Reminders

- Homework this week is extra credit
- There **IS** lab this week (Lab B)
- Final Exam: Friday, May 13, 10:15am-12:15pm **CR 306**
- Sample equation sheet available

Ch 16.4-6: Resonance & Interference

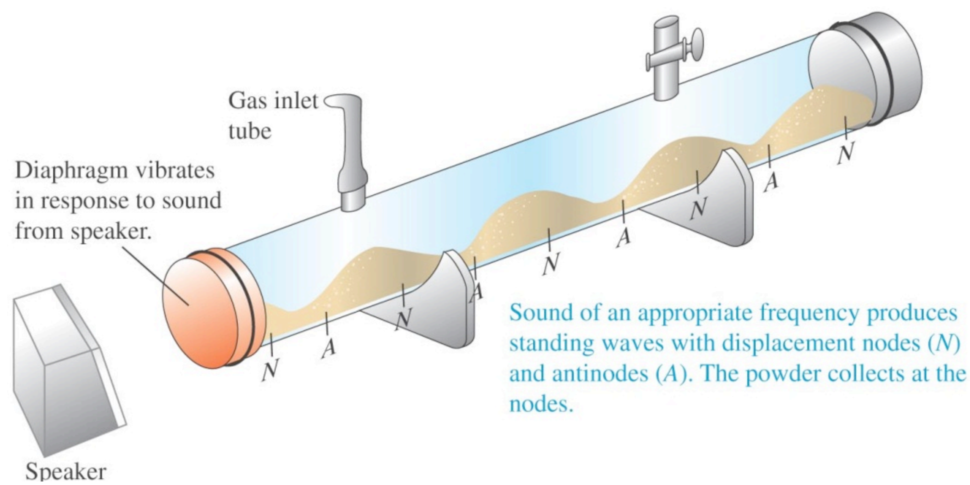
PHYS 1210 -- Prof. Jang-Condell

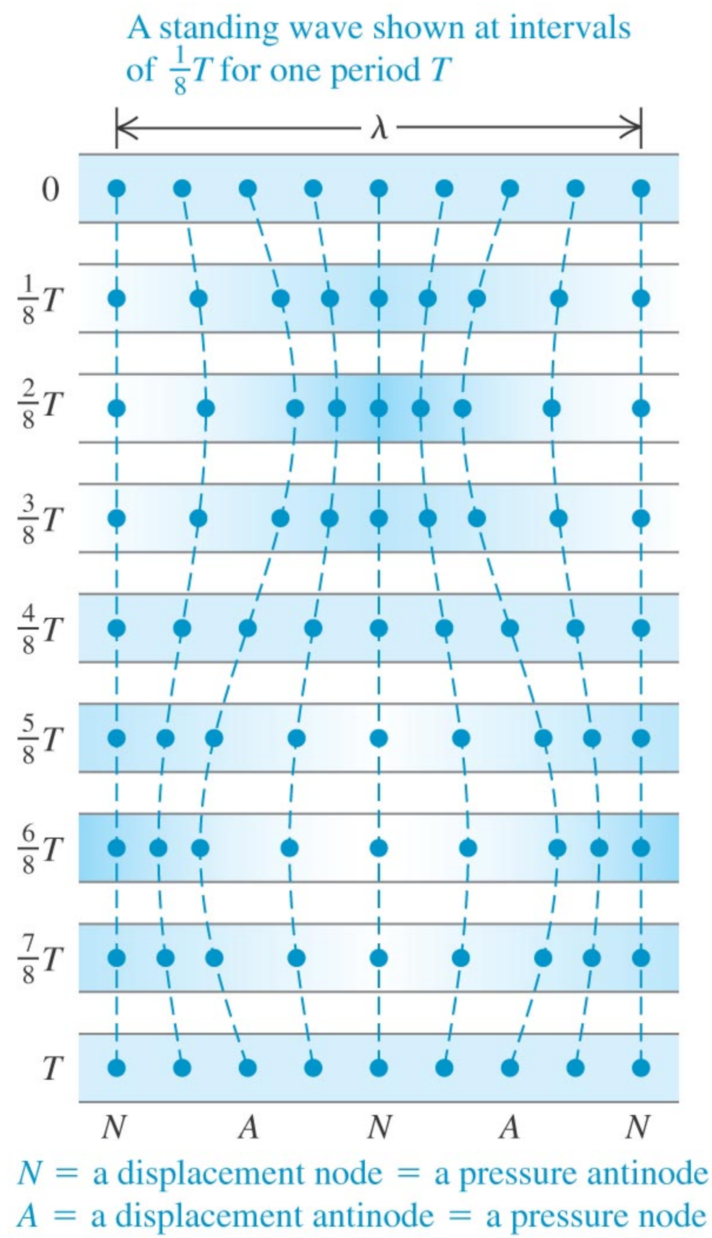
Goals for Chapter 16

- To describe sound waves in terms of particle displacements or pressure variations
- To calculate the speed of sound in different materials
- To calculate sound intensity
- To find what determines the frequencies of sound from a pipe
- To study resonance in musical instruments
- To see what happens when sound waves overlap
- To investigate the interference of sound waves of slightly different frequencies
- To learn why motion affects pitch

Standing sound waves and normal modes

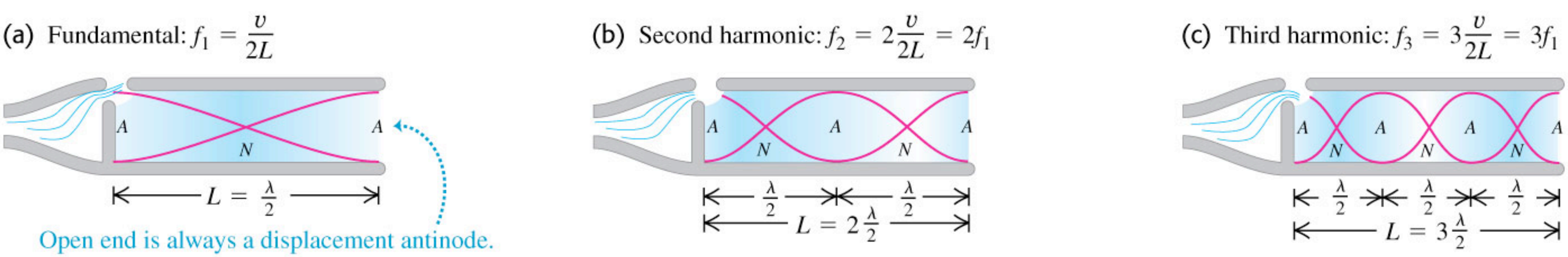
- The bottom figure shows displacement nodes and antinodes.
- A pressure node is always a displacement antinode, and a pressure antinode is always a displacement node, as shown in the figure at the right.





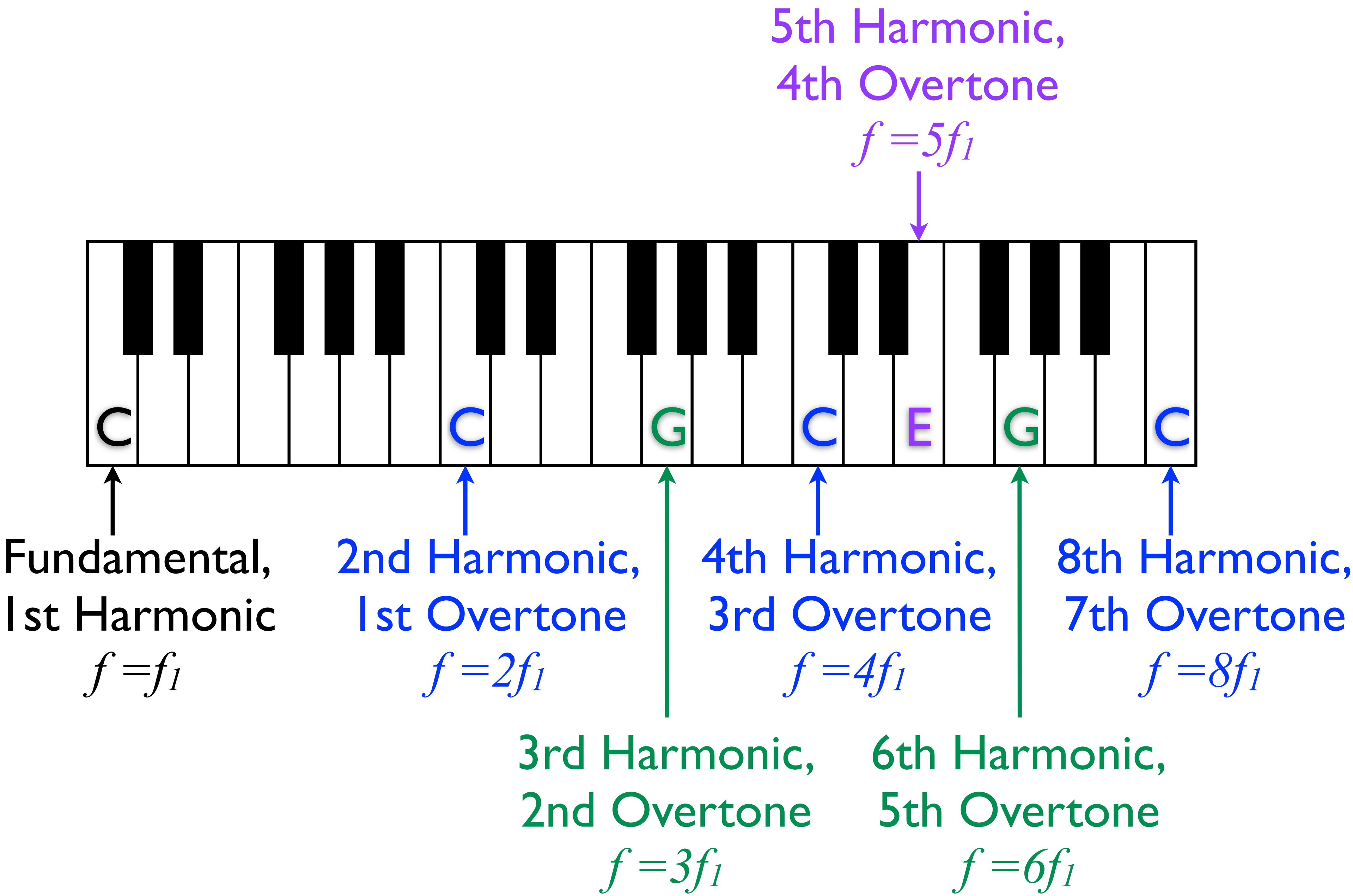
Harmonics in an open pipe

- An *open pipe* is open at both ends.
  – Examples: flute, recorder, organ pipe
- For an open pipe $\lambda_n = 2L/n$ and $f_n = nv/2L$ $(n = 1, 2, 3, \ldots)$.
- Figure 16.17 below shows some harmonics in an open pipe.



Pitch and Harmonics

- 1st harmonic = fundamental = root
- 2nd harmonic = 1 octave up
- 3rd harmonic = 1 octave up + 5th
- 4th harmonic = 2 octaves up
- 5th harmonic = 2 octaves up + major 3rd
- 6th harmonic = 2 octaves up + major 5th
- 7th harmonic
- 8th harmonic = 3 octaves up


5th Harmonic,
4th Overtone
$f = 5f_1$
C
C
G
C
E
G
C
Fundamental,
1st Harmonic
$f = f_1$
2nd Harmonic,
1st Overtone
$f = 2f_1$
4th Harmonic,
3rd Overtone
$f = 4f_1$
8th Harmonic,
7th Overtone
$f = 8f_1$
3rd Harmonic,
2nd Overtone
$f = 3f_1$
6th Harmonic,
5th Overtone
$f = 6f_1$

Equal-tempered scale

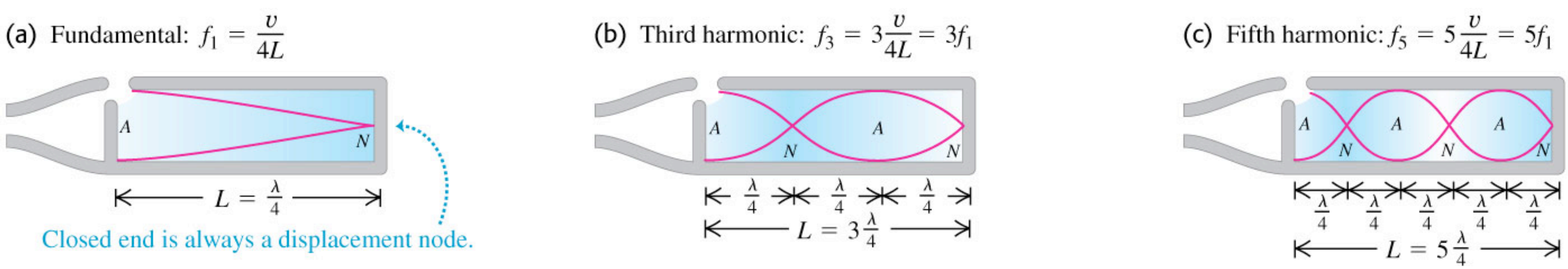
- If two notes f_1 and f_2 are a half step apart, then the ratio of the frequencies is

$$f_2/f_1 = 2^{1/12}$$

- Concert A (A_4) is 440 Hz.
  - 3rd harmonic =1320 Hz, E_5 is 1319 Hz.
  - 5th harmonic = 2200 Hz, C#$_7$ is 2217 Hz

Harmonics in a closed pipe

- A *closed pipe* is open at one end and closed at the other end.
  - Examples: clarinet, reed instruments
- For a closed pipe $\lambda_n = 4L/n$ and $f_n = nv/4L$ $(n = 1, 3, 5, \ldots)$.
- Figure 16.18 below shows some harmonics in a closed pipe.



Q16.4

The air in an organ pipe is replaced by helium, which has a ***higher sound speed*** than air at the same temperature. How does this affect the normal-mode ***wavelengths*** of the pipe?

A. The normal-mode wavelengths are unaffected.

B. The normal-mode wavelengths increase.

C. The normal-mode wavelengths decrease.

D. The answer depends on whether the pipe is open or closed.

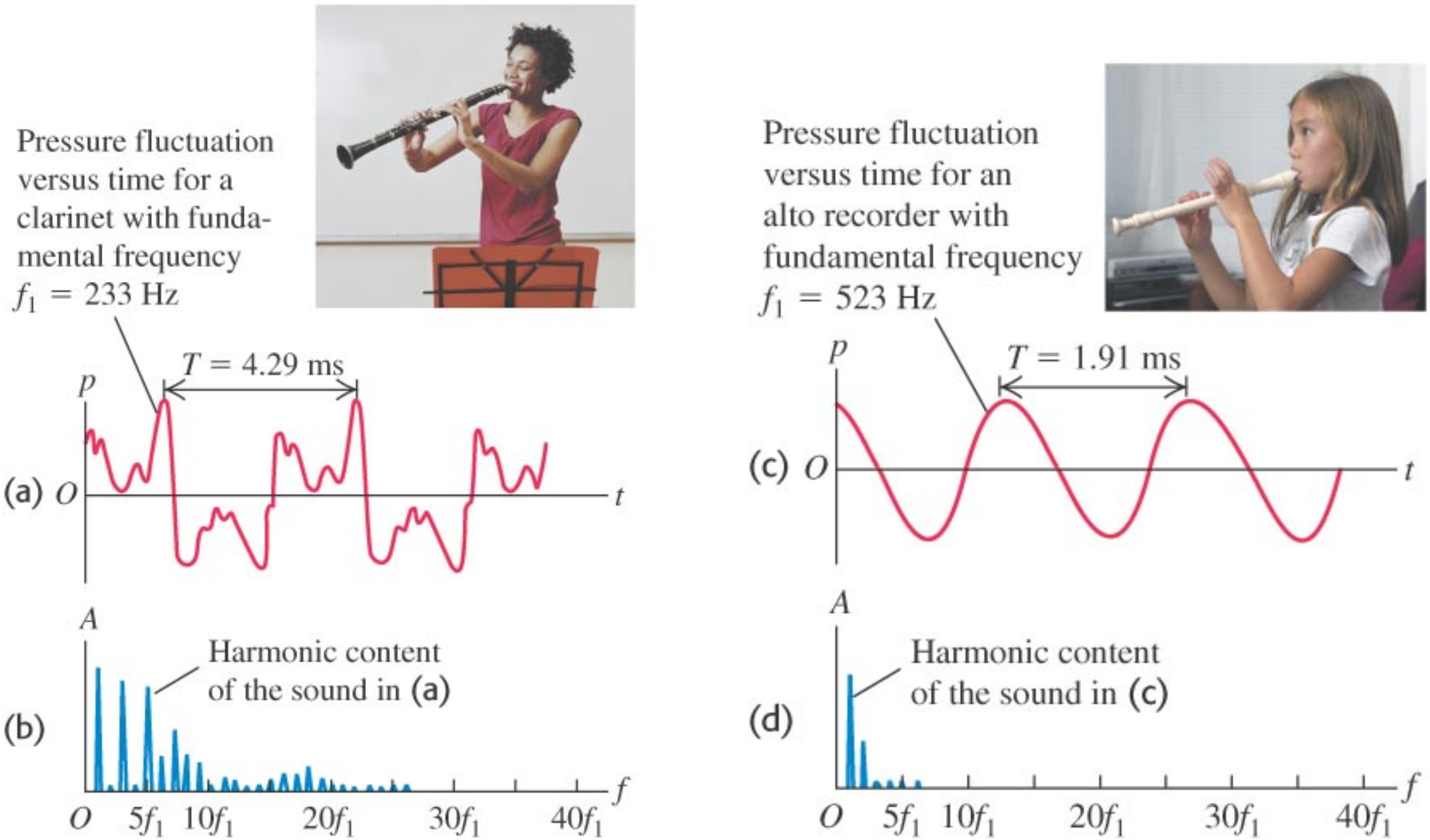
Normal Modes Demo

Resonance

- Objects have characteristic frequencies at which standing waves are sustained
- Lowest frequency = **fundamental**
- Higher frequencies = **overtones**
- Sustained motion is a combination of normal modes: *harmonic content*

Perception of sound waves

- The *harmonic content* greatly affects our perception of sound.



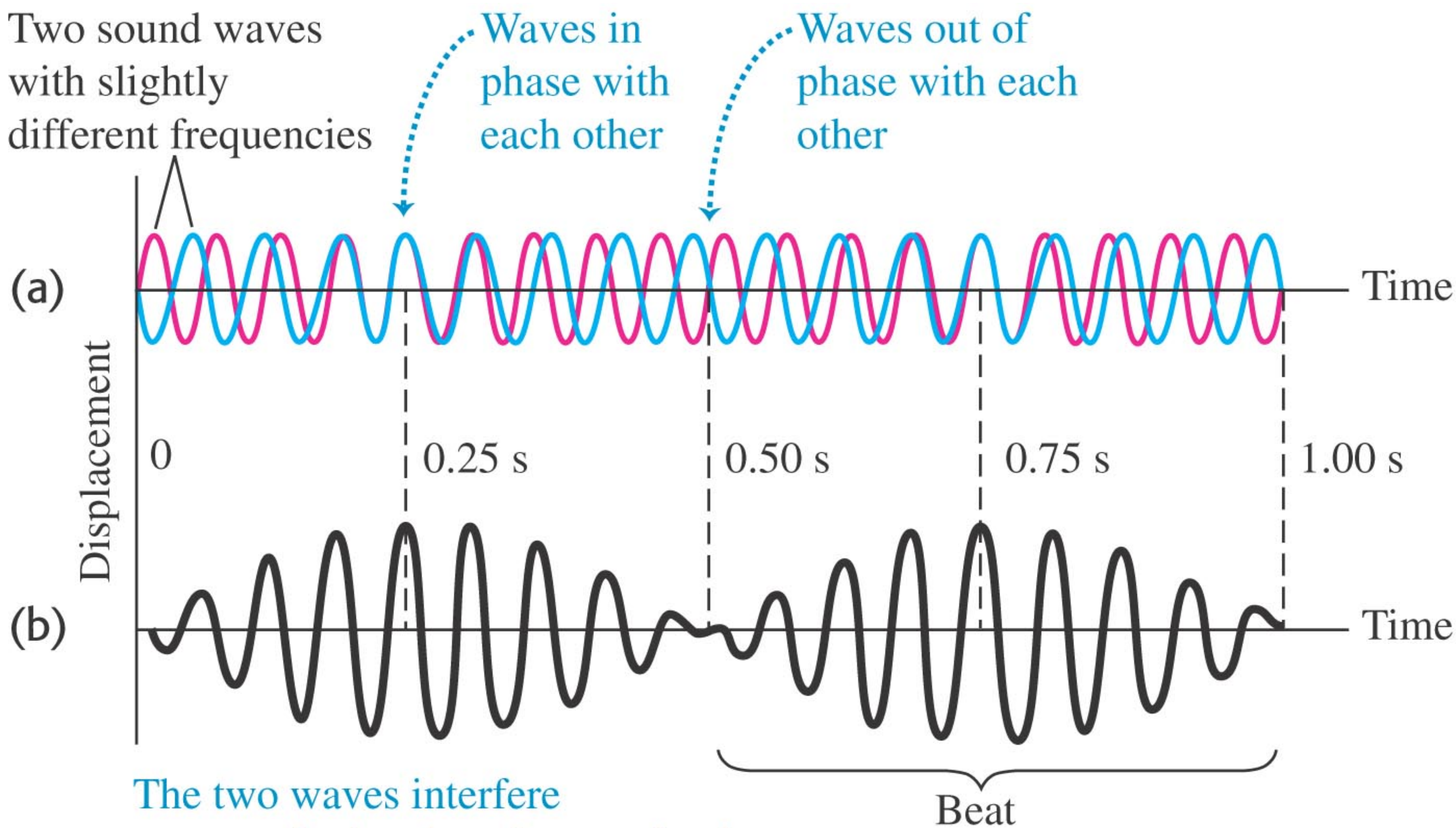
Resonance

- 1-D (strings, tubes) can be solved analytically (tube demo)
- 2-D or 3-D: more complicated

Interference

Interference in 1D

- Standing waves
- Beats (demo)



The two waves interfere constructively when they are in phase and destructively when they are a half-cycle out of phase. The resultant wave rises and falls in intensity, forming beats.

Beats

- Interference at similar frequencies

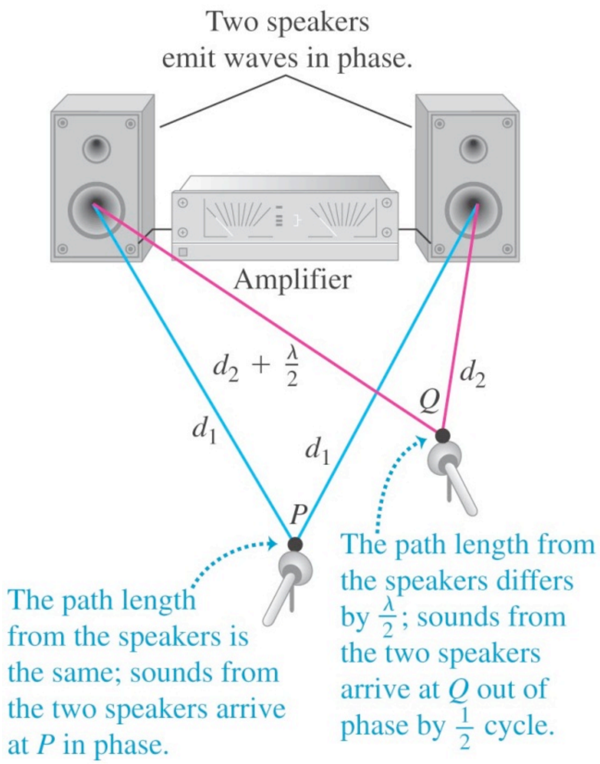
$$\cos(\omega_1 t) + \cos(\omega_2 t) =$$

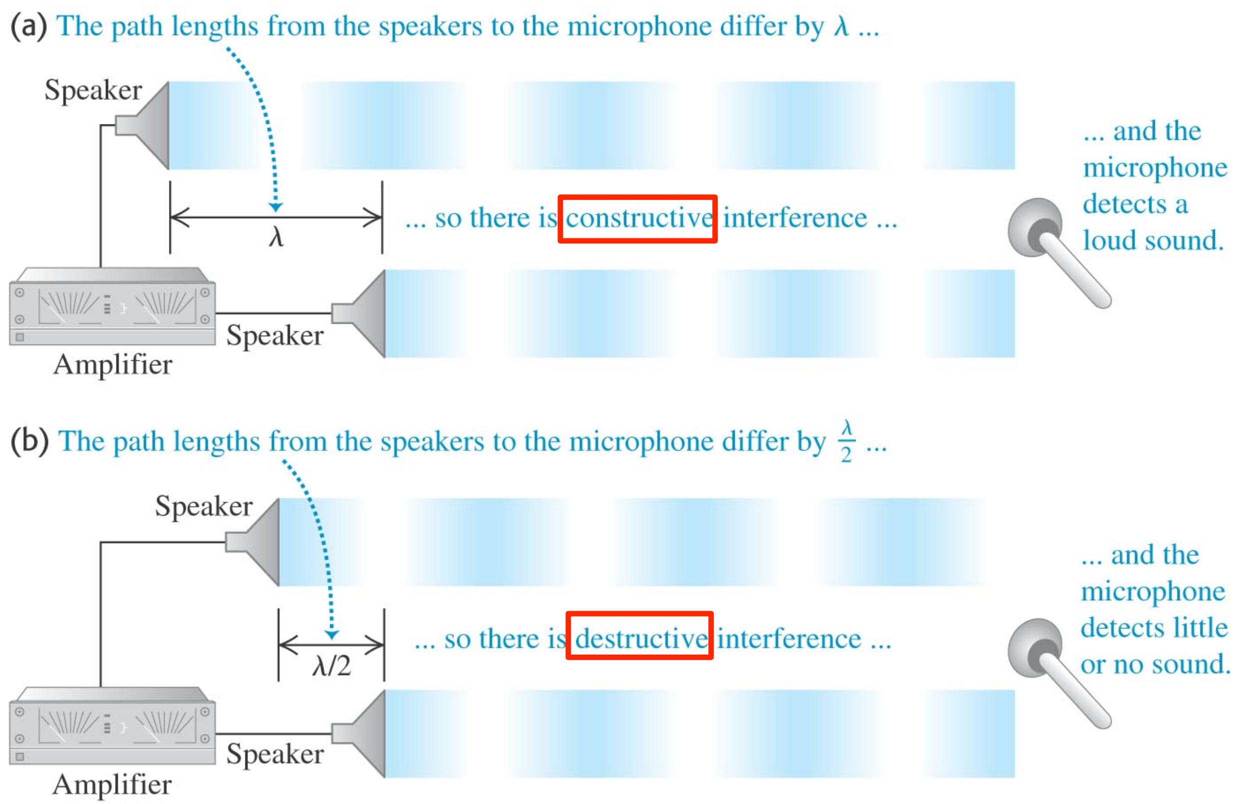
$$2\cos\left[\frac{(\omega_1+\omega_2)t}{2}\right]\cos\left[\frac{(\omega_1-\omega_2)t}{2}\right]$$

- Oscillation frequency: average of f_1 and f_2
- **Beat** frequency: difference between f_1 and f_2

Interference

- The difference in the lengths of the paths traveled by the sound determines whether the sound from two sources interferes **constructively** or **destructively**, as shown in the figures below.





Interference in 2D