Music 175: Waves, Vibration and Resonance

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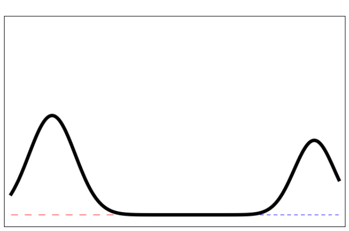
## What is a wave?

- 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: 



## 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:

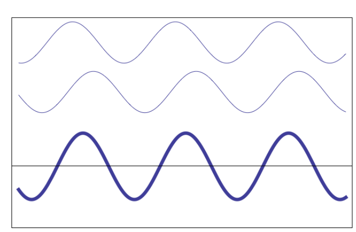


- **The principle of superposition**:
  - displacement of the medium at any point in space or time is **the sum of individual displacements**;
  - only true if medium is **nondispersive** (all frequencies travel at the same speed).



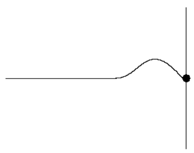
## Constructive and Destructive Interference

- 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 inrease 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:

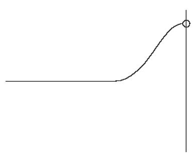


## Reflections at Boundaries

- 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:



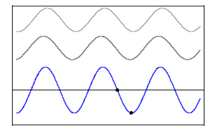
- At a **free end** the displacement wave is *not inverted*.
- Click image for animation:





## 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.

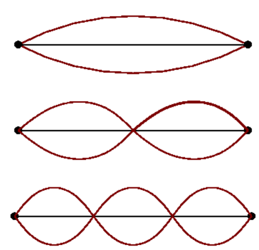


Figure 1: Standing waves on a guitar string.

- 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:

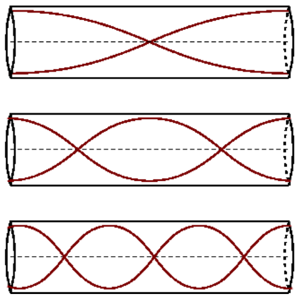


Figure 2: Standing displacement waves in an open tube.

- 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:

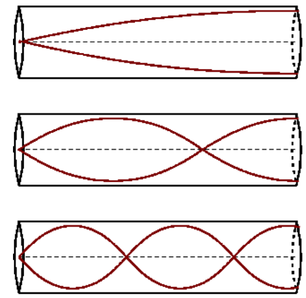


Figure 3: Standing waves for displacement in an closed-open tube

- 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 $1/3^{\text{rd}}$ 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: $n = 1, 3, 5, \ldots$

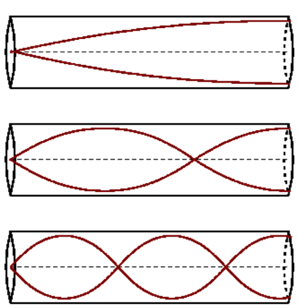


Figure 4: Standing waves for pressure in an closed tube

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