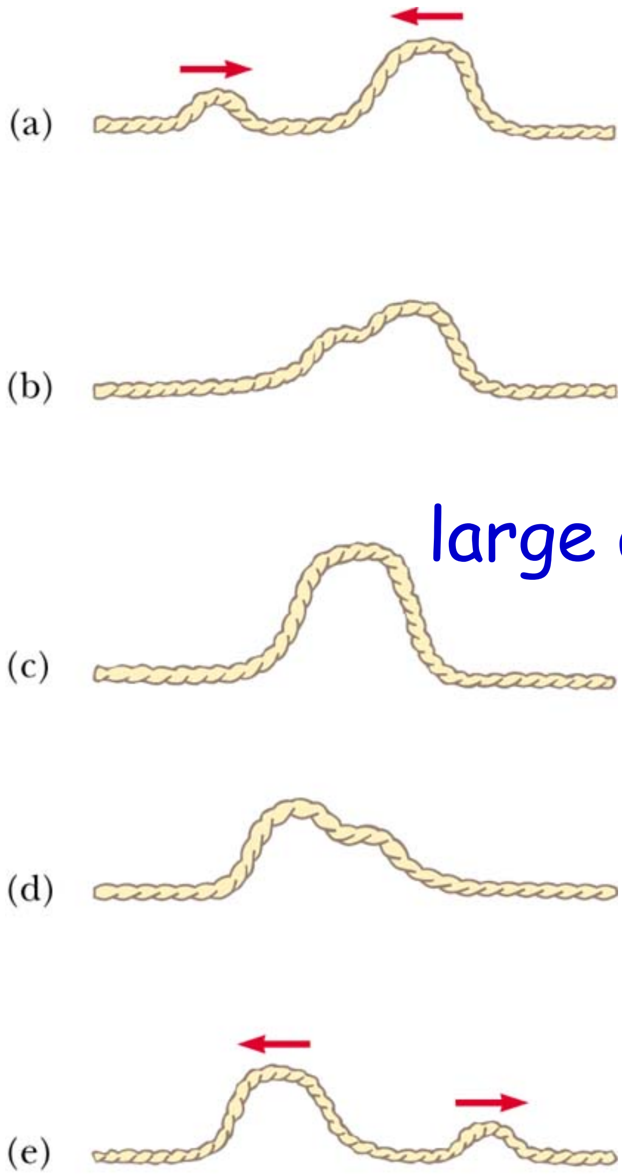
Musical Acoustics

Lecture 7

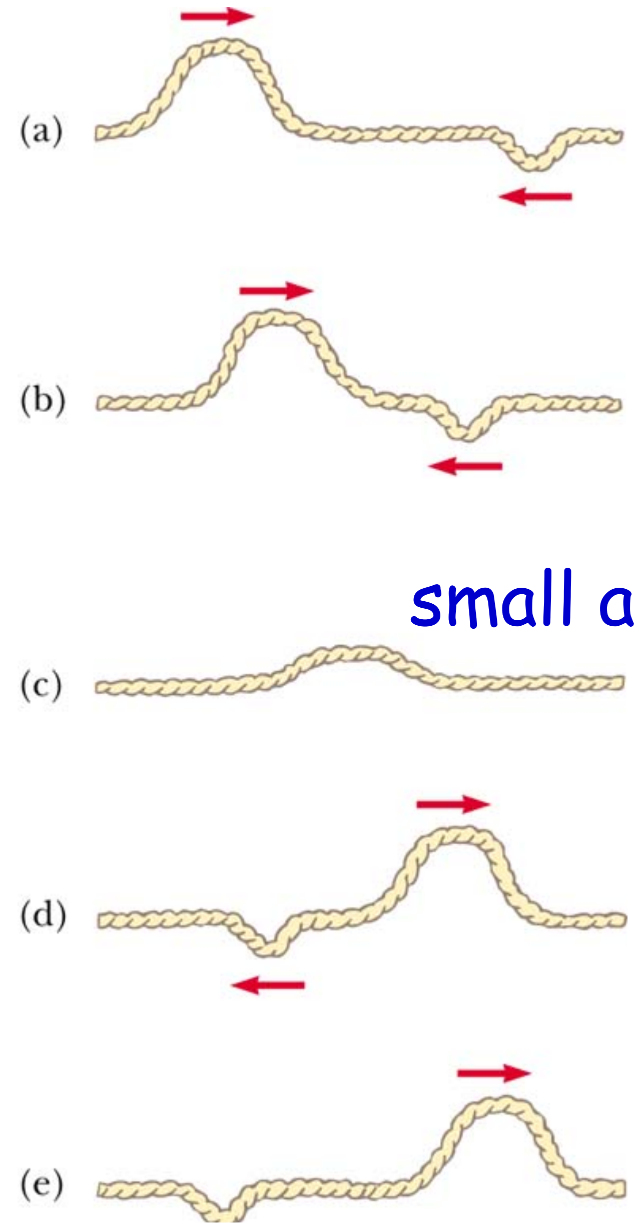
Waves - 2

Interference in one dimension



large amplitude

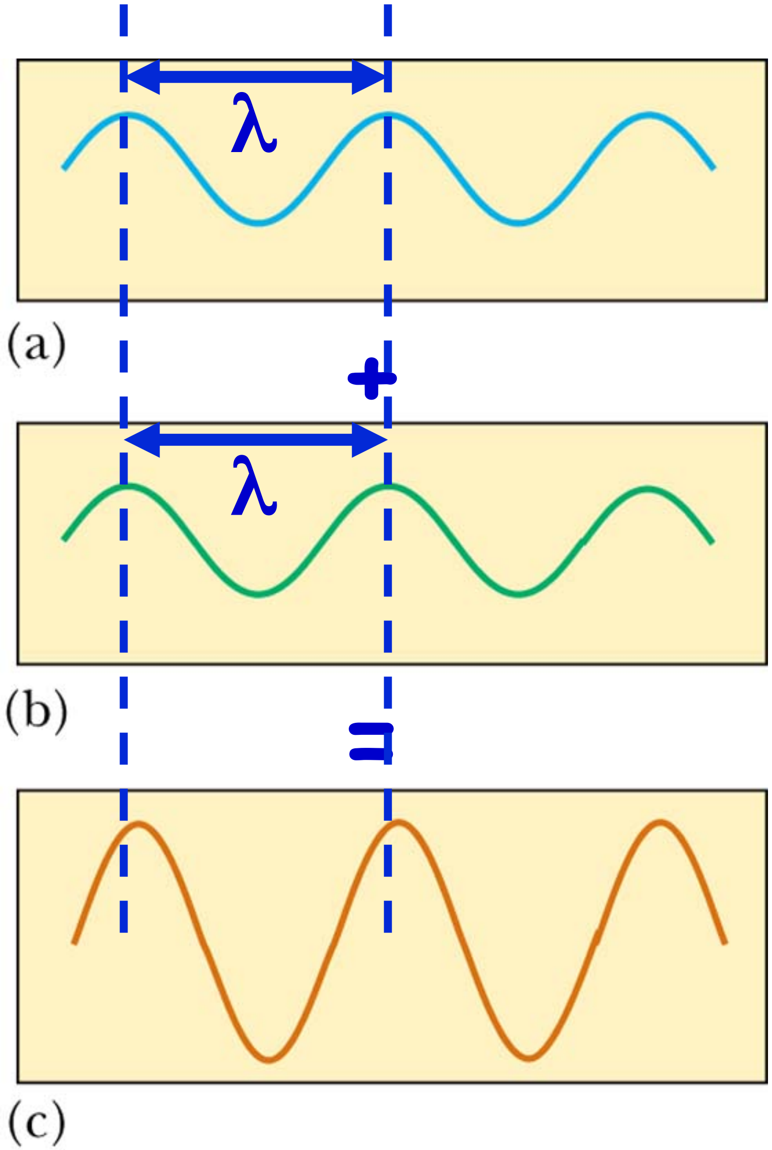
constructive interference



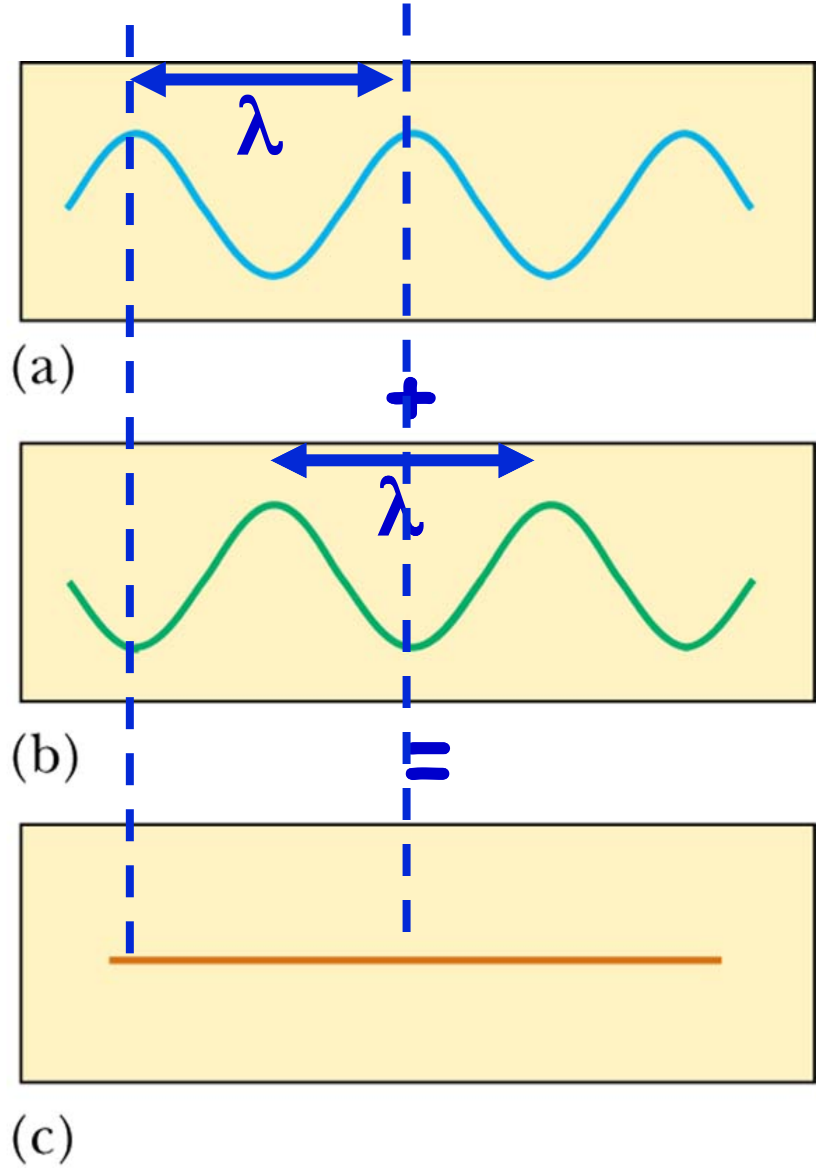
small amplitude

destructive interference

Interference in one dimension: standing waves

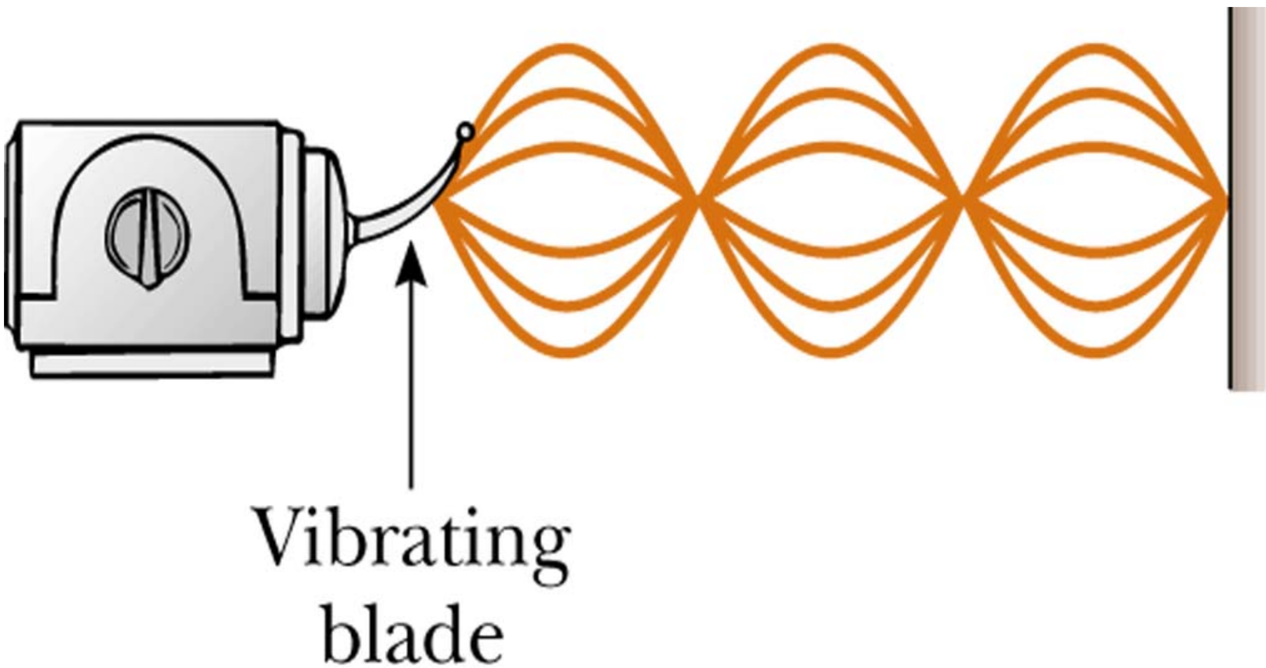


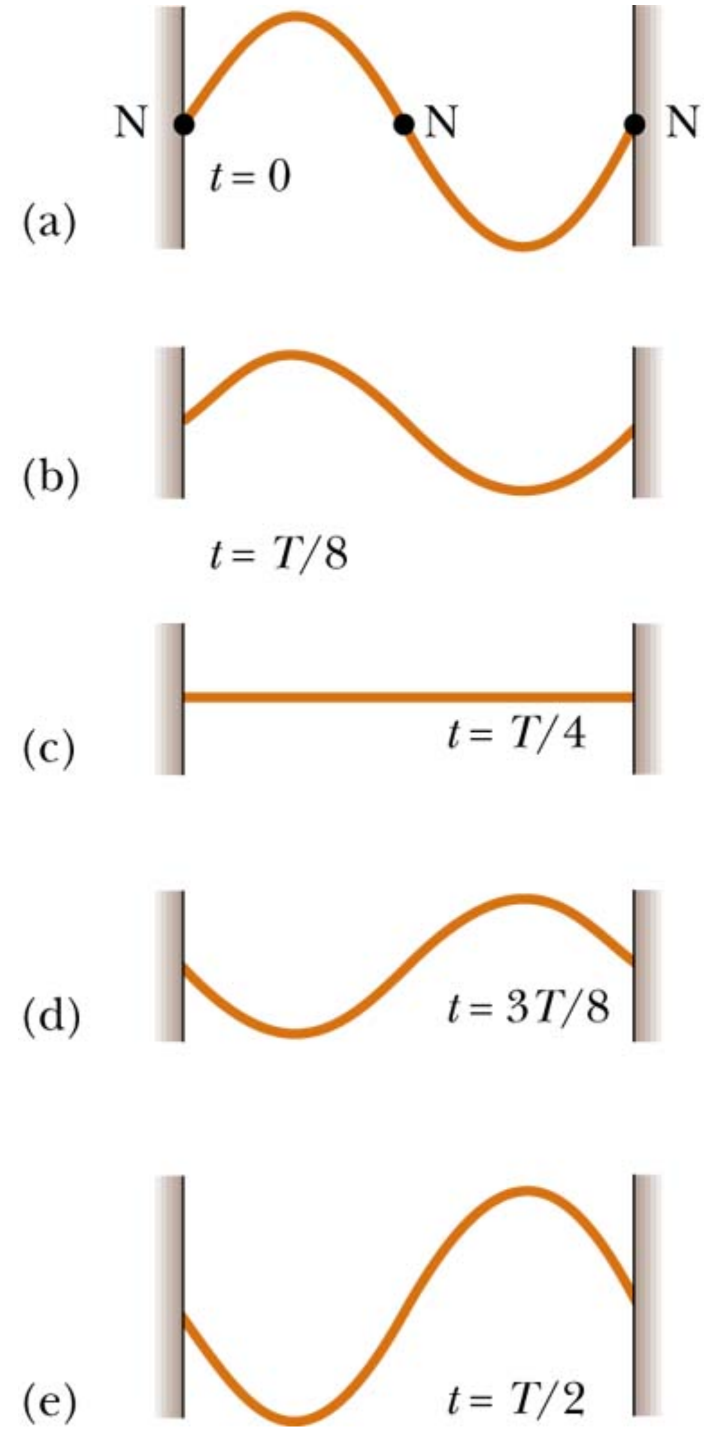
constructive interference
waves in phase



destructive interference
waves ½λ out of phase

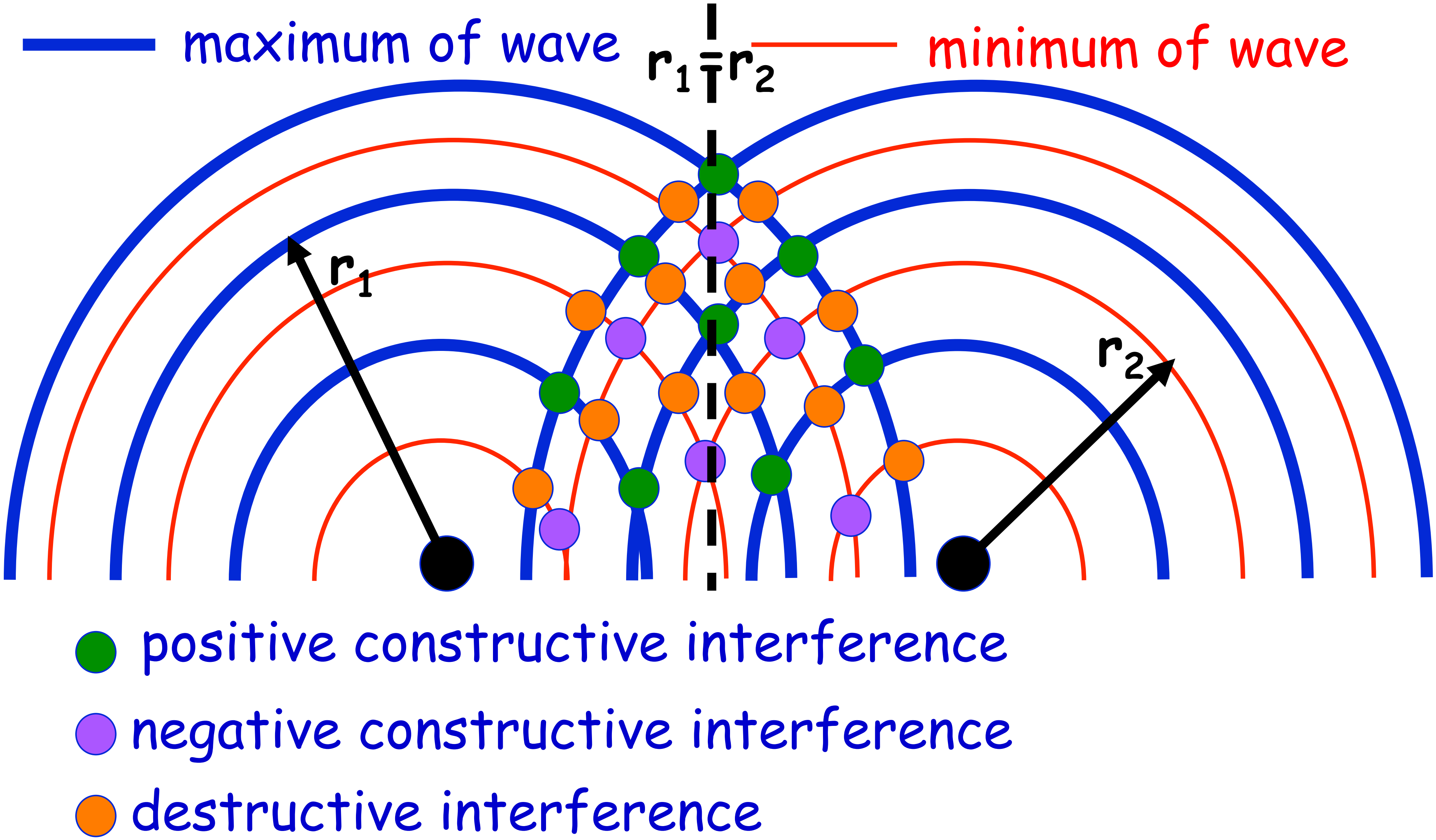
How to create standing waves: a rope





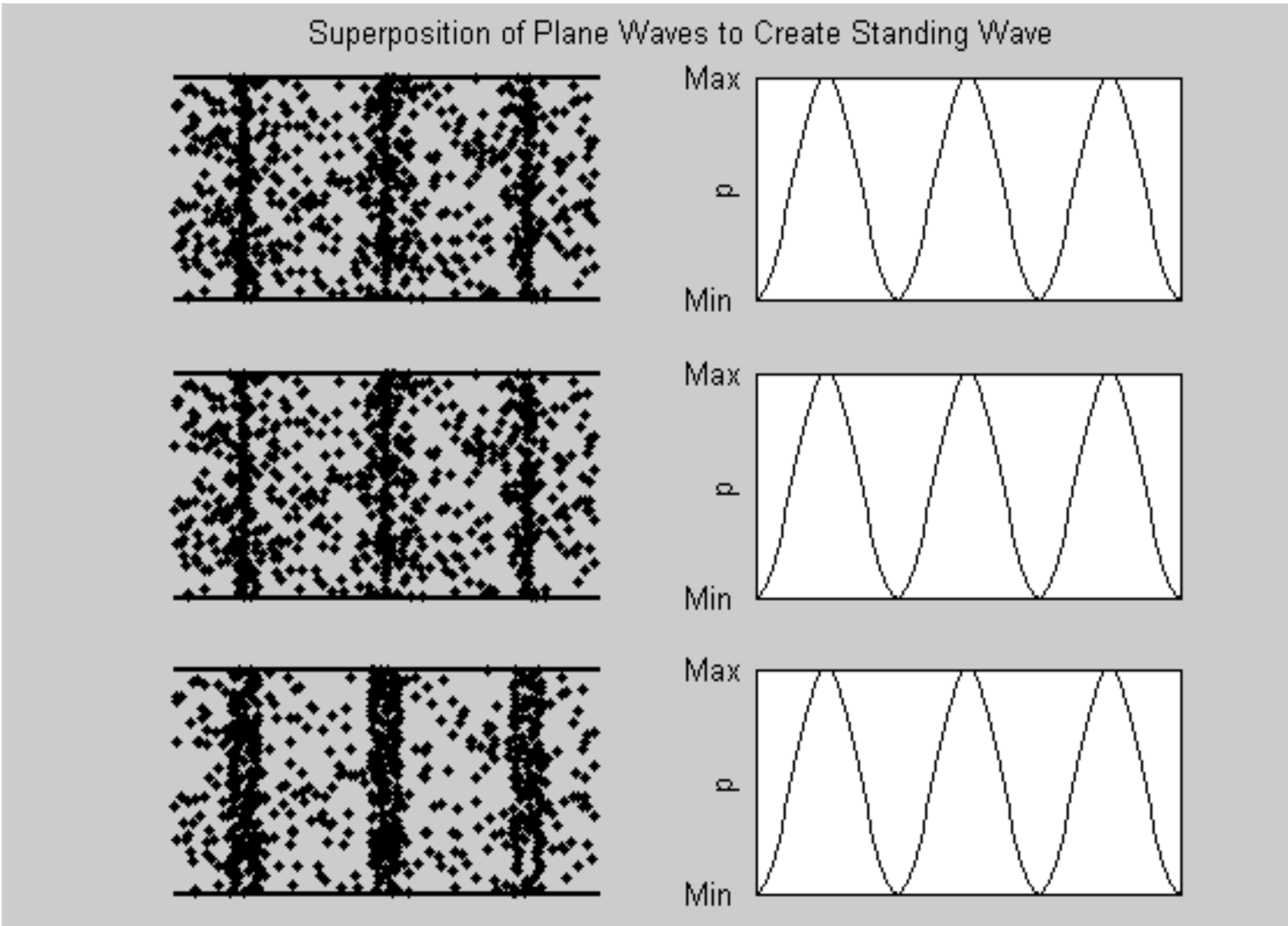
The oscillations in the rope are reflected from the fixed end (amplitude is reversed) and create a standing wave.

Interference in spherical waves



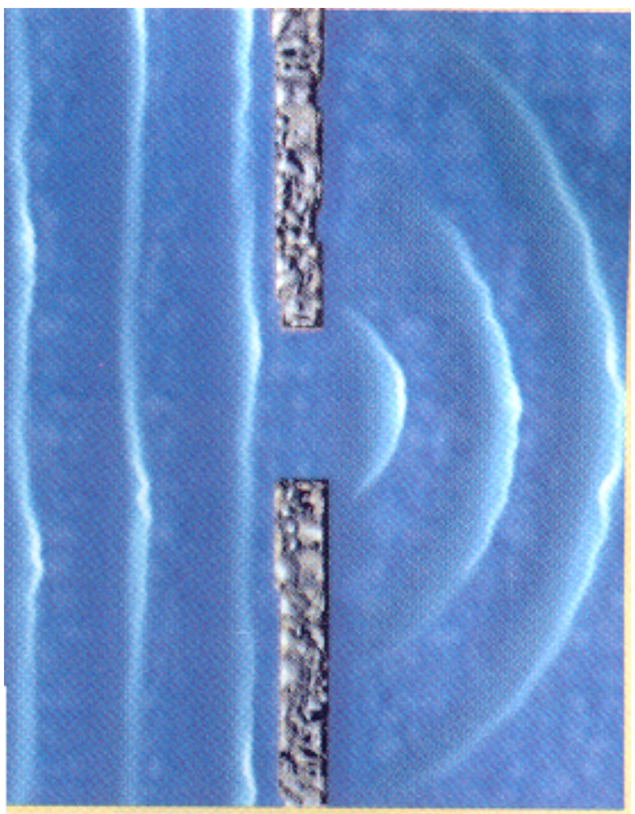
Standing waves in air columns

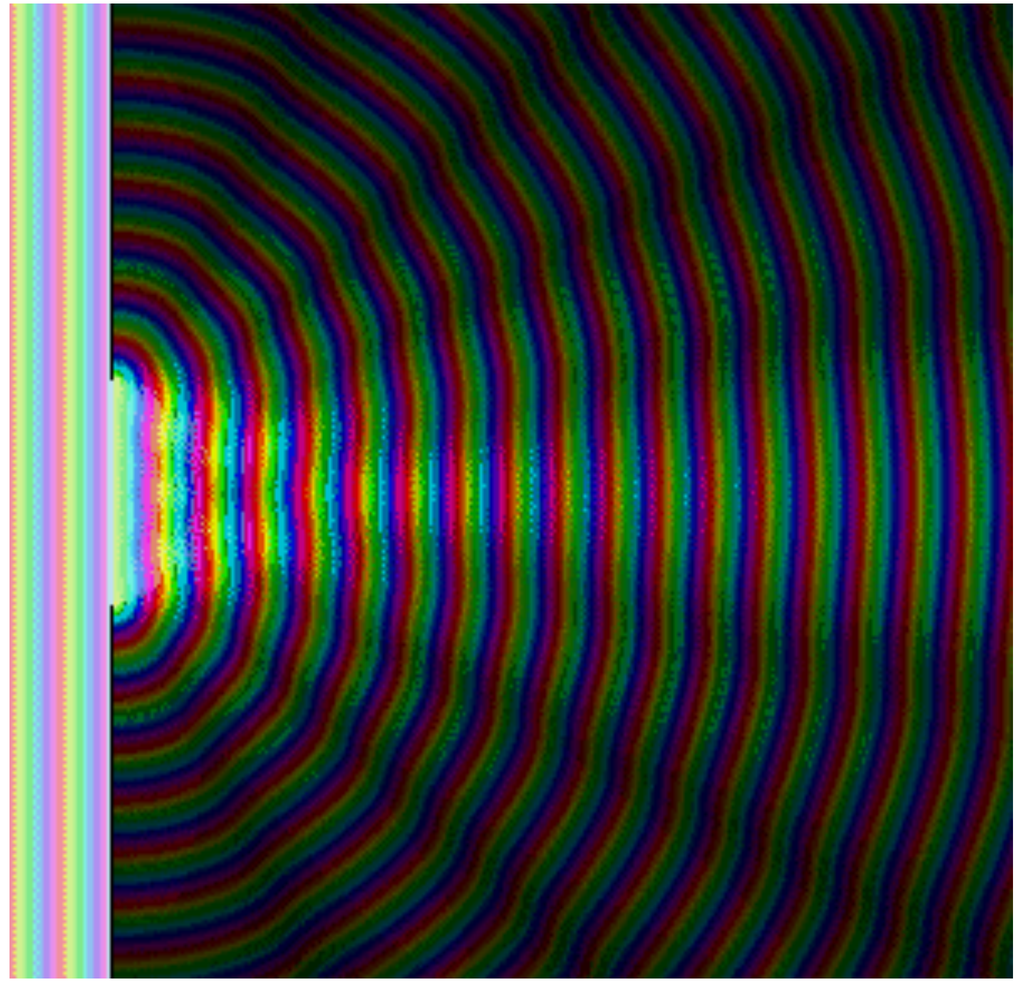
Just like standing waves in transverse oscillations, one can make standing waves in longitudinal oscillations as well.



Diffraction

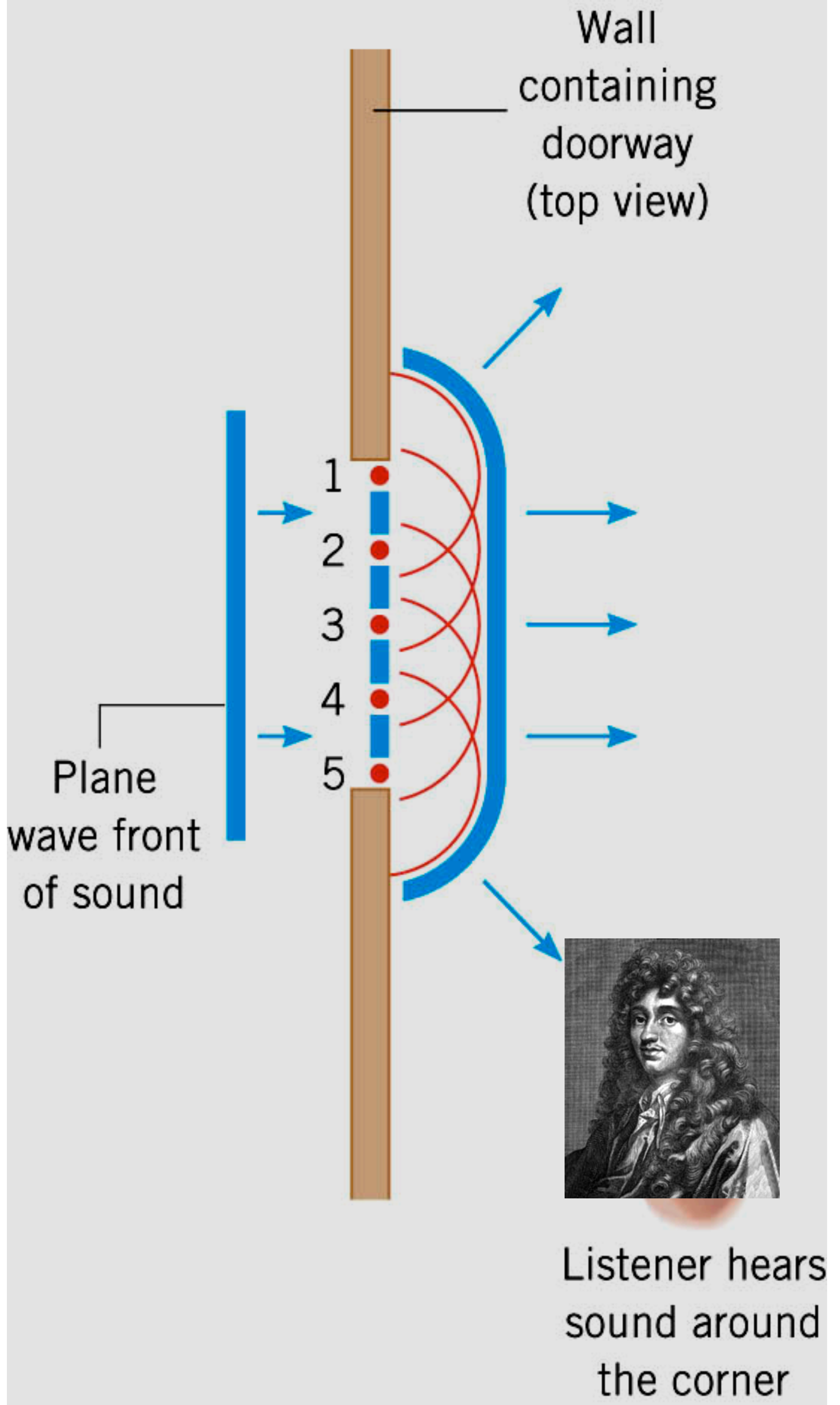
- diffraction of a wave is the bending of the wave front as to moves around obstacles and edges





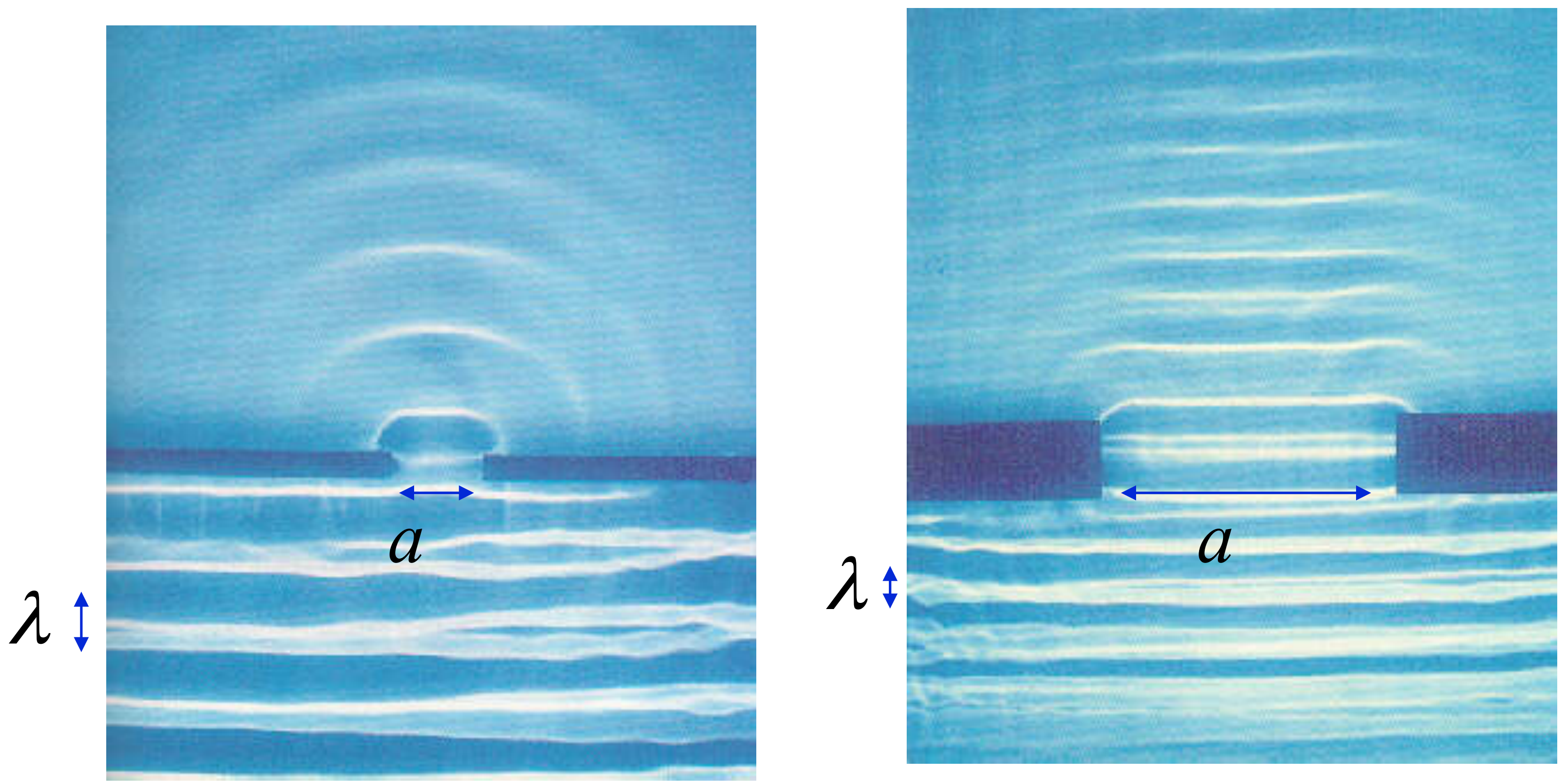
Diffraction

- **Huygen's principle** offers an explanation for why and how diffraction occurs
  - every point on a wave front acts as a source of tiny spherical *wavelets* that travel forward with the same speed as the wave
  - the wave front at a later time is then the linear superposition of all the wavelets
  - diffraction occurs because of *interference* between the wavelets

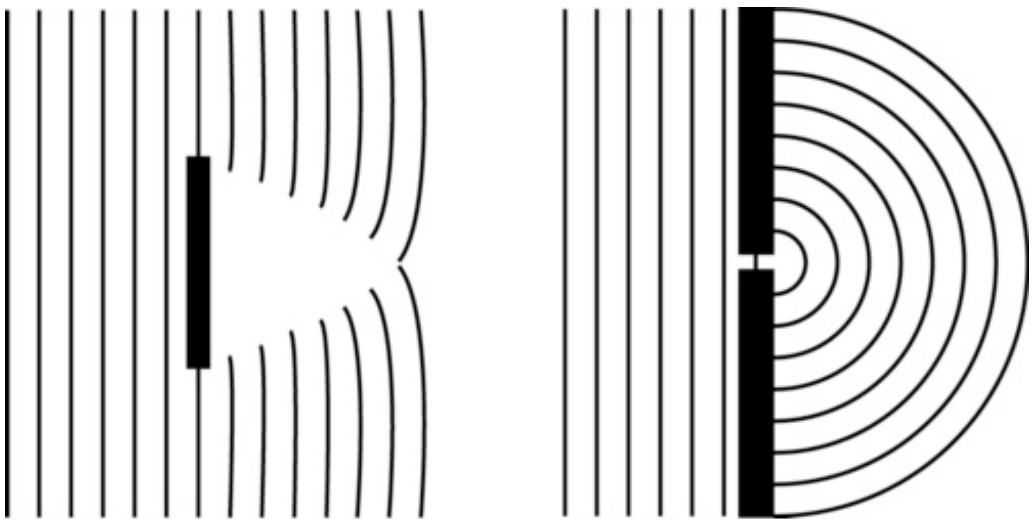


Diffraction

- The extent to which a wave bends when passing around the edge of an opening is related to the ratio λ/a:



Diffraction



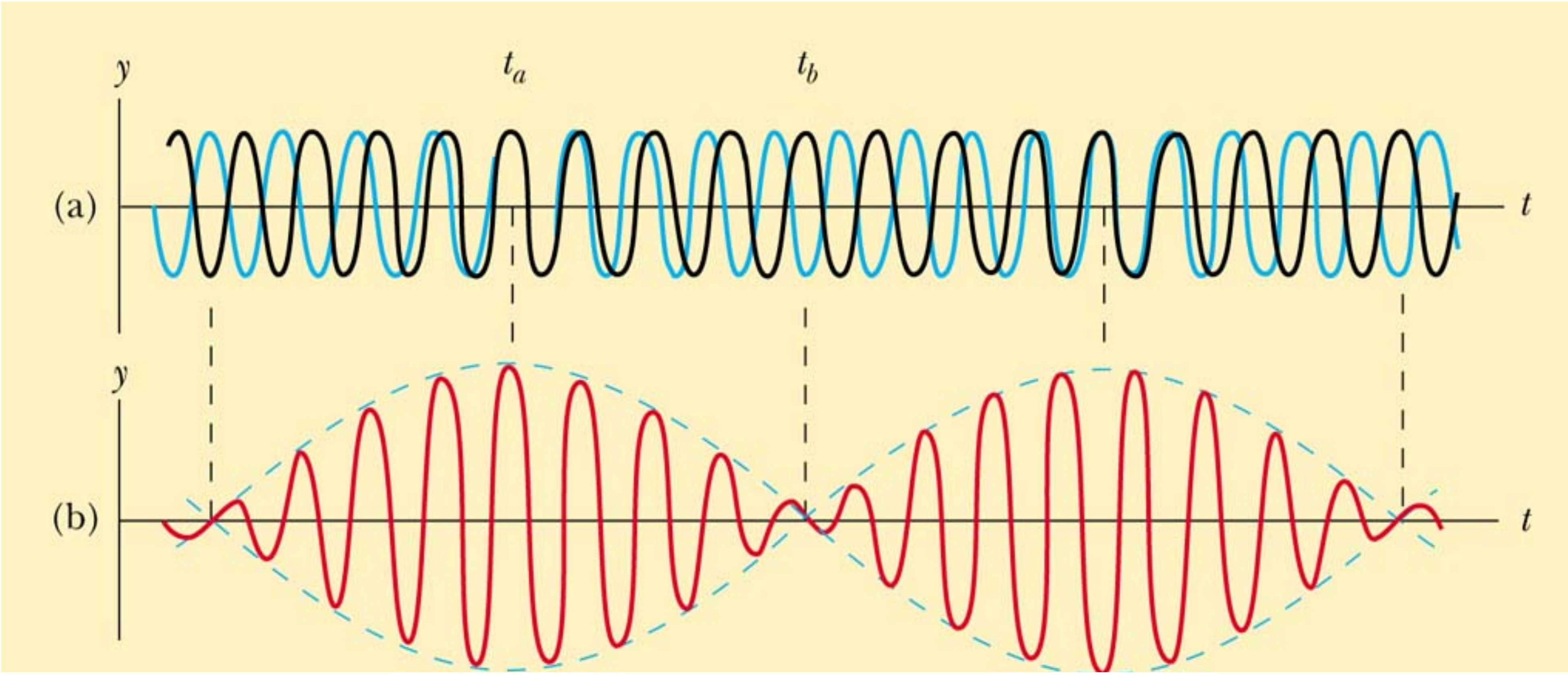
Waves also diffract if pass around an object whose size is comparable to its wavelength

- *Diffraction, a "bending around" obstacles because every point on a wave is a source; waves cannot terminate abruptly.*

- *Huygens Principle: every point on the wave is the source of a new (spherical) "wavelet."*

Beats

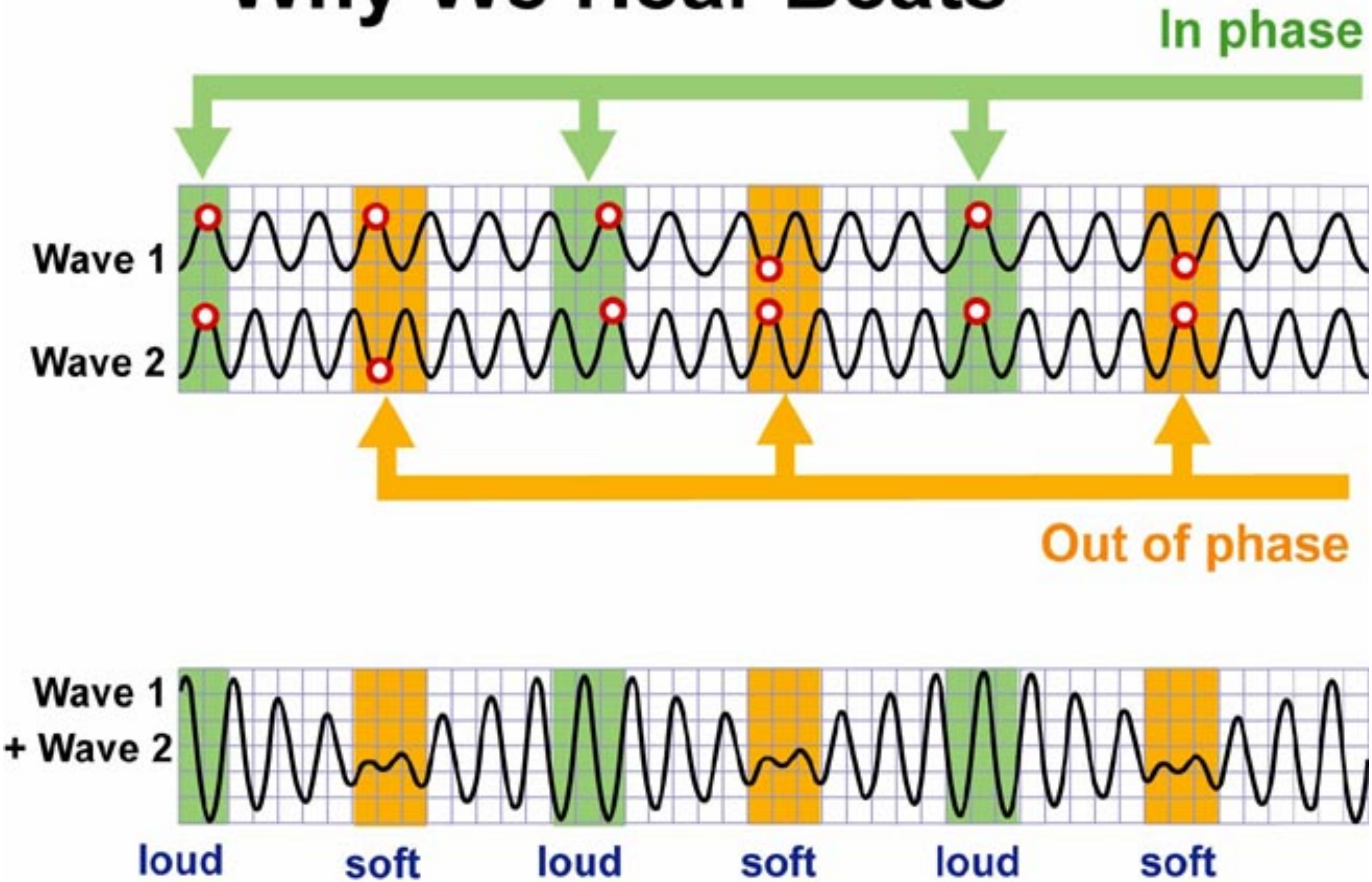
Superposition of 2 waves with slightly different frequency



The amplitude changes as a function of time, so the intensity of sound changes as a function of time.

The beat frequency (number of intensity maxima/minima per second): $f_{beat} = |f_a - f_b|$

Why We Hear Beats



Beat Frequency Derivation

After time T_{beat}, two sounds will differ by one complete cycle.

$$n_1 - n_2 = 1$$

$$f_1 T_{beat} - f_2 T_{beat} = 1$$

$$T_{beat} = \frac{1}{f_1 - f_2}$$

$$f_{beat} = \frac{1}{T_{beat}}$$

$$f_{beat} = f_1 - f_2$$

Tuning a Guitar by Beats

Two tones of frequency f_1 and f_2 sound like one tone of mean frequency

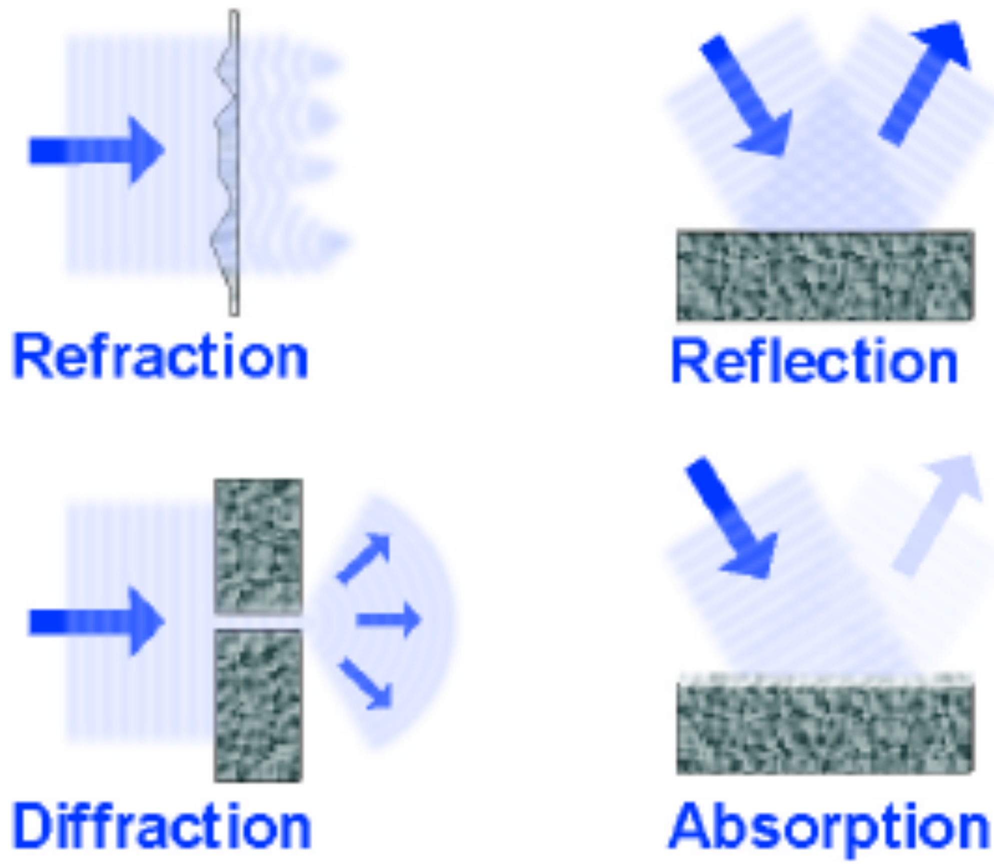
$$f_{mean} = (f_1 + f_2)/2$$

that beats at a beat frequency of

$$f_{beat} = f_1 - f_2 .$$

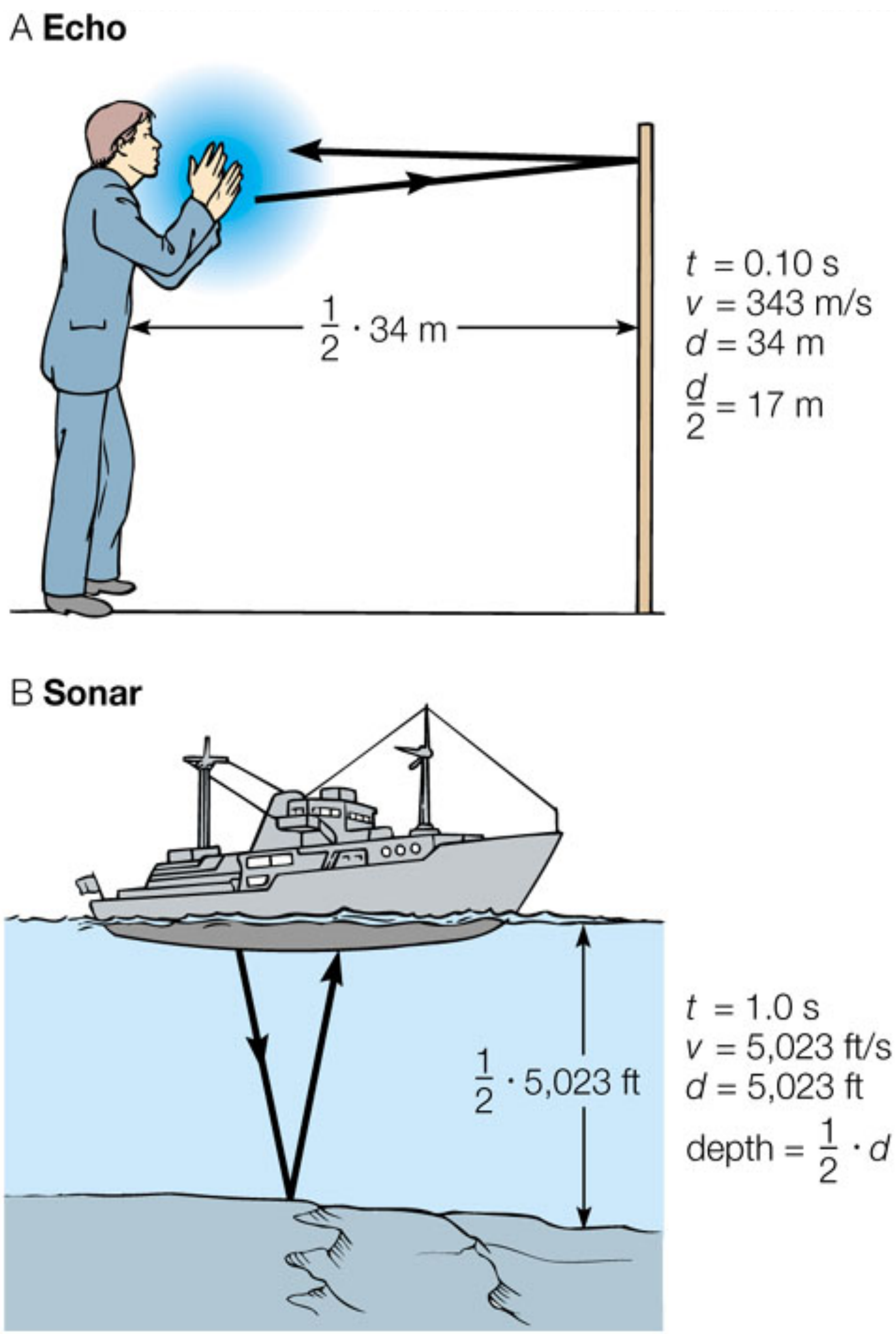
Sound waves and boundaries

- Like other waves, sound waves can be reflected by surfaces and refracted as they pass from one material to another.



- Sound waves reflect from hard surfaces.
- Soft materials can absorb sound waves.

Reflection



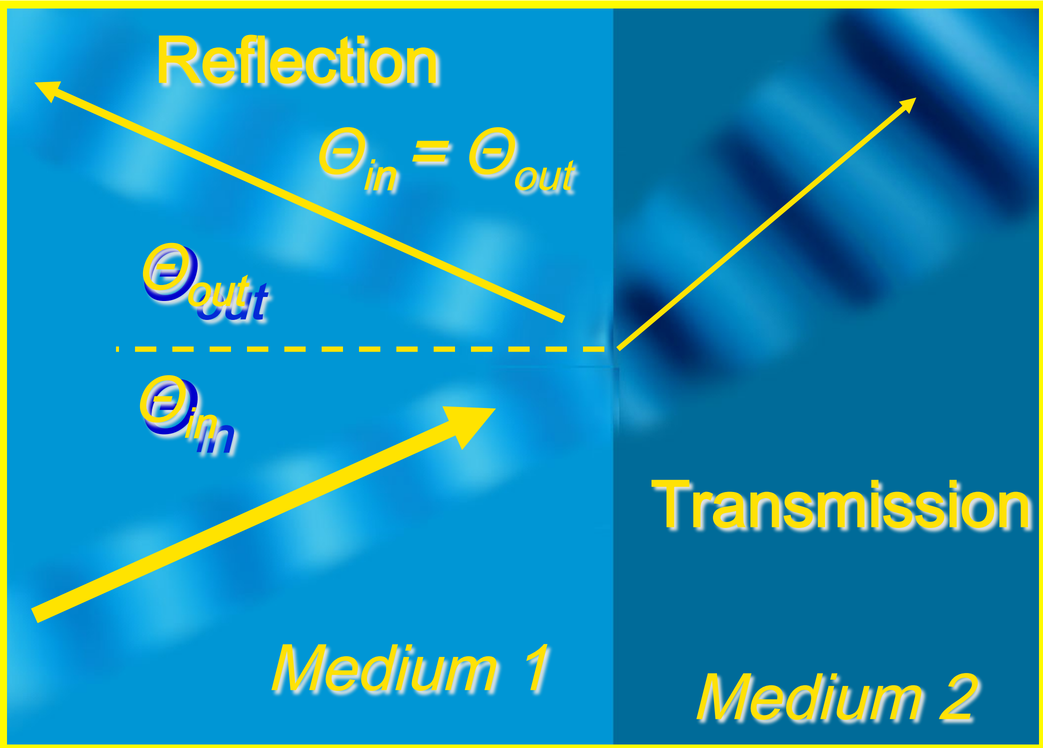
Wave rebounding off boundary surface

Reverberation - sound enhancement from mixing of original and reflected sound waves

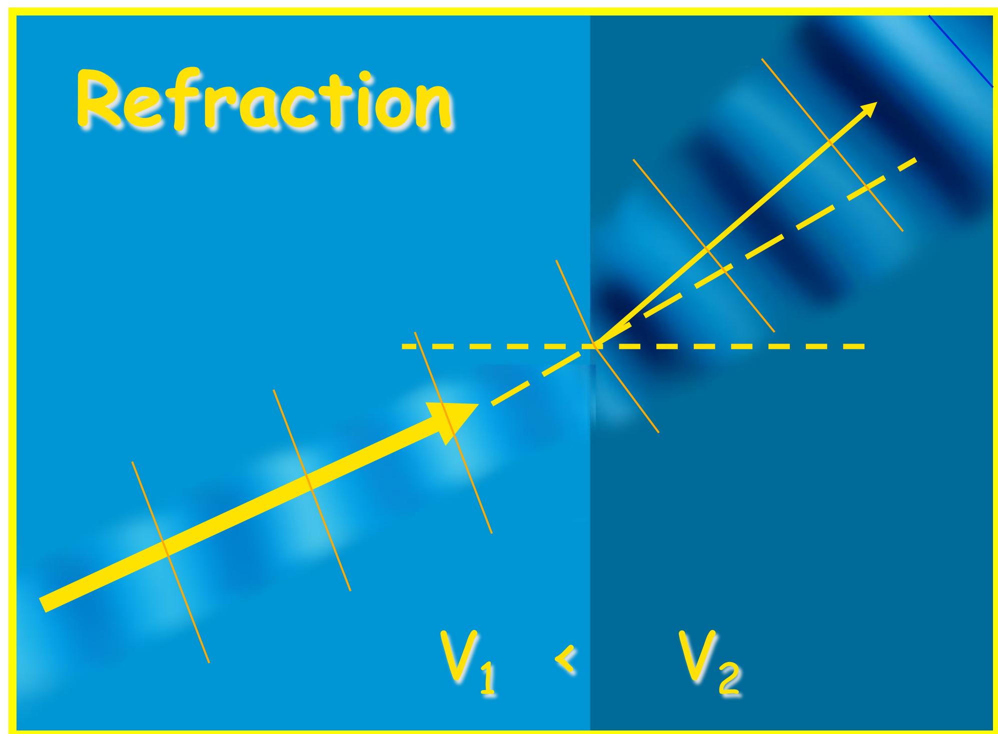
Echo

- Can be distinguished by human ear if time delay between original and reflected sound is greater than 0.1 s
- Used in sonar and ultrasonic imaging

Sound waves and boundaries: refraction



Refraction occurs when a wave "enters" a medium that has a different velocity.



Refraction - Bending!

- Bending of wave fronts upon encountering a boundary
    - Between two different media
    - Between different physical circumstances in the same medium
    - Wave bends into the slow medium (like car pulled into the mud)
- Example - temperature gradient in air
    - From my house I can sometimes hear a band practice