
  - The impedance of tissue is much greater than that of air. As a result, most of the ultrasound energy is reflected at the air-body interface and does not travel inside the body.
  - To overcome this problem, the area of the body to be scanned is covered with a gel that helps "match" the impedance between the emitter and the body surface.

Superposition Principle

- We have studied the behavior of a single wave traveling in a medium and initiated by a simple harmonic oscillator.
  – Most periodic or repetitive disturbances of a medium are combinations of two or more waves of the same or different frequencies traveling through the same medium at the same time.
- Now we investigate what happens when two or more waves simultaneously pass through a medium.

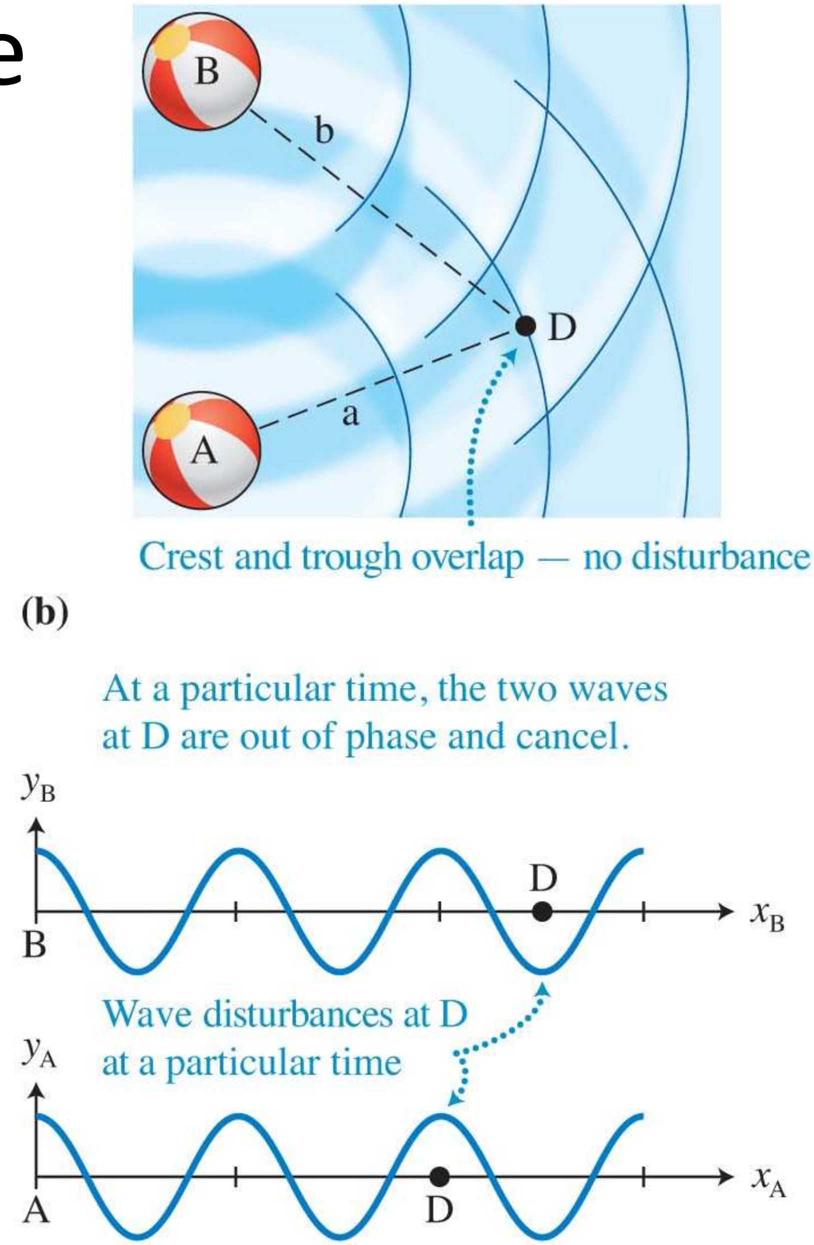
Superposition Principle

- Imagine we have two vibrating sources in water, each of which sends out sinusoidal waves.
  - Consider point C in the figure.



Superposition Principle

- Imagine we have two vibrating sources in water, each of which sends out sinusoidal waves.
  - Consider point D in the figure.

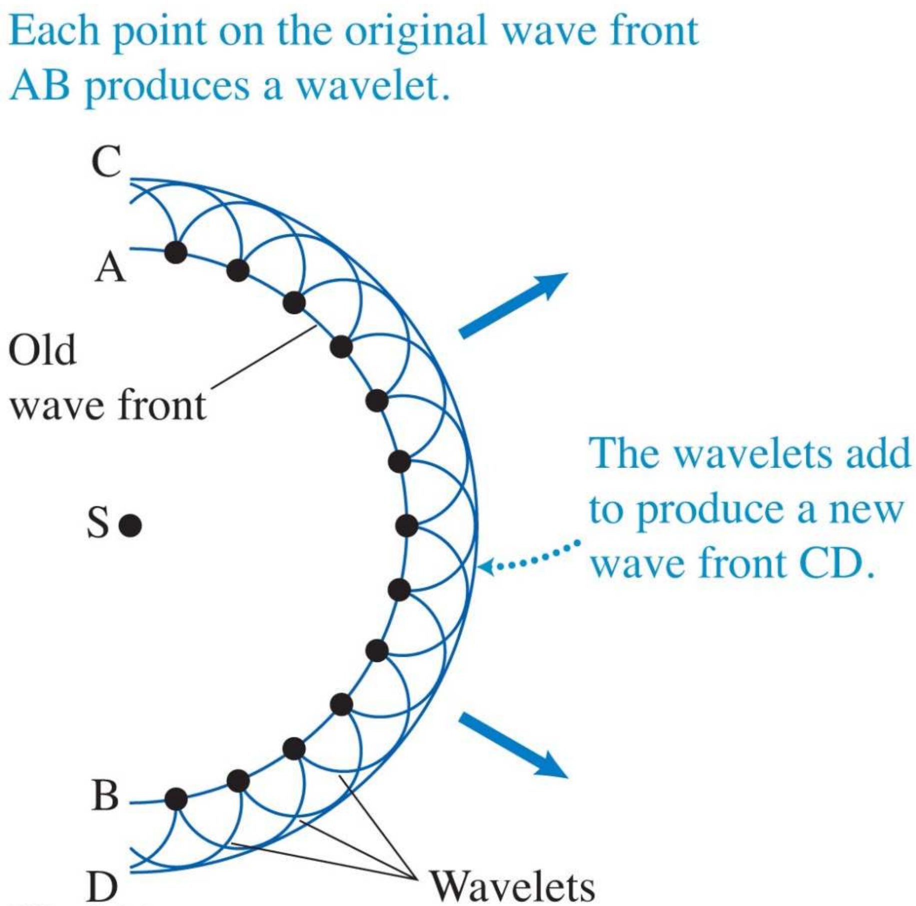


Superposition principle for waves

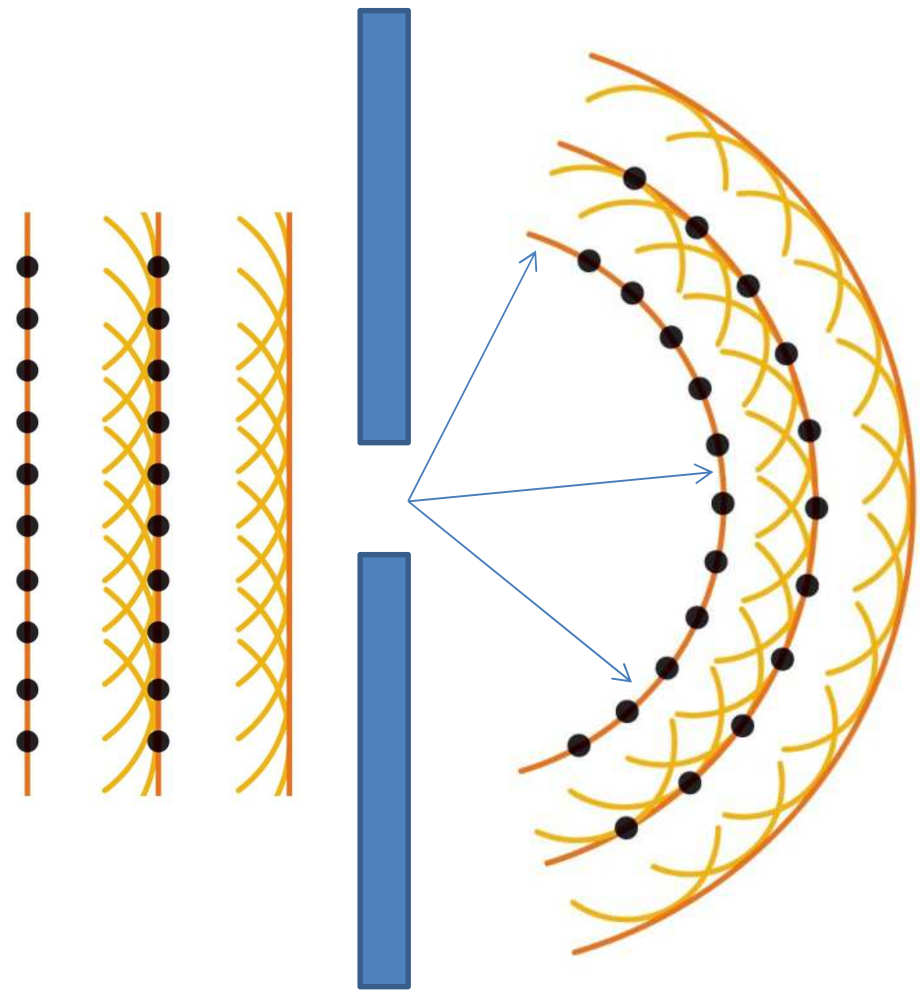
- The process in which two or more waves of the same frequency overlap is called interference.
  - Places where the waves add to create a larger disturbance are called locations of constructive interference.
  - Places where the waves add to produce a smaller disturbance are called locations of destructive interference.

Huygens' Principle

- We can explain the formation of the waves using the superposition principle, first explained by Christiaan Huygens (1629–1695).
  - Each arc represents a wavelet that moves away from a point on the original wave front.



Huygens' Principle



Loudness and intensity

- Loudness is determined primarily by the amplitude of the sound wave: the larger the amplitude, the louder the sound.
  - Equal-amplitude sound waves of different frequencies will not have the same perceived loudness to humans.
- To measure the loudness of a sound, we measure the intensity: the energy per unit area per unit time interval.

Intensity Level

- Because of the wide variation in the range of sound intensities, a quantity called intensity level is commonly used to compare the intensity of one sound to the intensity of a reference sound.
- Intensity level is defined on a base 10 logarithmic scale as follows:

$$\beta = \log_{10} \frac{I}{I_0}$$

Intensities and Intensity Levels of Common Sounds

Table 20.6 Intensities and intensity levels of common sounds.

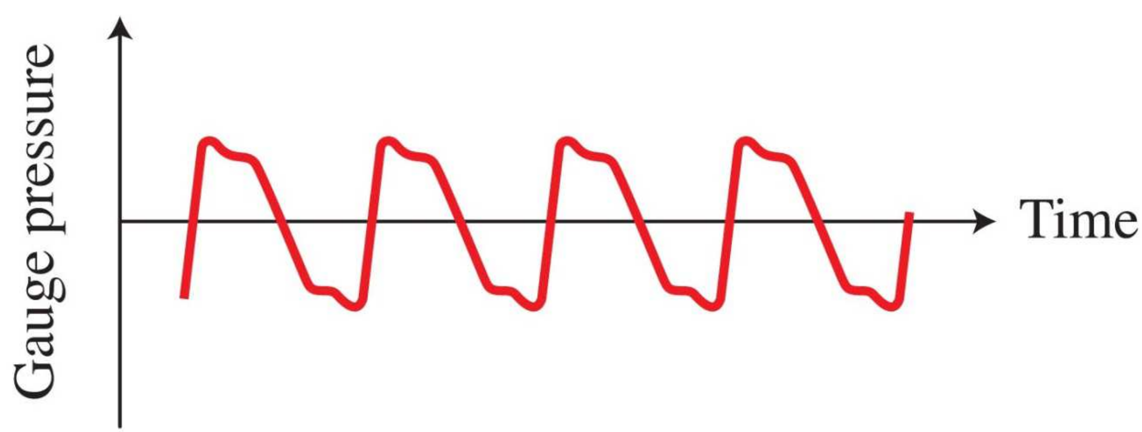
Source of sound	Intensity (W/m^2)	Intensity level (dB)	Description
Large rocket engine (nearby)	10^6	180	
Jet takeoff (nearby)	10^3	150	
Pneumatic riveter; machine gun (nearby)	10	130	
Rock concert with amplifiers (2 m); jet takeoff (60 m)	1	120	Pain threshold
Construction noise (3 m)	10^{-1}	110	
Moving subway train (nearby)	10^{-2}	100	
Heavy truck (15 m)	10^{-3}	90	Constant exposure
Niagara Falls (nearby)	10^{-3}	90	endangers hearing
Noisy office with machines; inside an average factory	10^{-4}	80	
Busy traffic	10^{-5}	70	
Normal conversation (1 m)	10^{-6}	60	
Quiet office	10^{-7}	50	Quiet
Library	10^{-8}	40	
Soft whisper (5 m)	10^{-9}	30	
Rustling leaves	10^{-10}	20	Barely audible
Normal breathing	10^{-11}	10	
	10^{-12}	0	Hearing threshold

Pitch, frequency and complex sounds

- Pitch is the perception of the frequency of a sound.
  - Tuning forks of different sizes produce sounds of approximately the same intensity, but we hear each as having a different pitch.
  - The shorter the length of the tuning fork, the higher the frequency and the higher the pitch.
- Like loudness, pitch is not a physical quantity but rather a subjective impression.

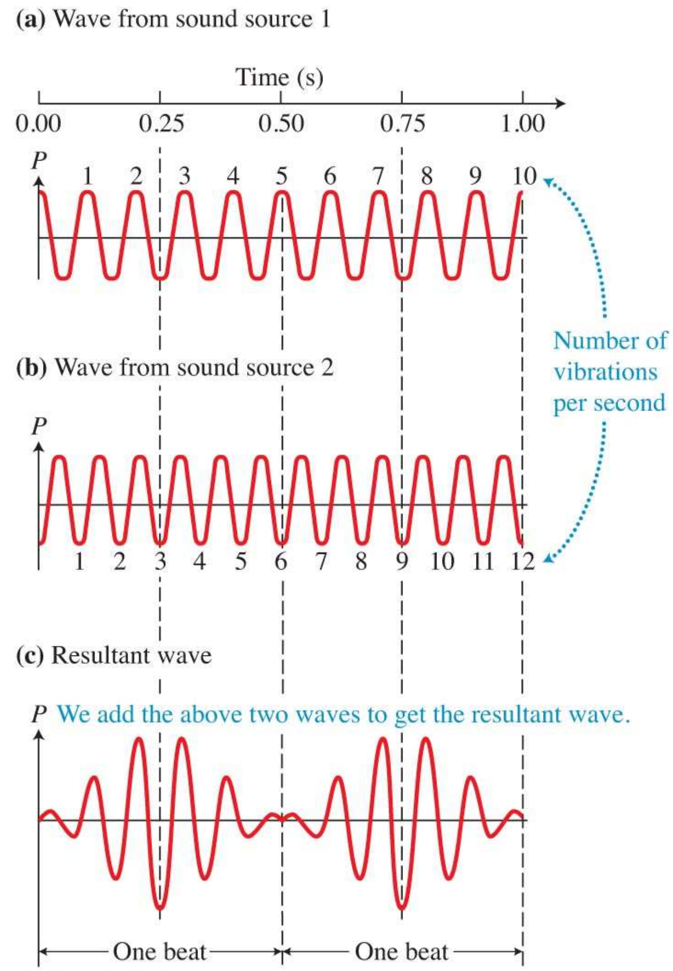
Complex sounds, waveforms and frequency spectra

- An oboe and a violin playing concert A equally loudly at 440 Hz sound very different.
  - Which other property of sound causes this different sensation to our ears?
  - Musical notes from instruments have a characteristic frequency, but the wave is not sinusoidal.



Beat and Beat Frequencies

- Two sound sources of similar (but not the same) frequency are equidistant from a microphone that records the air pressure variations due to the two sound sources as a function of time.



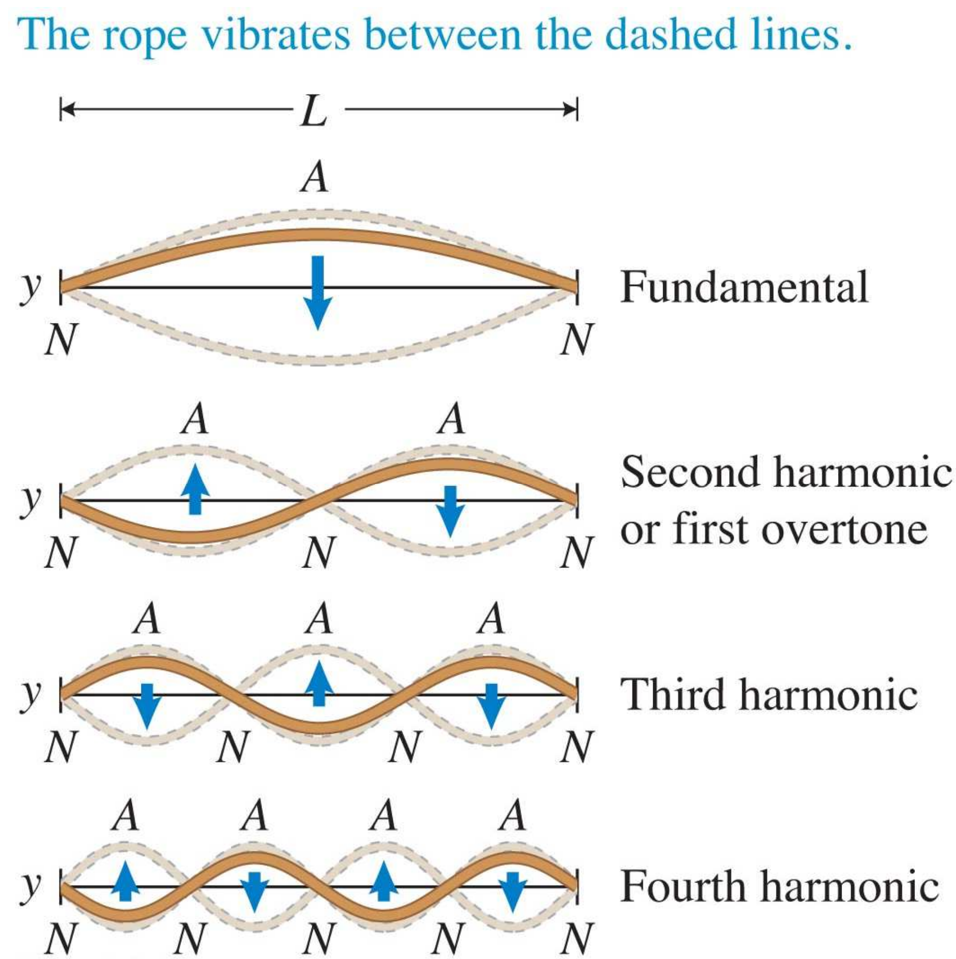
Beat and beat frequencies

A **beat** is a wave that results from the superposition of two waves of about the same frequency. The beat (the net wave) has a frequency equal to the average of the two frequencies and has variable amplitude. The frequency with which the amplitude of the net wave changes is called the **beat frequency** f_{beat}; it equals the difference in the frequencies of the two waves:

$$f_{beat} = |f_1 - f_2| \qquad (20.10)$$

Standing Waves on Strings

- You shake the end of a rope that is attached to a fixed support.
  - At specific frequencies, you notice that the rope has large-amplitude sine-shaped vibrations that appear not to be traveling.



Standing Waves on a String

- The lowest-frequency vibration of the rope is one up-and-down shake per time interval:

$$f_1 = \frac{1}{\tau} = \frac{1}{2L/v} = \frac{v}{2L}$$

- This frequency is called the fundamental frequency.