- **Resonance frequencies**
- **Lab #02 discussion, #03 work time**

Background reading and web activities:

- *AAP Ch 2, sec 2.1, second half*
- *"…Standing Wave Diagrams 1" (Zona Land)*
  "Wave Interference 2" (Zona Land)

0. Today’s objectives

After today’s class, you should be able to:

- Calculate the frequency of a sound wave in air (given its wavelength)
- Answer any remaining questions you have about Lab #02

1. Review: Resonances

- What is the relationship between **standing waves** and **resonances**?
- Why is this **important/relevant** in the context of our discussion last time?

1. Review: Resonances

- What "size" waves will "fit" a vibrating object?
  - A wave that "fits" a particular object is called a **resonance** of that object
  - A resonance forms a **standing wave**: an oscillating pattern, stable in space over time

- The resonances of a tube of air (like the **vocal tract**!) depend on its **physical length**, which we can measure or calculate

1. Review: Resonances

- Some key terminology:
  - **node** — physical position on standing wave that **always has zero amplitude**

    = location in space where a wave and its reflection always *cancel each other out*
  - **antinode** — physical position on standing wave with **maximum amplitude change from zero** (includes both **positive and negative** extreme values)

    = location in space where a wave and its reflection *maximally reinforce each other*

1. Review: Resonances

- The “compatible waves” (“waves that fit”) for a string or a tube are determined by
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1. Review: Resonances

- The “compatible waves” (“waves that fit”) for a string or a tube are determined by
  - its **length**
  - its **boundary conditions**

- **Boundary conditions**:

1. Review: Resonances

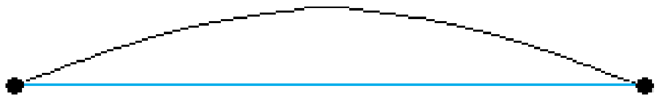
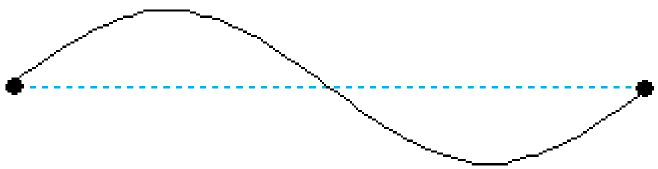
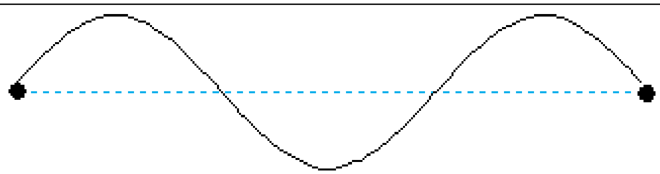
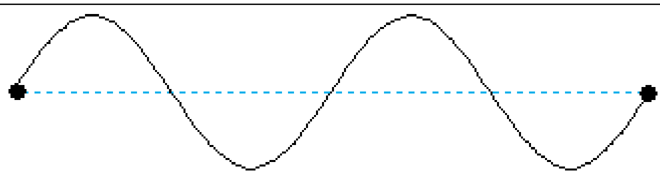
- The “compatible waves” (“waves that fit”) for a string or a tube are determined by
  - its **length**
  - its **boundary conditions**

- **Boundary conditions**: For each **end** of the string or tube, is it a **node** or an **antinode**?
  - String: ***fixed*** (**node**) or ***free*** (**antinode**)?
  - Tube: ***open*** (**node** of pressure wave) or ***closed*** (**antinode** of pressure wave)?

- **Pressure wave**? Review demo “Standing Sound Waves”

1. Review: Resonances

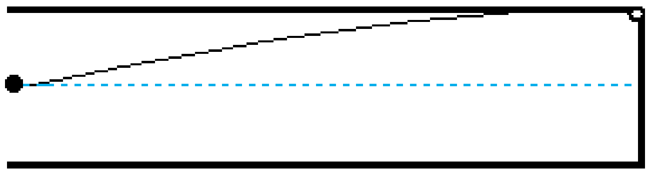
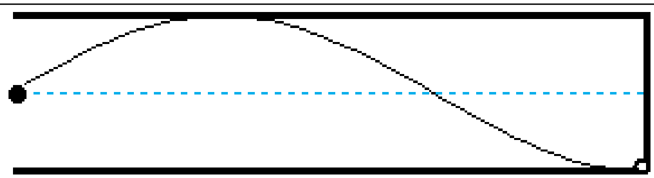
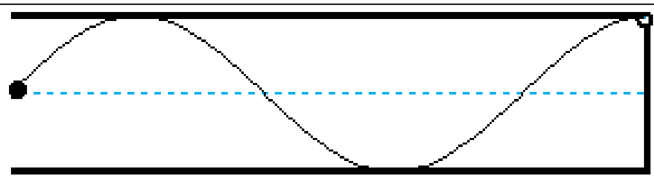
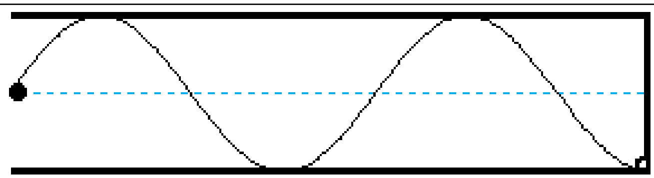
- Is this a **node/node** or a **node/antinode** system?

	$L = \frac{1}{2} \cdot \lambda_1$	$\lambda_1 = 2\,L$	$\lambda_1 = (2/1) \cdot L$
	$L = 1 \cdot \lambda_2$	$\lambda_2 = L$	$\lambda_2 = (2/2) \cdot L$
	$L = 1\frac{1}{2} \cdot \lambda_3$	$\lambda_3 = \frac{2}{3}\,L$	$\lambda_3 = (2/3) \cdot L$
	$L = 2 \cdot \lambda_4$	$\lambda_4 = \frac{1}{2}\,L$	$\lambda_4 = (2/4) \cdot L$

- ***General formula:*** $\boldsymbol{\lambda_n = (2/n)\,L}$ or $\boldsymbol{\lambda_n = 2L/n}$

1. Review: Resonances

- Is this a **node/node** or a **node/antinode** system?

	$L = \frac{1}{4} \cdot \lambda_1$	$\lambda_1 = 4\ L$	$\lambda_1 = (4/1) \cdot L$
	$L = \frac{3}{4} \cdot \lambda_2$	$\lambda_2 = 4/3\ L$	$\lambda_2 = (4/3) \cdot L$
	$L = 1\frac{1}{4} \cdot \lambda_3$	$\lambda_3 = 4/5\ L$	$\lambda_3 = (4/5) \cdot L$
	$L = 1\frac{3}{4} \cdot \lambda_4$	$\lambda_4 = 4/7\ L$	$\lambda_4 = (4/7) \cdot L$

- ***General formula:*** $\lambda_n = (4/(2n-1)) \cdot L$ or $\lambda_n = 4L\ /\ (2n-1)$

2. Calculating resonance frequencies

- Finally!—the **frequencies** of the resonances are what we really want to know
  - Knowing the resonance frequencies of a tube of air (in the vocal tract) helps us **model the acoustics of speech sounds**
- *Example:* Soon we will learn about the **source-filter model** of speech acoustics as applied to **vowels**
  - The **source** is the glottal-source wave
  - The **filter** is determined by the **resonance frequencies of the vocal tract**

2. Calculating resonance frequencies

- **Wavelength (λ)** and **frequency (*f*)** are related

  Imagine traffic moving by at a steady 35 mph

  - **Many** VW bugs (**short**) would go by in 1 minute
    → **higher frequency**
  - **Few** buses (**long**) would go by in 1 minute
    → **lower frequency**

- As **wavelength** goes **up**, **frequency** goes _______

2. Calculating resonance frequencies

- **Wavelength (λ)**, **frequency (*f*)** are ***inversely*** related
  - As **wavelength** goes **up**, **frequency** goes **down**
- Specifically, they have this relationship:

$$\boxed{c=\lambda f}$$

  - ***c*** is the speed of the wave (about **350 m/s** for sound in air, according to *AAP*)
  - **Long** wavelength means **low** frequency
  - **Short** wavelength means **high** frequency

2. Calculating resonance frequencies

- If we know wavelength, we can **solve for frequency**

  $c=\lambda f$

  $$\boxed{\boldsymbol{f=c/\lambda}}$$

- Find the **frequency** of the ***n*th resonance** (***f_n***):
  - Plug the wavelength λ_n into the formula
  - Solve for f_n

2. Calculating resonance frequencies

- For a **node/node** system with tube of length L

$\lambda_n = 2L/n$	relates wavelength to tube length
$f_n = c/\lambda_n$	relates frequency to wavelength
$f_n = c\ /\ (2L/n)$	relates frequency to tube length
$\boldsymbol{f_n = n \cdot c/2L}$	

- **Shortcut!** Once you know the **1st resonance f_1** :

$$\boldsymbol{f_n = n \cdot f_1}$$

→ The resonance frequencies in a **node/node** system are **whole-number multiples** of f_1

2. Calculating resonance frequencies

- For a **node/antinode** system with tube of length *L*

$\lambda_n = 4L / (2n-1)$	relates wavelength to tube length
$f_n = c/\lambda_n$	relates frequency to wavelength
$f_n = c / (4L / (2n-1))$	relates frequency to tube length

$$\boldsymbol{f_n = (2n-1) \cdot c / 4L}$$

- **Shortcut!** Once you know the **1st resonance $\boldsymbol{f_1}$** :

$$\boldsymbol{f_n = (2n-1) \cdot f_1}$$

→ The resonance frequencies in a **node/antinode** system are **odd-numbered multiples** of f_1

3. Checking in on Lab #02

- How do we calculate the f_0 of a complex wave from the frequencies of its components?
  - The general answer is NOT 'look at the spacing between the component frequencies'

1. What is the **general answer**?
2. What is the **special case** where the spacing between the component frequencies also happens to equal f_0?

3. Checking in on Lab #02

- Any other questions about Lab #02?

4. Upcoming

- Work time on Lab #03
  - Talk to your classmates if you have questions!

- Reading in *AAP* for Monday’s class
  - Remember pressure wave nodes/antinodes are the opposite of displacement (or velocity) nodes/antinodes for longitudinal waves (like air in a tube)