What is a wave?

- A wave is a *disturbance* that transfers energy progressively from one point to another.
- Though the medium through which the wave travels may experience local oscillations, *particles in the medium do not travel with the wave*.
- Example: When a *wave pulse* travels from left to right on a string, the string is displaced up and down, but the string itself does not experience any net motion.

![Click image for animation:](Music 175: Waves, Vibration and Resonance)
Superposition of Waves

• When two (or more) waves travel through the same medium at the same time they pass through each other without being disturbed.

• Click image for animation:

• The principle of superposition:
  – displacement of the medium at any point in space or time is the sum of individual displacements;
  – only true if medium is nondispersive (all frequencies travel at the same speed).
Constructive and Destructive Interference

- Consider the phase of the waves being added.
- The sum of waves in the same medium leads to:
  1. constructive interference: the two waves are in phase and their sum leads to an increase of amplitude
  2. destructive interference: the two waves are out of phase and the sum leads to a decrease in the overall amplitude.

- Click image for animation:
Reflections at Boundaries

- So how do we get two waves in the same medium?
- When a wave is confined to a medium (such as on a string), when it reaches a boundary it will reflect.
- At a fixed end the displacement wave is inverted.
- Click image for animation:

- At a free end the displacement wave is not inverted.
- Click image for animation:
Standing Waves

- Reflection causes destructive and constructive interference of *traveling waves*, leading to **standing waves**.

- **Click image for animation:**

- **Standing wave**: pattern of alternating *nodes* and *antinodes*.

- **Click image for animation:**

- The fundamental mode of oscillation, is determined by the *shortest* node-antinode pattern.
Standing Waves and Boundaries

- Standing waves created from a fixed boundary:
  Click image for animation:

- Standing waves created from a free boundary:
  Click image for animation:
Guitar String

- The guitar string is fixed at both ends—therefore it has a node at both ends.

![Standing waves on a guitar string.](image)

- For a string of length $L$ and each harmonic number $n$,
  - the wavelength is $\lambda_n = \frac{2}{n}L$.
  - the frequency is $f_n = n \frac{v}{2L} = nf_1$

(where $v$ is the speed of sound).
Open-Open Tube

- Displacement waves in a tube open at both ends:

![Standing displacement waves in an open tube.]

- Though opposite-phase to displacement on a string, the harmonics follow the same relationship:
  - Wavelength is \( \lambda_n = \frac{2}{n}L \).  
  - Frequency is \( f_n = n\frac{v}{2L} = nf_1 \).

- Pressure waves are opposite phase to displacement waves (they look like displacement on a guitar string).
Closed-Open Tube

- Displacement waves in tube closed at one end:

![Standing waves for displacement in a closed-open tube](image)

Figure 3: Standing waves for displacement in a closed-open tube

- The wavelength of the first harmonic is $\lambda_1 = 4L$.
- Adding an antinode/node creates the next standing wave pattern with wavelength $\lambda_3 = \frac{4}{3}L$.
- Since $\lambda_3$ is $\frac{1}{3}$rd the length of $\lambda_1$, the frequency is 3 times the fundamental and it is the “third” harmonic.
- Notice the second harmonic is missing!
Odd harmonics in a closed tube

- The closed tube has only odd harmonics:
  \[ n = 1, 3, 5, \ldots \]

![Standing waves for pressure in a closed tube](image)

- For odd \( n \), the harmonics of the closed tube have the following properties:
  
  - wavelength: \( \lambda = \frac{4}{n} L_n \).
  
  - frequency: \( f_n = n\frac{v}{4L} \).