Physics 1240: Sound and Music

<u>Today (7/25/19)</u>: Vibrating Air Columns, Organs

<u>Next time</u>: Woodwinds, Brass Instruments

Student performance:
flute

<u>Review</u>

Types of Instruments

(Hornbostel–Sachs classification)

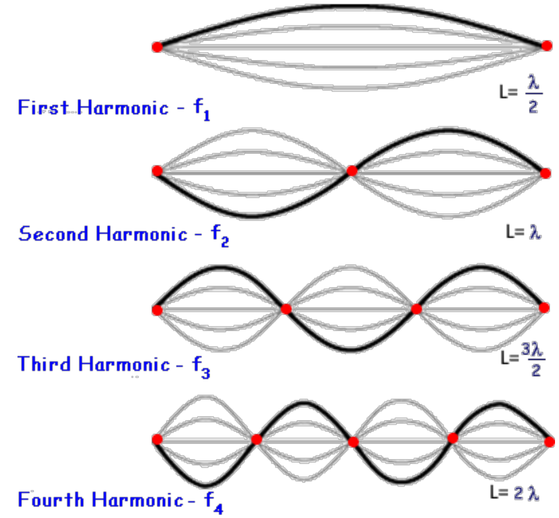
- <u>Chordophones</u>: vibrating strings

- <u>Aerophones</u>: vibrating columns of air

- <u>Idiophones</u>: vibrating the whole instrument

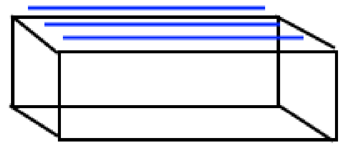
- <u>Membranophones</u>: vibrating membrane/skin
- <u>Electrophones</u>: vibrating loudspeaker

Review

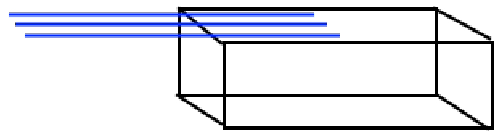


Chordophones

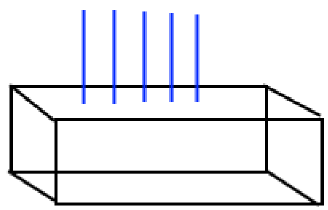
- Zithers



- Lutes

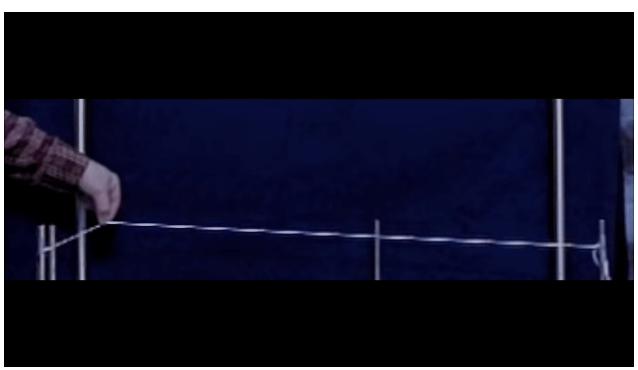


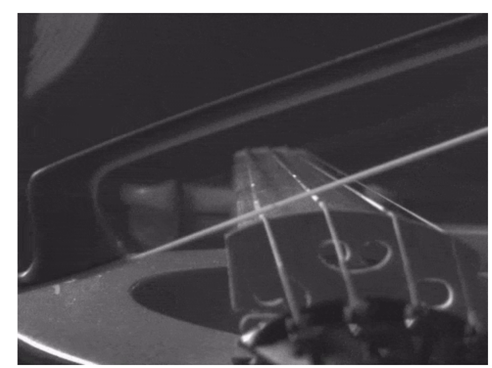
- Harps



$$f_n = \frac{n}{2L}\sqrt{\frac{T}{m/L}}$$

- How to create waves: initial displacement, velocity, or both





BA

Clicker Question 12.1

If you pluck a string at its halfway point, which of the first five harmonics will be present?

A) 1, 3, 4, 5
B) 1, 3, 5
C) 1
D) 2, 4
E) 1, 2, 3, 4, 5

BA

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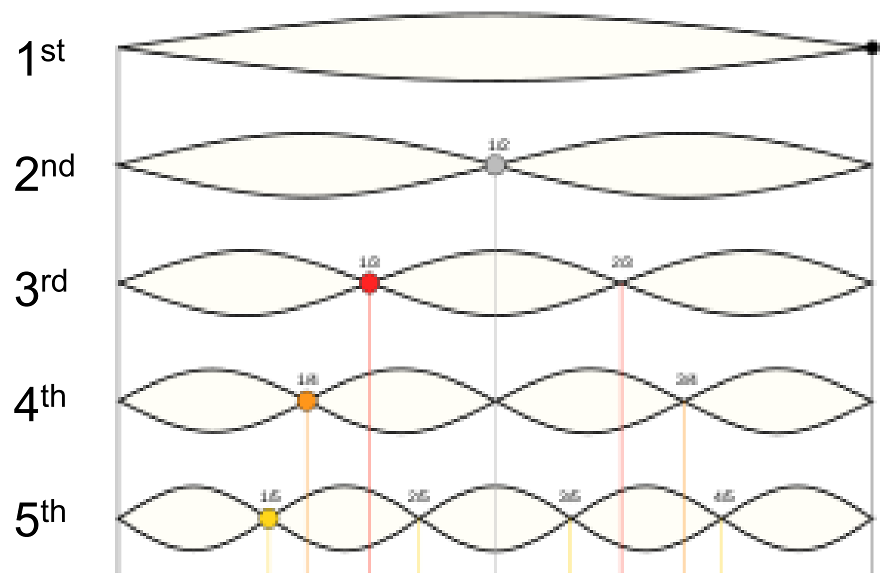

BA

Clicker Question 12.2

If the string on a grand piano for the note that plays middle C is 4 feet long, how long would the string for the lowest C (three octaves down) need to be if no changes are made to the string's tension or gauge?

A) 0.5 ft
B) 4 ft
C) 8 ft
D) 16 ft
E) 32 ft

BA

Clicker Question 12.2

If the string on a grand piano for the note that plays middle C is 4 feet long, how long would the string for the lowest C (three octaves down) need to be if no changes are made to the string's tension or gauge?

A) 0.5 ft
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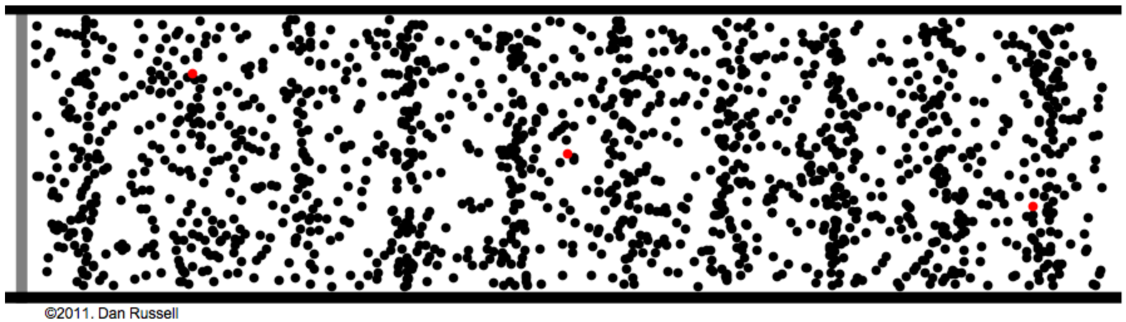
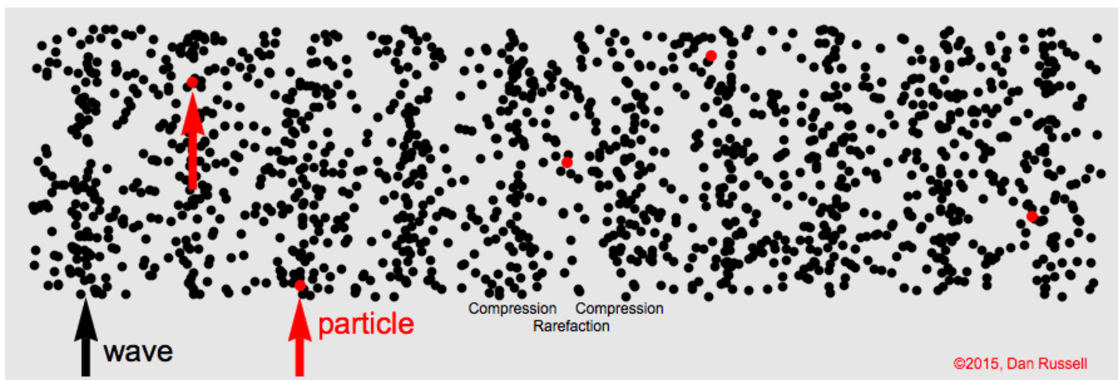
C) 8 ft
D) 16 ft
E) <u>32 ft</u>

$$f_n = \frac{n}{2L}\sqrt{\frac{T}{m/L}}$$

If f goes down three octaves (*decreases* by a factor of $2^3=8$), L must *increase* by a factor of 8

Aerophones: vibrating columns of air

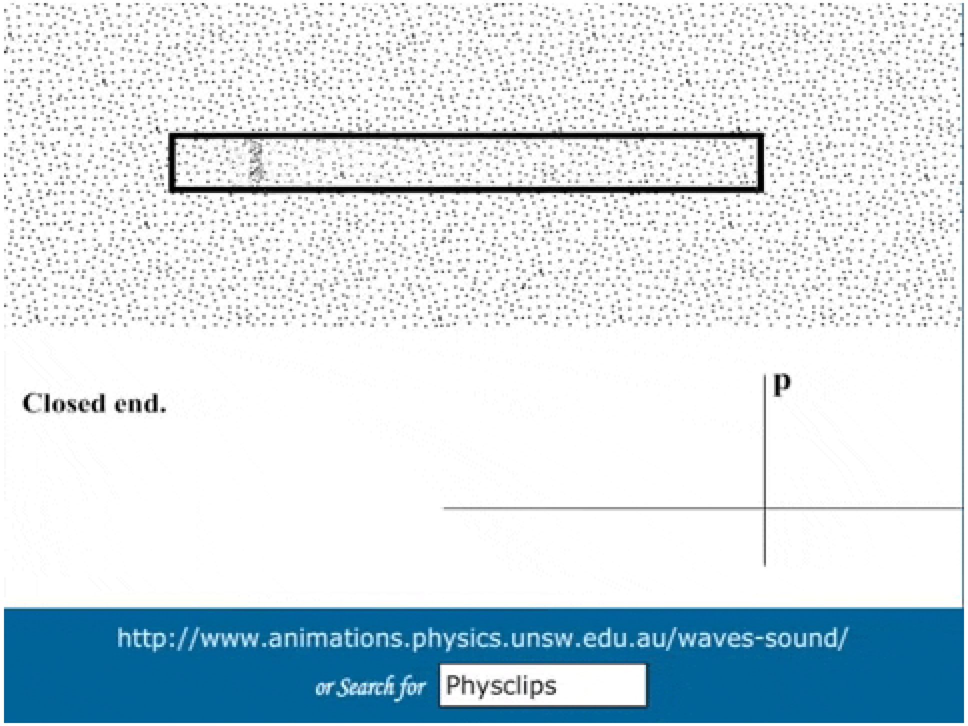




What happens when air gets to the edge of a pipe?
(for a string, it reflects and becomes upside-down)

Aerophones: vibrating columns of air

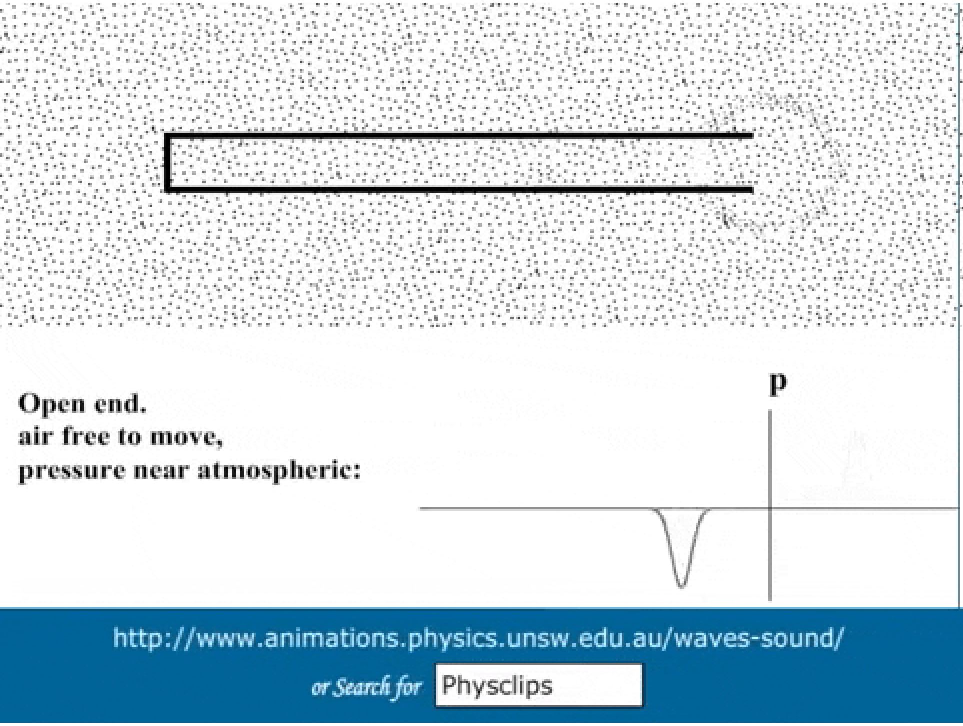
- Closed end: wave pulse reflects in a normal way



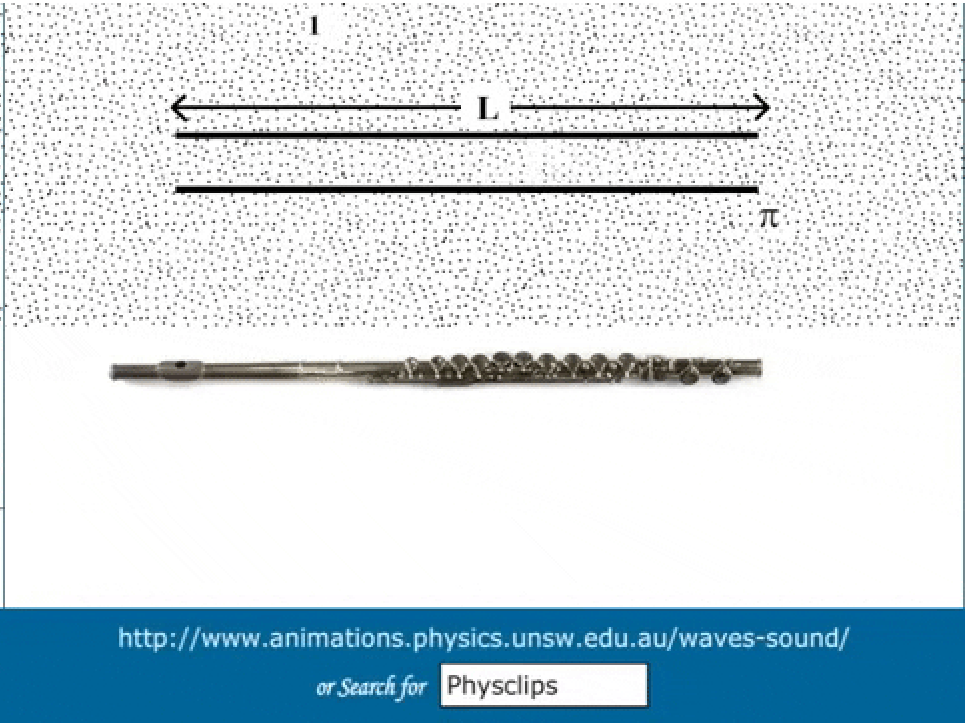
Aerophones: vibrating columns of air

- Open end: wave pulse reflects and inverts

$\lambda = 4L$



$\lambda = 2L$



Aerophones: vibrating columns of air

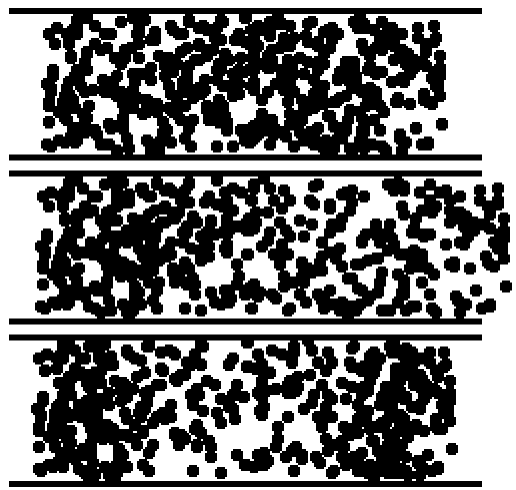
- Standing waves:

What do we plot so we don't have to draw longitudinal waves with air molecules?

1st harmonic

2nd harmonic

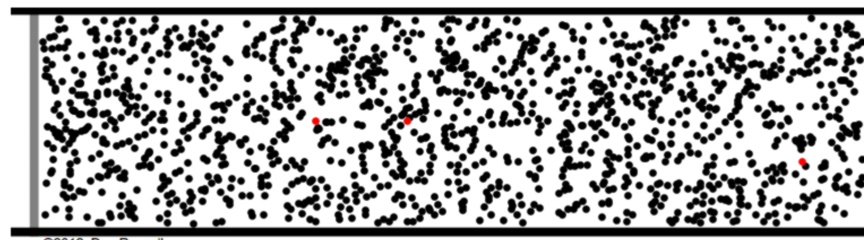
3rd harmonic

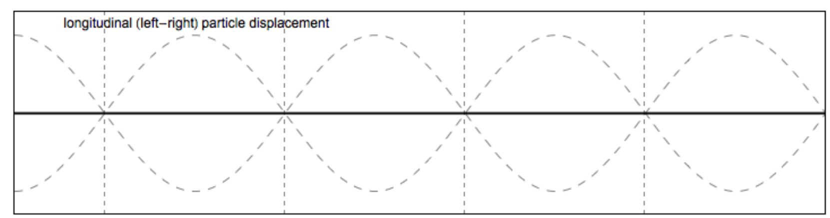


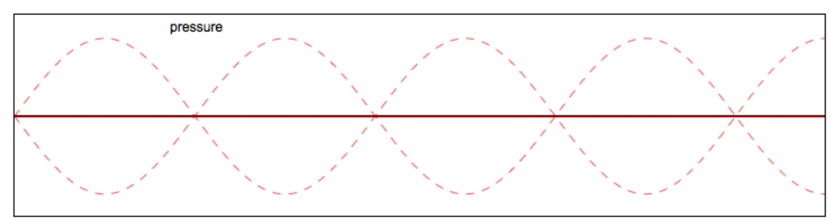
Aerophones: vibrating columns of air

- Standing waves:

- Two choices:
  1. Velocity/Displacement
  2. Pressure







- Closed end:
  velocity node,
  pressure antinode
- Open end:
  velocity antinode,
  pressure node

BA

Clicker Question 12.3

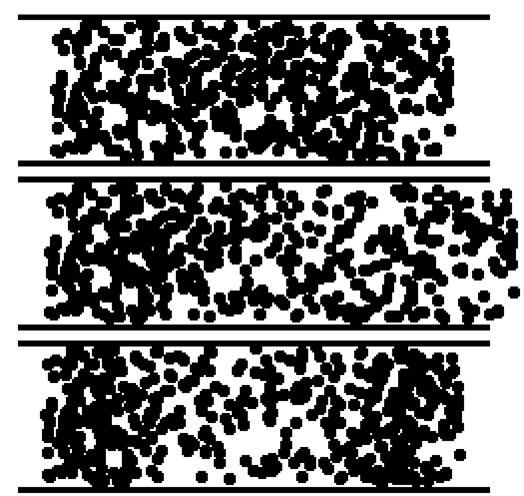
For a pipe open at both ends, what quantity has a node at the open ends?

A) Pressure
B) Velocity
C) None of the above

1st harmonic

2nd harmonic

3rd harmonic



BA

Clicker Question 12.3

For a pipe open at both ends, what quantity has a node at the open ends?

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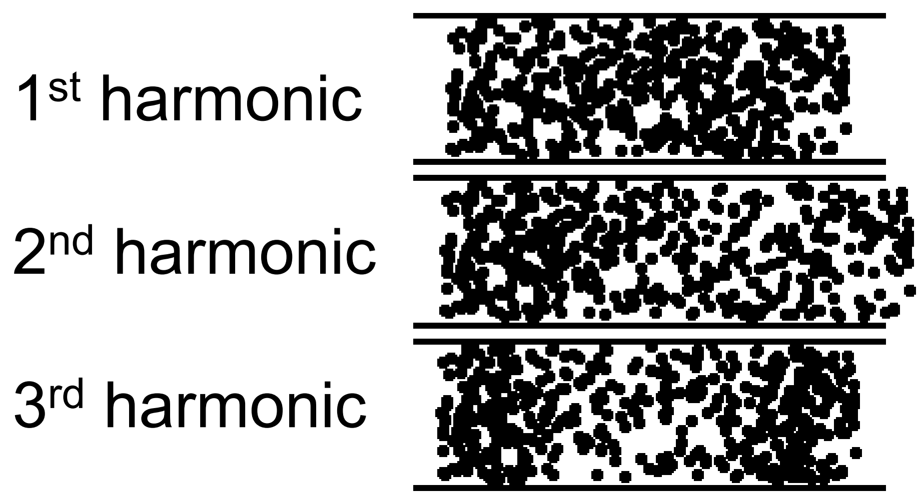


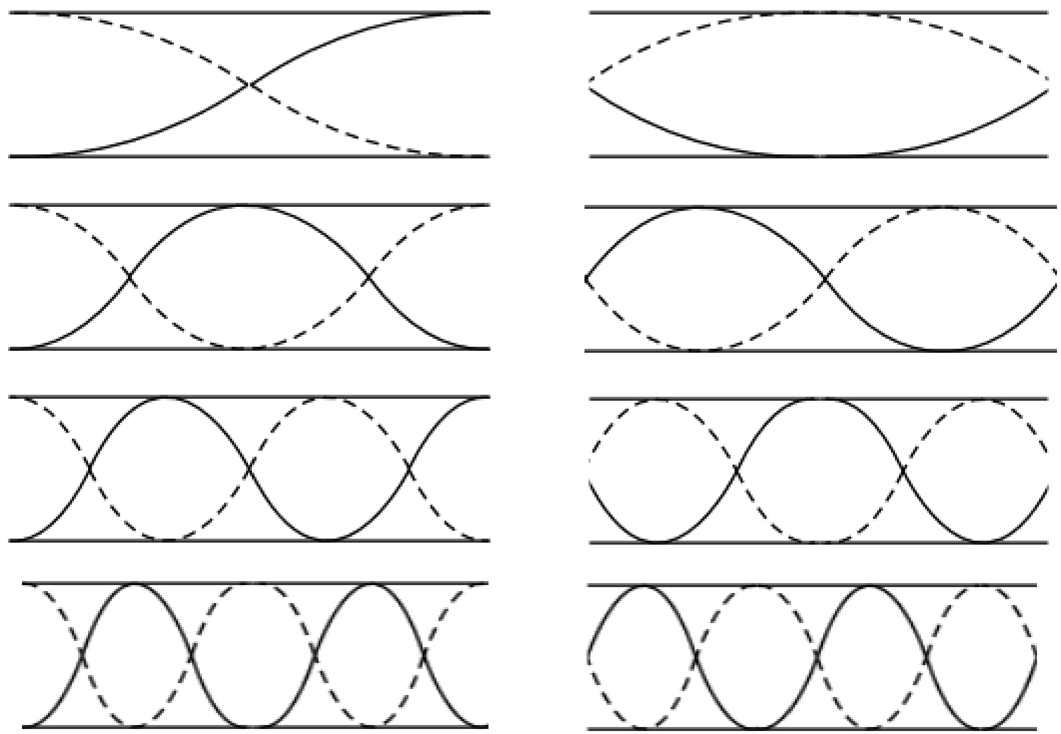
Aerophones: vibrating columns of air

- Open pipe:

$$f_n = n\frac{v}{2L}$$

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

Velocity | Pressure



1st harmonic: $L = \frac{\lambda}{2}$

2nd harmonic: $L = \lambda$

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

4th harmonic: $L = 2\lambda$

Aerophones: vibrating columns of air

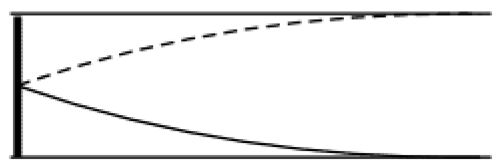
- Closed pipe:

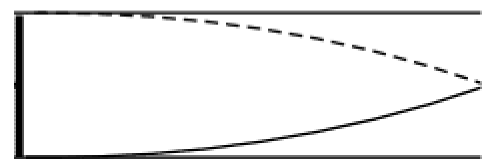
$$f_n = n\frac{v}{4L}$$

$$L = \frac{n\lambda}{4}$$

Velocity | Pressure

1st harmonic

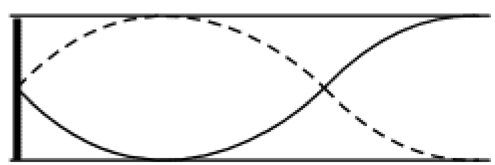


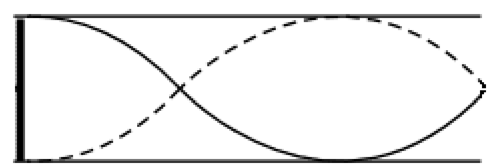


$$L = \frac{\lambda}{4}$$

(no 2nd harmonic)

3rd harmonic

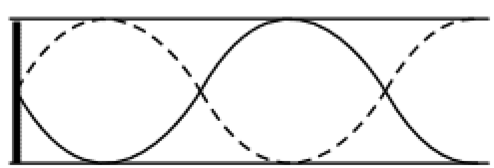


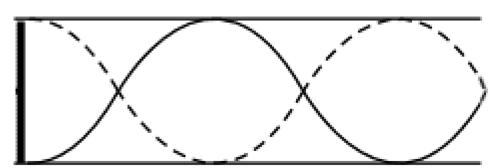


$$L = \frac{3\lambda}{4}$$

(no 4th harmonic)

5th harmonic





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

BA

Clicker Question 12.4

What is the fundamental frequency of a pipe that is open at both ends and is 1.715 meters long?

A) 200 Hz
B) 0.8575 m
C) 100 Hz
D) 3.43 m
E) 50 Hz

BA

Clicker Question 12.4

What is the fundamental frequency of a pipe that is open at both ends and is 1.715 meters long?

A) 200 Hz
B) 0.8575 m
C) <u>100 Hz</u>
D) 3.43 m
E) 50 Hz

$$f_1 = \frac{v}{2L} = \frac{343\ \text{m/s}}{2(1.715\ \text{m})} = 100\ \text{Hz}$$

BA

Clicker Question 12.5

Assume a flute behaves as a pipe open at both ends. What is the frequency of the third natural mode of a flute with a length of 0.8575 meters?

A) 100 Hz
B) 200 Hz
C) 300 Hz
D) 600 Hz
E) None of the above

BA

Clicker Question 12.5

Assume a flute behaves as a pipe open at both ends. What is the frequency of the third natural mode of a flute with a length of 0.8575 meters?

A) 100 Hz
B) 200 Hz
C) 300 Hz
D) 600 Hz
E) None of the above

$$f_3 = \frac{3v}{2L} = \frac{3(343\ \mathrm{m/s})}{2(0.8575\ \mathrm{m})} = 600\ \mathrm{Hz}$$

BA

Clicker Question 12.6

A clarinet can be closely approximated as a cylindrical pipe that is closed at one end. What might be the harmonics present for a clarinet (in Hz)?

A) 121, 233, 251, …
B) 120, 240, 360, …
C) 120, 360, 600, …
D) None of the above

BA

Clicker Question 12.6

A clarinet can be closely approximated as a cylindrical pipe that is closed at one end. What might be the harmonics present for a clarinet (in Hz)?

A) 121, 233, 251, …
B) 120, 240, 360, … (even harmonics absent)
C) 120, 360, 600, …
D) Not enough information to determine

Aerophones: vibrating columns of air

Demo: Rubens' tube

Aerophones: vibrating columns of air

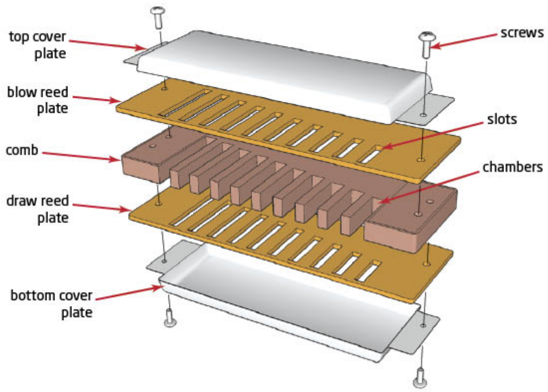
$$f_n = n\frac{v}{2L}\ \text{(open)}$$

$$f_n = n\frac{v}{4L}\ \text{(closed)}$$

- How to change pitch?
- Sound speed (v)?
- Length (L)?
  - valves, tone holes
- Harmonic number (n)?
  - overblowing, embouchure

Types of Aerophones

1. Free: does not contain the vibrating air (no standing waves)
   - Examples: siren, whip, harmonica, accordion, bullroarer
2. Flute-type: open-open tube; sound produced from edge tones
   - Examples: flute, recorder, organ pipe
3. Reed/brass: open-closed tube (cylindrical, conical, or flared bell); sound produced from vibrating reed/lips
   - Examples: clarinet, saxophone, trumpet, horn, didgeridoo



Aerophones

- How to create standing waves in pipes?

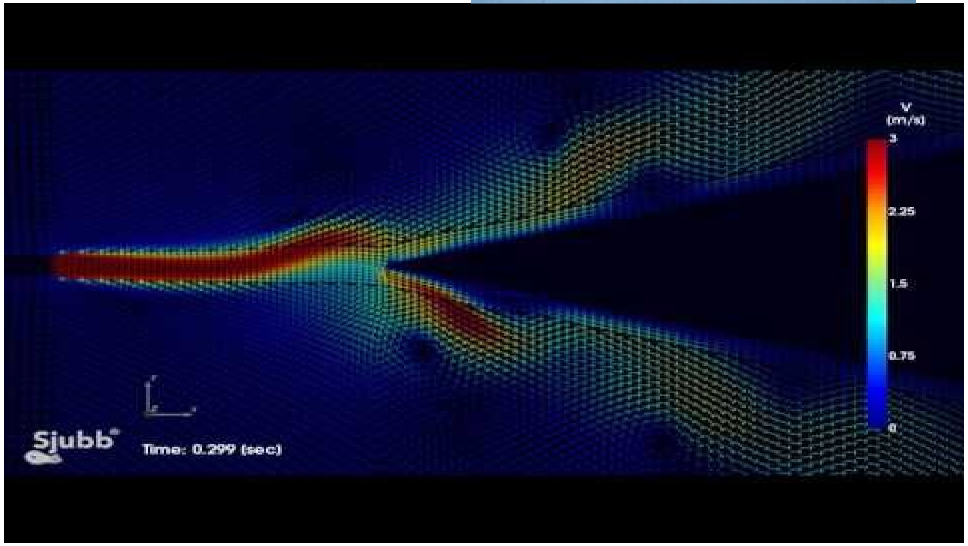
  1. Edge Tones

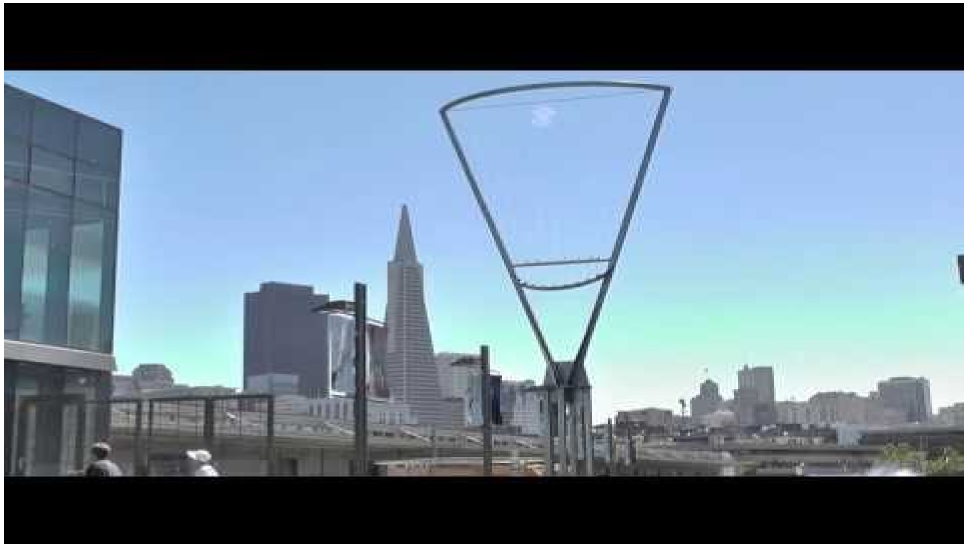
  2. Reeds

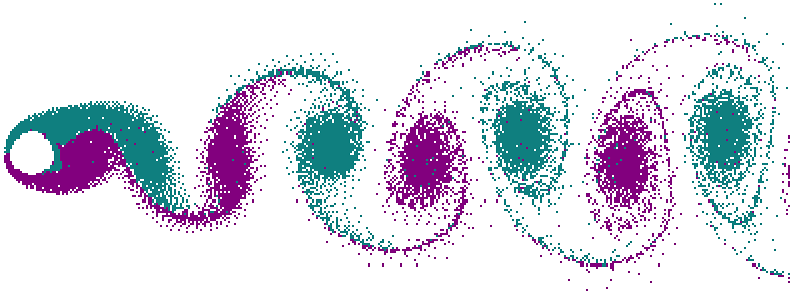
Edge Tones

- Fluid-flow instabilities: "vortex shedding"

- Examples:
  - Flag fluttering in wind
  - Seatbelt in fast car
  - Aeolian harp
  - Blowing on bottle lip
  - Whistle

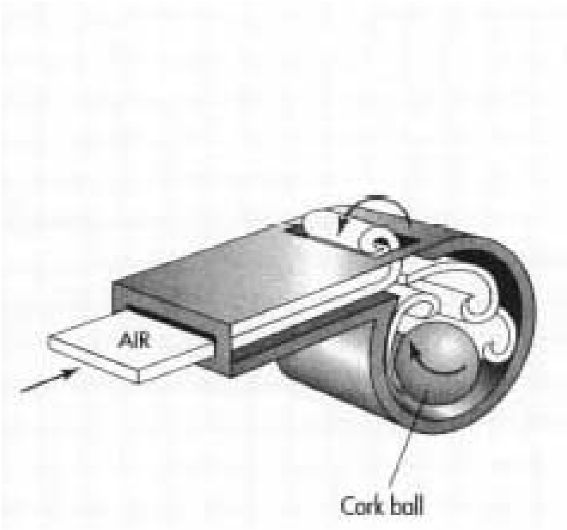




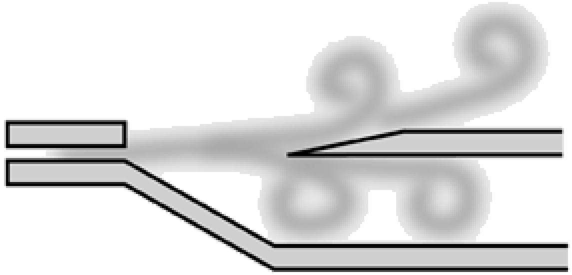


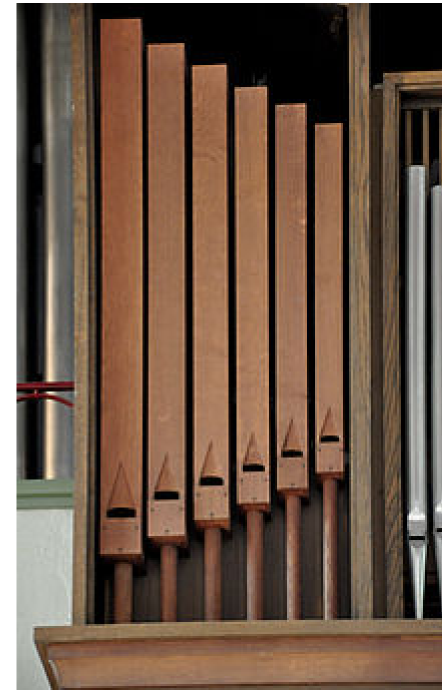
Edge Tones

- Ball whistle: vortex shedding on edge, plus turbulent feedback from redirected air



- Edge tones: frequency of oscillation increases with increasing wind speed





<u>Organs</u>

- Two types of pipes: flue pipes, reed pipes
- Console: keyboards, stops

Organs

- Stops: each one controls a different set ("rank") of pipes
  - Labelled by length of largest pipe (e.g. 8', 4', $1^5/_3$')