**Lecture 27 Announcements**

1. Thursday lecture: Final exam review
2. Additional TA-led final exam review:
   a. Time/day still TBA
3. Final exam
   a. Take in testing center anytime during finals week
4. Deadlines:
   a. All extra credit must be turned in by midnight Thurs Dec 11 (last day of classes)
   b. Instructor/course ratings must be done by Sat Dec 13
   c. All late homework must be turned in by midnight Fri Dec 19 (last day of finals)

**Interference of waves**

"Superposition": waves interfere by adding together

Demo: “Moire pattern” Transparencies

**Path length**

Path-length dependence

*Constructive* interference:

*Destructive* interference

**Worked Problem:** Two speakers are on a line (not stereo). Both emit the same sound waves (\(v=343\) m/s) at 500 Hz.

What is the wavelength?

How far back should one speaker be placed (\(\Delta x\)) to get a *minimum* where the boy is standing?

How far back should one speaker be placed (\(\Delta x\)) to get a *maximum* where the boy is standing?

Answers: 0.686 m, 0.343 m (or 1.029 m, 1.715 m, ...), 0.686 m (or 1.372 m, 2.058 m, ...)

In this configuration, suppose you vary the frequency of the sound from the speakers (from the same amplifier), not the distances:

What \(\lambda\)’s will give a maximum in the sound?

Answers: 4.944 m, 2.472 m, 1.648 m, ...

For a fixed position, many frequencies will work; for a fixed frequency, many positions will work.

Demo: two speaker interference

Ripple Tank image: wikipedia
Standing waves:
- Combination of forward- and backwards-moving waves
  Web demo: http://www.colorado.edu/physics/phet/simulations/stringwave/stringWave.swf
- Boundary conditions determine allowed vibration frequencies

Standing waves on “strings”
Demos: ¼ inch tubing, ladies belt

Harmonics
- L = _____
- L = _____
- L = _____

Resonance condition:
“Integer number of _______ fit into L.”
\[ \lambda_n = _____ \]
\[ f_n = _____ \]
\[ n = 1, 2, 3, ... \]

Open-open pipes
Pressure patterns:

Resonance condition:
“Integer number of _______ fit into L.”
\[ \lambda_n = _____ \]
\[ f_n = _____ \]
\[ n = 1, 2, 3, ... \]

Open-closed pipes
Pressure patterns:

“Odd integer number of _______ fit into L.”
\[ \lambda_n = _____ \]
\[ f_n = _____ \]
\[ n = 1, 3, 5, ... \]

How does “fundamental” \( f_1 \) here compare to open-open case?
Demo: open-closed pipe

Resonance
Swings and springs

Videos:
- Bowling ball pendulum
- Goblet shattering
- Tacoma Narrows bridge

Demo:
- Tuning fork sympathetic vibrations
- Trumpet, again
- Chladni plates
Web images: http://www.physics.utoronto.ca/nonlinear/chladni.html (including violin shape)
Clicker quiz: Which of these pressure patterns could correspond to a closed-open pipe?

- a
- b
- c

Clicker quiz: You change the frequency that you excite a pipe, and find some resonant frequencies at 600, 840, and 1080 Hz. (Others resonant frequencies exist, also.) What is the largest frequency possible for the fundamental? _____ Hz

- a. 60
- b. 120
- c. 200
- d. 300
- e. 600

Clicker quiz: Is this an open-open pipe, or a closed-open pipe?

- a. open-open
- b. closed-open
- c. could be either

Tone quality: why do various instruments (and voices) sound different for the same pitch?

Answer: real sounds are not usually pure sine waves

Chords in music

Consonant chords: simple frequency ratios… harmonics of each note overlap well.

Dissonant chords: not many harmonics match!

<table>
<thead>
<tr>
<th>Chord</th>
<th>Freq. Ratios</th>
</tr>
</thead>
<tbody>
<tr>
<td>Octave (C-C)</td>
<td>2:1</td>
</tr>
<tr>
<td>Major triad (C-E-G)</td>
<td>4:5:6</td>
</tr>
<tr>
<td>Minor triad (C-Eflat-G)</td>
<td>10:12:15</td>
</tr>
<tr>
<td>Diminished triad (C-Eflat-Gflat)</td>
<td>160:192:231 (approx. 20:24:29)</td>
</tr>
<tr>
<td>Major 7th (C-E-G-B)</td>
<td>8:10:12:15</td>
</tr>
<tr>
<td>Minor 7th (C-E-G-Bflat)</td>
<td>20:25:30:36</td>
</tr>
</tbody>
</table>

Aside: why are there 12 chromatic tones in a scale?

→ Because it’s the smallest number of tones that can give you close to the right ratios needed for consonant chords

freq of C# = 1.05946 × freq of C
freq of D = (1.05946)² × freq of C
freq of D# = (1.05946)³ × freq of C

... 

freq of F = (1.05946)⁵ × freq of C = 1.3348 × freq of C = 4/3 × freq of C
freq of G = (1.05946)⁶ × freq of C = 1.498 × freq of C = 3/2 × freq of C
freq of high C = (1.05946)¹² × freq of C = 2.000 × freq of C

Reference: [http://web.telia.com/~u57011259/Bellspectra.htm](http://web.telia.com/~u57011259/Bellspectra.htm)
Beats

Web demo: http://stokes.byu.edu/beats_script_flash.html

Demo: Tuning fork beats

\[ f(t) = \sin(30t) + \sin(31t) \]

\[ \text{Out[3]} = \sin(30t) + \sin(31t) \]

\[ \text{Out[4]} = \text{Plot\{f[t], \{t, 0, 15\}\}} \]

“beat period”

“beat frequency”: \( f_{\text{beat}} = |f_1 - f_2| \)

…and that’s all, folks!!