

PHYS11 CH13: Invisible Disturbances

How Energy Moves Without Moving Matter

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Outline

1 Introduction

2 Types of Waves

3 Wave Properties

4 Wave Interaction

5 Summary

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...

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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 pulse wave from periodic wave

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- **13.1:** Define mechanical waves and medium
- **13.1:** Distinguish pulse wave from periodic wave
- **13.1:** Distinguish longitudinal from transverse waves

13.1 Mechanical Waves

Nature's Rule

Mechanical waves require a medium (solid, liquid, or gas) to travel through.

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 - Waves on guitar strings

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- Water waves in ocean
- Earthquake waves in Earth
- Waves on guitar strings

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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Periodic Wave

- Repeating oscillation
- Many cycles
- Examples: wave pool, guitar string, radio

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Pulse Wave

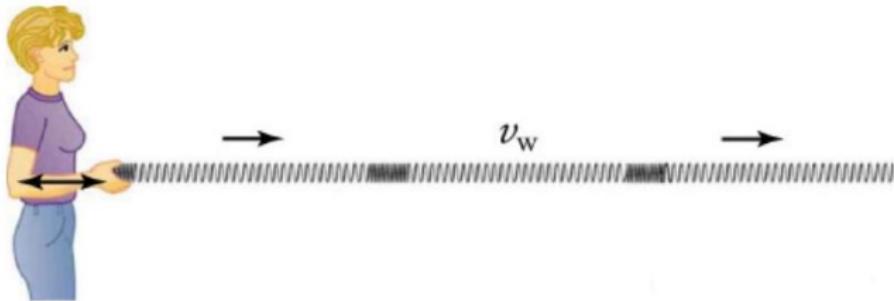
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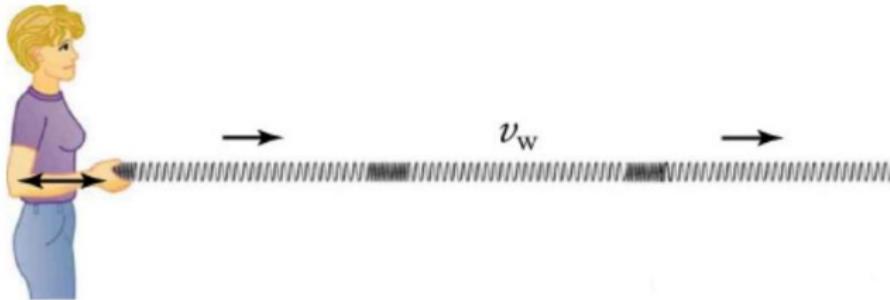
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Periodic waves involve simple harmonic motion.

13.1 Water Wave Anatomy



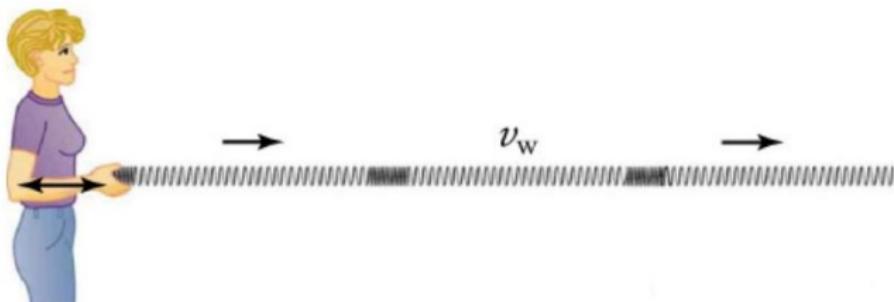
13.1 Water Wave Anatomy



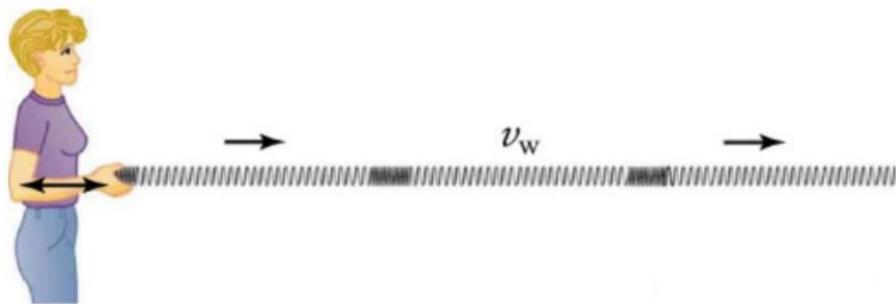
Key parts:

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

13.1 Transverse Waves



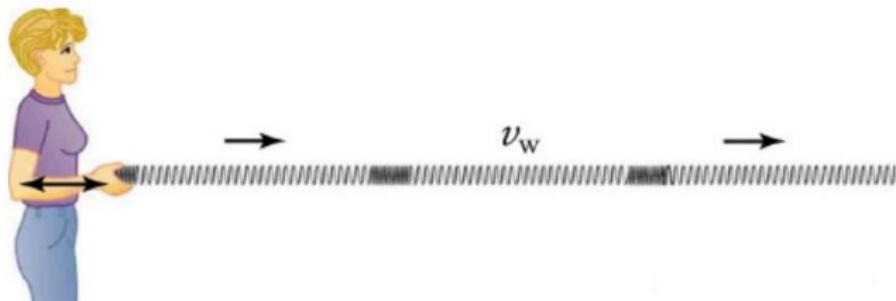
13.1 Transverse Waves



The Source Code

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

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The Source Code

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

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

13.1 Longitudinal Waves



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The Source Code

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

13.1 Longitudinal Waves



The Source Code

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

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

13.1 Sound: Longitudinal Wave



13.1 Sound: Longitudinal Wave



In the Real World

Guitar string: transverse wave (vibrates side-to-side)

Sound from speaker: longitudinal wave (air vibrates forward-backward)

13.1 Earthquake Waves

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 - Fastest, arrive first
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S-waves cannot pass through Earth's liquid core!

13.1 The Physics of Surfing



13.1 The Physics of Surfing



Ocean waves are **orbital progressive waves**:

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

Learning Objectives

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- **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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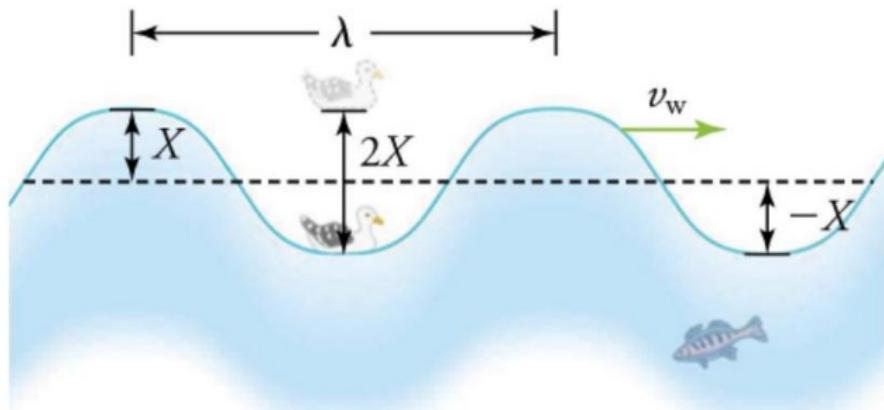
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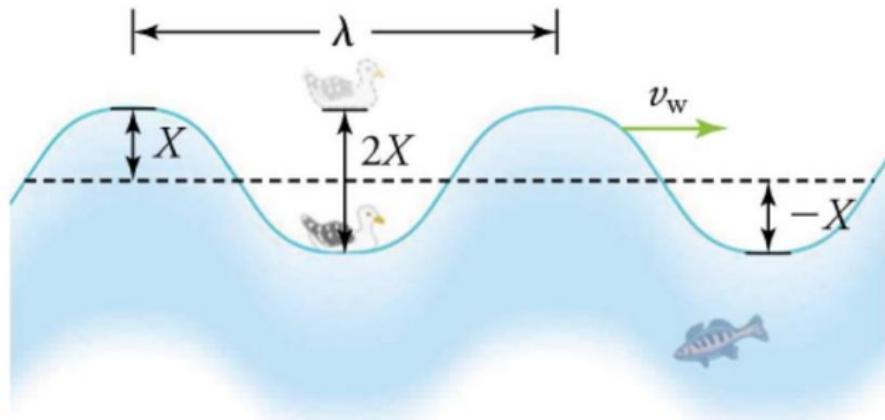
Wave velocity v_w : Speed of disturbance

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

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

Frequency equals one over period.

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Meaning:

- Higher frequency → shorter period
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Units: Frequency in hertz (Hz) = cycles per second

13.2 The Master Equation

Universal Law: Wave Equation

$$v_w = f\lambda$$

Wave velocity equals frequency times wavelength.

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Alternative form:

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

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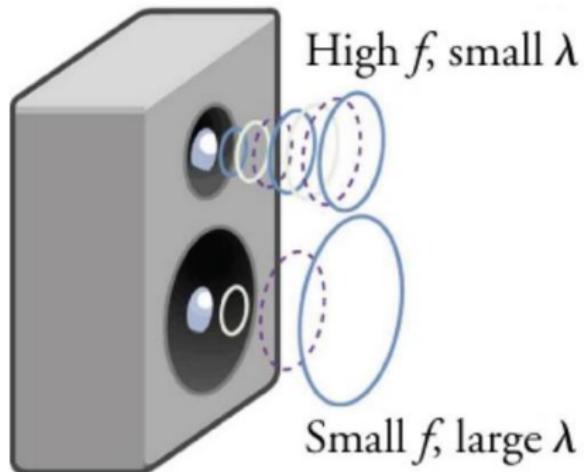
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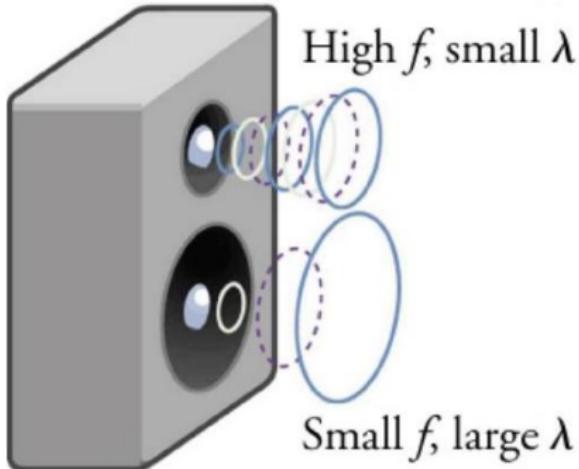
$$v_w = \frac{\lambda}{T}$$

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

13.2 Frequency and Wavelength



13.2 Frequency and Wavelength



In the Real World: Sound Speakers

Woofers (large): low frequency, long wavelength

Tweeters (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:

- $\lambda = 10.0 \text{ m}$
- $T = 5.00 \text{ s}$

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

Reveal: The Speed of Waves

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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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$$f = \frac{1}{T} = \frac{1}{5.00 \text{ s}} = 0.200 \text{ Hz}$$

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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:

- $f = 2 \text{ Hz}$ (2 waves per second)
- $\lambda = 0.9 \text{ m}$ (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?
 - ② Which velocity formula did you use?
 - ③ Did your units work out correctly?

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Part (a): Find period

Reveal: Spring Wave Solution

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

- **13.3:** Describe superposition of waves

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- **13.3:** Distinguish constructive from destructive interference
- **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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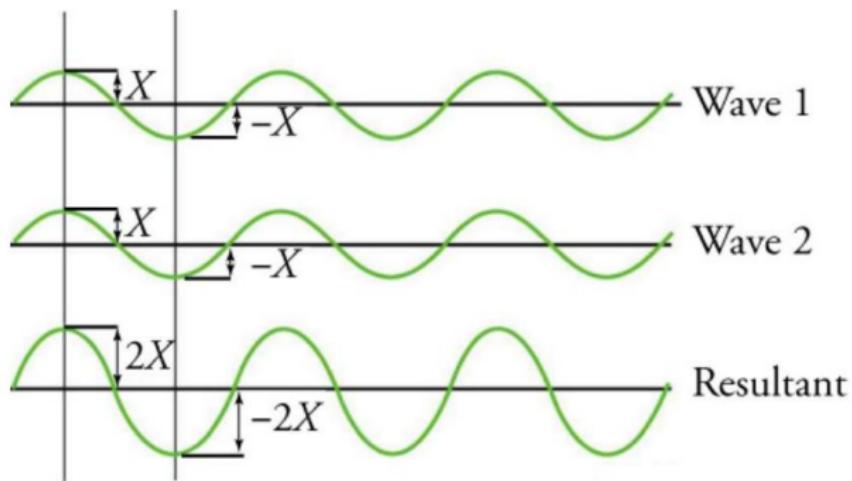
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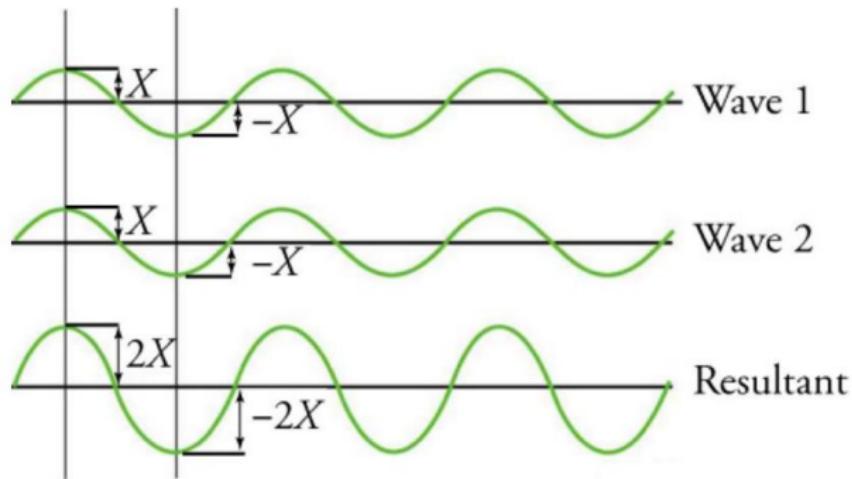
Key insight:

- Disturbances correspond to forces
- Forces add vectorially
- Resulting wave = sum of individual disturbances

13.3 Constructive Interference



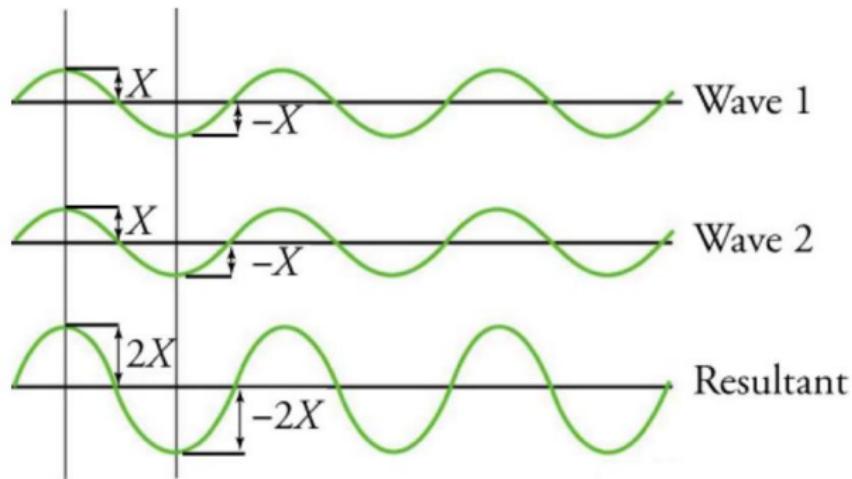
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Nature's Rule

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

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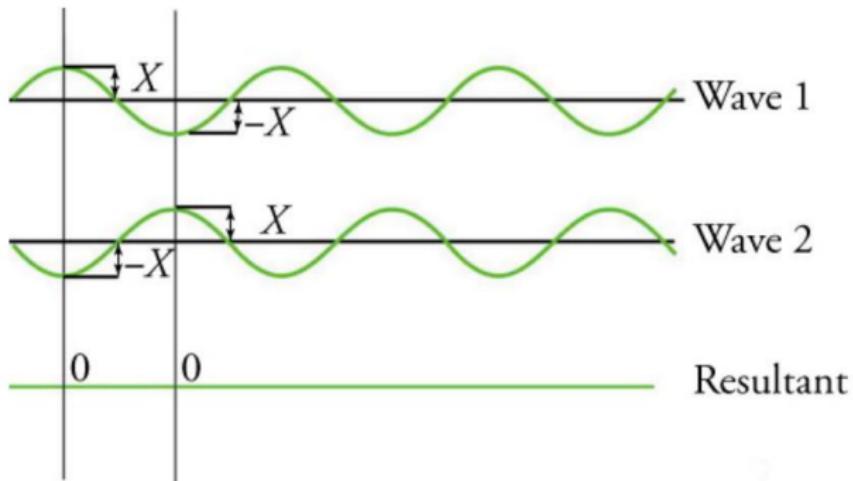


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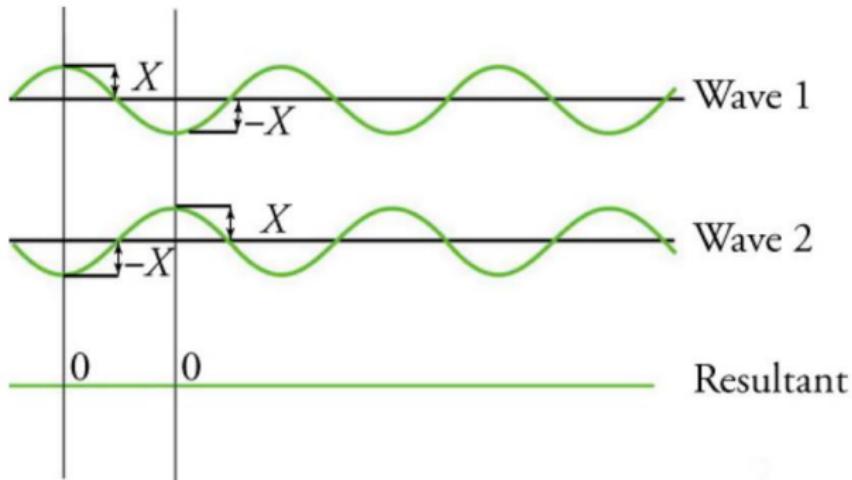
Constructive interference: waves exactly in phase combine to produce larger amplitude.

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

13.3 Destructive Interference



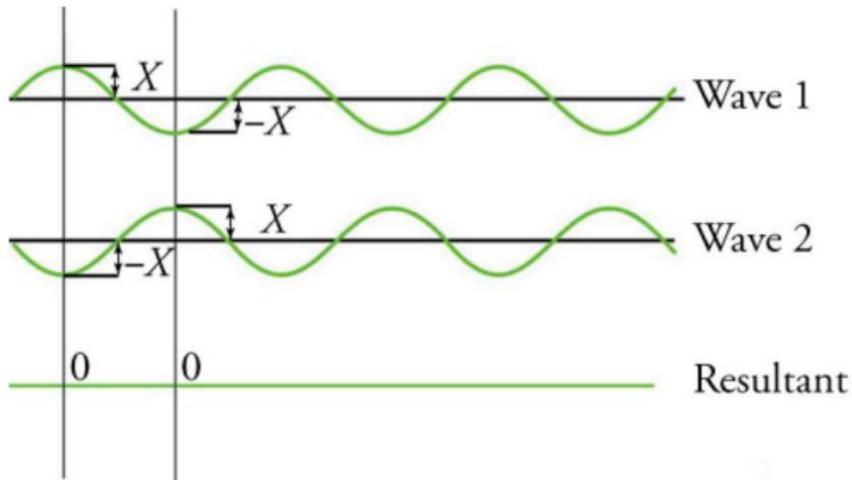
13.3 Destructive Interference



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

13.3 Mixed Interference



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

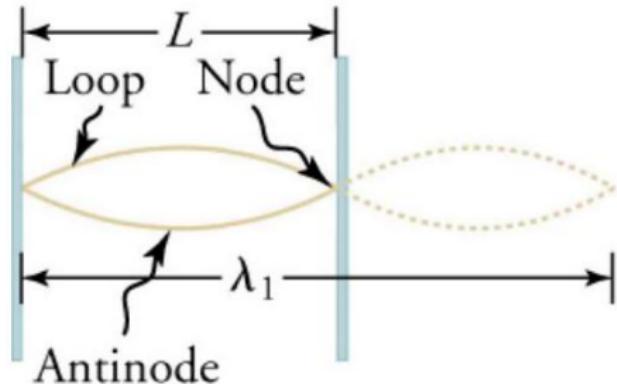


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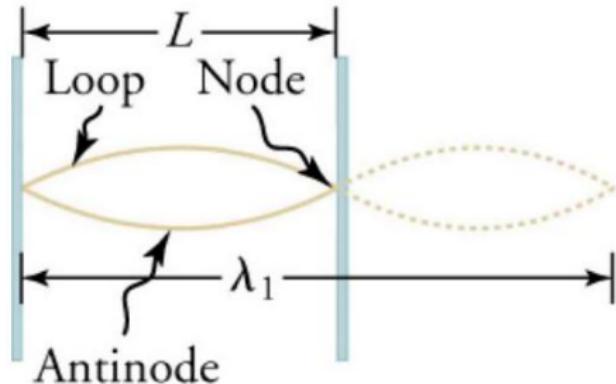
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Pattern oscillates in place - doesn't propagate!

13.3 Nodes and Antinodes

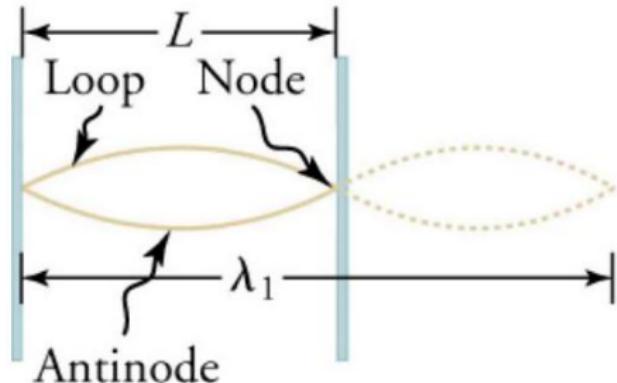


13.3 Nodes and Antinodes



Node: point of zero amplitude (no motion)

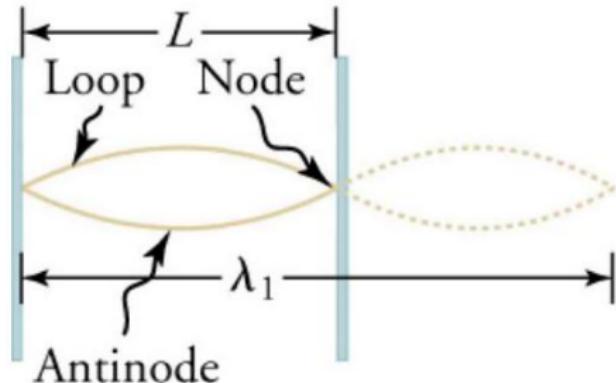
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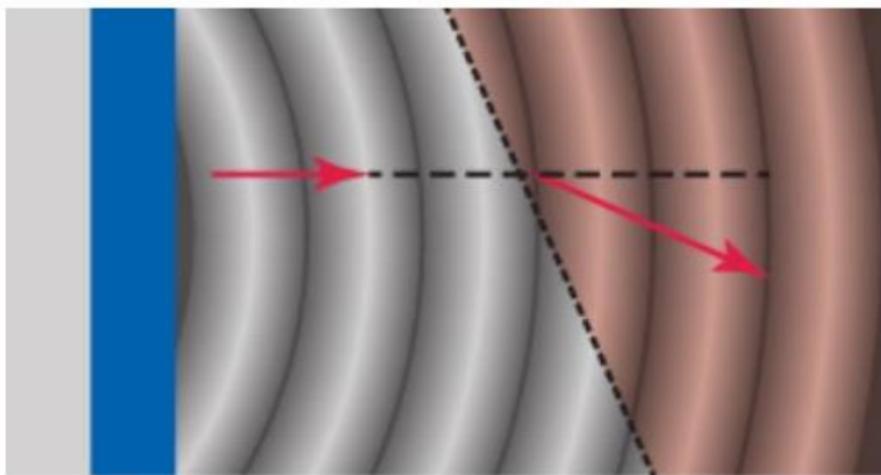


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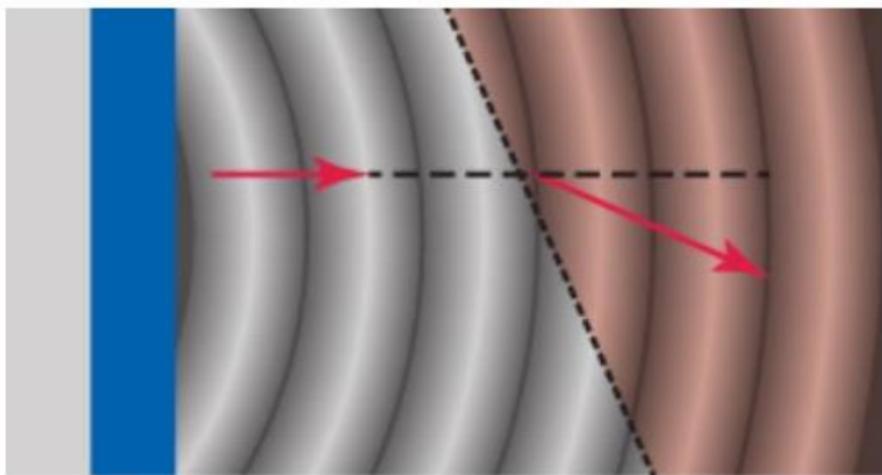
Antinode: point of maximum amplitude

Fixed ends must be nodes - string cannot move there.

13.3 Reflection of Waves



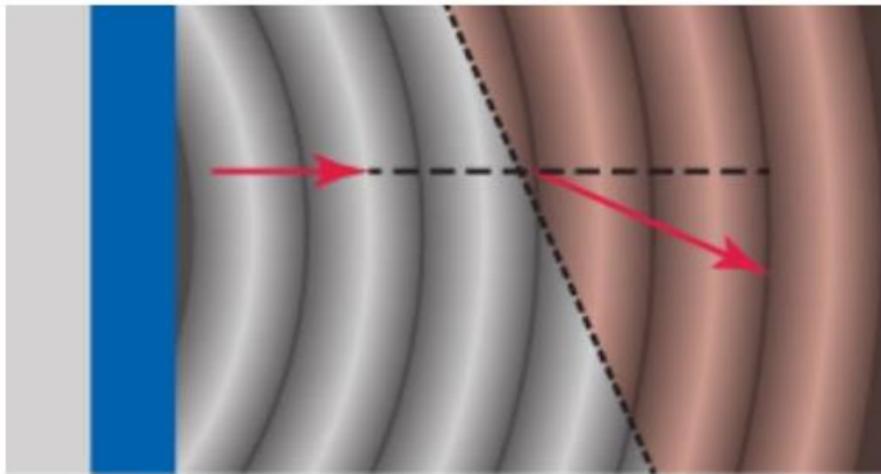
13.3 Reflection of Waves



Nature's Rule

Reflection: wave bounces off barrier and changes direction.

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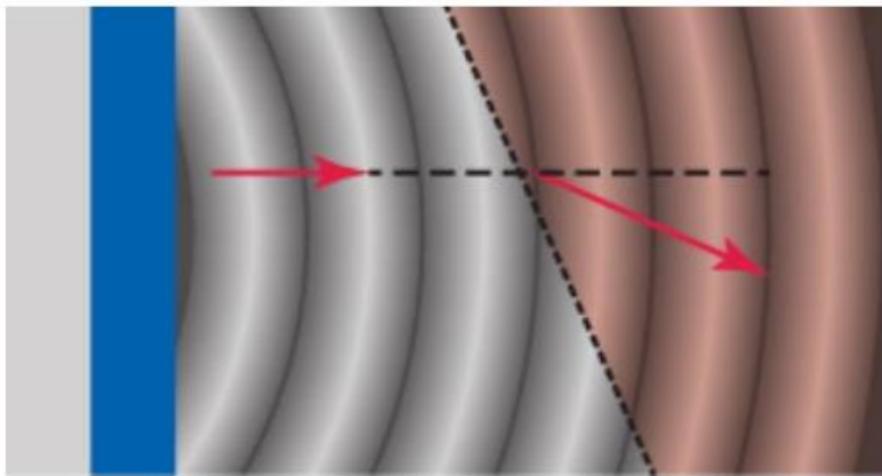


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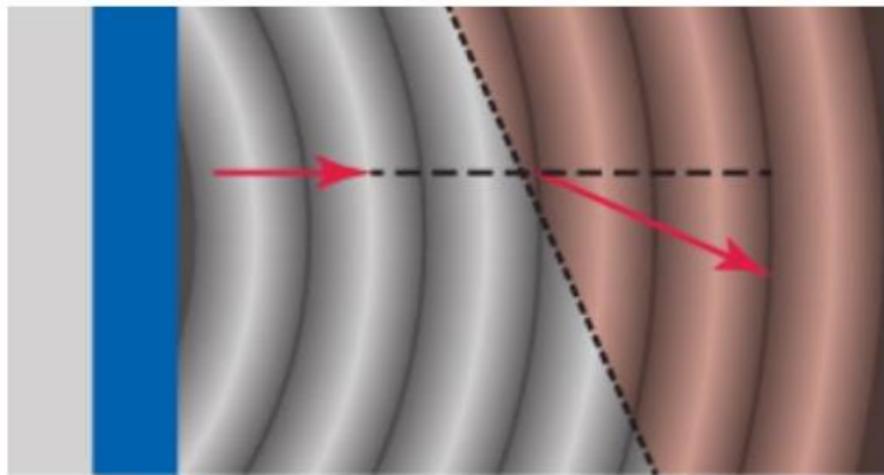
Reflection: wave bounces off barrier and changes direction.

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

13.3 Refraction of Waves



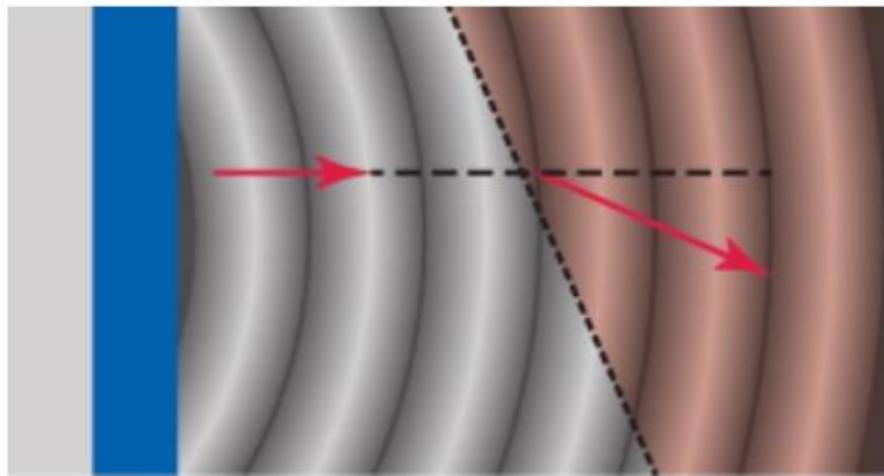
13.3 Refraction of Waves



Nature's Rule

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

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Nature's Rule

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

What changes: speed, wavelength, direction

What stays same: frequency

13.3 Earthquakes and Standing Waves

Real-World Application

Earthquake waves reflect off denser rocks, creating standing waves.

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- 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

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- ⑦ Standing waves, reflection, refraction

Key Equations

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

$$T = \frac{1}{f} \quad (2)$$

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

$$v_w = \frac{\lambda}{T} \quad (4)$$

Remember:

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

Homework

Complete the assigned problems
posted on the LMS