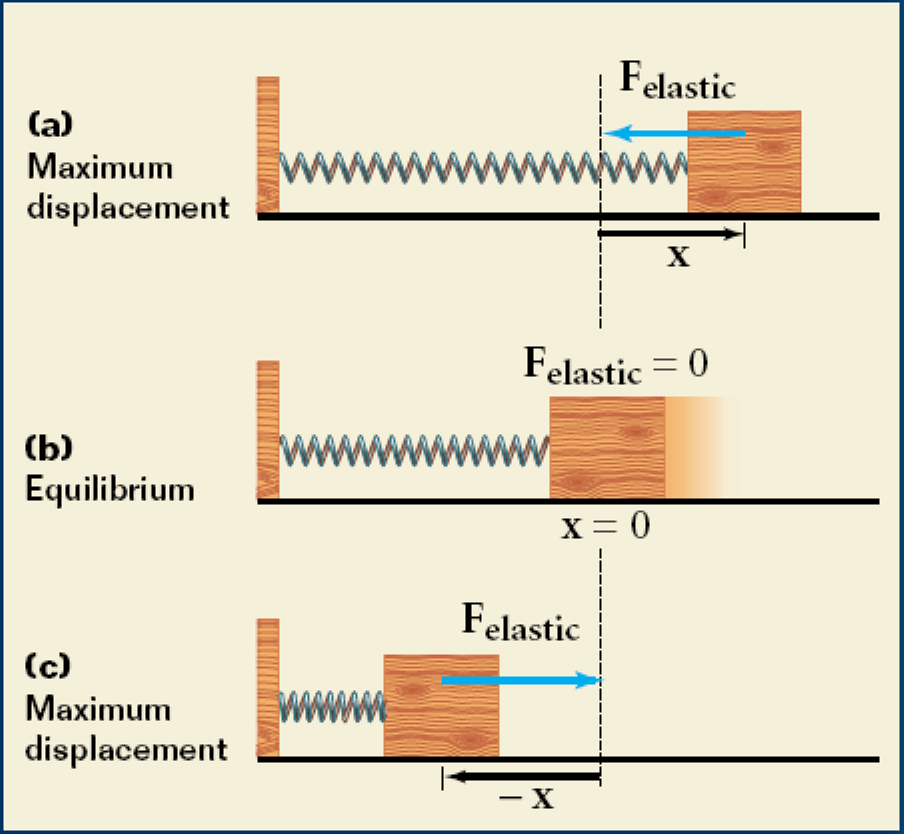
Preview

Objectives

- **Identify** the conditions of simple harmonic motion.
- **Explain** how force, velocity, and acceleration change as an object vibrates with simple harmonic motion.
- **Calculate** the spring force using Hooke's law.

Hooke's Law

- One type of **periodic motion** is the motion of a mass attached to a spring.
- The direction of the force acting on the mass ($F_{elastic}$) is always opposite the direction of the mass's displacement from equilibrium ($x = 0$).



Hooke's Law, *continued*

At equilibrium:

- The **spring force** and the mass's **acceleration** become **zero.**
- The **speed** reaches a **maximum.**

At maximum displacement:

- The **spring force** and the mass's **acceleration** reach a **maximum.**
- The **speed** becomes **zero.**

End of Slide

Hooke's Law, *continued*

- Measurements show that the **spring force,** or **restoring force,** is **directly proportional** to the **displacement** of the mass.

- This relationship is known as **Hooke's Law:**

$$F_{elastic} = -kx$$

spring force = –(spring constant × displacement)

- The quantity ***k*** is a positive constant called the **spring constant.**

End of Slide

Spring Constant

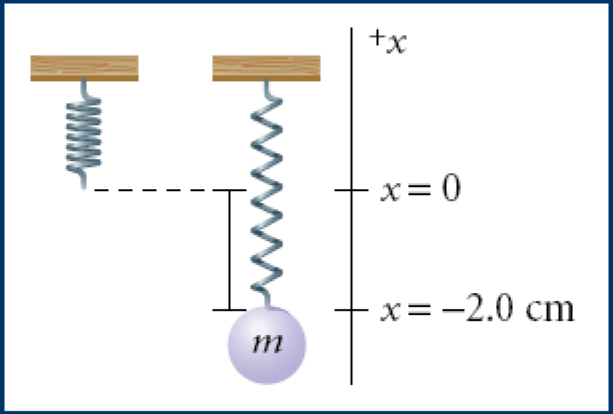
Click below to watch the Visual Concept.

Visual Concept

Sample Problem

Hooke's Law

If a mass of 0.55 kg attached to a vertical spring stretches the spring 2.0 cm from its original equilibrium position, what is the spring constant?



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Sample Problem, *continued*

1. Define

Given:

m = 0.55 kg

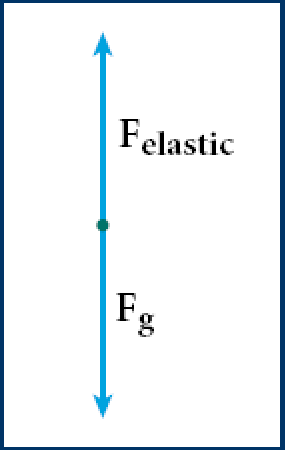
x = –2.0 cm = –0.02 m

g = 9.81 m/s^2

Unknown:

k = ?

Diagram:



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Sample Problem, *continued*

2. Plan

Choose an equation or situation: When the mass is attached to the spring,the equilibrium position changes. At the new equilibrium position, the net force acting on the mass is zero. So the spring force (given by Hooke’s law) must be equal and opposite to the weight of the mass.

$$\mathbf{F}_{\mathbf{net}} = 0 = \mathbf{F}_{\mathbf{elastic}} + \mathbf{F}_{\mathbf{g}}$$

$$F_{elastic} = -kx$$

$$F_g = -mg$$

$$-kx - mg = 0$$

End of Slide

Sample Problem, *continued*

2. Plan, ***continued***

Rearrange the equation to isolate the unknown:

$$kx - mg = 0$$

$$kx = -mg$$

$$k = -\frac{mg}{x}$$

End of Slide

Sample Problem, *continued*

3. Calculate

Substitute the values into the equation and solve:

$$k = -\frac{mg}{x} = -\frac{(0.55\ \text{kg})(9.81\ \text{m/s}^2)}{-0.020\ \text{m}}$$

$$\boxed{k = 270\ \text{N/m}}$$

4. Evaluate

The value of *k* implies that 270 N of force is required to displace the spring 1 m.

Simple Harmonic Motion

- The motion of a vibrating mass-spring system is an example of **simple harmonic motion.**

- **Simple harmonic motion** describes any periodic motion that is the result of a **restoring force** that is **proportional to displacement.**

- Because simple harmonic motion involves a restoring force, ***every simple harmonic motion is a back-and-forth motion over the same path.***

End of Slide

Simple Harmonic Motion

Click below to watch the Visual Concept.

Visual Concept

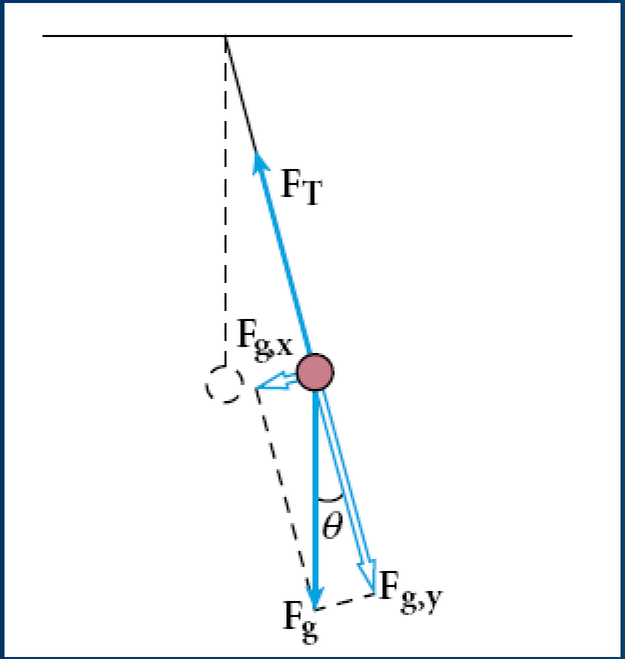
Force and Energy in Simple Harmonic Motion

Click below to watch the Visual Concept.

Visual Concept

The Simple Pendulum

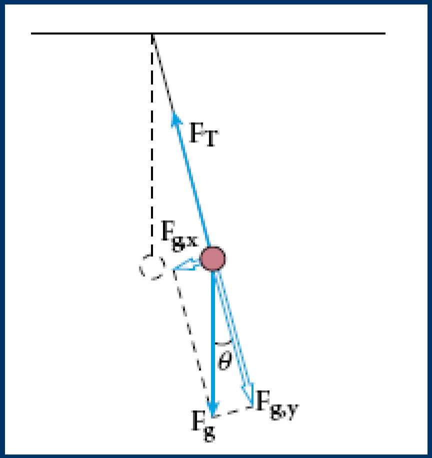
- A **simple pendulum** consists of a mass called a bob, which is attached to a fixed string.
- At any displacement from equilibrium, the **weight** of the bob (F_g) can be resolved into two components.
- The ***x* component** ($F_{g,x} = F_g \sin \theta$) is the only force acting on the bob in the direction of its motion and thus is the **restoring force.**



The forces acting on the bob at any point are the force exerted by the string and the gravitational force.

The Simple Pendulum, *continued*

- The magnitude of the restoring force ($F_{g,x} = F_g \sin \theta$) is proportional to $\sin \theta$.
- When the maximum angle of displacement θ is relatively small (<15°), $\sin \theta$ is approximately equal to θ in radians.



- As a result, **the restoring force is very nearly proportional to the displacement.**
- Thus, the pendulum's motion is an excellent approximation of **simple harmonic motion.**

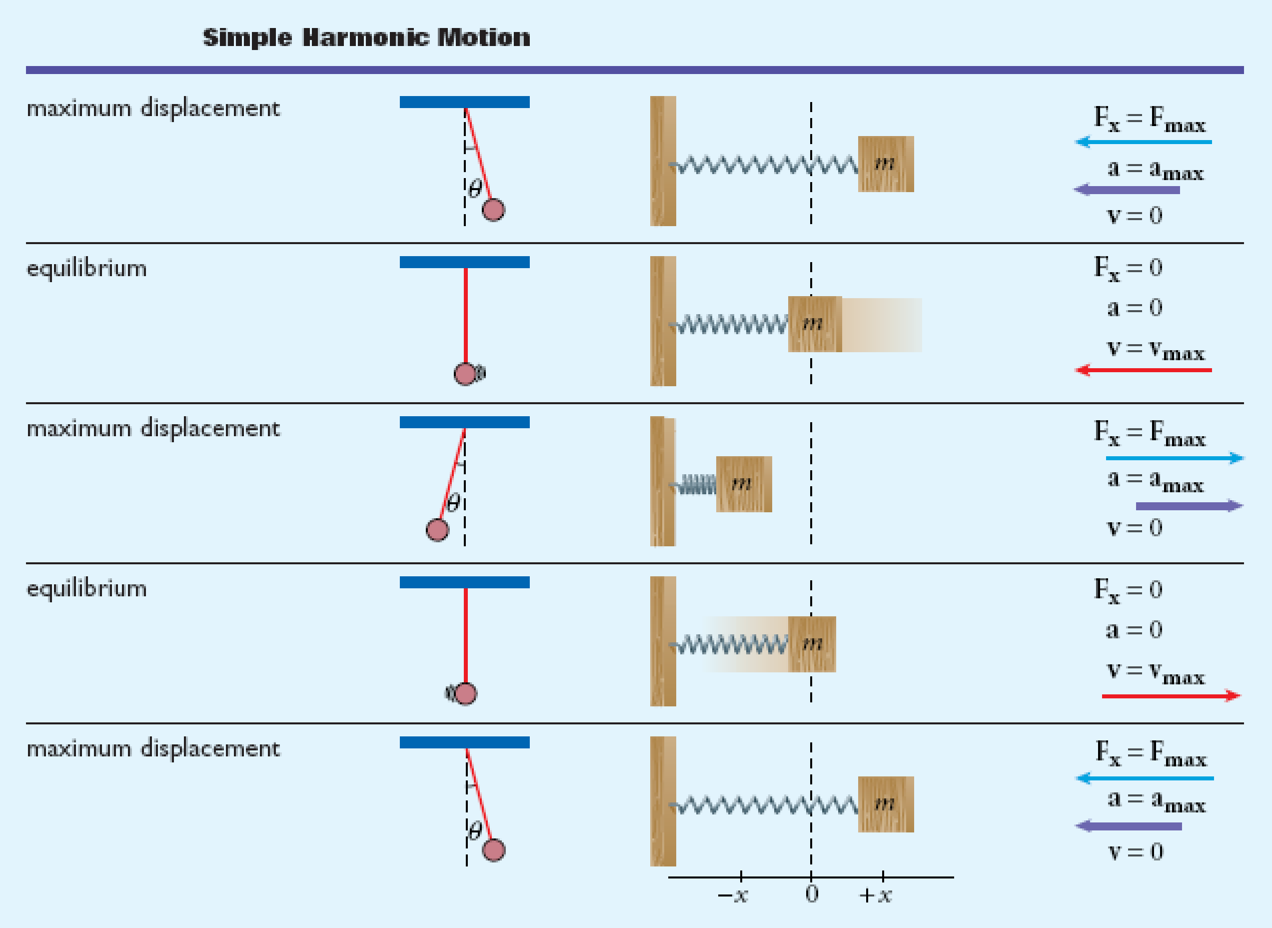
End of Slide

Restoring Force and Simple Pendulums

Click below to watch the Visual Concept.

Visual Concept

Simple Harmonic Motion



Preview

- Objectives
- Amplitude, Period, and Frequency in SHM
- Period of a Simple Pendulum in SHM
- Period of a Mass-Spring System in SHM

Objectives

- **Identify** the amplitude of vibration.
- **Recognize** the relationship between period and frequency.
- **Calculate** the period and frequency of an object vibrating with simple harmonic motion.

Amplitude, Period, and Frequency in SHM

- In SHM, the maximum displacement from equilibrium is defined as the **amplitude** of the vibration.
  - A **pendulum's** amplitude can be measured by the angle between the pendulum's equilibrium position and its maximum displacement.
  - For a **mass-spring system,** the amplitude is the maximum amount the spring is stretched or compressed from its equilibrium position.
- The **SI units** of amplitude are the **radian (rad)** and the **meter (m).**

End of Slide

Amplitude, Period, and Frequency in SHM

- The **period (*T*)** is the time that it takes a complete cycle to occur.
  - The **SI unit** of period is **seconds (s).**
- The **frequency (*f*)** is the number of cycles or vibrations per unit of time.
  - The **SI unit** of frequency is **hertz (Hz).**
  - Hz = s^{-1}

End of Slide

Amplitude, Period, and Frequency in SHM, *continued*

- Period and frequency are **inversely related:**

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

- Thus, any time you have a value for period or frequency, you can calculate the other value.

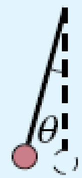
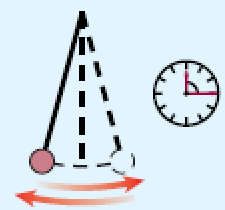
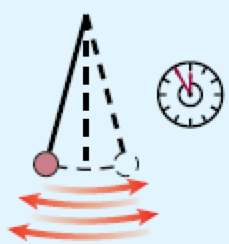
Measures of Simple Harmonic Motion

Click below to watch the Visual Concept.

Visual Concept

Measures of Simple Harmonic Motion

Table 2 Measures of Simple Harmonic Motion

Term	Example	Definition	SI unit
amplitude		maximum displacement from equilibrium	radian, rad meter, m
period, T		time that it takes to complete a full cycle	second, s
frequency, f		number of cycles or vibrations per unit of time	hertz, Hz ($Hz = s^{-1}$)

Period of a Simple Pendulum in SHM

- The **period** of a **simple pendulum** depends on the **length** and on the **free-fall acceleration.**

$$T = 2\pi\sqrt{\frac{L}{a_g}}$$

$$\text{period} = 2\pi\sqrt{\frac{\text{length}}{\text{free-fall acceleration}}}$$

- The period does not depend on the mass of the bob or on the amplitude (for small angles).

End of Slide

Period of a Mass-Spring System in SHM

- The **period** of an ideal **mass-spring system** depends on the **mass** and on the **spring constant.**

$$T = 2\pi\sqrt{\frac{m}{k}}$$

$$\text{period} = 2\pi\sqrt{\frac{\text{mass}}{\text{spring constant}}}$$

- The period does not depend on the amplitude.
- This equation applies only for systems in which the spring obeys Hooke's law.

Preview

- Objectives
- Wave Motion
- Wave Types
- Period, Frequency, and Wave Speed
- Waves and Energy Transfer

Objectives

- **Distinguish** local particle vibrations from overall wave motion.
- **Differentiate** between pulse waves and periodic waves.
- **Interpret** waveforms of transverse and longitudinal waves.
- **Apply** the relationship among wave speed, frequency, and wavelength to solve problems.
- **Relate** energy and amplitude.

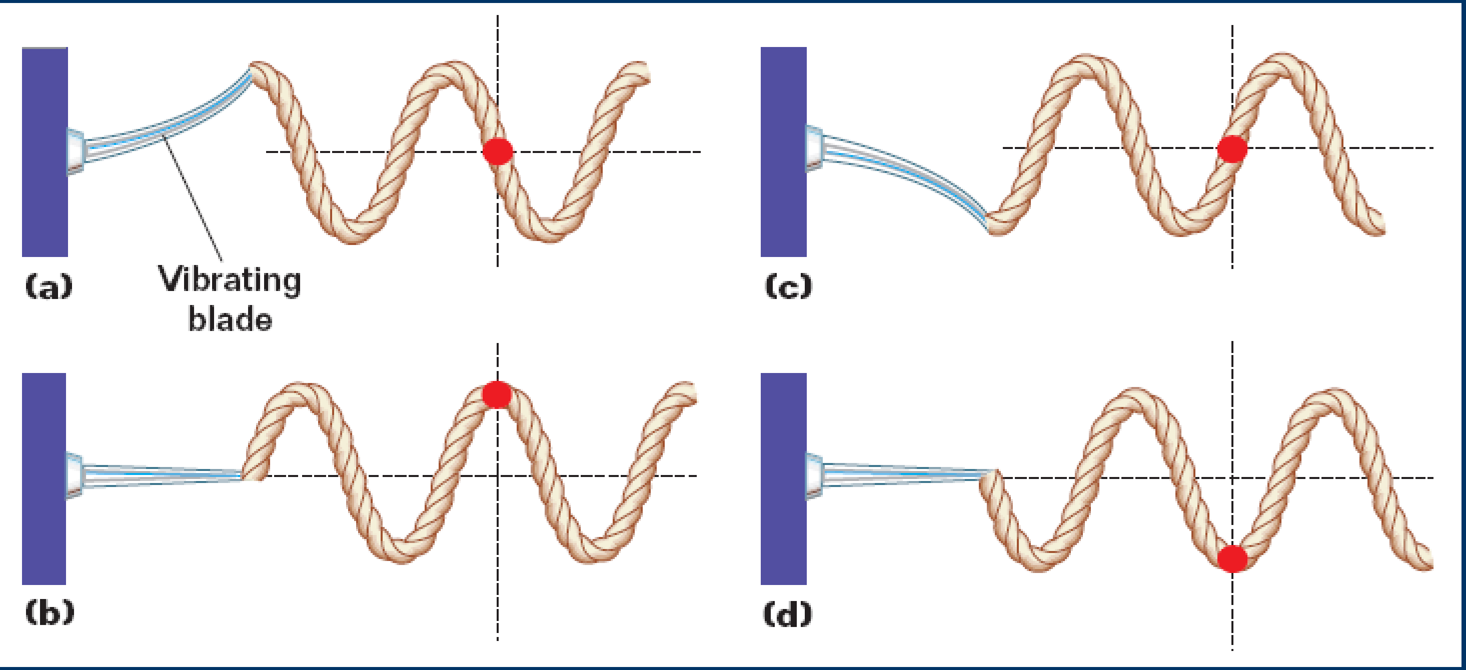
Wave Motion

- A **wave** is the motion of a disturbance.
- A **medium** is a physical environment through which a disturbance can travel. For example, water is the medium for ripple waves in a pond.
- Waves that require a medium through which to travel are called **mechanical waves.** Water waves and sound waves are mechanical waves.
- **Electromagnetic waves** such as visible light do not require a medium.

Wave Types

- A wave that consists of a single traveling pulse is called a **pulse wave.**
- Whenever the source of a wave's motion is a periodic motion, such as the motion of your hand moving up and down repeatedly, a **periodic wave** is produced.
- A wave whose source vibrates with simple harmonic motion is called a **sine wave.** Thus, a sine wave is a special case of a periodic wave in which the periodic motion is simple harmonic.

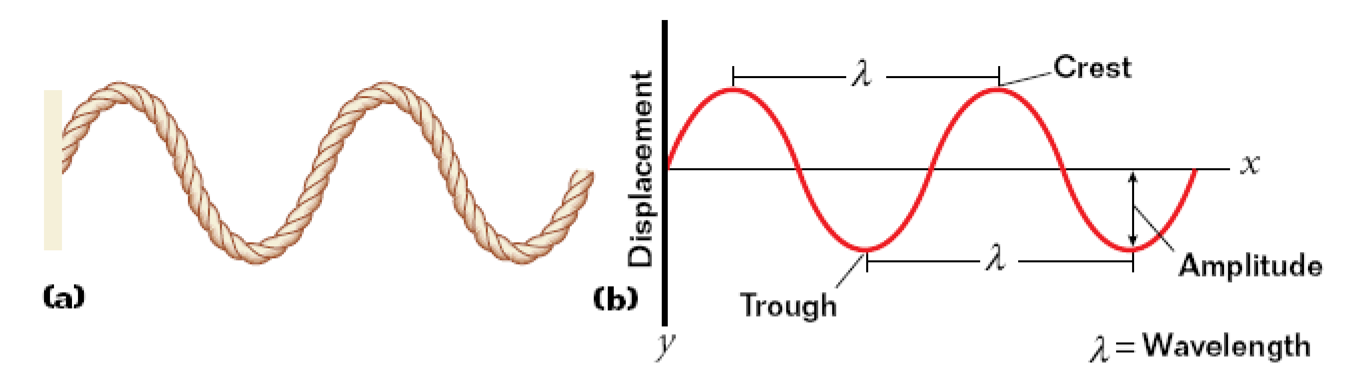
Relationship Between SHM and Wave Motion



As the sine wave created by this vibrating blade travels to the right, a single point on the string vibrates up and down with simple harmonic motion.

Wave Types, *continued*

- A **transverse wave** is a wave whose particles vibrate **perpendicularly** to the direction of the wave motion.
- The **crest** is the **highest** point above the equilibrium position, and the **trough** is the **lowest** point below the equilibrium position.
- The **wavelength (λ)** is the distance between two adjacent similar points of a wave.



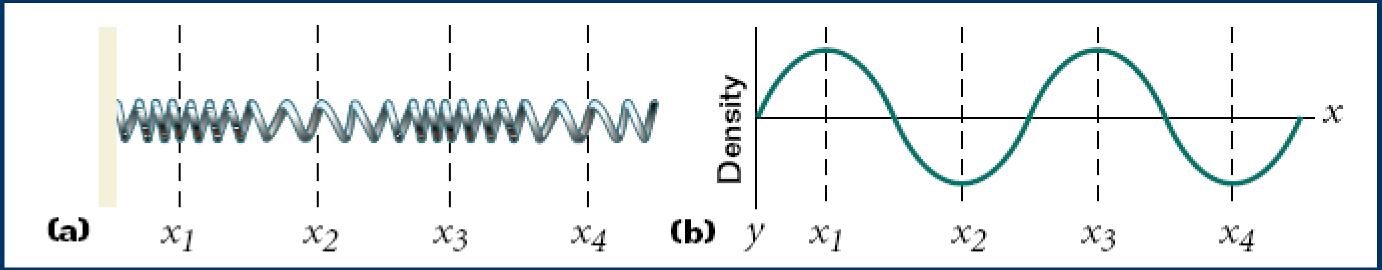
Transverse Waves

Click below to watch the Visual Concept.

Visual Concept

Wave Types, *continued*

- A **longitudinal wave** is a wave whose particles vibrate parallel to the direction the wave is traveling.
- A longitudinal wave on a spring at some instant *t* can be represented by a graph. The **crests** correspond to compressed regions, and the **troughs** correspond to stretched regions.
- The **crests** are regions of **high density and pressure** (relative to the equilibrium density or pressure of the medium), and the **troughs** are regions of **low density and pressure.**



End of Slide

Longitudinal Waves

Click below to watch the Visual Concept.

Visual Concept

Period, Frequency, and Wave Speed

- The **frequency of a wave** describes the number of waves that pass a given point in a unit of time.
- The **period of a wave** describes the time it takes for a complete wavelength to pass a given point.
- The relationship between period and frequency in SHM holds true for waves as well; the period of a wave is **inversely related** to its frequency.

End of Slide

Characteristics of a Wave

Click below to watch the Visual Concept.

Visual Concept

Period, Frequency, and Wave Speed, *continued*

- The **speed of a mechanical wave** is constant for any given medium.
- The **speed of a wave** is given by the following equation:

$$v = f\lambda$$

wave speed = frequency × wavelength

- This equation applies to both mechanical and electromagnetic waves.

End of Slide

Waves and Energy Transfer

- Waves **transfer energy** by the vibration of matter.
- Waves are often able to transport energy efficiently.
- The rate at which a wave transfers energy depends on the **amplitude.**
  - The greater the amplitude, the more energy a wave carries in a given time interval.
  - For a mechanical wave, the energy transferred is proportional to the square of the wave's amplitude.
- The amplitude of a wave gradually diminishes over time as its energy is dissipated.

End of Slide

Preview

Objectives

- **Apply** the superposition principle.
- **Differentiate** between constructive and destructive interference.
- **Predict** when a reflected wave will be inverted.
- **Predict** whether specific traveling waves will produce a standing wave.
- **Identify** nodes and antinodes of a standing wave.

End of Slide

Wave Interference

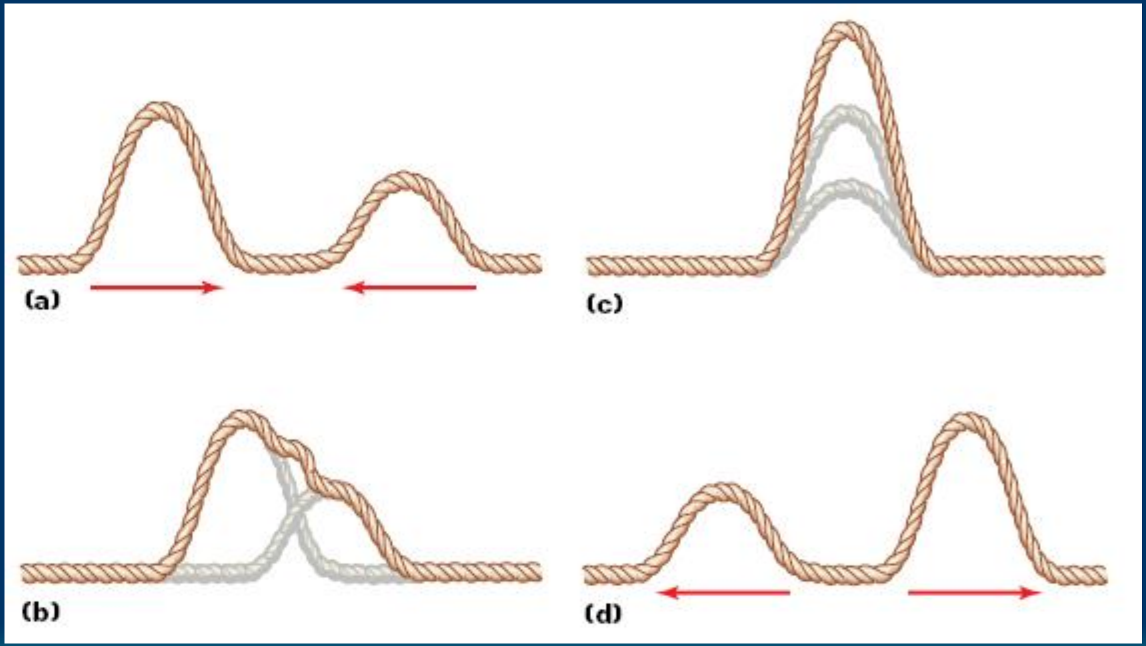
- Two different material objects can never occupy the same space at the same time.

- Because mechanical waves are not matter but rather are displacements of matter, **two waves *can* occupy the same space at the same time.**

- The combination of two overlapping waves is called **superposition.**

Wave Interference, *continued*

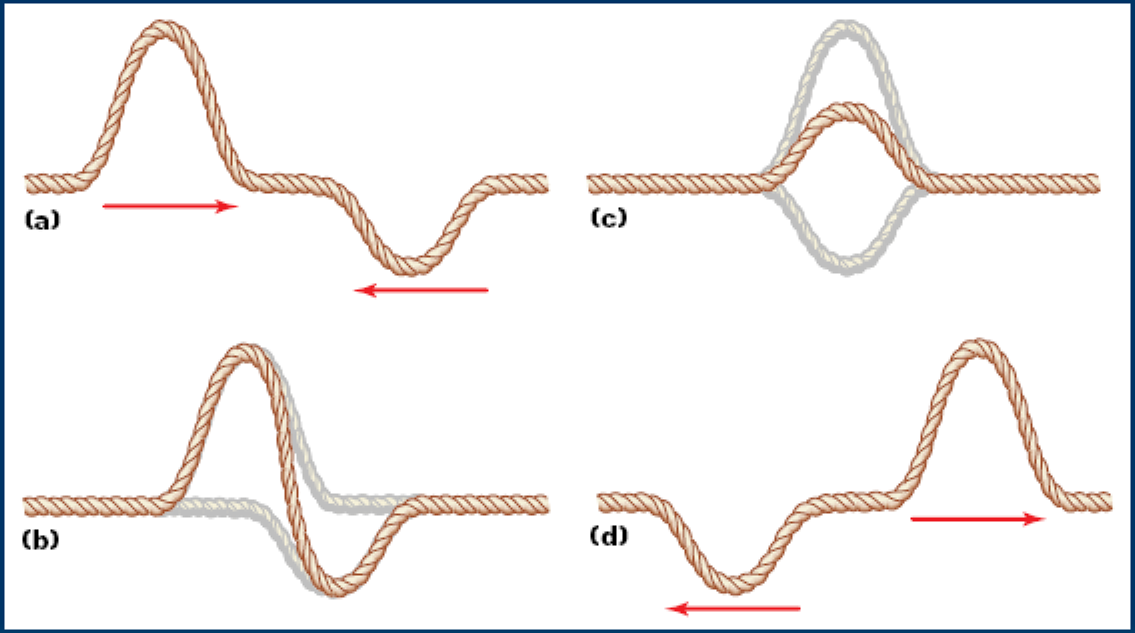
In **constructive interference,** individual displacements on the **same side** of the equilibrium position are added together to form the resultant wave.



End of Slide

Wave Interference, *continued*

In **destructive interference,** individual displacements on **opposite sides** of the equilibrium position are added together to form the resultant wave.



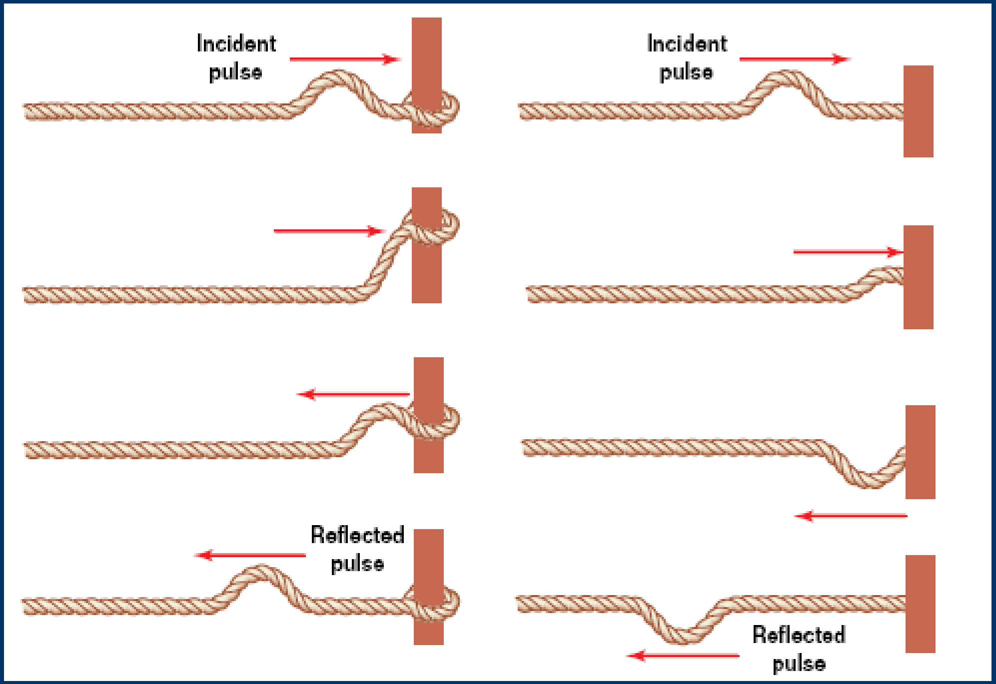
Comparing Constructive and Destructive Interference

Click below to watch the Visual Concept.

Visual Concept

Reflection

- What happens to the motion of a wave when it reaches a boundary?
- At a **free** boundary, waves are **reflected.**
- At a **fixed** boundary, waves are **reflected and inverted.**



Free boundary Fixed boundary

Standing Waves

Click below to watch the Visual Concept.

Visual Concept

Standing Waves

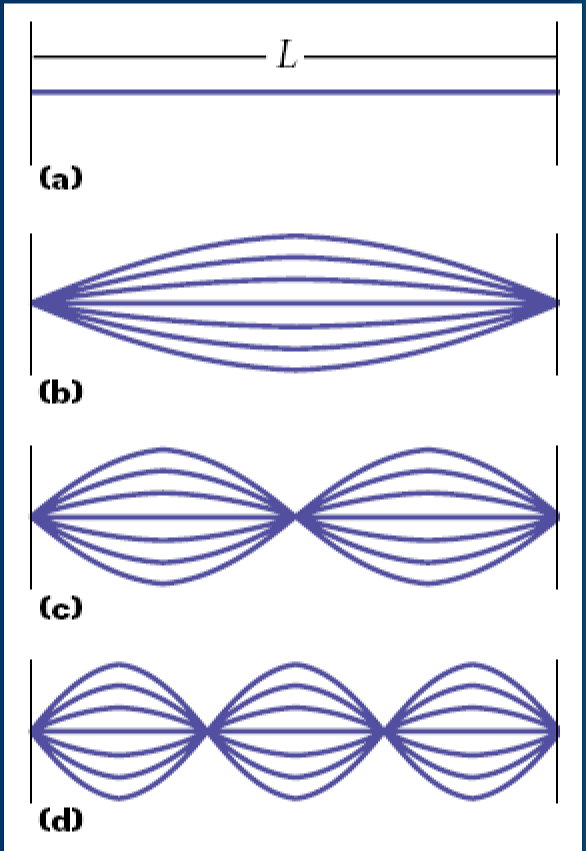
- A **standing wave** is a wave pattern that results when two waves of the same frequency, wavelength, and amplitude travel in opposite directions and interfere.

- Standing waves have nodes and antinodes.
  - A **node** is a point in a standing wave that maintains **zero displacement.**
  - An **antinode** is a point in a standing wave, halfway between two nodes, at which the **largest displacement** occurs.

End of Slide

Standing Waves, *continued*

- Only **certain wavelengths** produce standing wave patterns.
- The **ends** of the string must be **nodes** because these points cannot vibrate.
- A standing wave can be produced for any wavelength that allows both ends to be nodes.
- In the diagram, possible wavelengths include ***2L*** (b), ***L*** (c), and ***2/3L*** (d).



Standing Waves

This photograph shows four possible standing waves that can exist on a given string. The diagram shows the progression of the second standing wave for one-half of a cycle.