PHYS11 CH13: Invisible Disturbances

How Energy Moves Without Moving Matter

Mr. Gullo

December 2025

Outline

The Mystery

How does energy travel from one place to another *without moving matter?*

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Drop a rock in a pond. Ripples spread outward, but the water stays in place...

Only the disturbance moves.

Ocean Waves: Energy in Motion

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The Mental Model

Wave = disturbance that travels and carries energy, not mass.

Learning Objectives

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

- **13.1:** Define mechanical waves and medium

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- **13.1:** Distinguish longitudinal from transverse waves

13.1 Mechanical Waves

Nature's Rule

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The Exception

Light doesn't need a medium - it travels through vacuum of space!

13.1 Pulse Wave vs. Periodic Wave

Pulse Wave

- Sudden disturbance
- One or few waves
- Examples: thunder, explosion, pebble in water

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- Many cycles
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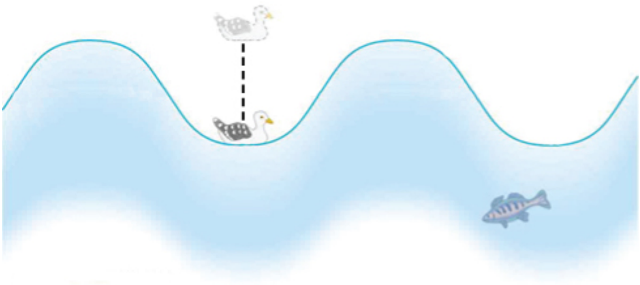
Periodic waves involve simple harmonic motion.

13.1 Water Wave Anatomy



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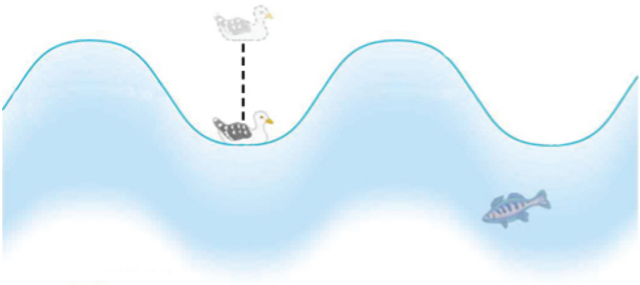
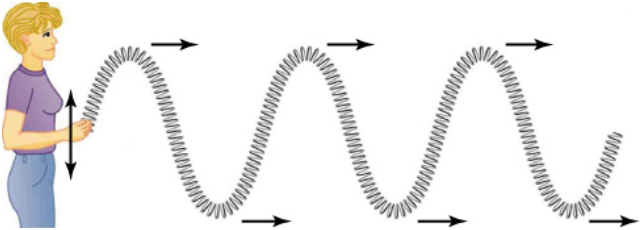


Key parts:

- Crest = highest point
- Trough = lowest point
- Seagull bobs up and down in simple harmonic motion

13.1 Transverse Waves



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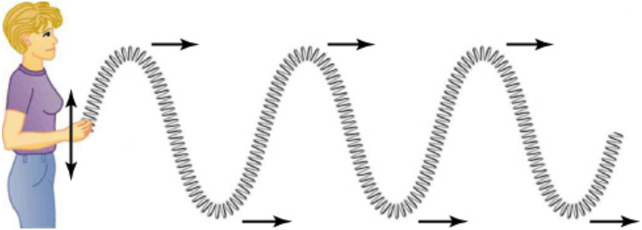

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Transverse wave: disturbance **perpendicular** to direction of propagation.

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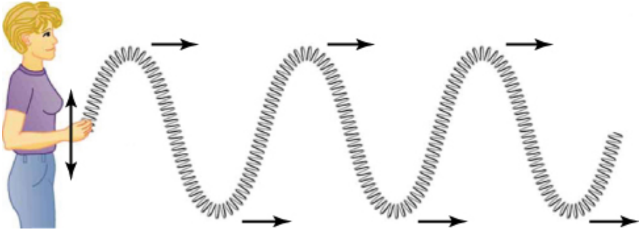

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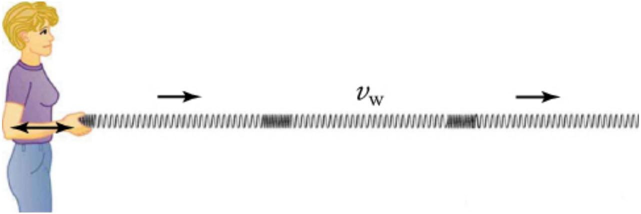
Transverse wave: disturbance **perpendicular** to direction of propagation.

Examples: waves on strings, light, water waves (mostly)

13.1 Longitudinal Waves



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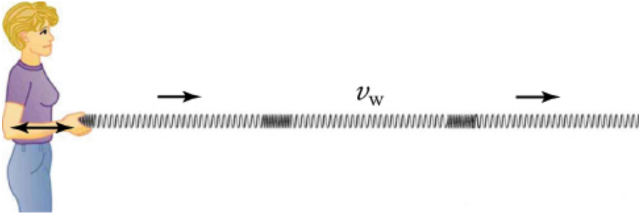

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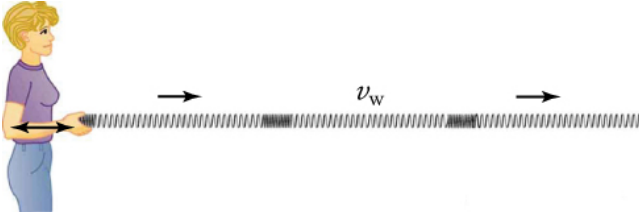

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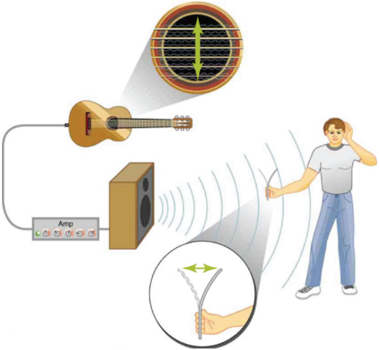
Longitudinal wave: disturbance **parallel** to direction of propagation.

Examples: sound waves, pressure waves, P-waves in earthquakes

13.1 Sound: Longitudinal Wave



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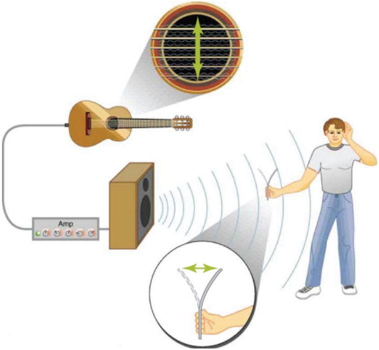

In the Real World

Guitar string: transverse wave (vibrates side-to-side)
Sound from speaker: longitudinal wave (air vibrates forward-backward)

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- **S-waves** (Secondary/Shear): transverse

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  - Slower, arrive second
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S-waves cannot pass through Earth's liquid core!

13.1 The Physics of Surfing

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Ocean waves are **orbital progressive waves**:

- Water particles move in circular paths
- Combination of transverse and longitudinal motion

Learning Objectives

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

- **13.2:** Define amplitude, frequency, period, wavelength, velocity

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- **13.2:** Define amplitude, frequency, period, wavelength, velocity
- **13.2:** Relate wave frequency, period, wavelength, and velocity
- **13.2:** Solve problems involving wave properties

13.2 Wave Variables

Universal Law: The Five Variables

Amplitude A: Maximum displacement from equilibrium
Wavelength λ: Distance between adjacent crests
Period T: Time for one complete cycle
Frequency f: Number of cycles per second (Hz)
Wave velocity v_w: Speed of disturbance

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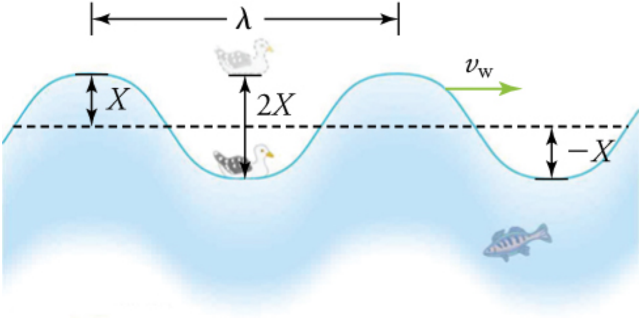
These five variables describe ALL waves in the universe.

13.2 Wave Anatomy Diagram



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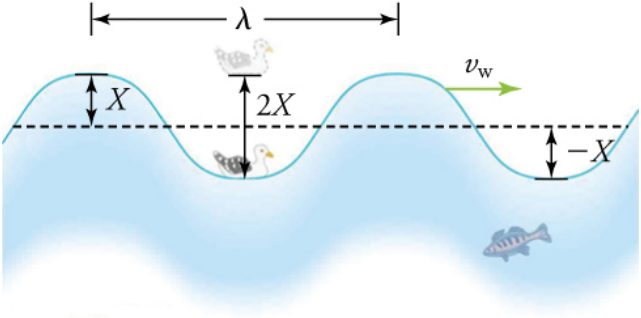

- λ = wavelength (crest to crest)
- A = amplitude (rest to crest)
- v_w = wave velocity (disturbance speed)

13.2 The Universal Relationship

Nature's Source Code

$$\boxed{f = \frac{1}{T}}$$

Frequency equals one over period.

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Meaning:

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Units: Frequency in hertz (Hz) = cycles per second

13.2 The Master Equation

Universal Law: Wave Equation

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

Wave velocity equals frequency times wavelength.

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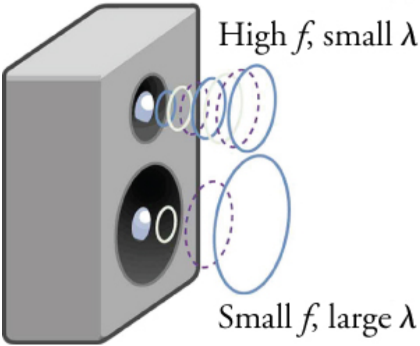
Key insight: In a given medium where v_w is constant, higher frequency means shorter wavelength.

13.2 Frequency and Wavelength



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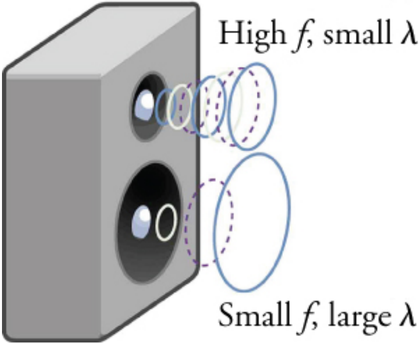

In the Real World: Sound Speakers

Woofer (large): low frequency, long wavelength
Tweeter (small): high frequency, short wavelength

13.2 Earthquake Energy

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Wave properties in earthquakes:

- P-waves: 4-7 km/s in Earth's crust
- S-waves: 2-5 km/s in Earth's crust
- Both faster in more rigid materials
- Energy related to amplitude - large amplitude = more damage

Attempt: Decoding Ocean Motion

The Challenge (3 min, silent)

Ocean waves have wavelength 10.0 m. A seagull bobs up and down once every 5.00 s.

Given:

- $\lambda = 10.0$ m
- $T = 5.00$ s

Find: Wave velocity v_w

Can you predict the wave speed? Work silently.

Compare: Wave Speed

Turn and talk (2 min):

1. What formula did you choose?
2. Did you use $v_w = f\lambda$ or $v_w = \frac{\lambda}{T}$?
3. If you used frequency, how did you find it?

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

Reveal: The Speed of Waves

Self-correct in a different color:

Method 1: Direct calculation

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$$v_w = \frac{\lambda}{T} = \frac{10.0\ \text{m}}{5.00\ \text{s}} = 2.00\ \text{m/s}$$

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Method 2: Using frequency

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$$v_w = f\lambda = (0.200\ \text{Hz})(10.0\ \text{m}) = 2.00\ \text{m/s}$$

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Check: 2 meters per second - reasonable for gentle ocean wave.

Attempt: Toy Spring Wave

The Challenge (3 min, silent)

A woman creates 2 waves per second on a toy spring. Each wave travels 0.9 m in one complete cycle.

Given:

- $f = 2$ Hz (2 waves per second)
- $\lambda = 0.9$ m (one cycle)

Find: (a) Period T (b) Wave velocity v_w

Two-part challenge. Work individually.

Compare: Spring Motion

Turn and talk (2 min):

1. How did you find the period from frequency?
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3. Did your units work out correctly?

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Name wheel: One pair share your approach for both parts.

Reveal: Spring Wave Solution

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Part (a): Find period

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Check: Could also use $v_w = \frac{\lambda}{T} = \frac{0.9}{0.5} = 1.8\ \text{m/s}$

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- **13.3:** Describe standing waves
- **13.3:** Distinguish reflection from refraction

13.3 Complex Wave Patterns

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Real waves look complex because multiple waves combine - **superposition**.

13.3 Superposition of Waves

Universal Law: The Principle of Superposition

When two or more waves meet, they combine by adding their disturbances.

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Key insight:

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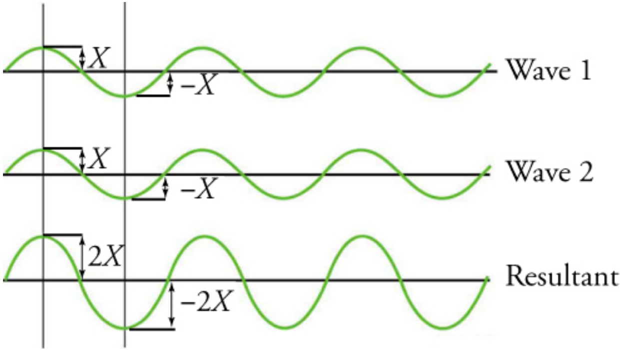
- Forces add vectorially
- Resulting wave = sum of individual disturbances

13.3 Constructive Interference



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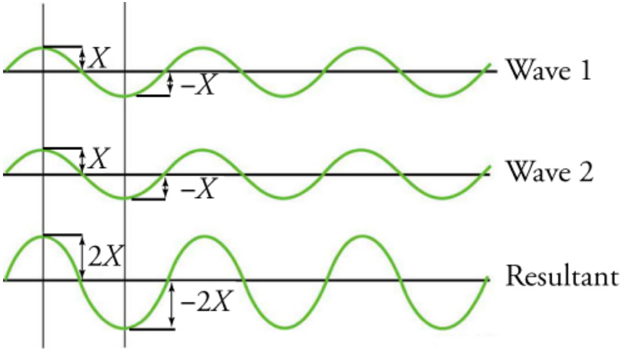

Nature's Rule

Constructive interference: waves exactly in phase combine to produce larger amplitude.

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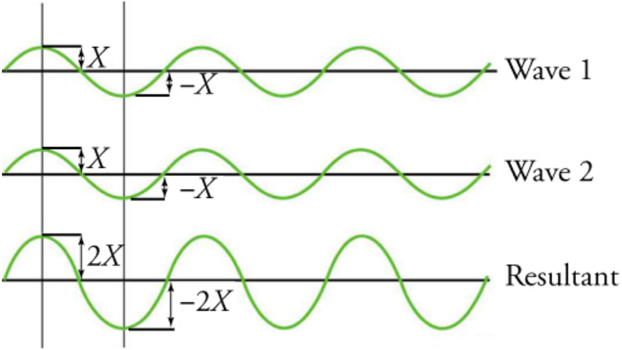
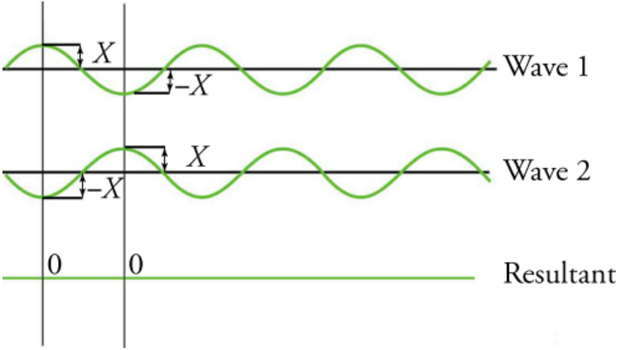


Nature's Rule

Constructive interference: waves exactly in phase combine to produce larger amplitude.

Amplitude doubles when two identical waves align crest-to-crest!

13.3 Destructive Interference



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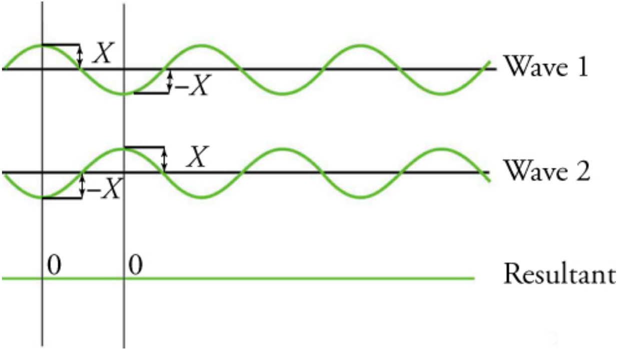

Nature's Rule

Destructive interference: waves exactly out of phase combine to cancel each other.

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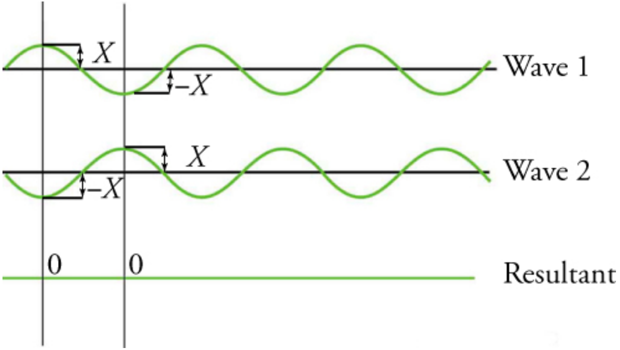


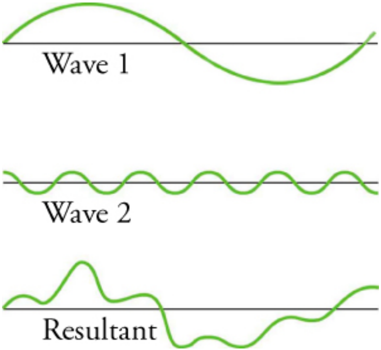
Nature's Rule

Destructive interference: waves exactly out of phase combine to cancel each other.

The Paradox

Two waves can add to create... nothing! Zero amplitude.

13.3 Mixed Interference



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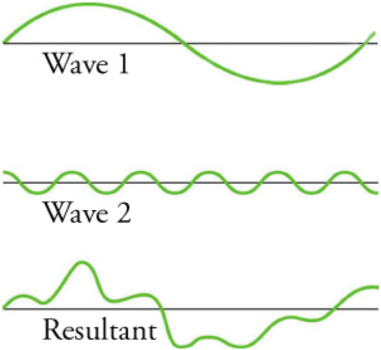

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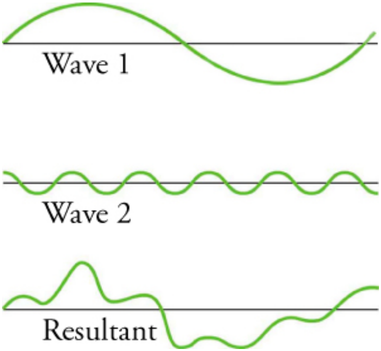
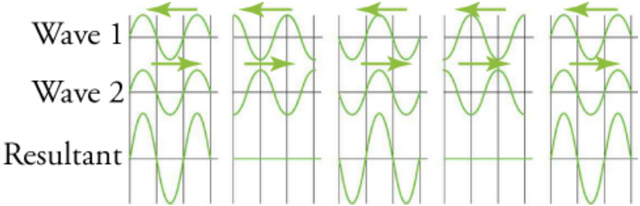


Most real-world waves show **partial** constructive and destructive interference.

Creates complex patterns that vary in space and time.

13.3 Standing Waves



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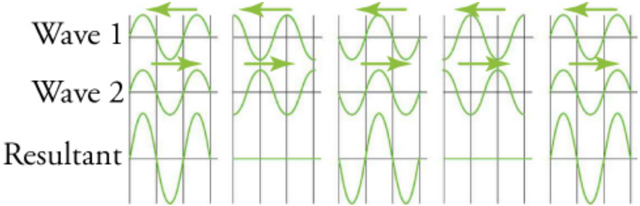
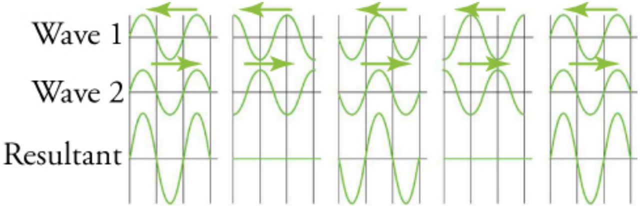


The Source Code

Standing wave: formed by superposition of two identical waves moving in opposite directions.

13.3 Standing Waves



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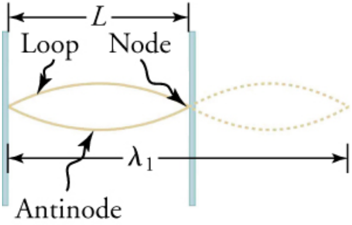
Pattern oscillates in place - doesn't propagate!

13.3 Nodes and Antinodes



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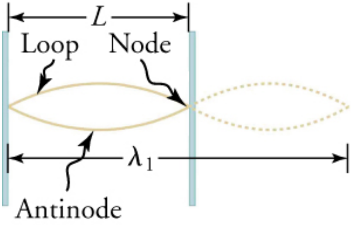
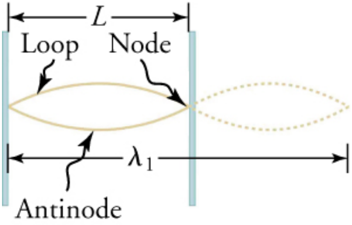


Node: point of zero amplitude (no motion)



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Antinode: point of maximum amplitude

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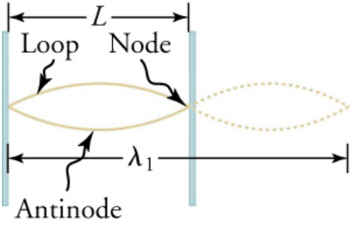

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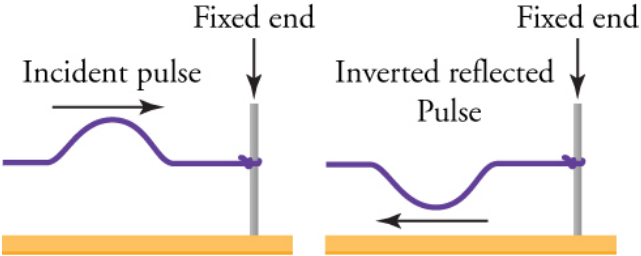
Fixed ends must be nodes - string cannot move there.

13.3 Reflection of Waves



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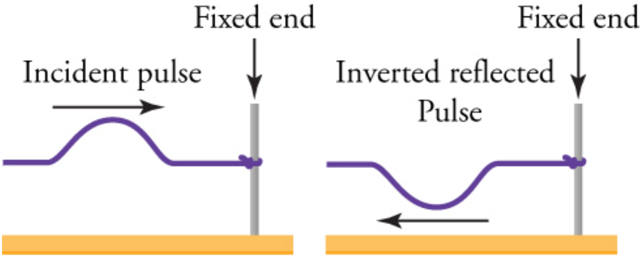
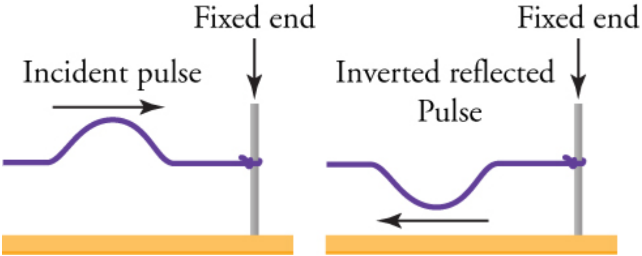


Nature's Rule

Reflection: wave bounces off barrier and changes direction.

13.3 Reflection of Waves

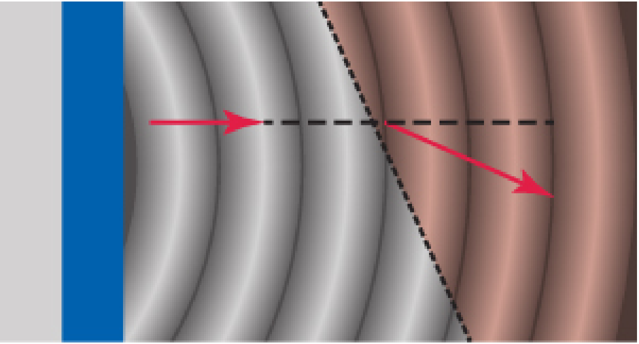


Nature's Rule

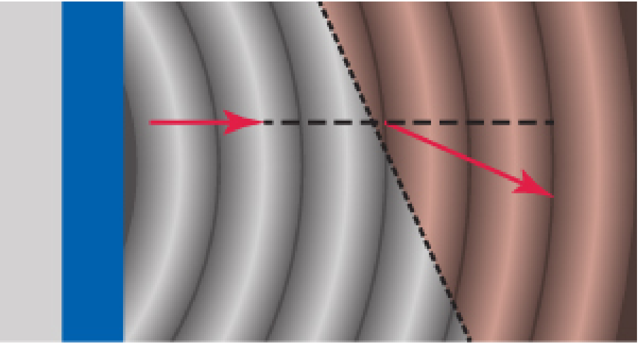
Reflection: wave bounces off barrier and changes direction.

Inversion: wave reflects from fixed end as inverted (crest becomes trough).

13.3 Refraction of Waves

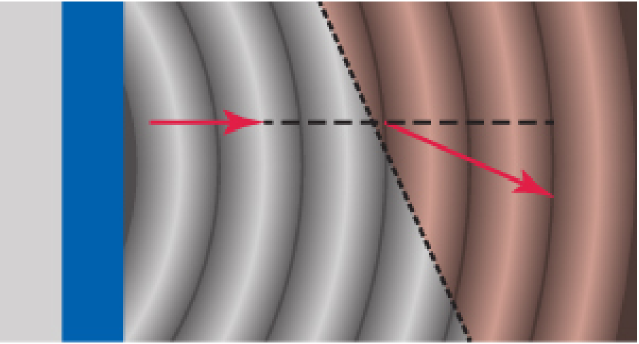


13.3 Refraction of Waves



Nature's Rule

Refraction: wave bends when passing from one medium to another.



Nature's Rule

Refraction: wave bends when passing from one medium to another.

What changes: speed, wavelength, direction

What stays same: frequency

Real-World Application

Earthquake waves reflect off denser rocks, creating standing waves.

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Result:

- Constructive interference at some locations (more damage)
- Destructive interference at other locations (less damage)
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The Paradox

Distance from epicenter doesn't always predict damage - interference patterns matter!

What You Now Know

The Revelations

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5. Superposition: waves add disturbances
6. Interference: constructive amplifies, destructive cancels
7. Standing waves, reflection, refraction

Key Equations

$$f = \frac{1}{T} \quad \text{(frequency and period)} \tag{1}$$

$$T = \frac{1}{f} \tag{2}$$

$$v_w = f\lambda \quad \text{(wave equation)} \tag{3}$$

$$v_w = \frac{\lambda}{T} \tag{4}$$

Remember:

- In constant medium, higher frequency $\rightarrow$ shorter wavelength
- Amplitude is independent of velocity
- All waves obey these relationships

Homework

Complete the assigned problems

posted on the LMS

Temporary page!

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