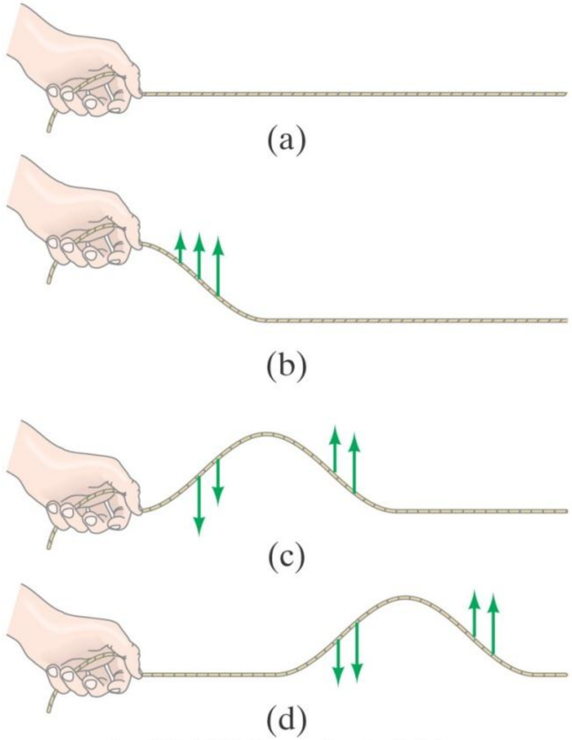
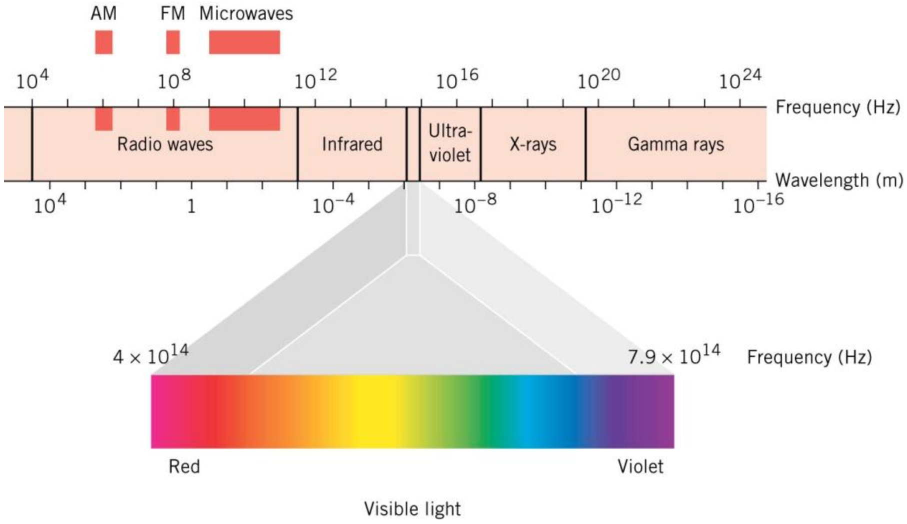
Chapters 11, 12
Waves

- Waves transfer energy NOT matter
- Two categories of waves
- Mechanical Waves
  - require a medium (matter) to transfer wave energy
- Electromagnetic waves
  - no medium required to transfer wave energy

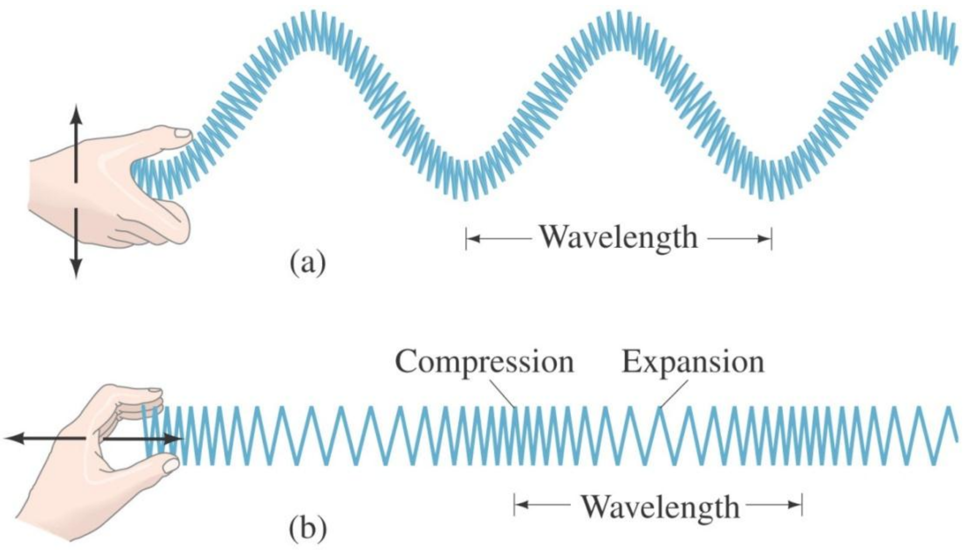




Mechanical Waves

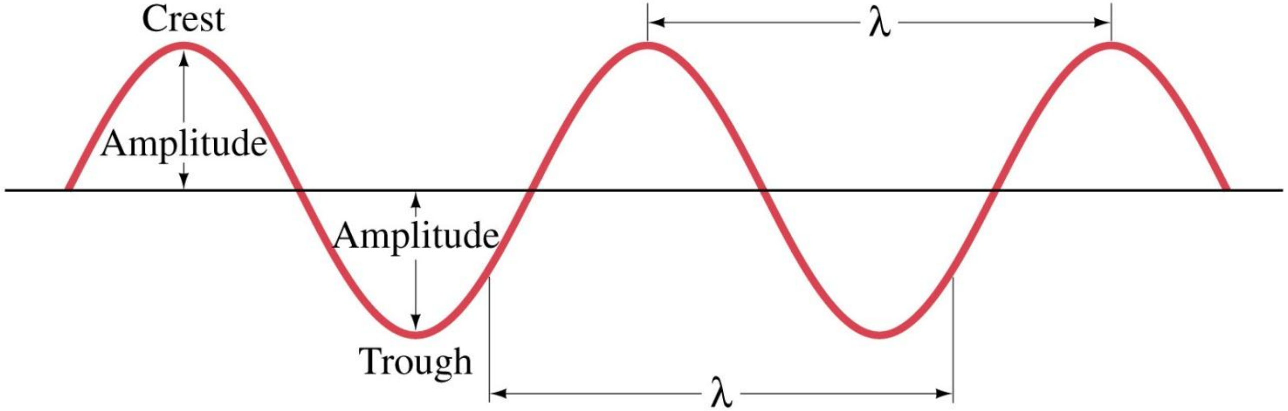
- Two types based on vibration direction
  - transverse
  - longitudinal
- Transverse – vibrating *Perpendicular* to velocity direction
- Longitudinal – vibrating *Parallel* to velocity direction

longitudinal



5 Wave Properties

- Velocity (v)   meters/second
- Wavelength (λ lambda) meters
  - straight line peak to peak distance for one full wave cycle
- Frequency (f) Hertz
  - # of wave cycles passing a fixed point per second
- Period (T) seconds
  - # of seconds for one full wave cycle to pass a fixed point
- Amplitude (A) in units of wave displacement
  - measure of the energy transferred by the wave



Wave Equation

v = $f\lambda$

- velocity = frequency x wavelength

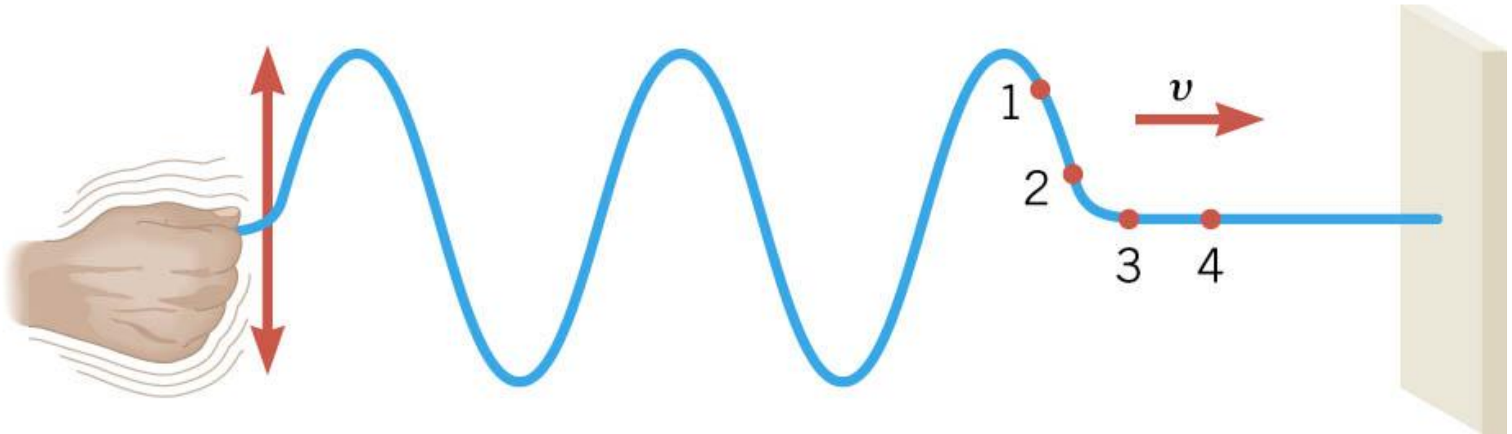
$$\frac{meters}{second} = \frac{\#of\ \ waves}{second}\, x\, \frac{meters}{wave}$$

What does wave speed depend on?

Wave velocity DOES NOT depend on frequency or wavelength

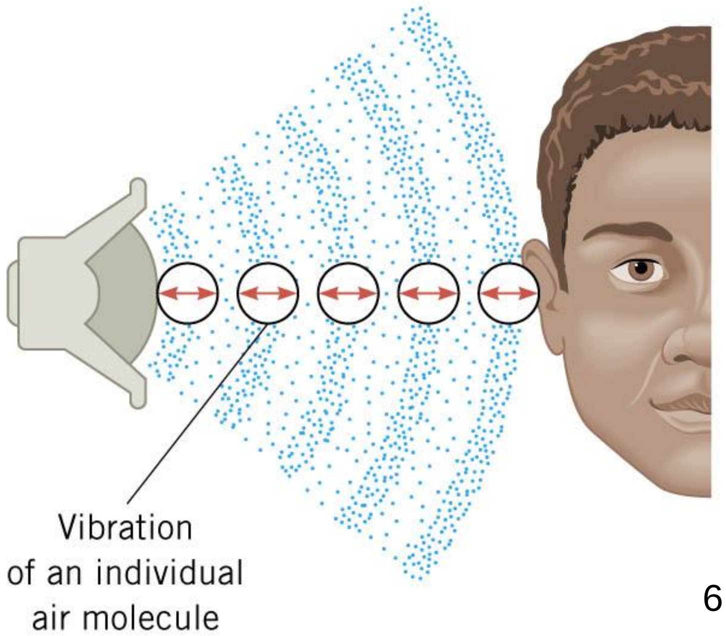
Medium type and its properties determine wave speed

Wave Source Controls Frequency



hand motion sets wave frequency of rope waves

speaker controls frequency of
sound waves



Frequency – Wavelength Relationship

- frequency is NOT speed

$$frequency = \frac{\#\,wave\ cycles}{\sec ond} \qquad speed = \frac{\#\,of\ \ meters\ \text{wave travels}}{\sec ond}$$

- equations for calculations

$$v = \frac{\mathrm{d}}{t} \qquad v = f\lambda \qquad f = \frac{1}{T} \qquad v = \frac{\lambda}{T}$$

Frequency – Wavelength Relationship

- Inverse relationship between frequency and wavelength

$$v = f\lambda$$

constant for fixed medium properties

when frequency increases

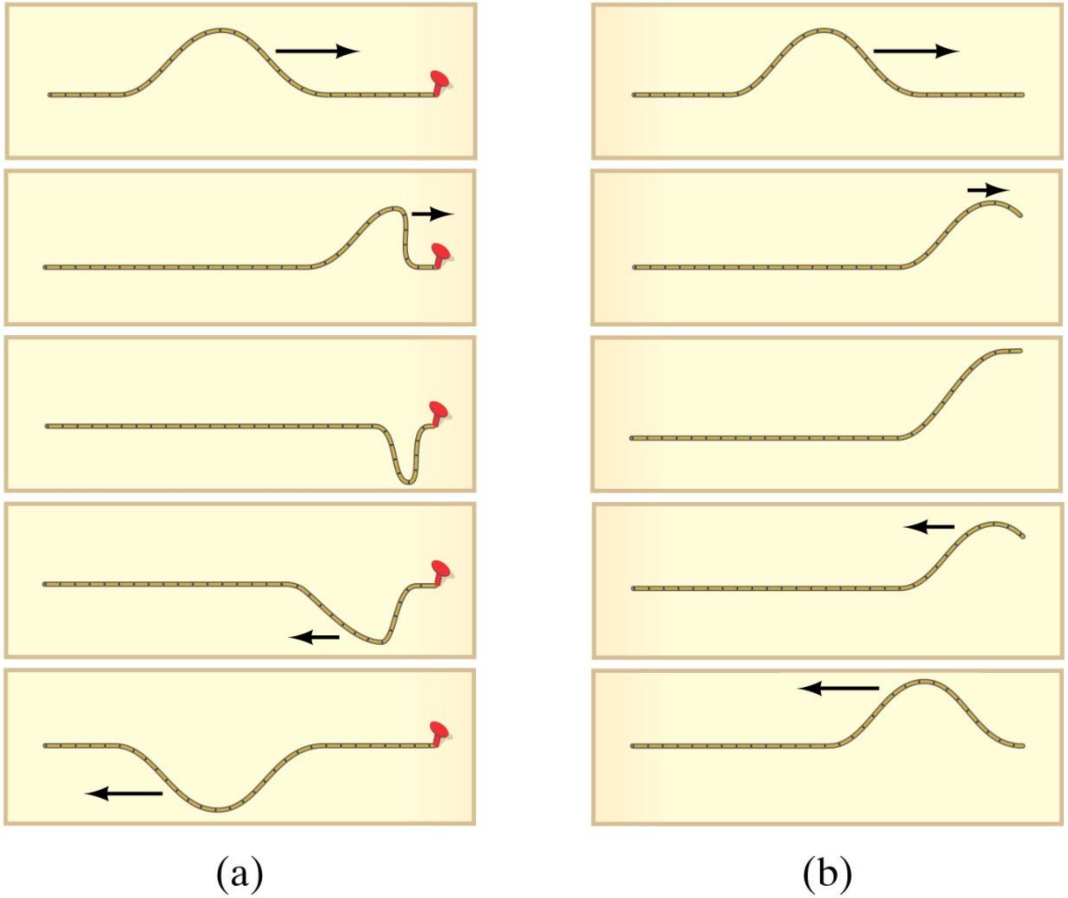
length of each wave decreases

Two ways to change wavelength

- Change frequency at the source
- Change velocity by changing medium

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

11-11 Reflection and Transmission of Waves



A wave reaching the end of its medium, but where the medium is still free to move, will be reflected (b), and its reflection will be upright.

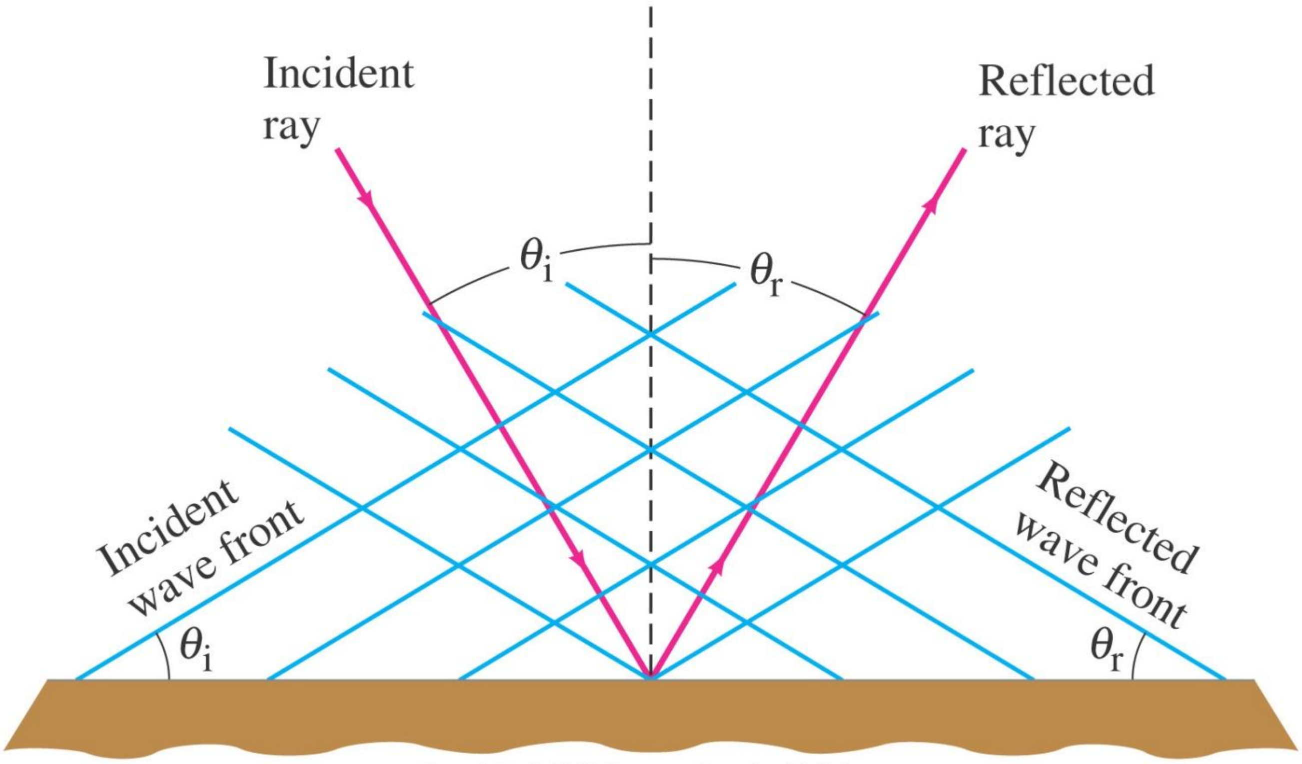
transverse

A wave hitting an obstacle will be reflected (a), and its reflection will be inverted.

Law of Reflection

- angle of incidence θ_i = angle of reflection θ_r

angles measured from the rays to the normal

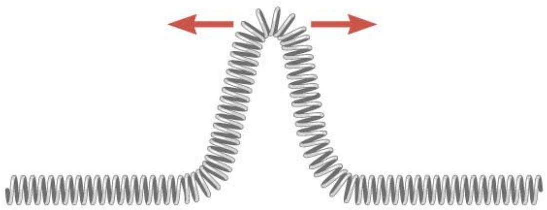


Wave Interference

- Wave pulses are energy not matter
- When pulses “collide” they overlap briefly
- Superposition principle
  - – wave pulses can co-exist at the same point in a medium at the same time
  - – they pass through without affecting each other
  - – overlapping pulses: the resultant displacement of the medium is the algebraic (+/–) sum of the pulse amplitudes

Constructive Interference

(*a*) Overlap begins



(*b*) Total overlap; the Slinky has twice the height of either pulse

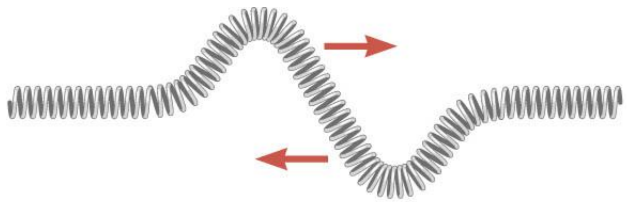
(*c*) The receding pulses

Two + amplitude pulses (upright) approaching

Total displacement is sum of individual pulses

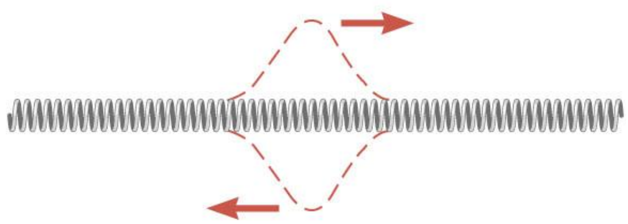
After interference each pulse is unchanged

Destructive Interference



(*a*) Overlap begins

+ amplitude, – amplitude
pulses approach



(*b*) Total overlap

complete destructive
interference

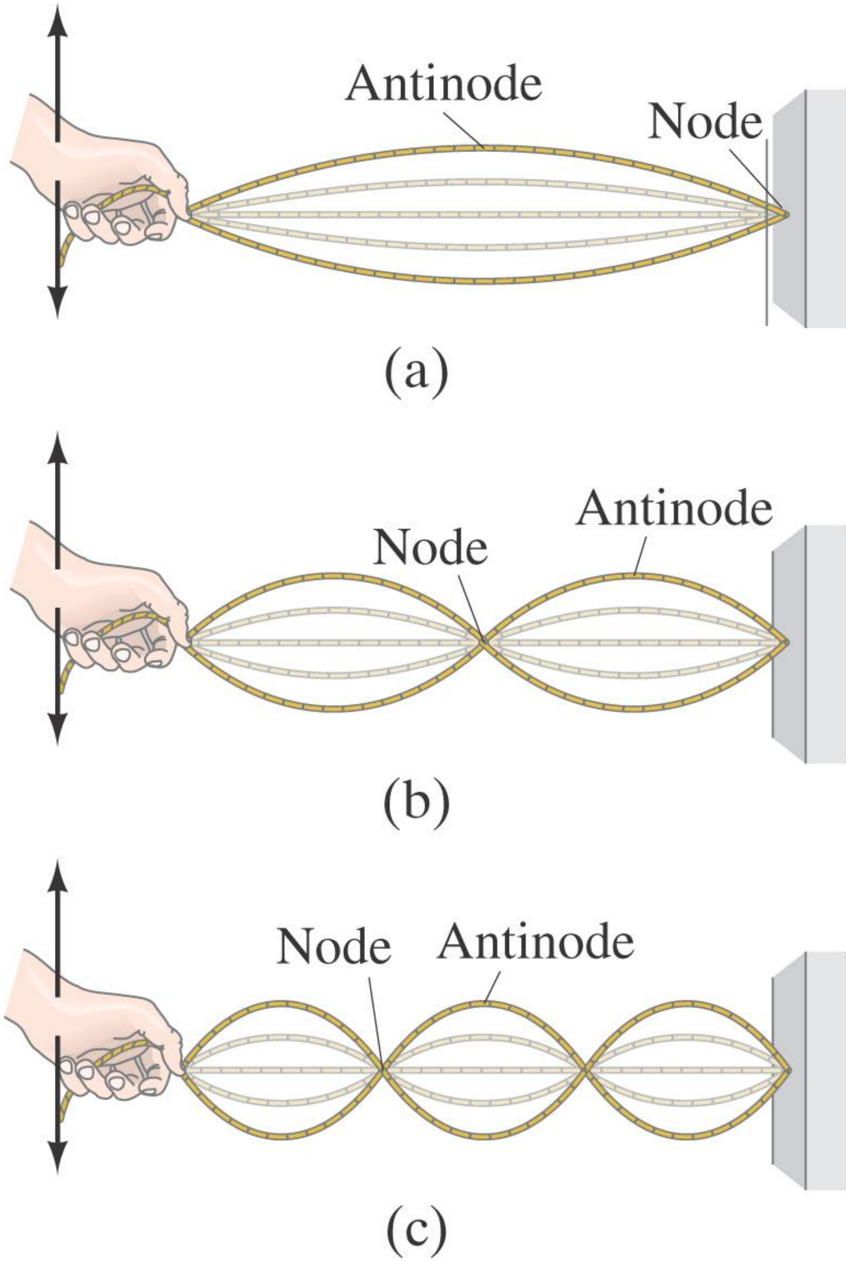
(*c*) The receding pulses

pulses unchanged after
interference

Resonance

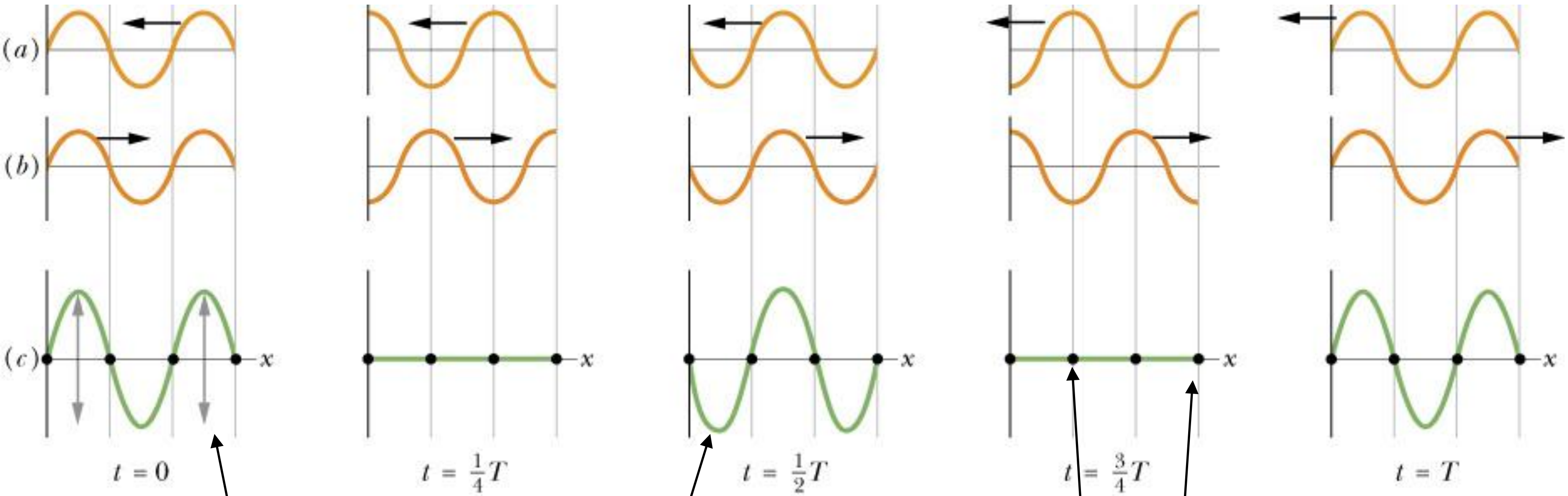
- A condition resulting in large amplitude oscillation (vibration) from a small amplitude input vibration or force
- Occurs only at specific “natural frequencies”
- Natural frequency determined by characteristics of the oscillating medium
  - Length and medium properties
  - series of natural frequencies exist for that medium
- Examples
  - child on a swing
  - wave apparatus
  - pendulum
  - tuning forks

11-13 Standing Waves; Resonance



Standing waves occur when both ends of a string are **fixed**. In that case, only waves which are **motionless** at the ends of the string can persist. There are **nodes**, where the amplitude is always zero, and **antinodes**, where the amplitude varies from zero to the maximum value.

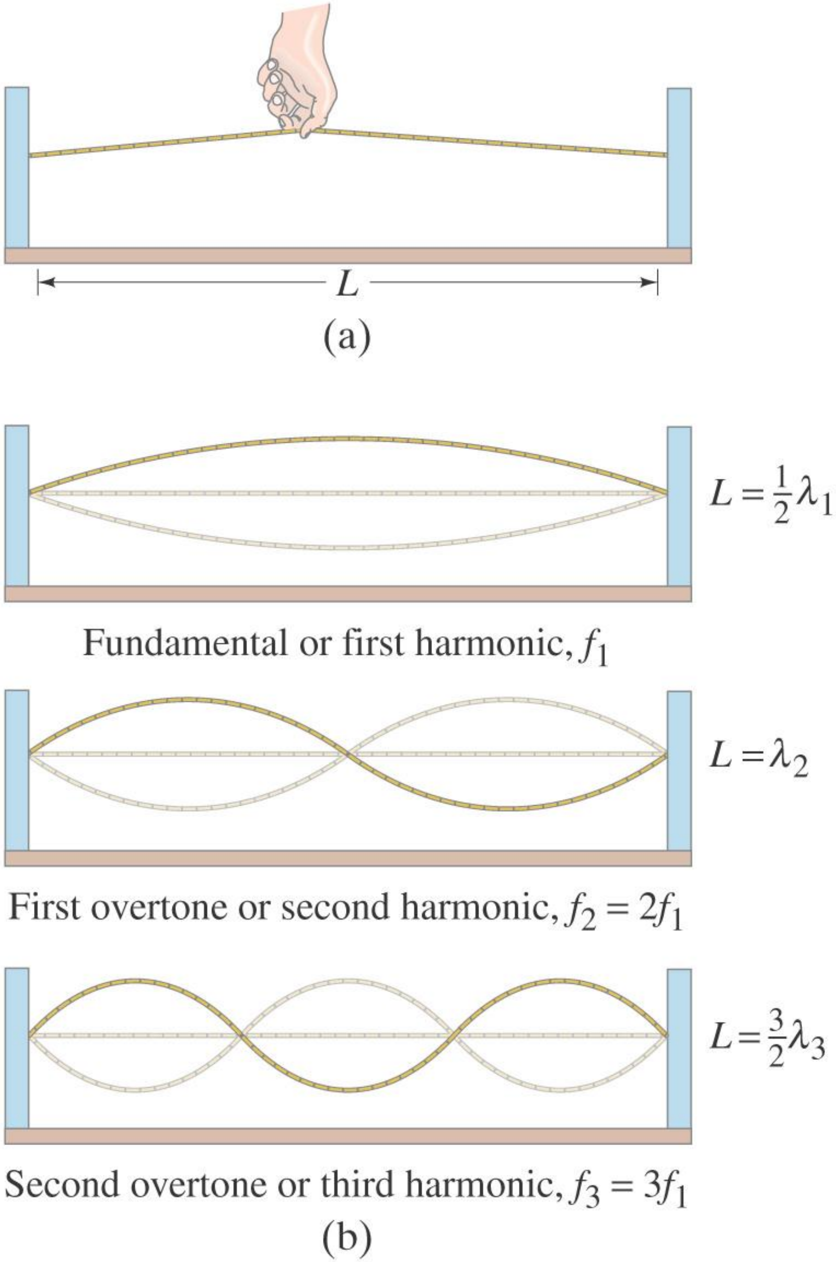
Standing Wave Formation



Constructive Interference creates antinodes

Destructive interference creates nodes

11-13 Standing Waves; Resonance



The frequencies of the standing waves on a particular string are called resonant frequencies.

They are also referred to as the fundamental and harmonics.

next higher harmonic comes when $\lambda/2$ is added into medium

11-13 Standing Waves; Resonance

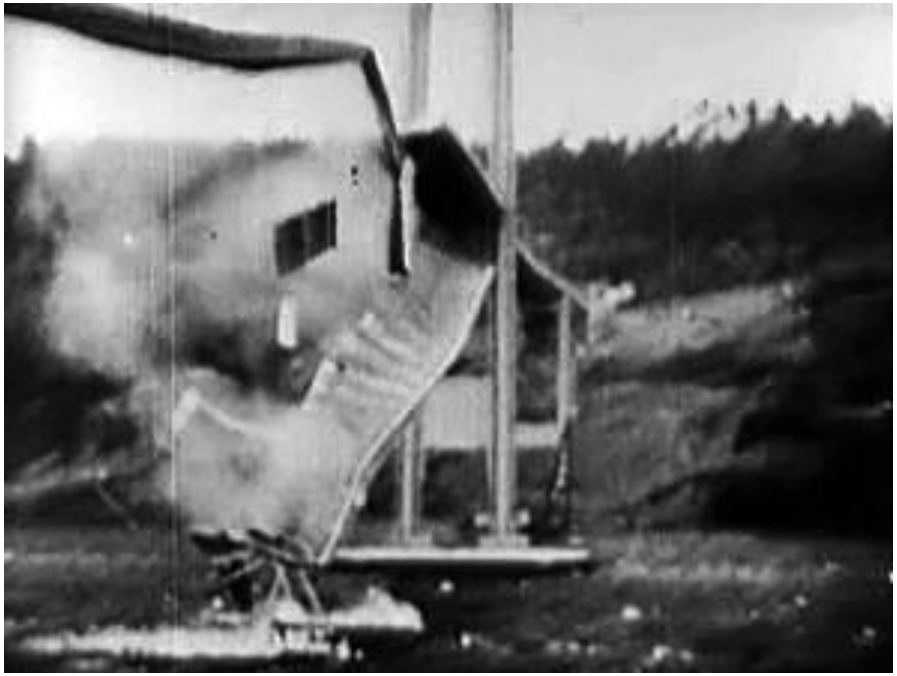
The **wavelengths** and **frequencies** of standing waves in rope fixed at both ends are:

$$\lambda_n = \frac{2L}{n}, \qquad n = 1, 2, 3, \cdots \qquad \textbf{(11-19a)}$$

$$f_n = \frac{v}{\lambda_n} = n\frac{v}{2L} = nf_1, \qquad n = 1, 2, 3, \cdots \qquad \textbf{(11-19b)}$$

fundamental is lowest resonant frequency n = 1

higher harmonics are integer multiples of fundamental



4 wave interactions

1) Interference – overlapping of waves with each other

2) Reflection – bouncing off a boundary or different medium

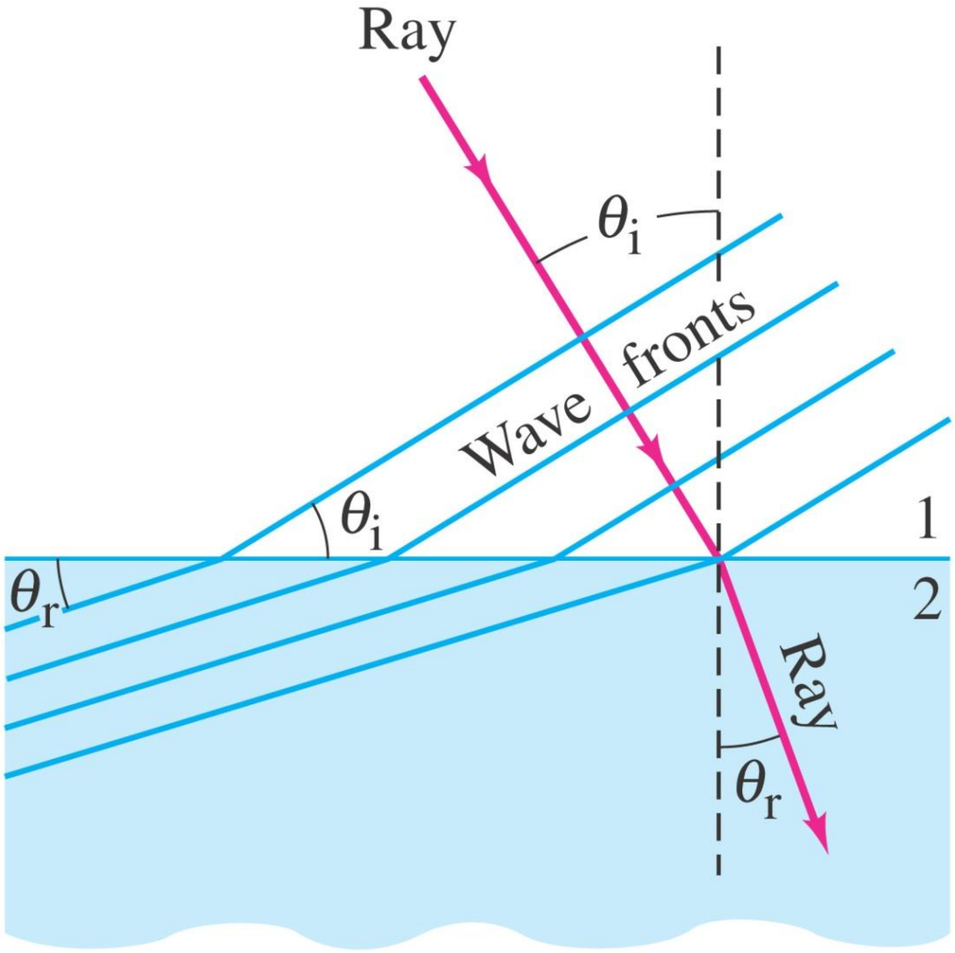
3) Diffraction – bending around an obstacle

4) Refraction – change in direction when wave changes speed in a different medium

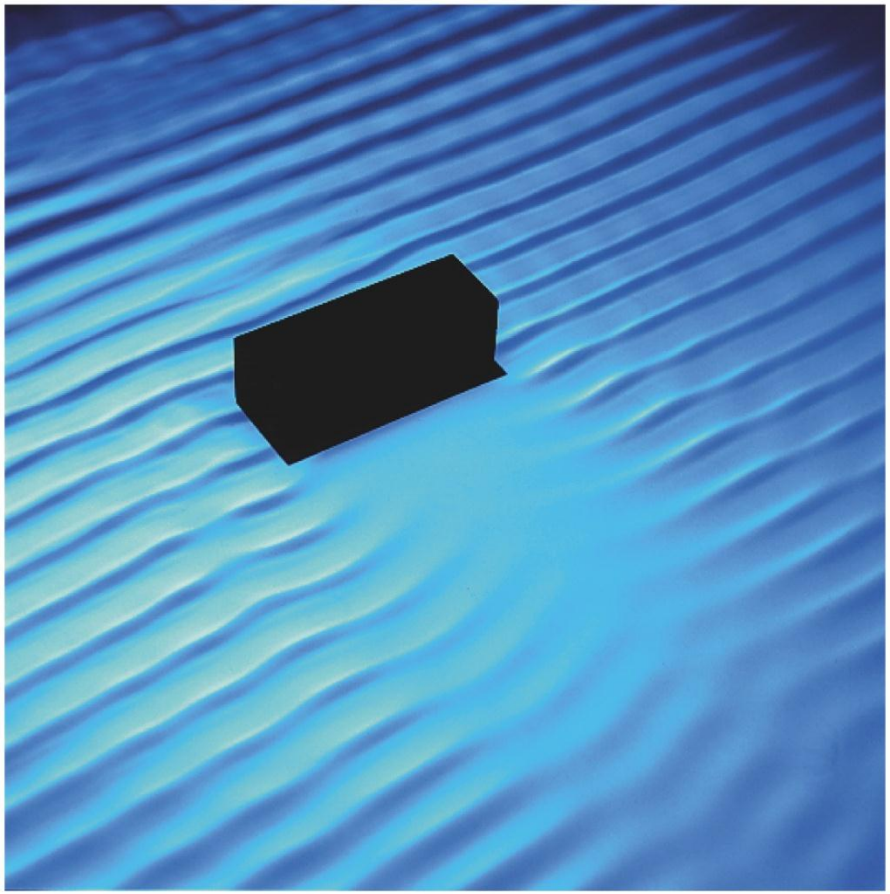
11-14 Refraction

If the wave enters a medium where the wave speed is different, it will be refracted – its wave fronts and rays will change direction.

(11-20)



11-15 Diffraction

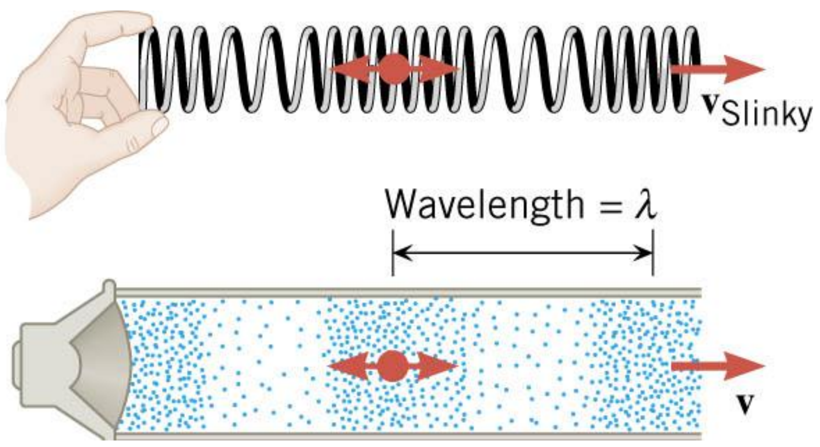


When waves encounter an **obstacle**, they bend around it, leaving a "shadow region." This is called **diffraction**.

Chapter 12
Sound

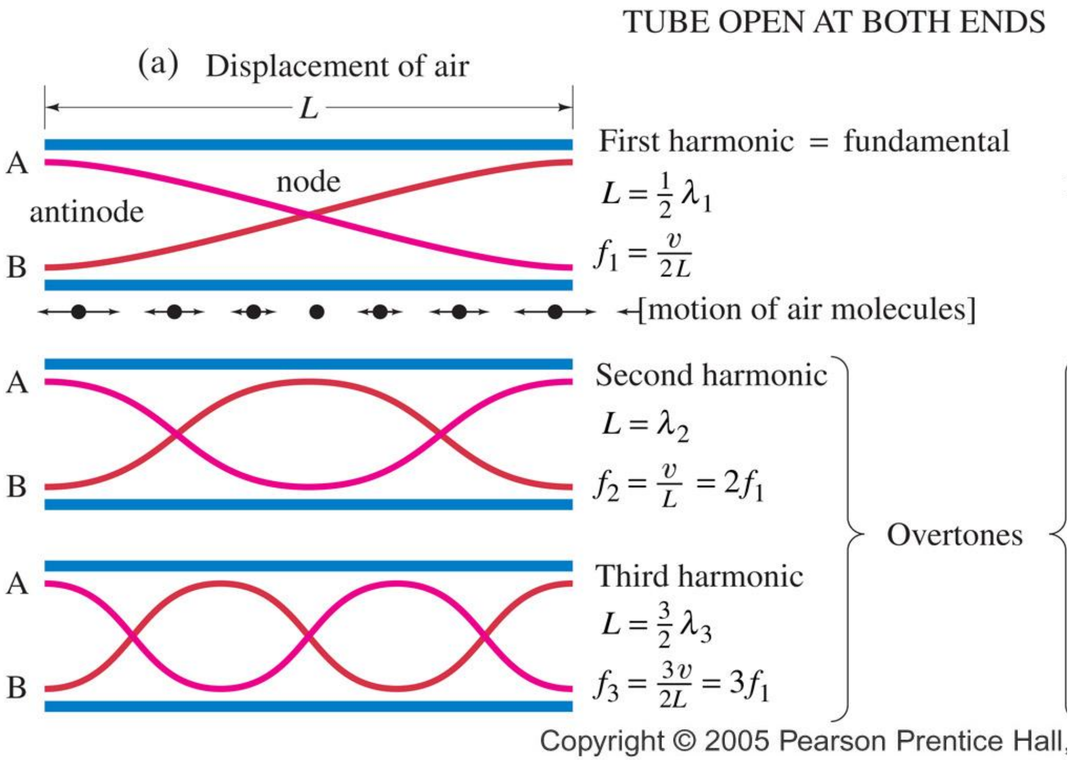
Sound Waves

- Mechanical – requires a medium
- Longitudinal oscillations in air pressure



Resonance in columns of air

Open-pipe resonator



Resonant frequency formula is the same as with a rope

$$f_n = \frac{nv}{2L}$$

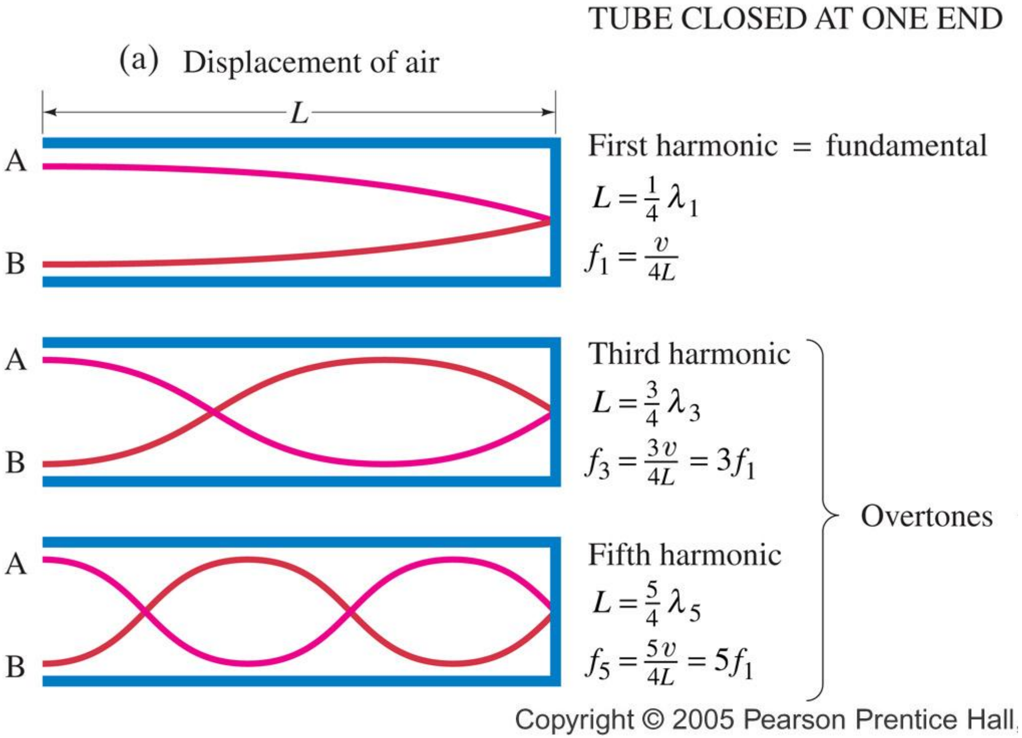
f_1 = fundamental

higher harmonics are integer multiples of f_1

n = 1, 2, 3, 4…

next higher harmonic comes when $\lambda/2$ is added into medium

Closed pipe resonator



Not all harmonics form due to reflection from closed end

$$f_n = \frac{nv}{4L}$$

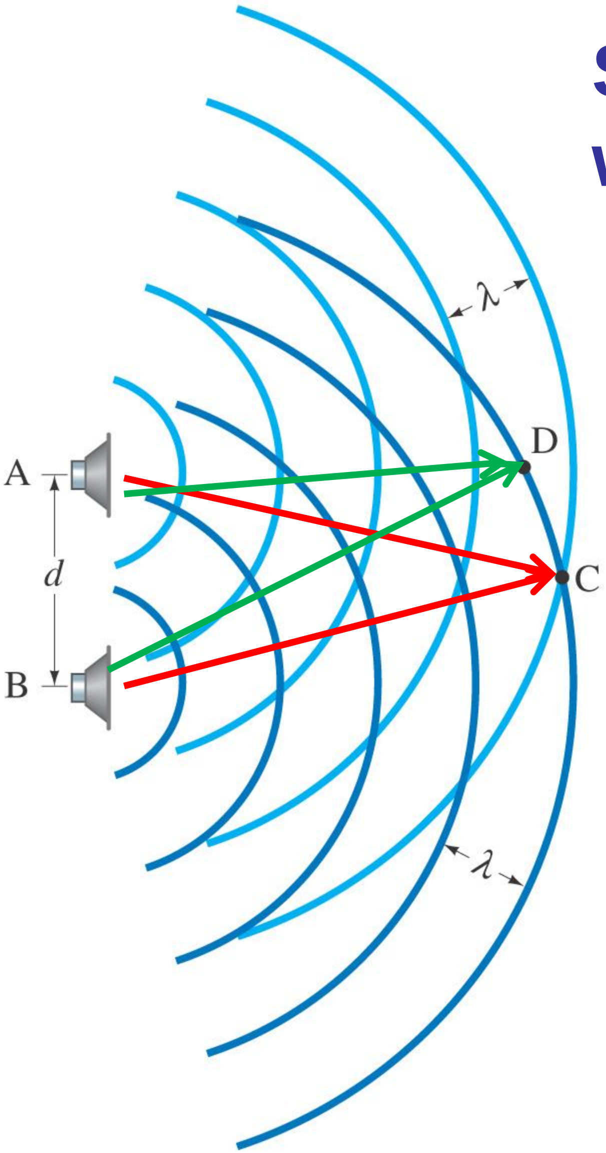
f_1 = fundamental

higher harmonics are integer multiples of f_1

$n = 1, 3, 5$

next higher harmonic comes when $\lambda/2$ is added into medium

12-6 Interference of Sound Waves; Beats



Sound waves **interfere** in the same way that other waves do in space.

When path lengths of 2 sound waves are equal they interfere constructively (at point C) yielding maximum intensity sound

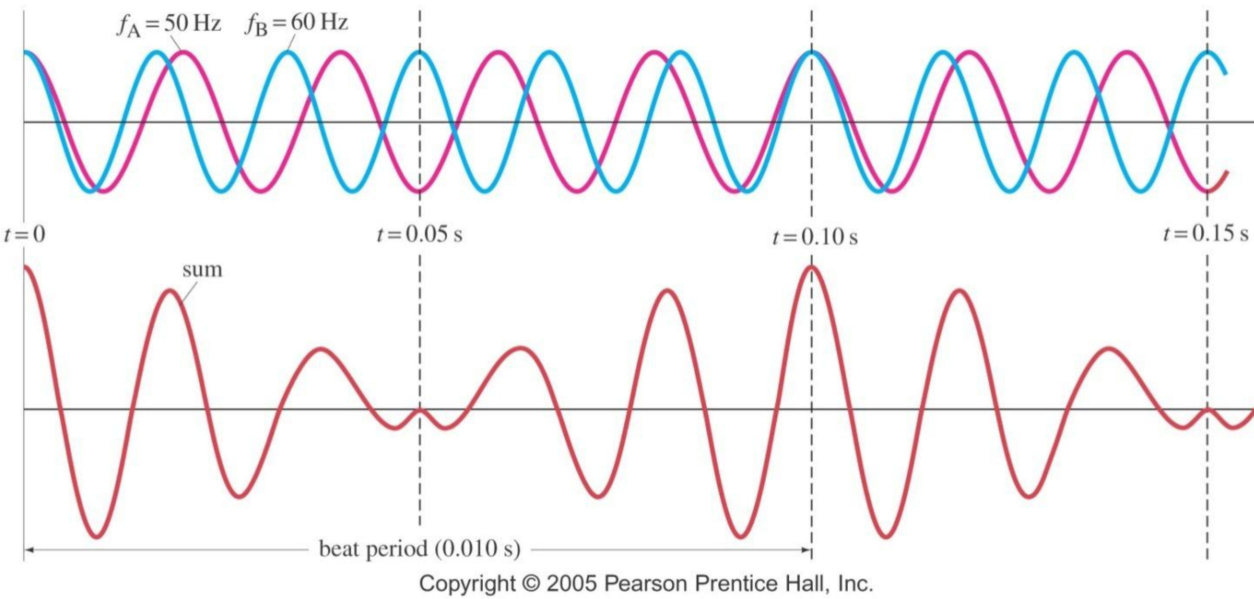
When path lengths of 2 sound waves differ by $\lambda/2$ they interfere destructively (at point D) yielding zero intensity sound

interference of sound

12-6 Interference of Sound Waves; Beats

Waves can also interfere in time, causing a phenomenon called beats. Beats are the slow "envelope" around two waves that are relatively close in frequency.

Beat frequency = difference in frequencies



beat frequency = 60 – 50 = 10 Hz

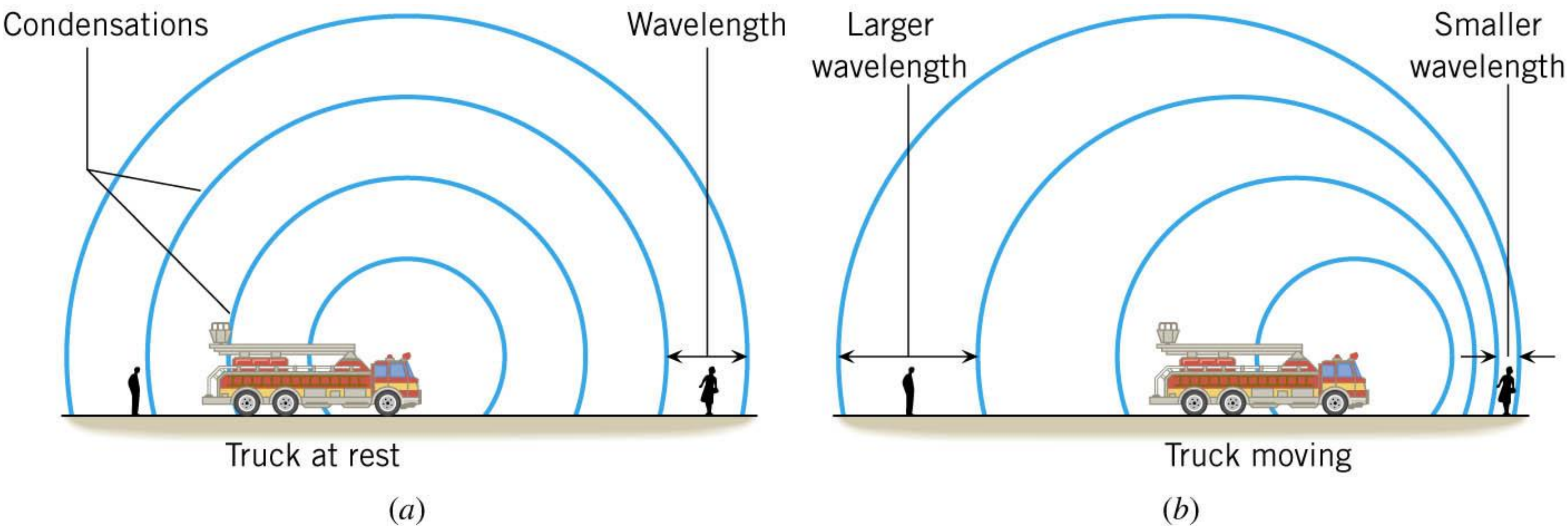
1 beat every 0.10 s = 10 Hz frequency

beats

Doppler Effect

- Change in frequency (pitch) that is perceived by an observer because of relative motion between sound source and observer
- “eee-yow”
- You MUST distinguish between cause and effect
  - Cause: compression or expansion of wavelength due to relative motion
  - Effect: Ear hears higher or lower pitch

Doppler Effect – Stationary Observer



Source approaching observer: shorter wavelength results in pitch heard by observer being higher than actual

Source moving away from observer: longer wavelength results in pitch heard by observer being lower than actual

$$f' = \left[\frac{(343 \pm v_{obs})}{(343 \pm v_{source})} \right] \times f_{source}$$

car demo