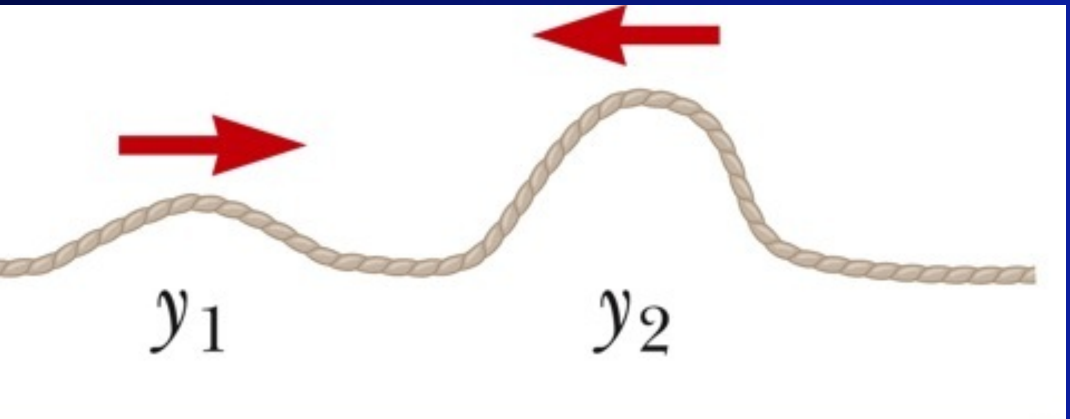
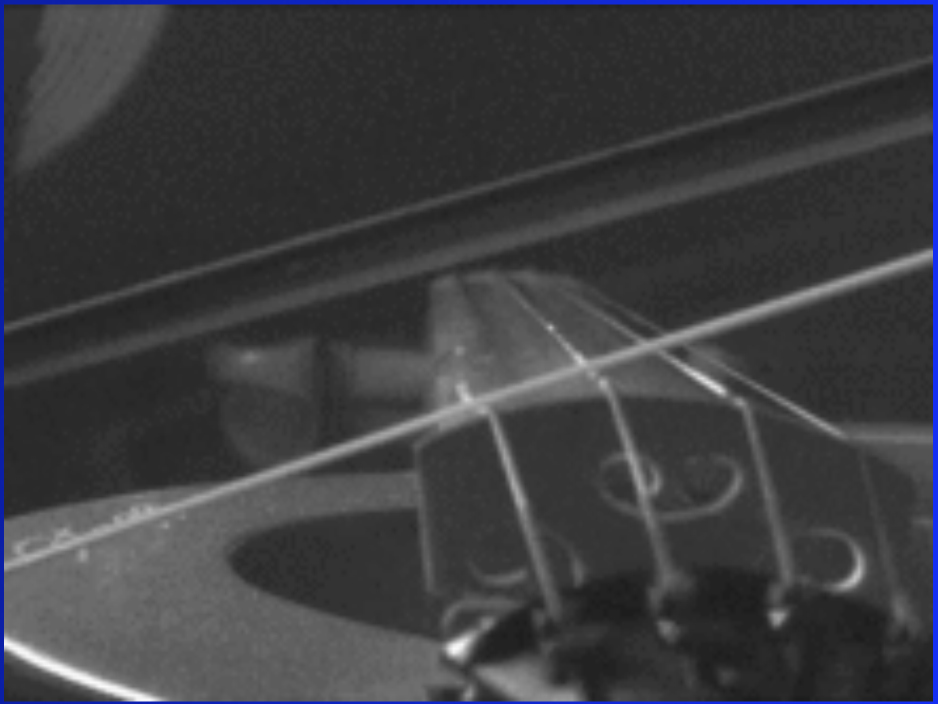
Physics 1C: Superposition and Standing Waves

Friday, 17 April 2015



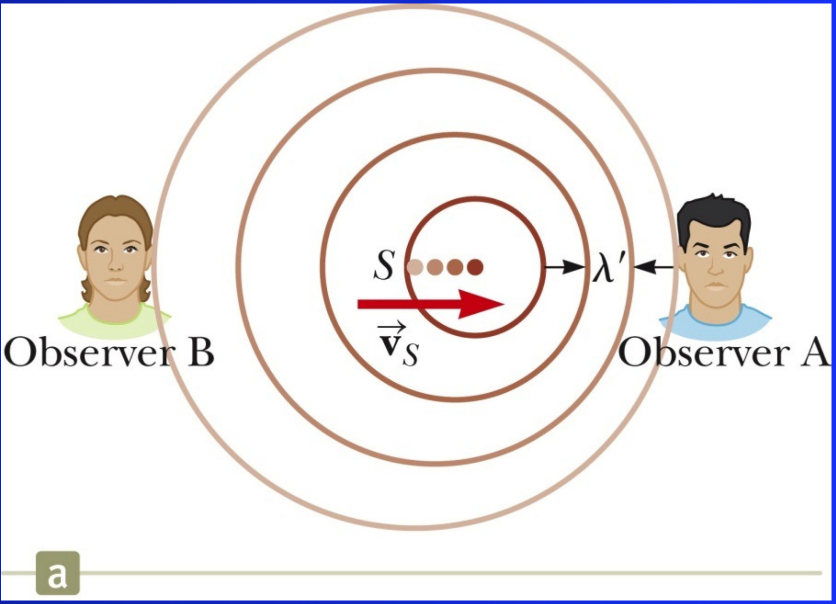


Physics News!

- astrophysics: Hubble Space Telescope's 25th anniversary; preparations for James Webb Space Telescope (2018 launch)
- physics at UCSD: Audio Spatialization Lab and "Soundbender"
- other news: putting out (small) fires with collimated low-frequency sound waves?
- American Physical Society mtg.: Dark Energy Survey results; nuclear cargo-screening tech using γ-rays

Questions from Wednesday's class…

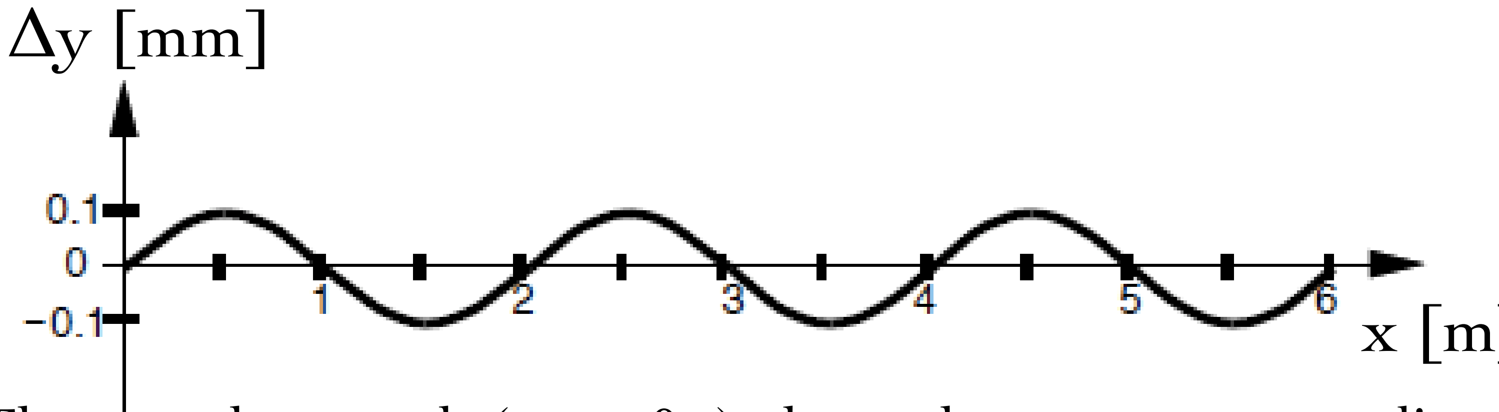
- question about an example in class and about traveling waves and the Doppler effect



- Monday class's slides from guest lecturer will be available on Ted website too

- sound waves and the Doppler effect are the concepts from chapter 13 to understand for next Friday's quiz! You should have read through most of chapter 14 by now too.

example: analyzing a traveling wave



The snapshot graph (at t = 0 s) above shows a wave traveling to the right with speed 4.0 m/s. What is the first time (t > 0) that a particle of the medium located at x = 3 m experiences zero velocity and negative acceleration?

A. 1/8 s
B. 2/8 s
C. 3/8 s
D. 4/8 s
E. none of these

use the fact that $v = \mathrm{d}y/\mathrm{d}t$ and $a = \mathrm{d}v/\mathrm{d}t$ and

$y = A \sin(kx - \omega t) = A \sin((2\pi/\lambda)x - (2\pi v/\lambda)t)$…

describing the Doppler effect

If either the speed changes (because we're moving) or the wavelength changes (because the source is moving), then the frequency we hear, f', will change, because of $f = v/\lambda$. (We are the observer, O.)

Always remember: if the source and observer are moving toward each other, then $f' > f$. If the source and observer are moving away from each other, then $f' < f$.

$$f' = f\left(\frac{v + v_O}{v - v_S}\right)$$

example: applying the Doppler effect

$$f' = f\left(\frac{v + v_O}{v - v_S}\right)$$

An ambulance siren is blaring at you with 800 Hz sound. The ambulance is heading east at 50 mph, and we know that the speed of sound is 340 m/s.

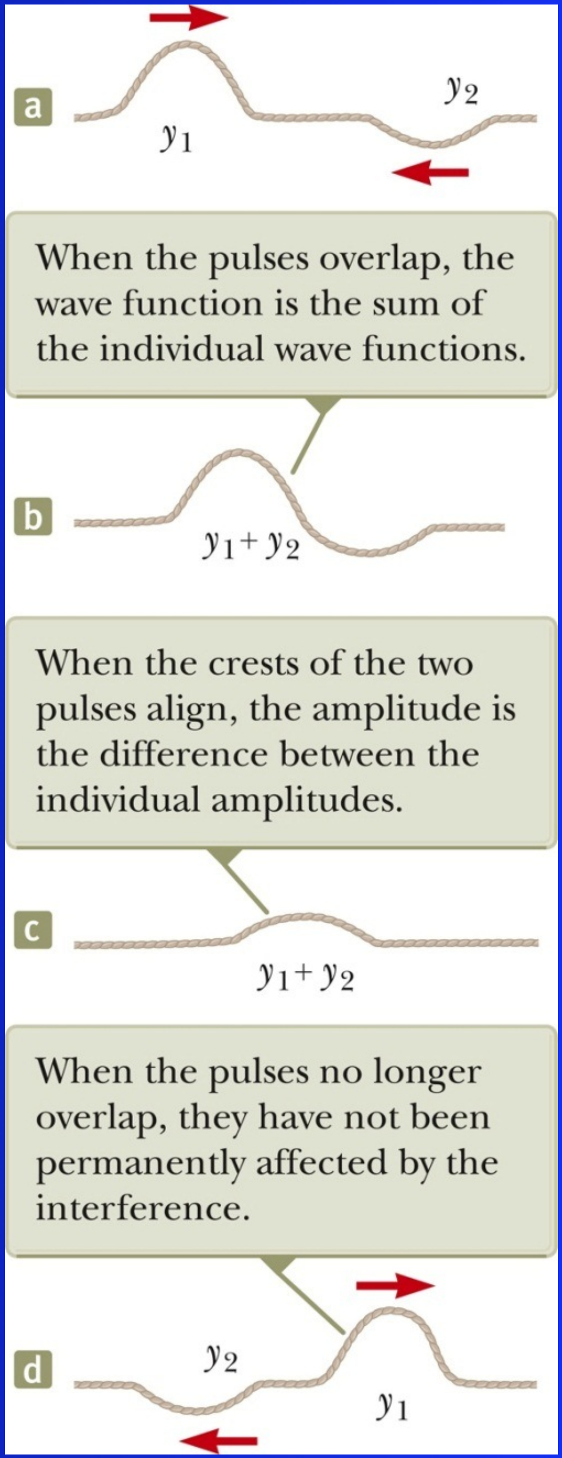
A. You stop as the ambulance approaches you on the road. What frequency of sound do you hear?

B. The ambulance passes and you start up again, so you're heading east too but at 35 mph behind it. Now what frequency of sound do you hear?

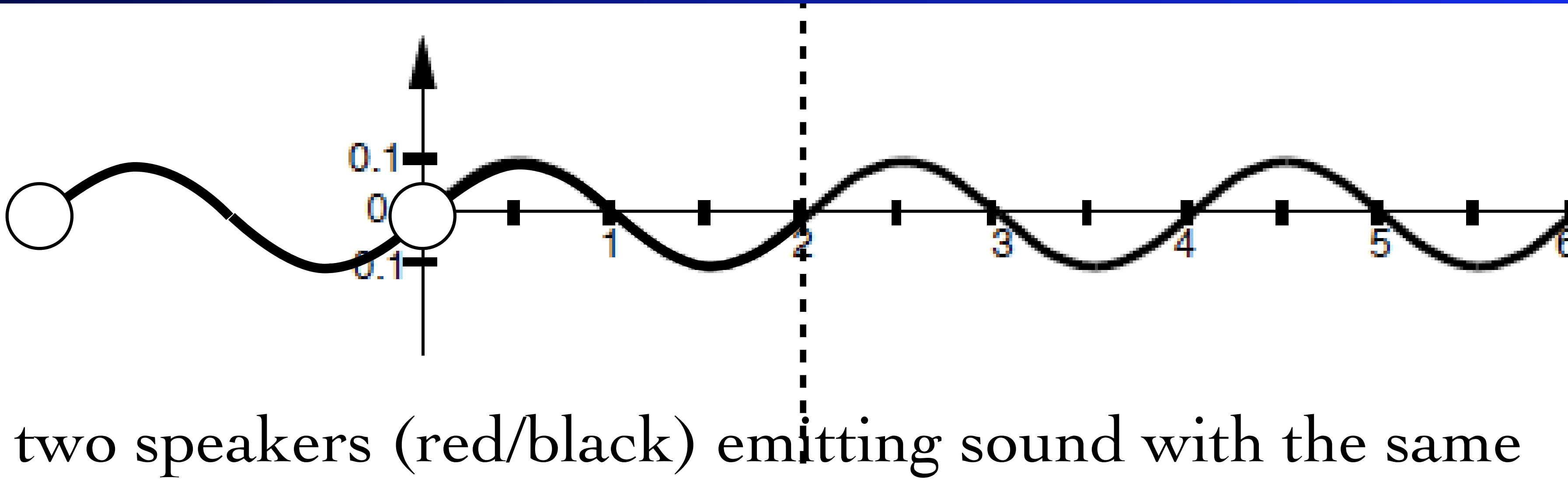
Superposition of Waves

- *Constructive interference* occurs when the displacements caused by the two pulses are in the *same* direction
  - amplitude of resultant pulse is greater than either individual pulse

- *Destructive interference* occurs when the displacements caused by the two pulses are in *opposite* directions
  - amplitude of resultant pulse is less than either individual pulse



What happens if...

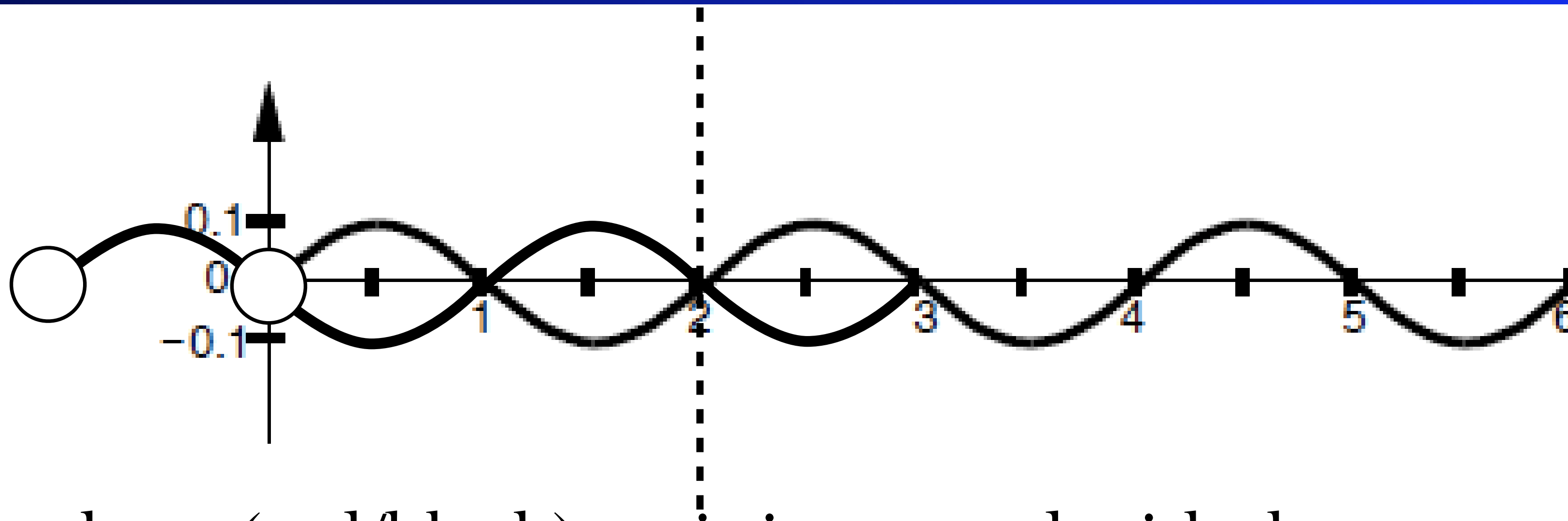


two speakers (red/black) emitting sound with the same frequency and in phase with each other

as the waves travel, the two always add to make a larger wave:
constructive interference

$$\Delta r = \lambda, 2\lambda, \ldots$$

What happens if...



two speakers (red/black) emitting sound with the same frequency and in phase with each other

as the waves travel, the two always subtract to make a smaller wave:
destructive interference

$$\Delta r = \frac{1}{2}\lambda, \frac{3}{2}\lambda, \ldots$$

Constructive/Destructive Interference

Constructive Interference

$$\Delta r = \lambda, 2\lambda, \ldots$$

Destructive interference

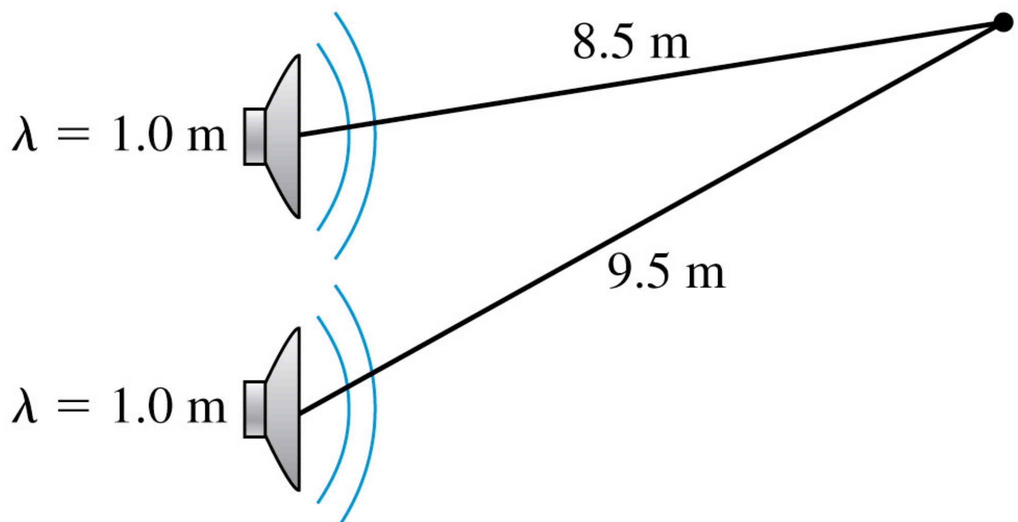
$$\Delta r = \frac{1}{2}\lambda, \frac{3}{2}\lambda, \ldots$$

Δr: the difference in the distance from location to each source of waves

Wave Interference: Example

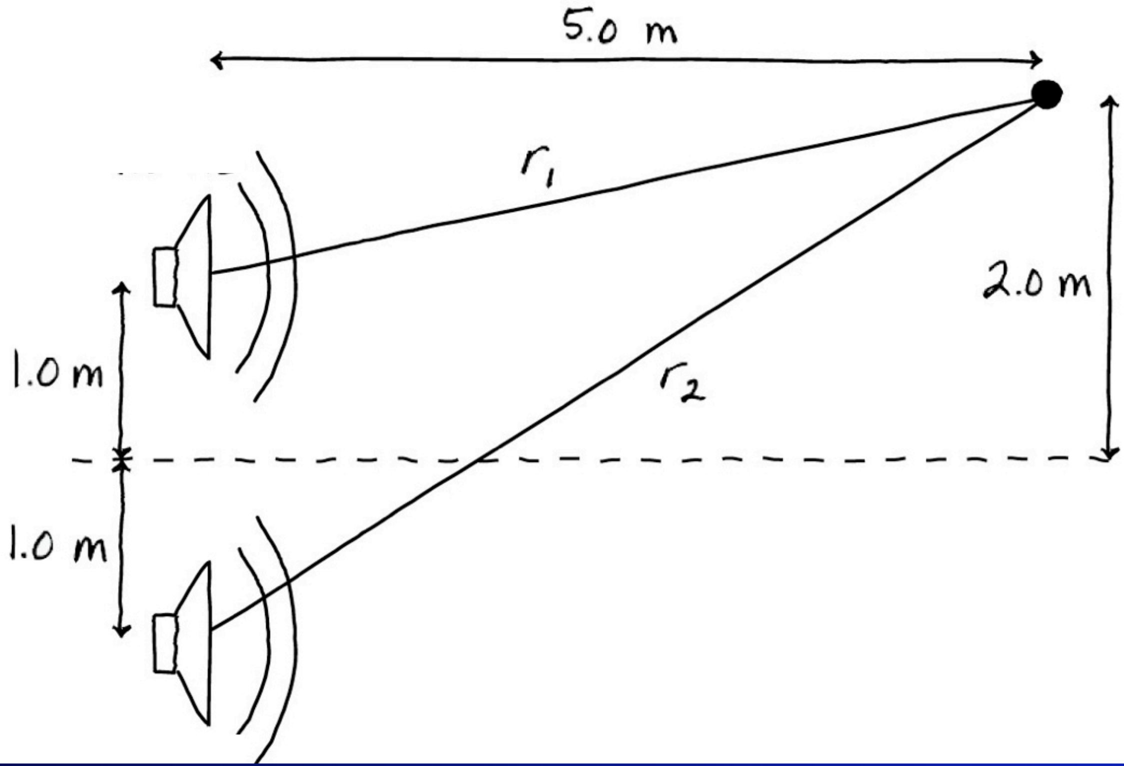
Two speakers emit sound waves in phase with each other with wavelength 1.0 m. The distance from a given location to each speaker is shown. A listener at the location shown will experience:

A. constructive interference
B. destructive interference
C. something in between the two
D. huh?



example of wave interference

You move about and notice that when you stand at the location shown, there is a minimum in the intensity of sound. What is the longest wavelength for which this could occur? the second longest? (Hint: calculate Δr)



example: standing wave frequency

We have a string instrument and we pluck a string, which is fixed at both ends. Which of the following actions would create a higher pitch (and therefore a higher frequency)?

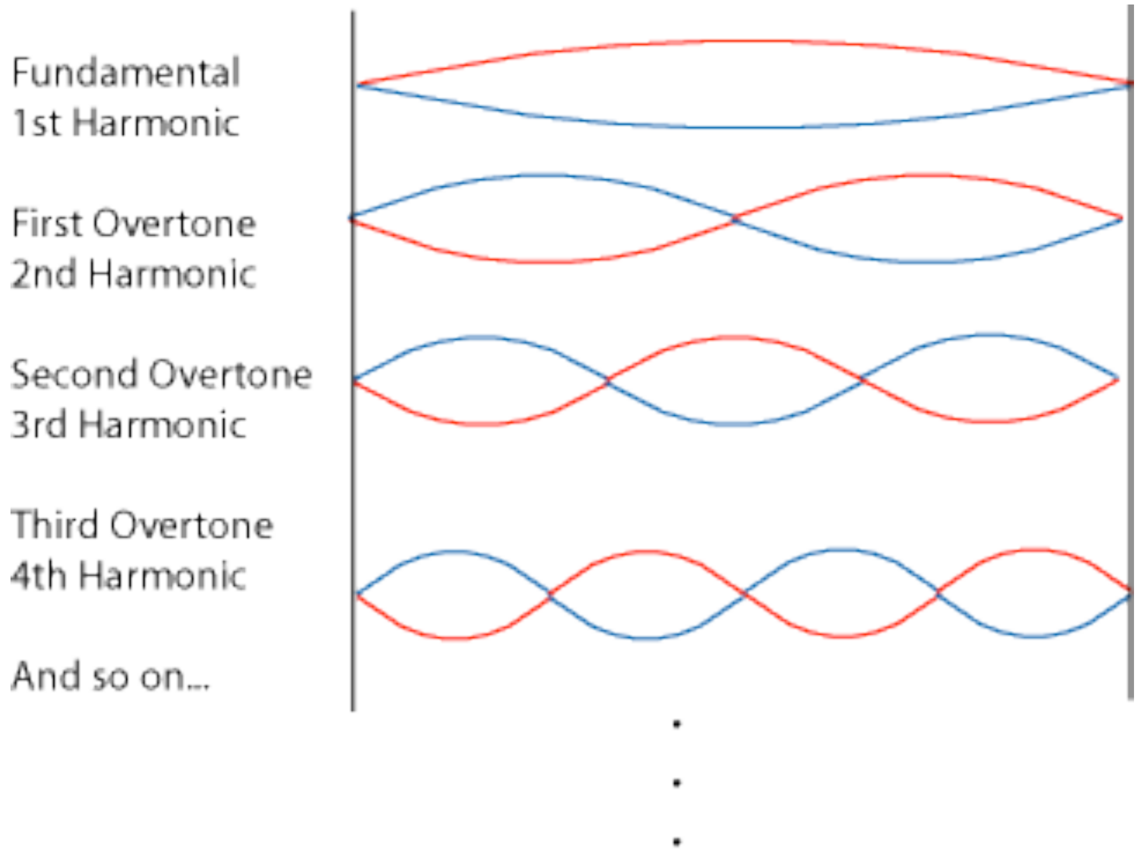
I. Increase the tension in the string
II. Shorten the string

A. I only
B. II only
C. I and II
D. neither of these
E. not sure

$$f = \frac{v}{(2L/n)}$$

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

Waves under Boundary Conditions: Harmonics



$$\lambda_1 = 2L$$

$$\lambda_2 = L$$

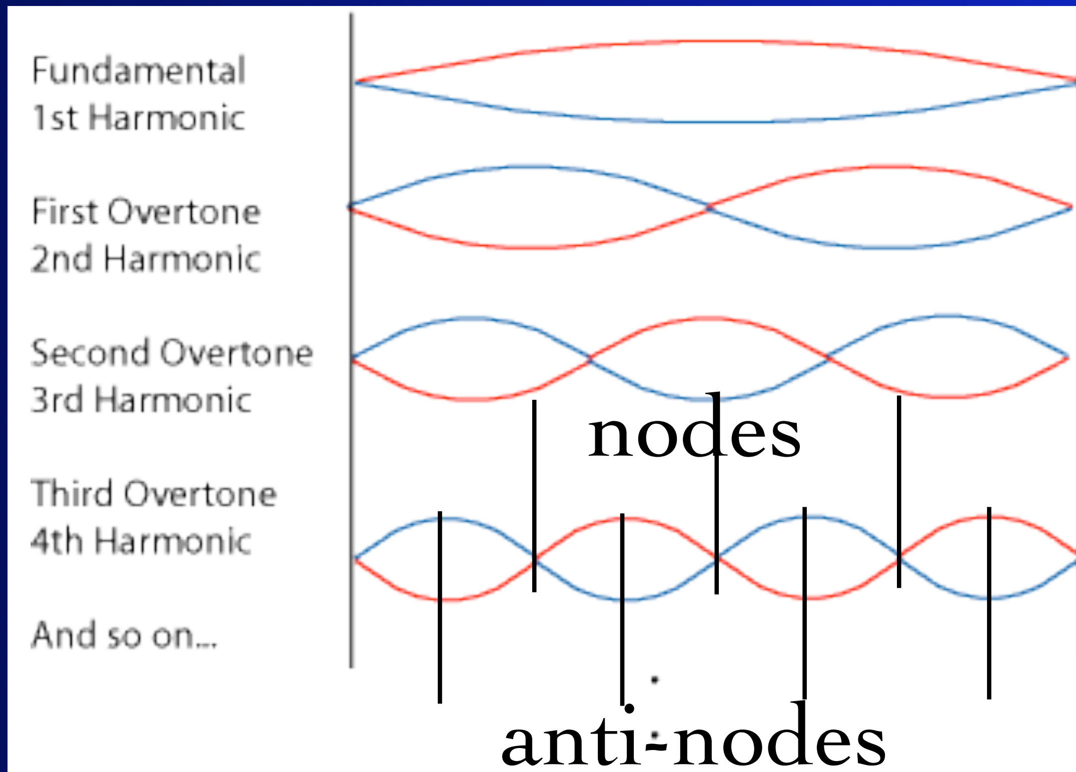
$$\lambda_3 = \frac{2L}{3}$$

$$\lambda_4 = \frac{L}{2}$$

$$\lambda_n = \frac{2L}{n}$$

- **fundamental frequency** f_1 is frequency of first harmonic, and $f_n = n\, f_1$

Nodes & Anti-nodes



$$\lambda_1 = 2L$$

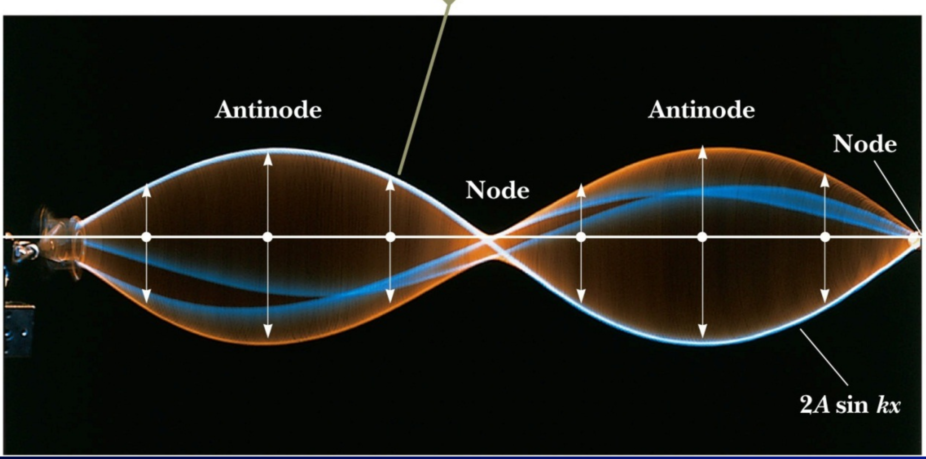
$$\lambda_2 = L$$

$$\lambda_3 = \frac{2L}{3}$$

$$\lambda_4 = \frac{L}{2}$$

$$\lambda_n = \frac{2L}{n}$$

The amplitude of the vertical oscillation of any element of the string depends on the horizontal position of the element. Each element vibrates within the confines of the envelope function $2A \sin kx$.



Example: C note on a piano

- The middle C string on a piano has a fundamental frequency of 262 Hz. Calculate the frequencies of the next two harmonics of the string:

$$f_2 = 2f_1 = 524 \text{ Hz}$$

$$f_3 = 3f_1 = 786 \text{ Hz}$$

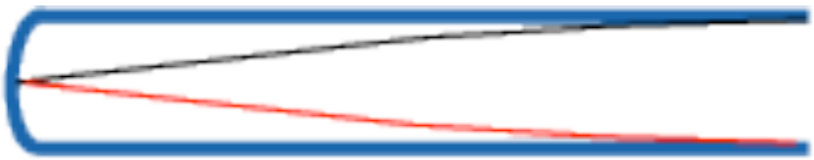
- The string for the first A above the middle C has a fundamental frequency of 440 Hz. If both strings have the same linear mass density μ and length *L*, what's the ratio of tensions in the two strings?

$$f_1 = \frac{1}{2L}\sqrt{\frac{T}{\mu}}$$

$$\frac{f_{1\text{A}}}{f_{1\text{C}}} = \sqrt{\frac{T_\text{A}}{T_\text{C}}} \quad \rightarrow \quad \frac{T_\text{A}}{T_\text{C}} = \left(\frac{f_{1\text{A}}}{f_{1\text{C}}}\right)^2 = \left(\frac{440}{262}\right)^2 = 2.82$$

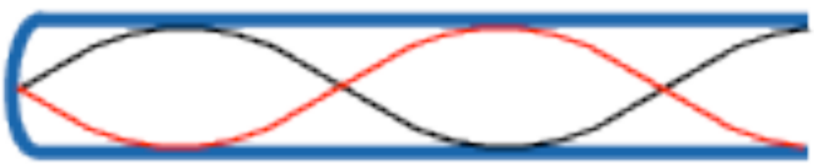
Standing Waves in an Air Column

- nodes at closed ends, anti-nodes at open ends



$$\lambda_1 = 4L$$

$$\lambda_3 = \frac{4L}{3}$$



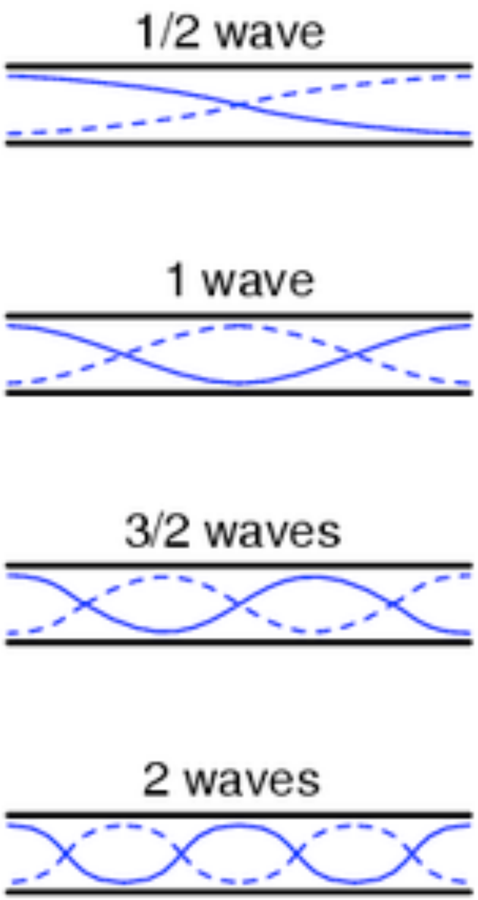
$$\lambda_3 = \frac{4L}{5}$$

$$\lambda_n = \frac{4L}{n} \quad n = 1, 3, 5, \ldots$$

$$f_n = n\frac{v}{4L} \quad n = 1, 3, 5, \ldots$$

Standing Waves in an Air Column

- nodes at closed ends, anti-nodes at open ends



$$\lambda_1 = 2L$$

$$\lambda_2 = L$$

$$\lambda_3 = \frac{2L}{3}$$

$$\lambda_n = \frac{2L}{n} \quad n = 1, 2, 3, \ldots$$

$$f_n = n\, v / (2L)$$

example: wind in a culvert

A section of drainage culvert 1.23m in length makes a howling noise when the wind blows through its open ends. ("culvert" is a fancy name for "tunnel.")

- What is the frequency of the first (fundamental) harmonic if the culvert is cylindrical and open at both ends? Take v=343 m/s as the speed of sound in air.

a) 69.7 Hz

b) 139.4 Hz

c) 209.1 Hz

d) need to know the sound's wavelength

recall that:

if open at both ends, then $f_n = n\ v/(2L)$

if open at one end, then $f_n = n\ v/(4L)$

example: wind in a culvert

A section of drainage culvert 1.23m in length makes a howling noise when the wind blows across its open ends.

- What is the frequency of the first (fundamental) harmonic if the culvert is cylindrical and open at both ends? Take v=343 m/s as the speed of sound in air.

$$f_1 = \frac{v}{2L} = \frac{343\ \mathrm{m/s}}{2(1.23\ \mathrm{m})} = 139\ \mathrm{Hz}$$

$$f_2 = 2f_1 = 279\ \mathrm{Hz}$$

$$f_3 = 3f_1 = 418\ \mathrm{Hz}$$

example: wind in a culvert

A section of drainage culvert 1.23m in length makes a howling noise when the wind blows across its open ends.

- Now if the culvert were blocked at one end, what are the three lowest natural frequencies?

$$f_1 = \frac{v}{4L} = \frac{343\ \mathrm{m/s}}{4(1.23\ \mathrm{m})} = 69.7\ \mathrm{Hz}$$

$$f_3 = 3f_1 = 209\ \mathrm{Hz}$$

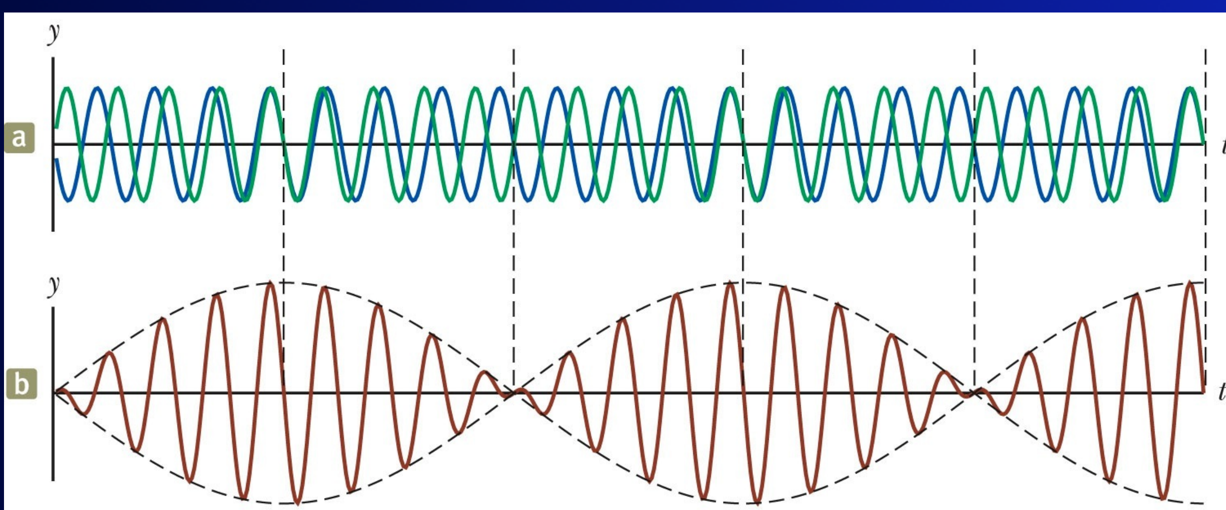
$$f_5 = 5f_1 = 349\ \mathrm{Hz}$$

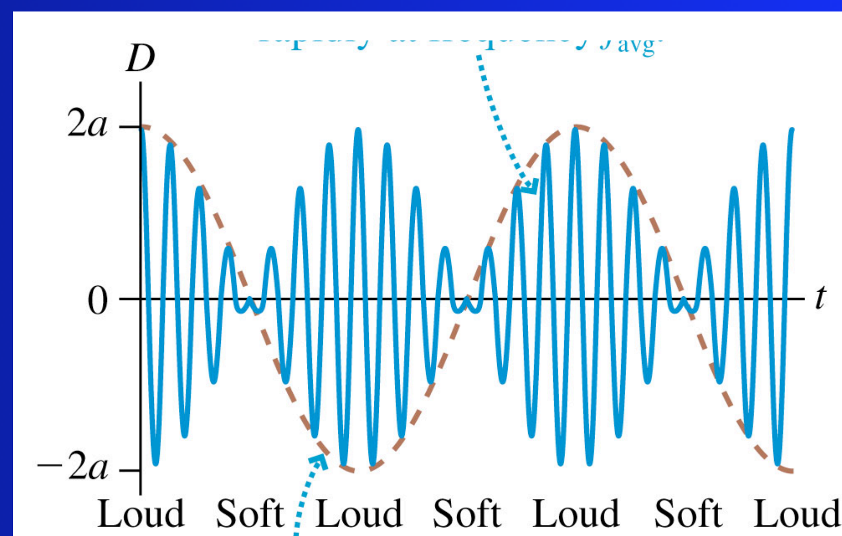
Beats: Interference in Time

beats are due to sound waves with slightly different frequencies

beat frequency: number of amplitude maxima one hears per second:

$$f_b = |f_1 - f_2|$$



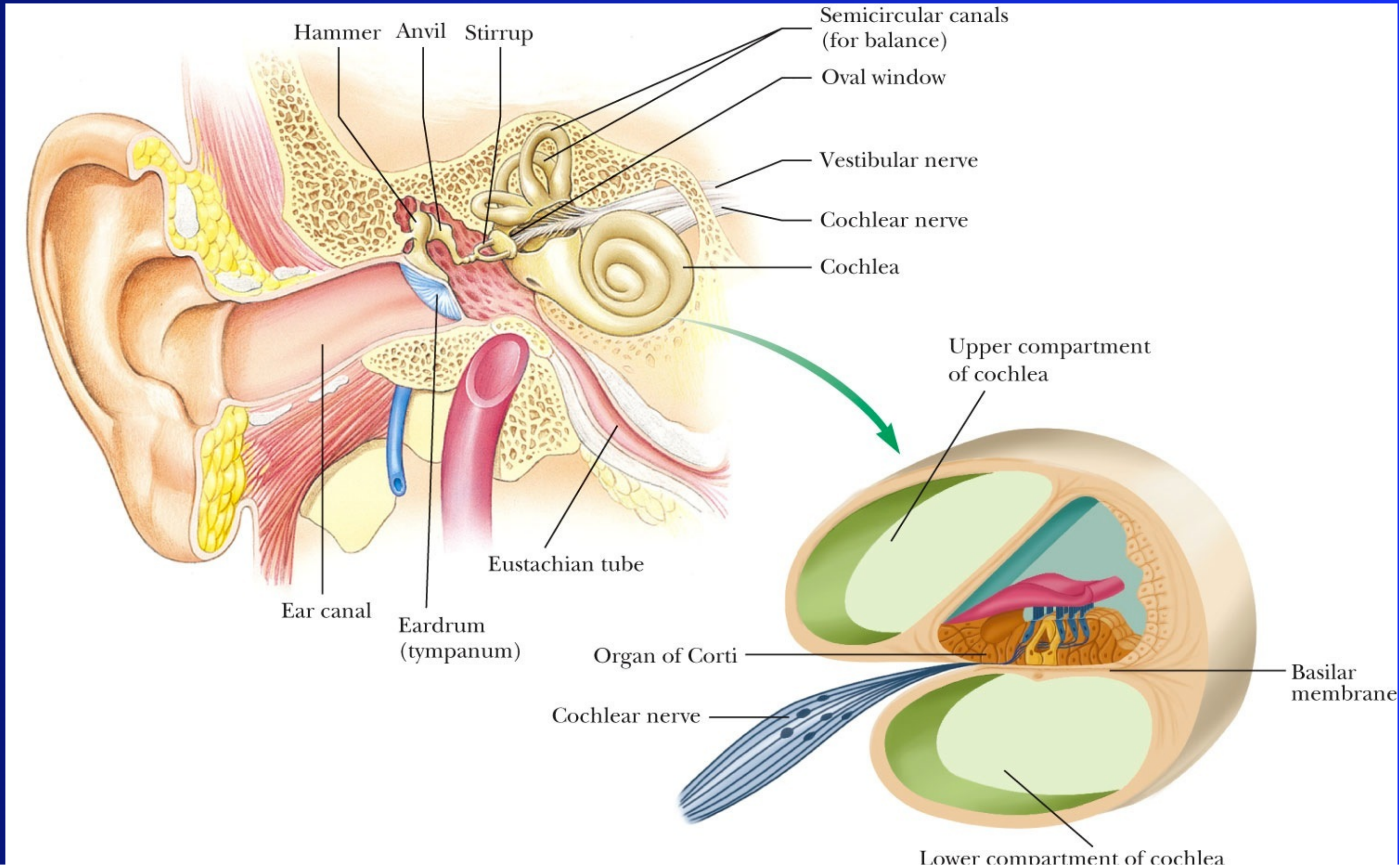


The Ear & Theories of Pitch Perception

The outer ear consists of ear canal (open to the air), which ends at the eardrum.

Sound waves travel down to the eardrum, which vibrates in response to alternating high & low pressures of the waves

Different parts of basilar membrane inside the ear resonate at different frequencies

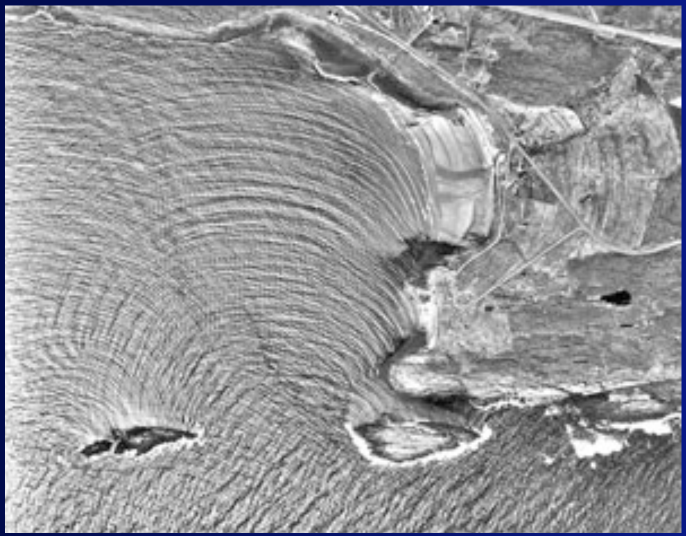


Wave Optics: introduction

- light is an *electromagnetic wave* created by vibration of electric charges
- *wave optics* describe phenomena not explained by geometric (ray) optics
- light experiences constructive & destructive interference
- light also experiences *diffraction*, where waves spread out as they pass through an opening

Diffraction

- waves can bend around obstacles
- waves spread out when traveling through small openings or slits
- small obstacles/openings → lots of diffraction; large obstacles/openings → less diffraction (but depends on wavelength λ)



Diffraction

Why do we more easily notice diffraction in sound waves than in light waves?

- sound wavelengths often ~centimeters, but visible light wavelengths in nanometers (nm, or 10^{-9} m)
- diffraction occurs when obstacle size is approx same size or smaller than wavelength
- next time: we'll talk about Young's famous double-slit experiment

For Monday:

1. finish reading chapter 14 and start chapter 27…we’ll continue with *interference* of *electromagnetic waves*

2. make sure you understand the chapter 14 concepts and HW problems, as they’ll be important for next Friday’s quiz and for the physics concepts we’ll explore in upcoming weeks

3. have a good weekend!

4. please come to office hours on Monday if you have questions or feedback about the class