Ch 16 Sound

Key words: sound waves; pressure waves; intensity; decibels (dB); sound level β; resonance; vibrating strings, open/closed tube; fundamental frequency ($n = 1$), resonant frequencies; harmonics & overtones; interference; Doppler effect

Objective:

Solve problems involving **standing waves**

- ☐ By considering the endpoints (**node/antinode**) and identifying patterns in wavelength.
- ☐ By finding a mathematical expression for the **resonant frequencies**.

Content Review: [10mins]

Standing Waves

- What the heck is a standing wave??!

  Watch this 5-min YouTube video that illustrates how standing waves form.

  Check out the question in the Slido poll (link in Zoom chat)

- 2 common examples are: **mechanical waves on a string** and **sound waves in a tube**.

For **standing waves on a string**,

- ☐ We are looking at the **displacement of the string**.
- ☐ The endpoints are both **fixed**, corresponding to **displacement nodes**.
- ☐ **Displacement:** A **displacement antinode** occurs at points where the string is allowed to move widely; while a **displacement node** occurs at places such as the endpoints where the string is fixed and not moving freely.

For **standing sound waves in a tube**,

- ☐ We are looking at either the **pressure in the air** or the **displacement of air particles**.
- ☐ The tube's ends could be **open-open**, **closed-closed**, or **open-closed**.
- ☐ **Pressure:** A **pressure node** occurs at open-ends as that is where the air pressure equals that of the surrounding environmental pressure; while a **pressure antinode** occurs at closed-ends since the air pressure builds up against the inner walls.
- ☐ **Displacement:** A **displacement antinode** occurs at an open-end as air particles are allowed to move freely; while a **displacement node** occurs at closed-ends since the air particles' motion is restricted.

	pressure	**displacement**
open-end	node	antinode
closed-end	antinode	node

NOTE: In general, for sound waves within a tube:

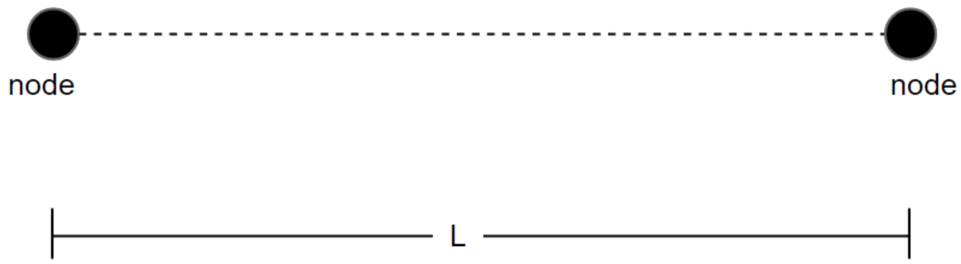
pressure nodes $\Longleftrightarrow$ displacement antinodes   pressure antinodes $\Longleftrightarrow$ displacement nodes

Guided Practice [10mins]

Derivation: Standing Waves on a String

Consider a string of length L tied on both ends. Let's derive a mathematical expression for the **resonant frequencies** that would produce standing waves on the string.

Let's begin by drawing the various possible standing wave formations on the string.



Solution

For **strings tied on both ends**, **open-open tubes**, and **closed-closed tubes**: the resonant frequencies f_n are given by

$$f_n = n\,\frac{v}{2L} \qquad \text{for } n = 1, 2, 3, \ldots$$

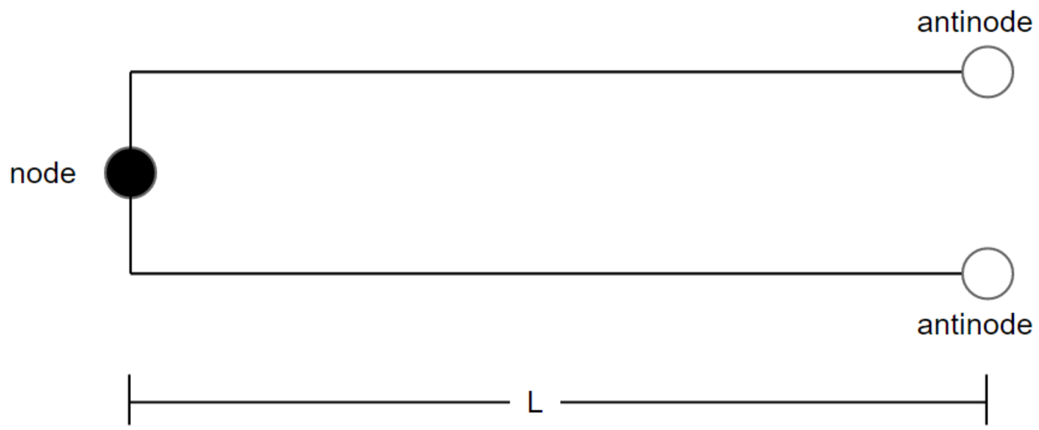
where L is the length of the string/tube and v is the velocity of the traveling waves.

Group Activity

Derivation Standing Sound Waves in a Open-Closed Tube

Consider an open-closed tube; that is, a tube that is open on one end and closed on the other. Let's derive a mathematical expression for the **resonant frequencies** that would produce standing sound waves within the tube.

Let's begin by drawing the various possible standing wave formations within the tube.



Solution

For **open-closed tubes**, the resonant frequencies f_n are given by

$$f = n\frac{v}{4L} \qquad \text{for } n = 1, 3, 5, \ldots \text{ (odd integers only)}$$

where L is the length of the tube and v is the velocity of the traveling waves.

Group Activity

Organ Pipe

An organ pipe is 124-cm long. Determine the fundamental and first 3 audible overtones if the pipe is

(a) closed at one end (and open at the other end)

(b) open at both ends

Solution

(a) closed at one end: $f_1 = 69.2\,\mathrm{Hz},\ f_3 = 207\,\mathrm{Hz},\ f_5 = 346\,\mathrm{Hz},\ f_7 = 484\,\mathrm{Hz}$

(a) open at both ends: $f_1 = 138\,\mathrm{Hz},\ f_2 = 277\,\mathrm{Hz},\ f_3 = 415\,\mathrm{Hz},\ f_4 = 553\,\mathrm{Hz}$

Group Activity

Violin String

A violin string vibrates at $441\,\mathrm{Hz}$ when unfingered. At what frequency will it vibrate if it is fingered one-third of the way down from the end? (That is, only two-thirds of the string vibrates as a standing wave).

Solution

$$f = 662\,\mathrm{Hz}$$