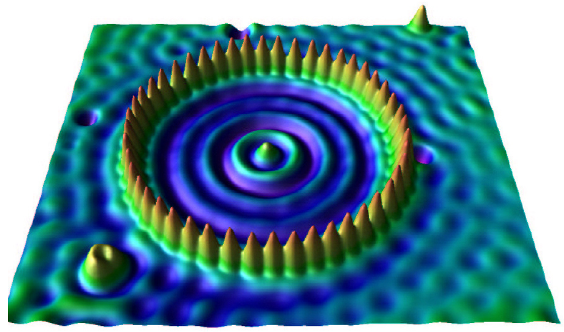
Lecture 27 Announcements

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 http://studentratings.byu.edu
   c. All late homework must be turned in by midnight Fri Dec 19 (last day of finals)

Interference of waves



Electron waves on a copper surface with iron atoms added, viewed by scanning tunneling microscope.

"Superposition": waves interfere by adding together

Demo: "Moire pattern" Transparencies

Path length

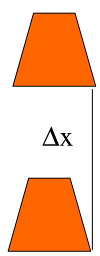
Path-length dependence

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.

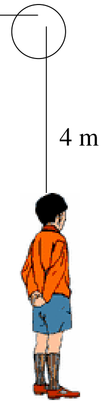
What is the wavelength?



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

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

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



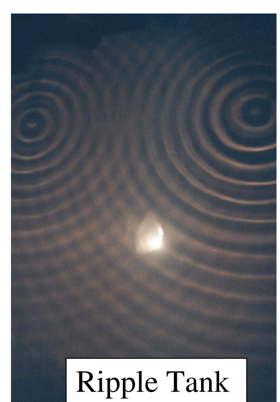
In this configuration, suppose you vary the *frequency* of the sound from the speakers (from the same amplifier), not the distances:

What λ'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

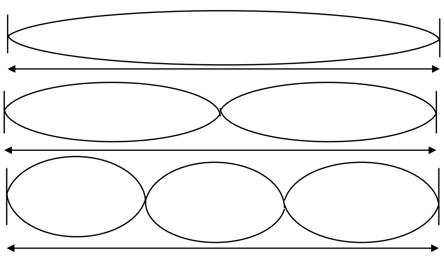
- *Boundary conditions* determine allowed vibration frequencies

Standing waves on "strings"

Demos: ¼ inch tubing, ladies belt

nodes vs. antinodes

Harmonics



L=_____

L =_____

L =_____

L

Resonance condition:
"Integer number of ________________ fit into L."

λ_n = _______

f_n = _______

n=1,2,3,... n = the ________________

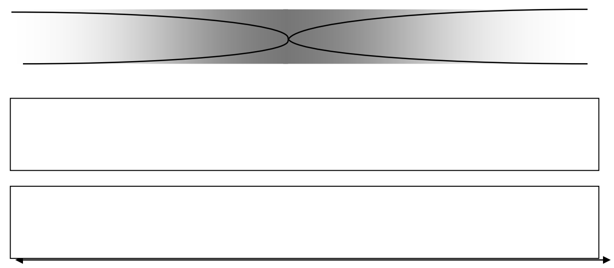
Standing waves in air

Demos: trumpet, organ pipe
Demo: gas lit tube

Open-open pipes

Pressure patterns:

Open end Open end



L=_____

L =_____

L =_____

L

Resonance condition:
"Integer number of ________________ fit into L."

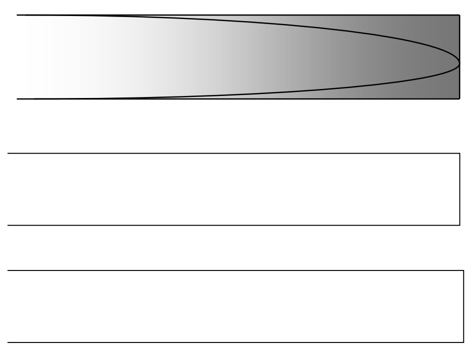
λ_n = _______

f_n = _______

n=1,2,3,...

Open-closed pipes

Pressure patterns:



L=_____

L =_____

L =_____

L

"Odd integer number of ________________ fit into L."

λ_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

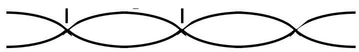
Demo: Tuning fork sympathetic vibrations

Demo: Trumpet, again

Demo: 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

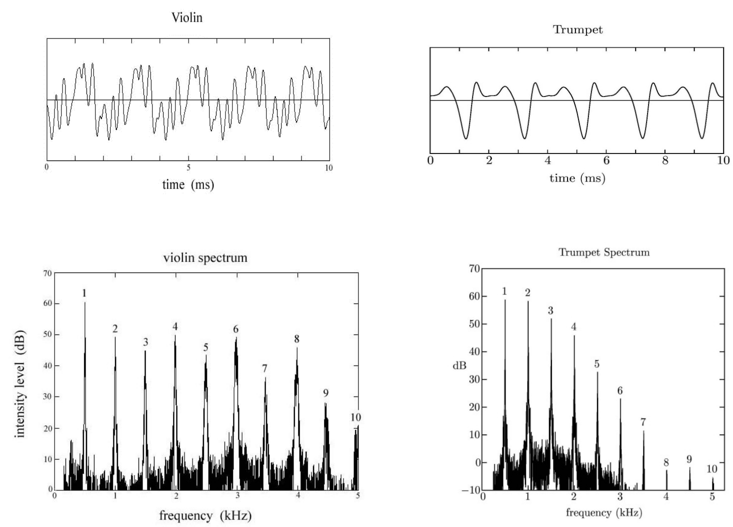
a. 60 b. 120 c. 200 d. 300 e. 600

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*

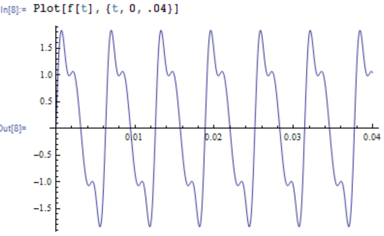


→ using a frequency "spectrum analyzer"

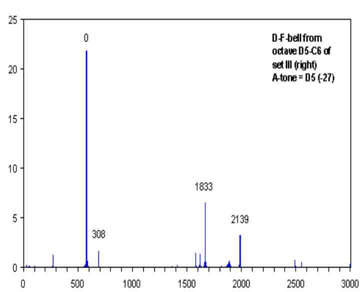
Sine waves add together "nicely" when they are multiples (harmonics) of the same frequency.

```
In[1]:= f[t_] = 1.5*Sin[1000 t] + 0.4*Sin[2000 t] +
          0.5 * Sin[3000 t] + 0.13 * Sin[4000 t]
Out[1]= 1.5 Sin[1000 t] + 0.4 Sin[2000 t] +
          0.5 Sin[3000 t] + 0.13 Sin[4000 t]
In[8]:= Plot[f[t], {t, 0, .04}]
```

Out[8]=

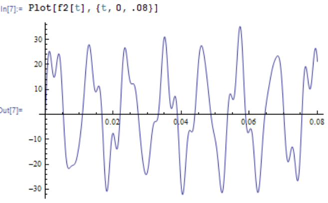


Sine waves add together "strangely" when their frequencies are not related




```
In[3]:= f2[t_] = 23*Sin[580 t] + 2*Sin[690 t] +
          7*Sin[1670 t] + 4*Sin[2000 t]
Out[3]= 23 Sin[580 t] + 2 Sin[690 t] + 7 Sin[1670 t] + 4 Sin[2000 t]
In[7]:= Plot[f2[t], {t, 0, .08}]
```

Out[7]=



Reference: http://web.telia.com/~u57011259/Bellspectra.htm

"Strange instruments" = tonal percussion: bells, xylophone, tympani, etc.

Chords in music

Consonant chords: simple frequency ratios… harmonics of each note overlap well.
Dissonant chords: not many harmonics match!

Chord	Freq. Ratios
Octave (C-C)	2:1
Major triad (C-E-G)	4:5:6
Minor triad (C-E_{flat}-G)	10:12:15
Diminished triad (C-E_{flat}-G_{flat})	160:192:231 (approx. 20:24:29)
Major 7^{th} (C-E-G-B)	8:10:12:15
Dominant 7^{th} (C-E_{flat}-G-B_{flat})	10:12:15:18
Minor 7^{th} (C-E-G-B_{flat})	20:25:30:36

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

$\sqrt[12]{2}$

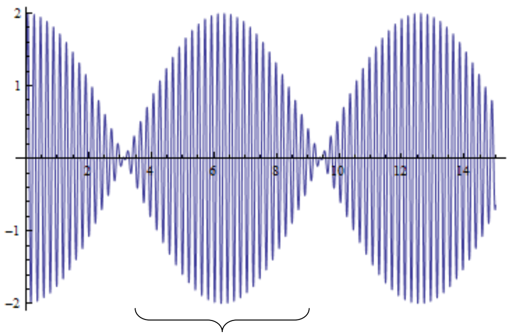
freq of C# = 1.05946 × freq of C
freq of D = $(1.05946)^2$ × freq of C
freq of D# = $(1.05946)^3$ × freq of C
…
freq of F = $(1.05946)^5$ × freq of C = 1.3348 freq of C ≈ 4/3 freq C
freq of G = $(1.05946)^7$ × freq of C = 1.498 freq of C ≈ 3/2 freq C
freq of high C = $(1.05946)^{12}$ × freq of C = 2.000 × freq C

Beats

Web demo: http://stokes.byu.edu/beats_script_flash.html
Demo: Tuning fork beats

```
In[3]:= f[t_] = Sin[30 t] + Sin[31 t]
Out[3]= Sin[30 t] + Sin[31 t]
In[8]:= Plot[f[t], {t, 0, 15}]
```

Out[8]=



"beat period"

"beat frequency": $f_{beat} = \lvert f_1 - f_2 \rvert$

…and that's all, folks!!