PHYS11 CH:14 Invisible Vibrations

From Silence to Symphony

Mr. Gullo

December 2025

Outline

The Mystery

If a tree falls in the forest
and no one is there to hear it,
does it make a sound?

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The answer depends on how you define sound...

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The answer depends on how you define sound...

Physics says: yes, but no one perceives it.

Fallen Tree

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The Mental Model

Tree hits ground → disturbs air particles → creates pressure waves → sound wave travels outward.

Learning Objectives

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- **14.1:** Describe speed of sound and how it changes in media
- **14.1:** Relate speed of sound to frequency and wavelength

14.1 Sound as a Mechanical Wave

Nature's Rule

Sound is a disturbance of matter transmitted from source outward as a longitudinal wave.

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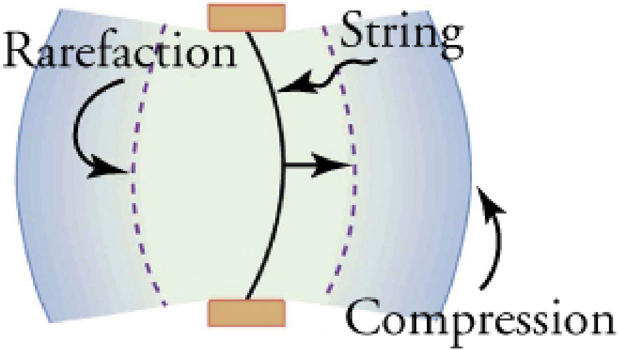
What makes it sound:

- Matter must vibrate (compression and rarefaction)
- Energy transfers through medium
- Requires matter - no sound in vacuum

14.1 Vibrating String Creates Sound



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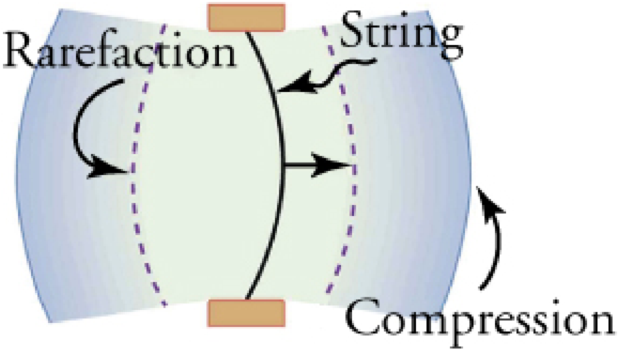
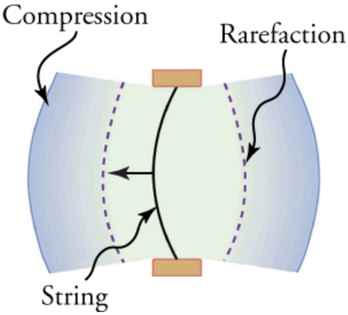


String oscillates $\rightarrow$ compresses air $\rightarrow$ creates pressure waves $\rightarrow$ longitudinal sound wave

14.1 Compressions and Rarefactions



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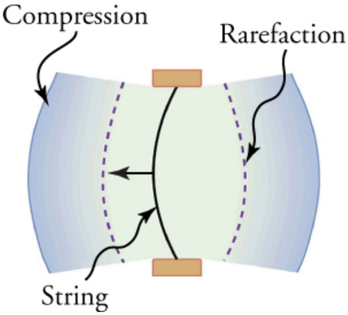

Analogy to Transverse Waves

- Compression = crest (high pressure)
- Rarefaction = trough (low pressure)
- Wavelength = distance between compressions

14.1 Sound Wave Enters Ear

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Compressions and rarefactions force eardrum to vibrate $\rightarrow$ converted to nerve impulses $\rightarrow$ brain interprets as sound

The Intuition Trap

Your brain expects: Denser material = slower sound
Reality: Speed depends on BOTH rigidity and density.

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- More rigid (less compressible) = faster sound
- Greater density = slower sound
- Solids: very rigid, so sound travels FAST despite density

14.1 Fireworks and Light vs Sound

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You see the flash BEFORE you hear the boom. Why?
Light: 3×10^8 m/s   Sound: ~ 340 m/s in air

The Law of All Waves

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

Speed equals frequency times wavelength.

14.1 The Universal Wave Equation

The Law of All Waves

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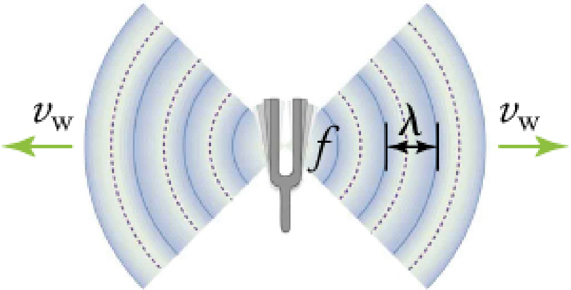
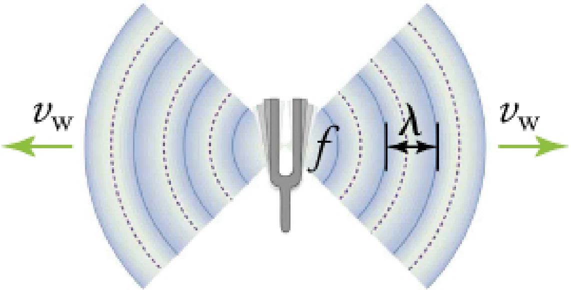
Speed equals frequency times wavelength.

For sound:

- v = speed of sound (m/s) - depends on medium
- f = frequency (Hz) - set by source
- λ = wavelength (m) - adjusts automatically

14.1 Sound Wave Anatomy





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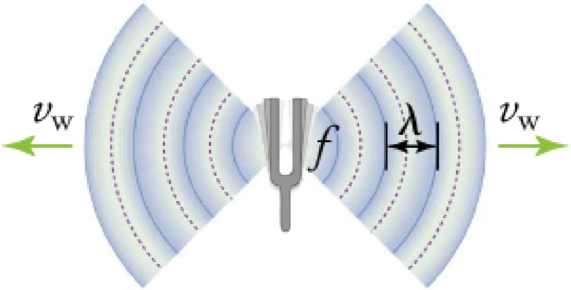

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Distance between adjacent compressions = one wavelength

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But all instruments arrive in sync, regardless of distance.

The Consequence

Since $v = f\lambda$ and v is constant, higher frequency means shorter wavelength.

Attempt: Decoding Audible Sound

The Challenge (3 min, silent)

Calculate the wavelengths of sounds at the extremes of human hearing, 20 Hz and 20,000 Hz, when sound travels at 348.7 m/s.

Given:

- $v = 348.7$ m/s
- $f_{\text{min}} = 20$ Hz, $f_{\text{max}} = 20,000$ Hz

Find: λ_{max} and λ_{min}

Can you decode the range? Work silently.

Compare: Wavelength Calculation

Turn and talk (2 min):

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2. How did you solve for wavelength?
3. Which frequency gives the LONGEST wavelength? Why?

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Name wheel: One pair share your approach (not your answer).

Reveal: The Range of Human Hearing

Self-correct in a different color:

Equation: $v = f\lambda \rightarrow \lambda = \frac{v}{f}$

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Check: Deep bass (20 Hz) has wavelength of a bus. High treble (20 kHz) is the size of your thumb.

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- **14.2:** Describe the decibel scale for measuring intensity
- **14.2:** Solve problems involving sound intensity
- **14.2:** Describe how humans produce and hear sounds

14.2 Loudness and Amplitude

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The Connection

Louder sound = greater amplitude = more energy transferred

Universal Law: Intensity

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14.2 Sound Intensity

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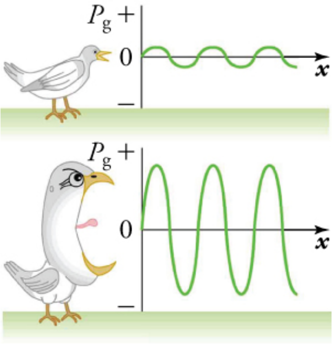
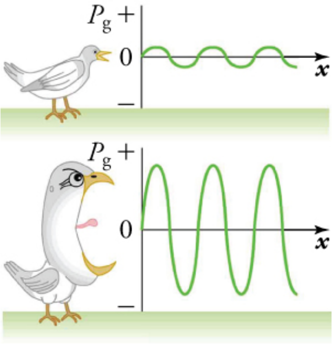
Key insight: $I \propto (\Delta p)^2$ where Δp is pressure amplitude.
Intensity is proportional to amplitude squared!

14.2 Pressure Amplitude Graphs





More intense sound has larger pressure maxima and minima, greater forces on objects.

14.2 Why Decibels?

Civilian View vs. Reality

Civilian: "Intensity in W/m^2 makes sense."
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The Decibel Scale

$$\beta \text{ (dB)} = 10 \log_{10}\left(\frac{I}{I_0}\right)$$

where $I_0 = 10^{-12}$ W/m^2 (threshold of human hearing)

Key patterns:

- Each factor of 10 in intensity = 10 dB

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- 90 dB is 10^3 times more intense than 60 dB
- Doubling intensity adds about 3 dB
- 0 dB $=$ threshold of hearing (10^{-12} W/m^2)

Examples

- Whisper: 20 dB
- Conversation: 60 dB
- Rock concert: 120 dB (pain threshold)

Attempt: Calculating Decibels

The Challenge (3 min, silent)

A sound wave in air at 0°C has pressure amplitude 0.656 Pa. Calculate the sound intensity level in decibels.

Given:

- $\Delta p = 0.656$ Pa
- $v = 331$ m/s (air at 0°C)
- $\rho = 1.29$ kg/m^3 (air density)
- $I_0 = 10^{-12}$ W/m^2

Find: β in dB

Two steps: find intensity, then decibels. Work silently.

Compare: Decibel Calculation

Turn and talk (2 min):

1. What formula did you use to find intensity from pressure?
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Self-correct in a different color:

Step 1 - Find intensity: $I = \frac{(\Delta p)^2}{2\rho v}$

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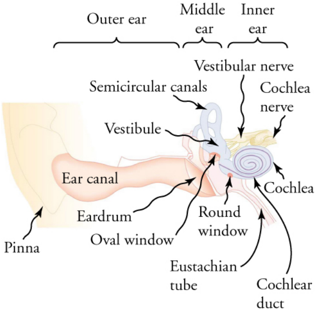
$$\boxed{\beta = 87.0\ \text{dB}}$$

Check: 87 dB is about as loud as heavy traffic - reasonable.

14.2 How We Hear



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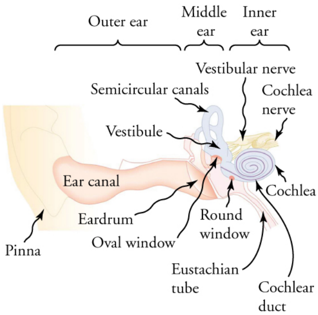

Sound waves → eardrum vibrates → bones amplify → cochlea converts to electrical signals → brain interprets

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- **14.3:** Calculate frequency shift using Doppler formula

The siren isn't changing pitch.
Your ears are being fooled.

Why Ambulances Lie to You

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The Illusion

Ambulance plays one constant note. You hear two different pitches approaching vs. receding.
What's happening?

14.3 Stationary Source and Observers

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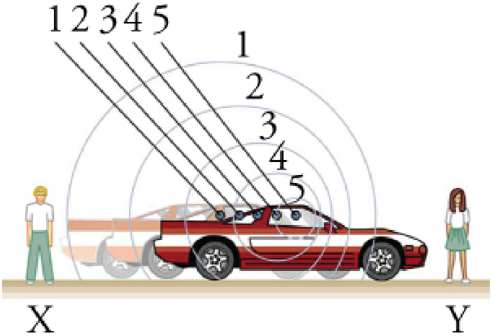
When source and observers are stationary, wavelength and frequency are same in all directions.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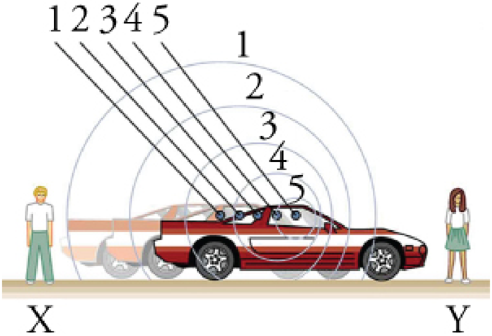
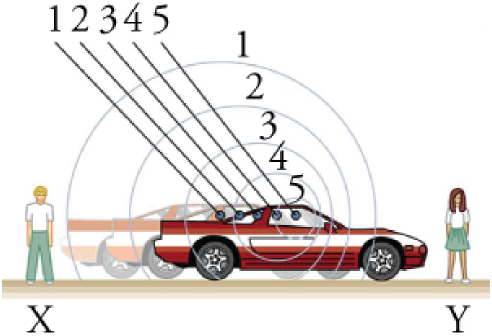
X
Y



Source moving right → waves bunch up ahead, spread out behind



Source moving right $\rightarrow$ waves bunch up ahead, spread out behind
Observer on right: shorter λ, higher f
Observer on left: longer λ, lower f

14.3 The Doppler Effect Formula

For Moving Source, Stationary Observer

$$f_{\text{obs}} = f_s \left(\frac{v_w}{v_w \pm v_s} \right)$$

Use minus for motion toward observer, plus for motion away.

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Intuition check:

- Source approaching: denominator smaller $\rightarrow$ frequency higher
- Source receding: denominator larger $\rightarrow$ frequency lower

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What happens when source speed approaches sound speed?

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Observed frequency approaches infinity!

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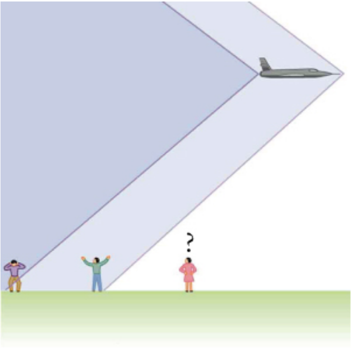
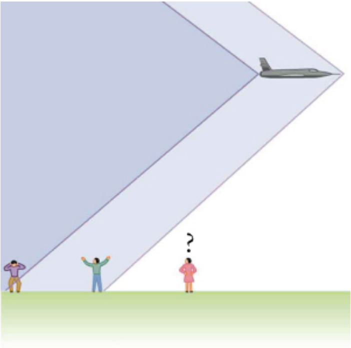
Sonic Boom

Constructive interference of sound created by object moving faster than sound.
All waves superimpose at same instant $\to$ huge amplitude $\to$ BOOM!

14.3 Sonic Boom Geometry





Two booms: one from nose, one from tail. Time separation equals time for aircraft to pass by a point.

Attempt: Doppler Shift Calculation

The Challenge (3 min, silent)

A train has 150 Hz horn and moves at 35 m/s. Speed of sound is 340 m/s. What frequencies are observed by stationary person as train approaches and recedes?

Given:

- $f_s = 150$ Hz
- $v_s = 35$ m/s
- $v_w = 340$ m/s

Find: $f_{\text{obs, approaching}}$ and $f_{\text{obs, receding}}$

Which sign for approaching? Receding? Work silently.

Compare: Doppler Strategy

Turn and talk (2 min):

1. Which formula did you use?
2. Approaching: plus or minus sign? Why?
3. Receding: plus or minus sign? Why?
4. How did you check if answer was reasonable?

Compare: Doppler Strategy

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Name wheel: One pair share your sign logic.

Reveal: Train Horn Doppler Shift

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Check: Shift up by 20 Hz, down by 10 Hz. Asymmetric - correct!

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By the end of this section, you will be able to:

- **14.4:** Describe resonance and beats
- **14.4:** Define fundamental frequency and harmonics
- **14.4:** Contrast open-pipe and closed-pipe resonators
- **14.4:** Solve problems involving harmonics and beat frequency

14.4 Resonance

Universal Law: Resonance

Systems oscillate best at their natural frequency. Driving a system at its natural frequency produces resonance.

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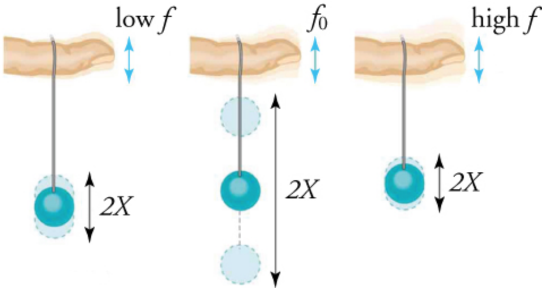
The Mental Model

Resonance is when driving frequency matches natural frequency, creating maximum energy transfer.

14.4 Paddle Ball Resonance



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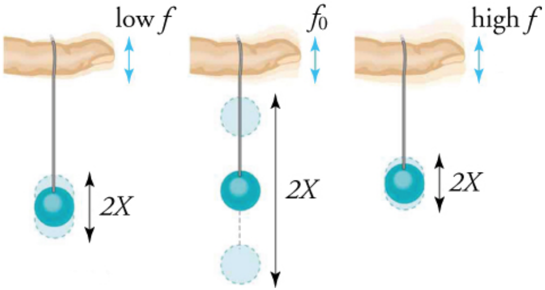

Move finger at ball's natural frequency → amplitude grows dramatically

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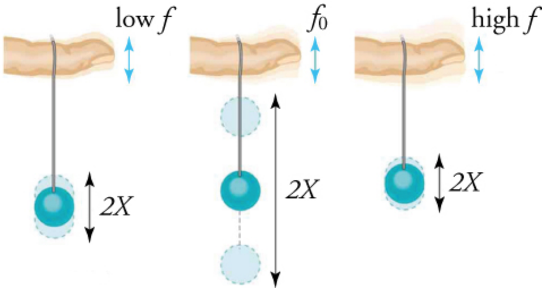

Move finger at ball's natural frequency $\rightarrow$ amplitude grows dramatically
Move too slow or too fast $\rightarrow$ amplitude stays small

14.4 Beat Frequency

Beats from Superposition

Two waves with slightly different frequencies superimpose $\rightarrow$ alternating constructive and destructive interference $\rightarrow$ amplitude varies in time.

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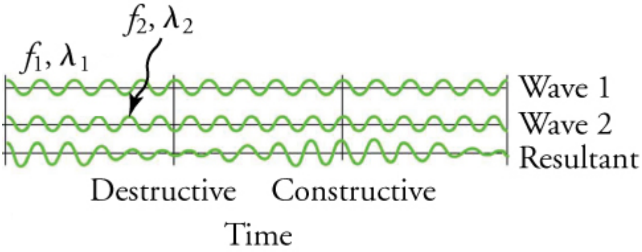
$$f_B = |f_1 - f_2|$$

You hear average frequency getting louder and softer at beat frequency.

14.4 Beat Pattern



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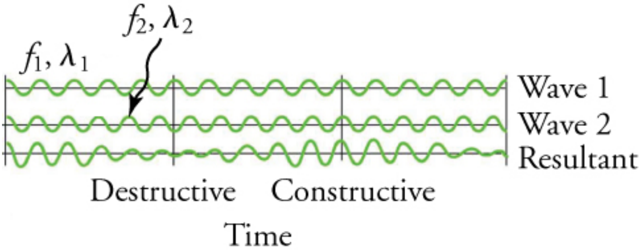
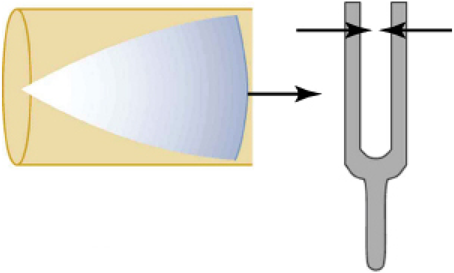


Amplitude oscillates at beat frequency while wave oscillates at average frequency.

14.4 Standing Waves in Closed Pipe



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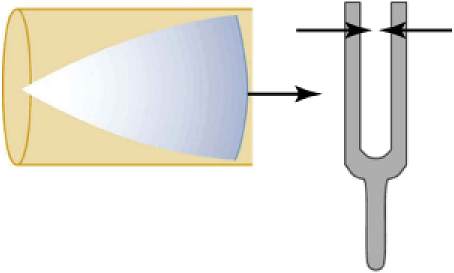

Closed end: node (no displacement)
Open end: antinode (maximum displacement)

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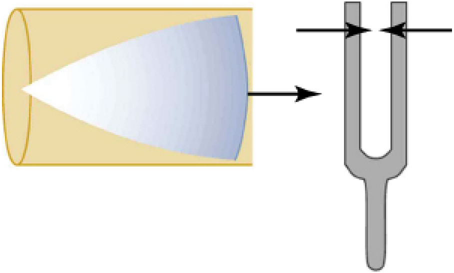
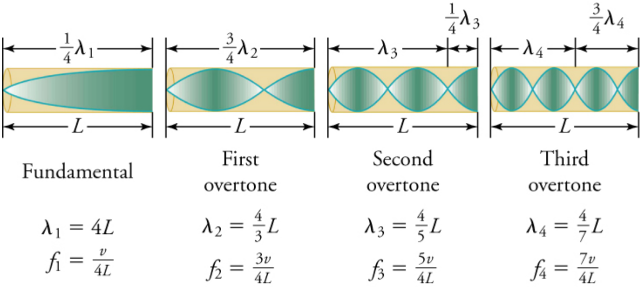
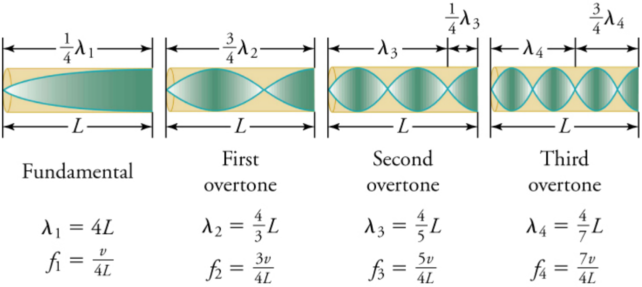


Closed end: node (no displacement)
Open end: antinode (maximum displacement)
Fundamental: $\lambda = 4L$ so $f_1 = \frac{v}{4L}$

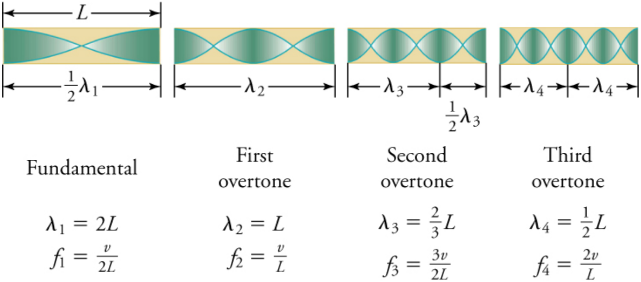
14.4 Harmonics in Closed Pipe

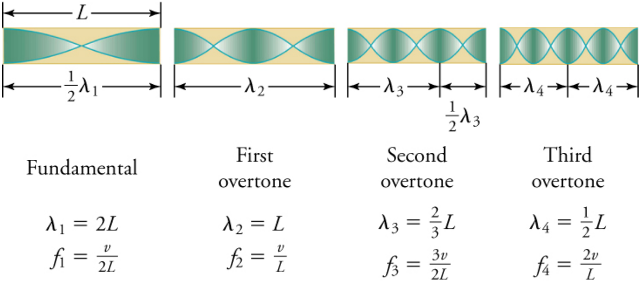




Closed-pipe resonator: $f_n = n\frac{v}{4L}$ where $n = 1, 3, 5, \ldots$
Only odd harmonics!

14.4 Open-Pipe Resonator





Both ends: antinodes (maximum displacement)

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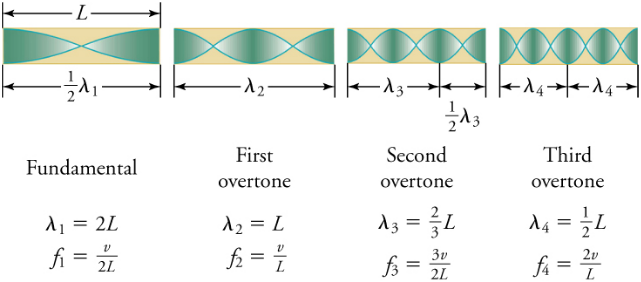

Both ends: antinodes (maximum displacement)
Open-pipe resonator: $f_n = n\frac{v}{2L}$ where $n = 1, 2, 3, \ldots$
All harmonics!

Attempt: Closed-Pipe Length

The Challenge (3 min, silent)

Sound travels at 344 m/s. What length should a tube closed at one end have for fundamental frequency of 128 Hz?

Given:

- $f_1 = 128$ Hz (fundamental)
- $v = 344$ m/s

Find: Length L

Which formula for closed pipe? Work silently.

Compare: Pipe Length Strategy

Turn and talk (2 min):

1. Closed pipe or open pipe formula?
2. What is n for the fundamental?
3. How did you solve for length L?

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Name wheel: One pair share your approach.

Reveal: Tube Length for Resonance

Self-correct in a different color:

Closed-pipe formula: $f_n = n\frac{v}{4L}$ with $n = 1$ for fundamental

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$$L = \frac{344 \text{ m/s}}{4(128 \text{ Hz})} = \frac{344}{512} = \boxed{0.672 \text{ m} = 67.2 \text{ cm}}$$

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Check: About 2 feet - reasonable for a musical instrument.

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5. Resonance: driving at natural frequency maximizes energy
6. Harmonics: geometry restricts allowed frequencies

Key Equations

$$v = f\lambda \tag{1}$$

$$I = \frac{P}{A} = \frac{(\Delta p)^2}{2\rho v} \tag{2}$$

$$\beta \text{ (dB)} = 10 \log_{10}\left(\frac{I}{I_0}\right) \tag{3}$$

$$f_{\text{obs}} = f_s \left(\frac{v_w}{v_w \pm v_s}\right) \tag{4}$$

$$f_B = |f_1 - f_2| \tag{5}$$

$$f_n = n\frac{v}{4L} \text{ (closed)}, \quad n = 1, 3, 5, \ldots \tag{6}$$

$$f_n = n\frac{v}{2L} \text{ (open)}, \quad n = 1, 2, 3, \ldots \tag{7}$$

Complete the assigned problems

posted on the LMS

Temporary page!

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this extra page has been added to receive it.
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