Musical instruments: strings and pipes

Physics 211
Syracuse University, Physics 211 Spring 2017
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Announcements

- Exam 3 corrections in recitation this week – opportunity to earn more points
- Extra credit homework posted, due next Friday
- HW9 posted, due next Tuesday
- Final exam prep schedule announced next class
- Office hours tonight as normal: 5:10-6:50 PM, in the Clinic

Standing waves, a reminder

- Only certain wavelengths can persist as standing waves in a "one-dimensional cavity"
- 1D cavity: waves on a string, sound waves in a pipe... things we make musical instruments out of!
- Waves are *linear* – multiple standing waves of different wavelengths can coexist

Sine waves

- We're particularly concerned with waves that look like sines and cosines
- These waves have two new properties: **wavelength** λ and **frequency** f
  - Wavelength: distance from crest to crest
  - Frequency: how many crests go by per second, equal to $1/T$ (T = period)

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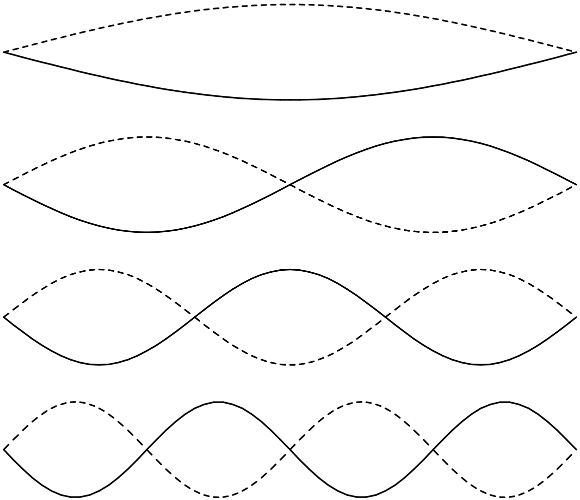
- What kind of sine and cosine waves can we put on our string?
- Not any wavelengths will do, since the ends have to be fixed

Standing waves, in more detail



Fundamental: $\lambda = \frac{2L}{1}$

2nd harmonic: $\lambda = \frac{2L}{2}$

3rd harmonic: $\lambda = \frac{2L}{3}$

4th harmonic: $\lambda = \frac{2L}{4}$

Can we write these wavelengths in terms of f using $c = f\lambda$?

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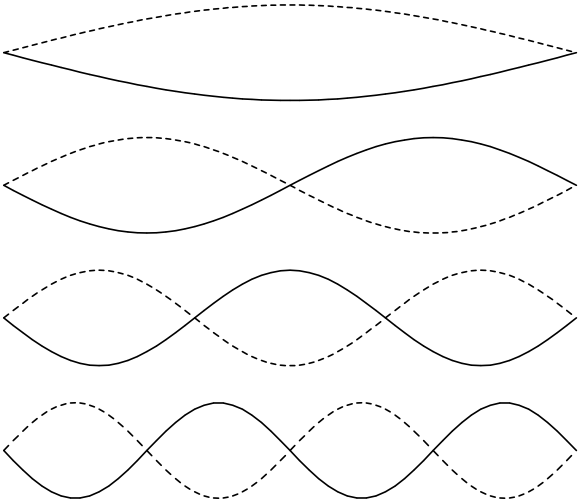

Fundamental: $f_1 = \frac{c}{2L}$

2nd harmonic: $f_2 = 2f_1$

3rd harmonic: $f_3 = 3f_1$

4th harmonic: $f_4 = 4f_1$

Musical instruments: in general

- Vibrating strings or columns of air inside tubes all can support all of these modes
  - You can select for particular ones, however: what happens if you pluck a string in its center?

Musical instruments: in general

- Vibrating strings or columns of air inside tubes all can support all of these modes
    - You can select for particular ones, however: what happens if you pluck a string in its center?
    - Only odd-numbered modes are excited: the even ones have a node there
- In general, when you excite a string or air column, you produce them all
- Often we choose to excite strings in ways that prefer some modes over others
- The unique sound of each instrument comes mostly from the relative strengths

Controlling pitch

- Any instrument needs a way of changing f_1 to play different notes
- Modern piano: f_1 from 28.5 Hz to 4 kHz
- Human voice: f_1 from 65 Hz to 1 kHz, with rare exceptions (oktavists, coloraturas...)
- Human hearing: sensitive from 20 Hz to 20 kHz (roughly)

Stringed instruments

- Make a string vibrate, its vibrations cause sound waves (not very efficient)
- Make a string vibrate, couple it mechanically to something bigger which makes the air vibrate: better!
- Three ways to control the fundamental frequency of sound in a string:
  - Speed of sound on a stretched string: $c = \sqrt{T/\lambda}$
  - T is the tension, λ is the linear mass density (kg per meter)
  - If $c = f\lambda$, then $f_1 = \frac{\sqrt{T}}{2L\sqrt{\lambda}}$
- More tension makes the frequency go up (how these instruments are tuned
- A longer string makes the frequency go down (bass vs. violin)
- A thicker string makes the frequency go down (wound strings)

Wind instruments

- Same idea, except we have a column of air instead of a string
- Here the wave speed c is just the speed of sound in air
- Classic example: the pipe organ
  - Each pipe only sounds one note
  - Pipes up to 32 feet long $\rightarrow f_1 = 17$ Hz!
- Others: use one pipe to sound multiple notes by opening and closing holes
- Excite vibrations with either a reed or something akin to a whistle (on a flute)
- How does the octave key on a saxophone work

Brass instruments

- Don't be fooled by the funny shapes: they (mostly) act like straight pipes
- Here there are two tricks for controlling pitch: change the length of the tube...
  - Trombone: physically make the tube longer
  - Trumpet etc.: Add/subtract lengths of tubing
- ... or match the buzzing of the player's lips to frequencies other than f_1
- How does a trumpeter play a scale?