Chapter 17
Mechanical Waves and Sound

17.1 Mechanical Waves

What Are Mechanical Waves?

A mechanical wave is created when a source of energy causes a vibration to travel through a medium.

What Are Mechanical Waves?

A mechanical wave is a disturbance in matter that carries energy from one place to another.

- **The material through which a wave travels is called a medium.**
- **Mechanical waves require a medium to travel through.**
- **A vibration is a repeating back-and-forth motion.**

Types of Mechanical Waves

3 main types of mechanical waves

transverse waves

longitudinal waves

surface waves

Mechanical waves are classified by the way they move through a medium.

Types of Mechanical Waves

A transverse wave is a wave that causes the medium to vibrate at right angles to the direction in which the wave travels.

The wave carries energy from left to right, in a direction perpendicular to the up-and-down motion of the rope.

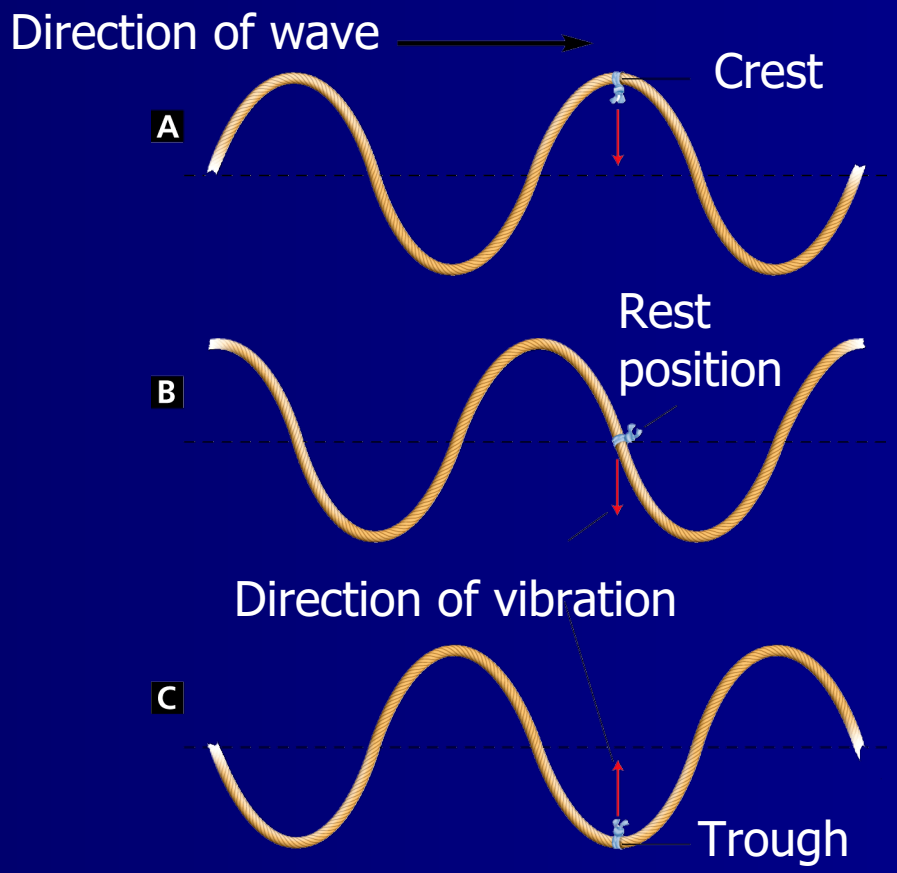
Types of Mechanical Waves

Transverse Waves

- **The highest point of the wave is the crest.**
- **The lowest point of the wave is the trough.**

Types of Mechanical Waves

Transverse Waves



Types of Mechanical Waves

Longitudinal Waves

A longitudinal wave is a wave in which the vibration of the medium is parallel to the direction the wave travels.

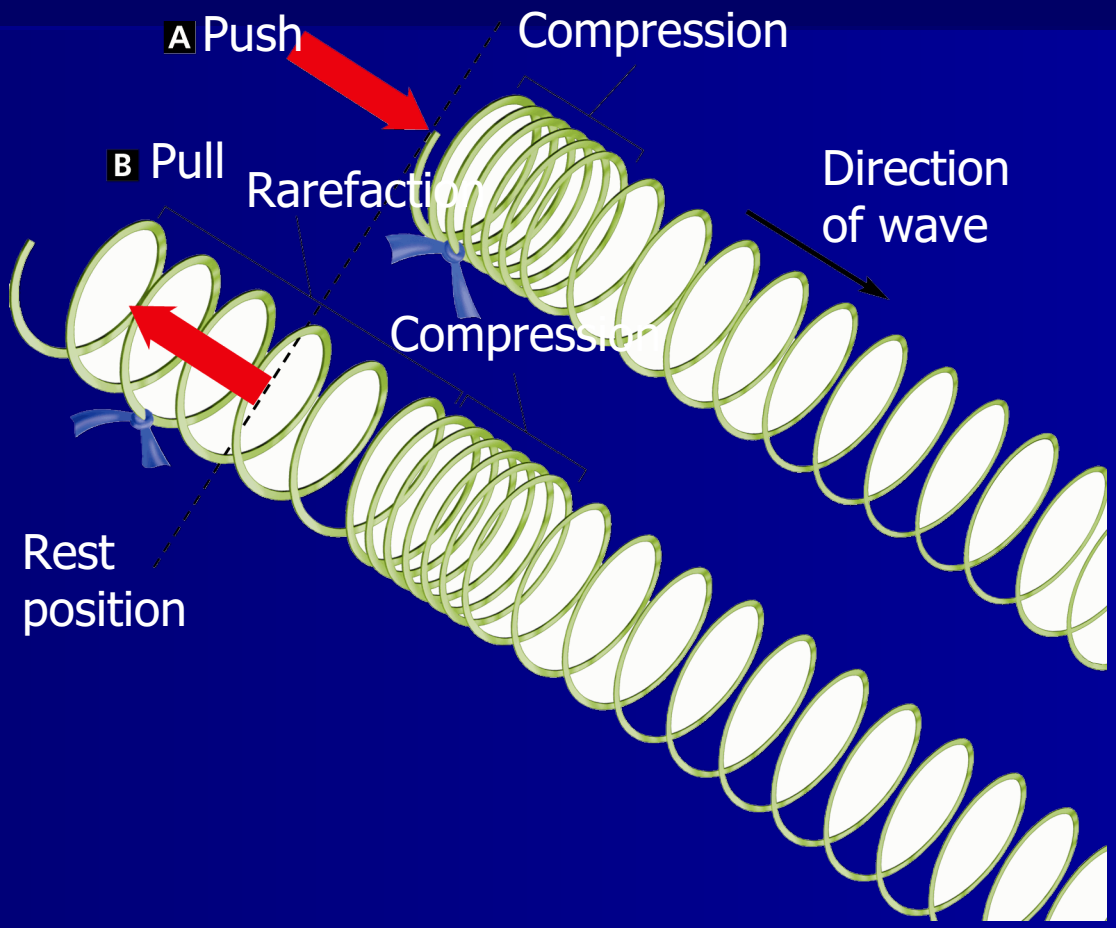
Types of Mechanical Waves

Longitudinal Waves

- **An area where the particles in a medium are spaced close together is called a compression.**
- **An area where the particles in a medium are spread out is called a rarefaction.**

Types of Mechanical Waves

Longitudinal Waves



Types of Mechanical Waves

As compressions and rarefactions travel along the spring, each coil vibrates back and forth around its rest position.

Types of Mechanical Waves

Surface Waves

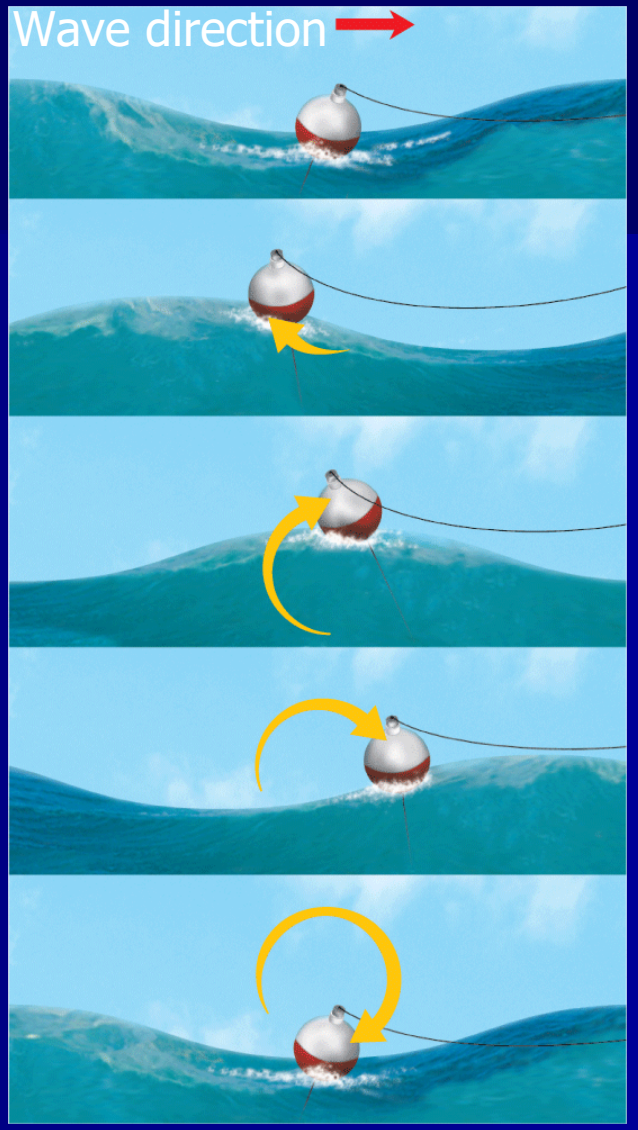
A surface wave is a wave that travels along a surface separating two media.

Ocean waves are the most familiar kind of surface waves.

Types of Mechanical Waves

Surface Waves

As the ocean wave moves to the right, the bobber moves in a circle, returning to its original position.



Assessment Questions

1. A mechanical wave carries energy from one place to another through the
   a. physical transfer of matter.
   b. interaction of electromagnetic fields.
   c. phase changes of a medium.
   d. vibration of a medium.

Assessment Questions

1. A mechanical wave carries energy from one place to another through the
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Assessment Questions

2. In what type of wave is the vibration of the medium parallel to the direction in which the wave travels?
   a. transverse wave
   b. longitudinal wave
   c. surface wave
   d. rarefaction

Assessment Questions

2. In what type of wave is the vibration of the medium parallel to the direction in which the wave travels?

   a. transverse wave

   b. longitudinal wave

   c. surface wave

   d. rarefaction

Assessment Questions

3. As a surface wave travels across water, molecules of water move in a circular pattern.

   True
   False

Assessment Questions

3. As a surface wave travels across water, molecules of water move in a circular pattern.

True
False

Chapter 17: Mechanical Waves and Sound

17.2 Properties of Mechanical Waves

Frequency and Period

Any motion that repeats at regular time intervals is called periodic motion.

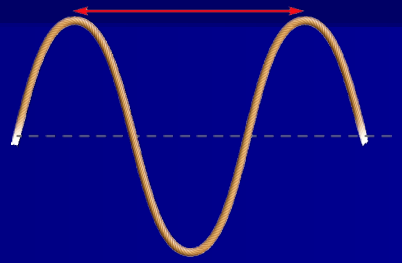
- **The time required for one cycle is called the period.**
- **Frequency is the number of complete cycles in a given time.**
- **Frequency is measured in cycles per second, or hertz (Hz).**

Frequency and Period

A. A wave vibrating at one cycle per second has a frequency of 1.0 Hz.

Frequency = 1.0 hertz

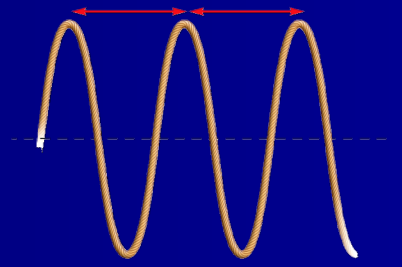
A One cycle per second



B. A wave vibrating at two cycles per second has a frequency of 2.0 Hz.

Frequency = 2.0 hertz

B Two cycles per second



Wavelength

Wavelength is the distance between a point on one wave and the same point on the next cycle of the wave.

Increasing the frequency of a wave decreases its wavelength.

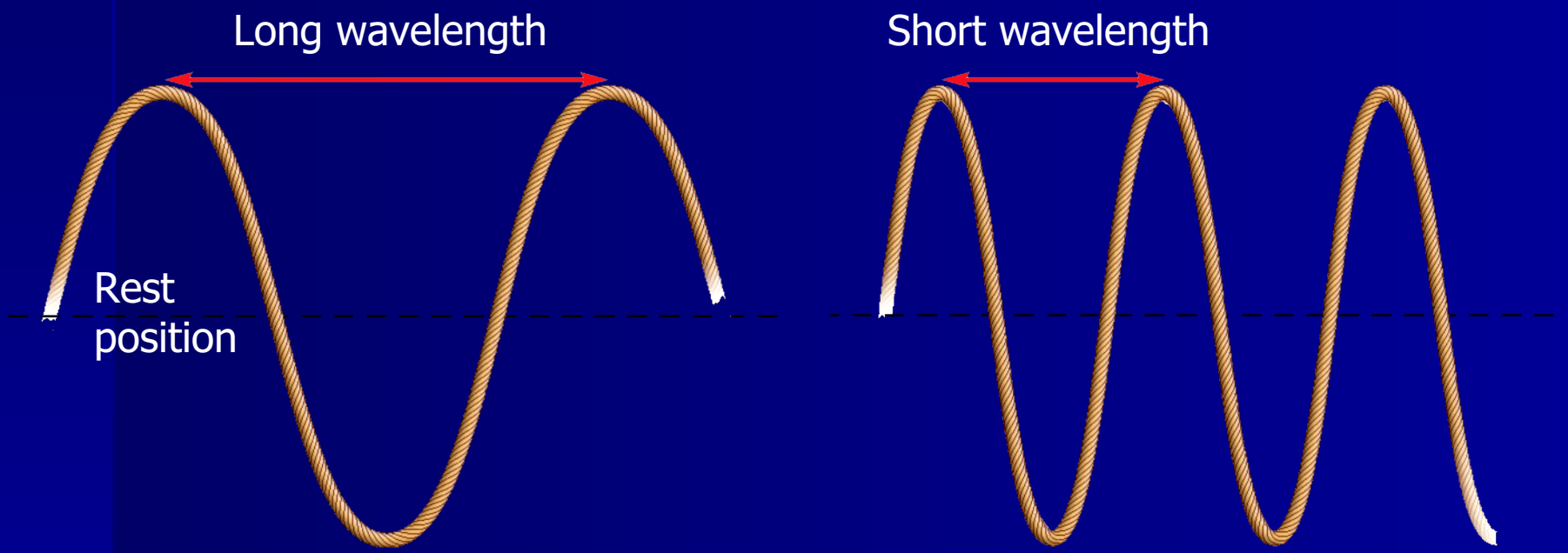
Wavelength

Transverse wavelength is measured between adjacent crests or between adjacent troughs.

Longitudinal wavelength is the distance between adjacent compressions or rarefactions.

Wavelength

Wavelength can be measured from any point on a wave to the same point on the next cycle of the wave.



Wave Review

1. If the horizontal distance from a crest to trough is 1.0 m, what is the wavelength?
2. If 20 waves pass a point in 5 s, what is the frequency?

Wave Review

1. If the horizontal distance from a crest to trough is 1.0 m, what is the wavelength? 1.0 m
2. If 20 waves pass a point in 5 s, what is the frequency?

   20 waves / 5 seconds =

   4 waves per second = 4Hz

Wave Speed

How are frequency, wavelength, and speed related?

If you assume that waves are traveling at a constant speed, then wavelength is inversely proportional to frequency.

Wave Speed

When the wavelength is in meters, and the frequency is in hertz, the units for speed are meters per second.

The speed of a wave is also calculated by dividing its wavelength by its period.

Speed of Waves

$$\text{Speed} = \text{Wavelength} \times \text{Frequency}$$

Wave Speed

Speed of Mechanical Waves

One end of a rope is vibrated to produce a wave with a wavelength of 0.25 meter. The frequency of the wave is 3.0 hertz. What is the speed of the wave?

Wave Speed

Speed of Mechanical Waves

One end of a rope is vibrated to produce a wave with a wavelength of 0.25 meter. The frequency of the wave is 3.0 hertz. What is the speed of the wave?

Speed of Waves

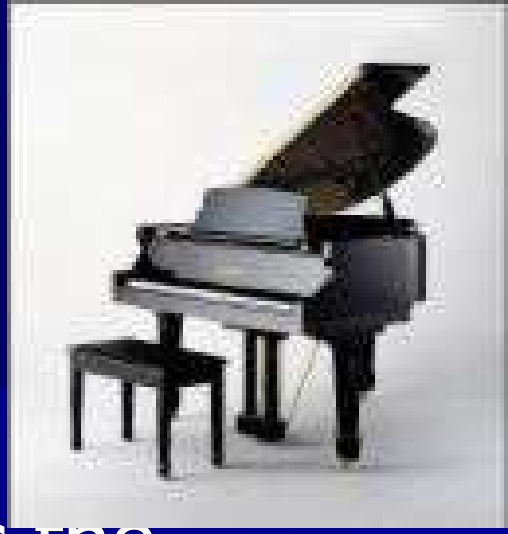
$$\text{Speed} = \text{Wavelength} \times \text{Frequency}$$

Speed = 0.25m x 3.0Hz = 0.75m/s

Wave Speed Example

- The string of a piano that produces the note middle C vibrates with a frequency of 264 Hz. If the sound waves in air have a wavelength of 1.3 m, what is the speed of sound in air?

Wave Speed Example



- The string of a piano that produces the note middle C vibrates with a frequency of 264 Hz. If the sound waves in air have a wavelength of 1.3 m, what is the speed of sound in air?

Speed of Waves

$$\text{Speed} = \text{Wavelength} \times \text{Frequency}$$

- Speed = 1.3m x 264Hz = 363.2m/s

Wave Speed Practice

1. If wavelength is 15.0 m and the frequency is 0.100 Hz, what is the speed?

2. The speed of sound is 340 m/s. What is the wavelength of a sound wave with a frequency of 220 Hz?

Wave Speed Practice

1. If wavelength is 15.0 m and the frequency is 0.100 Hz, what is the speed?

Speed = 15.0m x .1Hz = 1.5 m/s

2. The speed of sound is 340 m/s. What is the wavelength of a sound wave with a frequency of 220 Hz?

340 m/s = m x 220Hz = 340/220 = 1.545m

Wave speed practice

3. A wave has a frequency of 10 Hz and a wavelength of 30 m, what is the speed?

4. At 25°C the speed of sound is 346 m/s, but at 0°C it is 332 m/s. Why?

Wave speed practice

3. A wave has a frequency of 10 Hz and a wavelength of 30 m, what is the speed?

Speed = 30m x 10Hz = 300m/s

4. At 25°C the speed of sound is 346 m/s, but at 0°C it is 332 m/s. Why?

Slower moving and closer together molecules in the medium (air) slow the ability of the wave to move

Amplitude

The amplitude of a wave is the maximum displacement of the medium from its rest position.

The more energy a wave has, the greater is its amplitude.

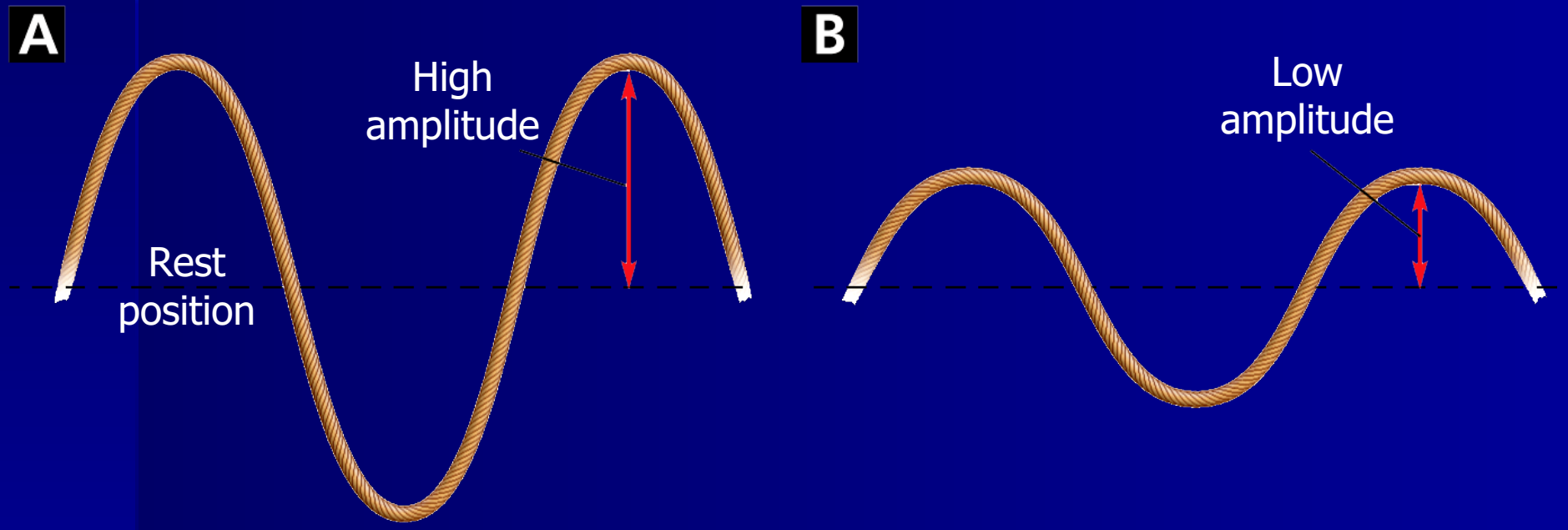
Amplitude

The amplitude of a transverse wave is the distance from the rest position to a crest or a trough.

It takes more energy to produce a wave with higher crests and deeper troughs.

Amplitude

The more energy a wave has, the greater is its amplitude.



Amplitude

The amplitude of a longitudinal wave is the maximum displacement of a point from its rest position.

The more energy the wave has, the more the medium will be compressed or displaced.

Assessment Questions

1. While wading in shallow waters, six waves crash into your legs in a 24-second span. What is the frequency of the waves?

   a. 4 Hz

   b. 18 Hz

   c. 0.25 Hz

   d. 2 Hz

Assessment Questions

1. While wading in shallow waters, six waves crash into your legs in a 24-second span. What is the frequency of the waves?

   a. 4 Hz

   b. 18 Hz

   c. 0.25 Hz= 6 waves / 24 seconds

   d. 2 Hz

Assessment Questions

2. What is the speed of an earthquake wave if it has a wavelength of 2.3 km and a frequency of 3 Hz?
   a. 6.9 km/s
   b. 5.3 km/s
   c. 6.0 km/s
   d. 1.3 km/s

Assessment Questions

2. What is the speed of an earthquake wave if it has a wavelength of 2.3 km and a frequency of 3 Hz?
   a. 6.9 km/s = 2.3km x 3Hz
   b. 5.3 km/s
   c. 6.0 km/s
   d. 1.3 km/s

Chapter 17: Mechanical Waves and Sound

17.3 Behavior of Waves

Reflection

Reflection occurs when a wave bounces off a surface that it cannot pass through.

Reflection does not change the speed or frequency of a wave, but the wave can be flipped upside down.

Refraction

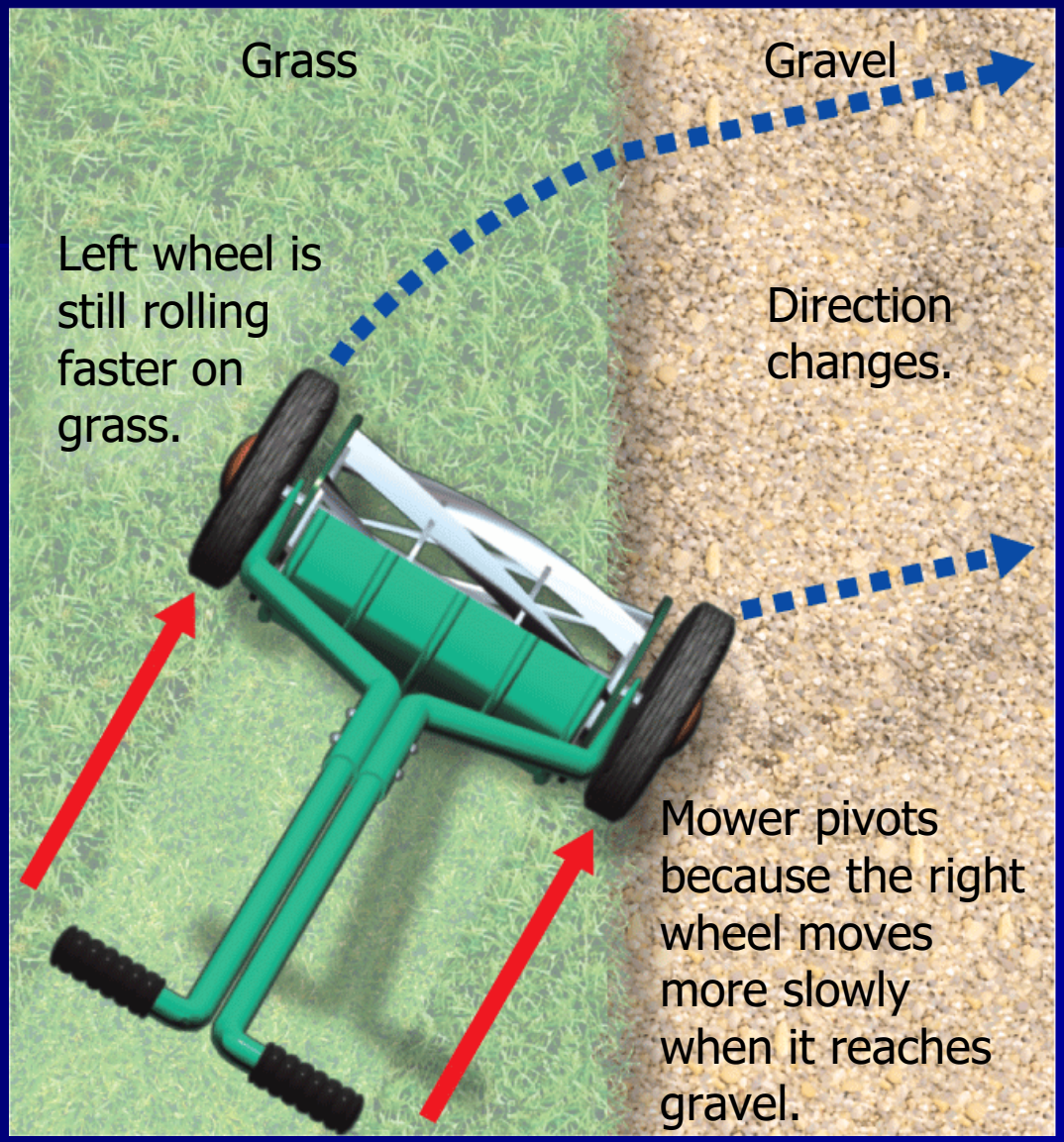
Refraction is the bending of a wave as it enters a new medium at an angle.

When a wave enters a medium at an angle, refraction occurs because one side of the wave moves more slowly than the other side.

Refraction

A lawnmower turns when it is pushed at an angle from the grass onto the gravel.

The wheel on the gravel slows down, but the other wheel is still moving at a faster speed on the grass.



Refraction

As an ocean wave approaches the shore at an angle, the wave bends, or refracts, because one side of each wave front slows down before the other side does.

Diffraction

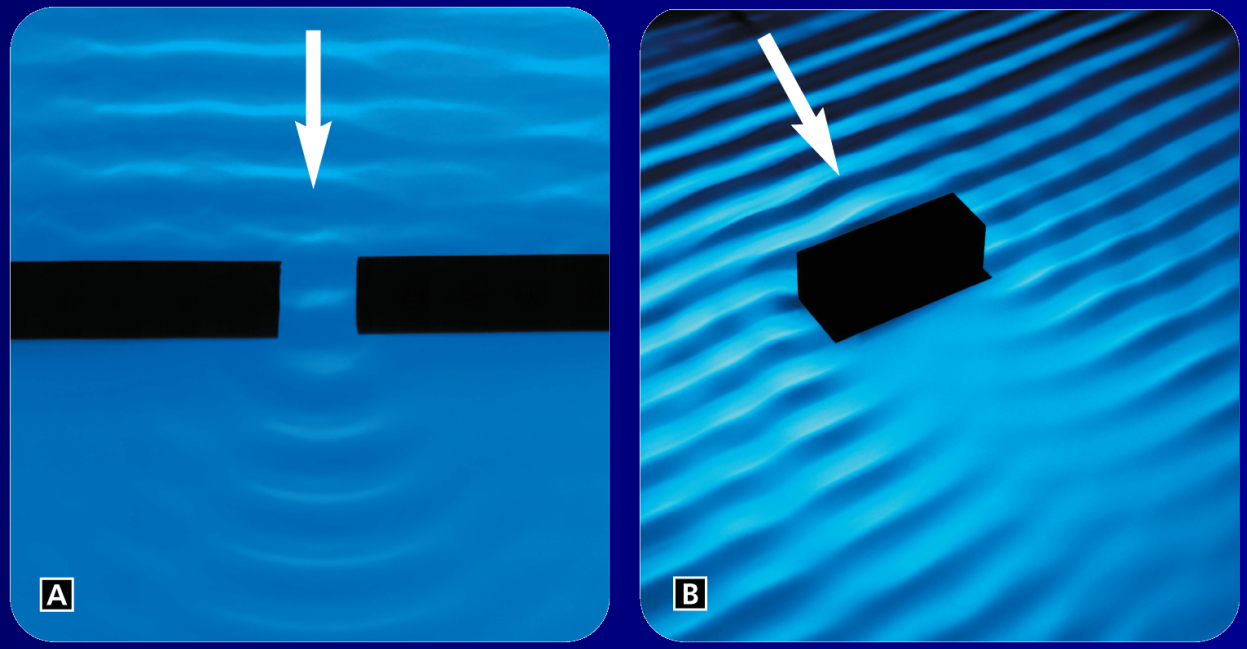
Diffraction is the bending of a wave as it moves around an obstacle or passes through a narrow opening.

A wave diffracts more if its wavelength is large compared to the size of an opening or obstacle.

Diffraction

A. This wave diffracts, or spreads out, after it passes through a narrow opening.

B. Diffraction also occurs when a wave encounters an obstacle.



Interference

Interference occurs when two or more waves overlap and combine together.

Two types of interference are constructive interference and destructive interference.

Interference

When waves collide, they can occupy the same region of space and then continue on.

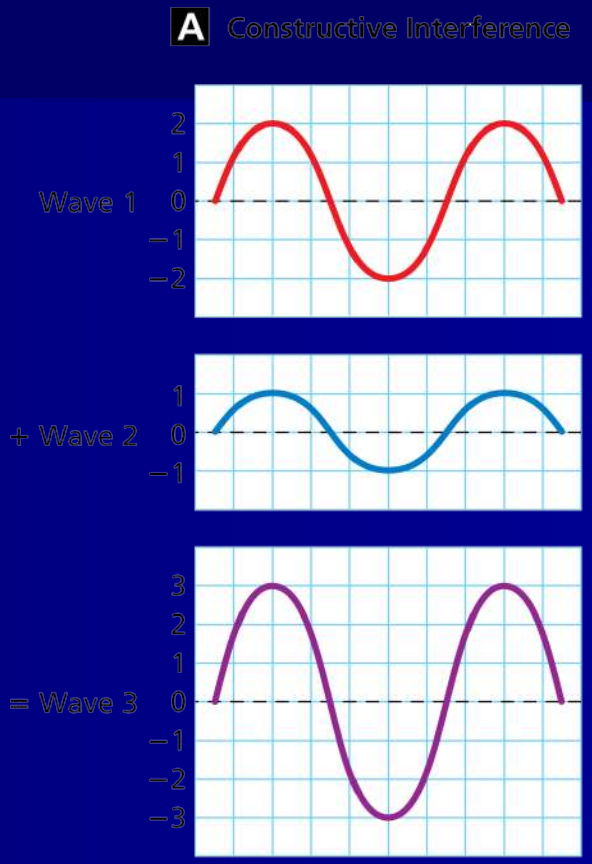
- **Constructive interference : when two or more waves combine to produce a wave with a larger displacement.**
- **Destructive interference : when two or more waves combine to produce a wave with a smaller displacement.**

Interference

Constructive Interference

Two waves with equal frequencies travel in opposite directions.

When a crest meets a crest, the result is a wave with an increased amplitude.

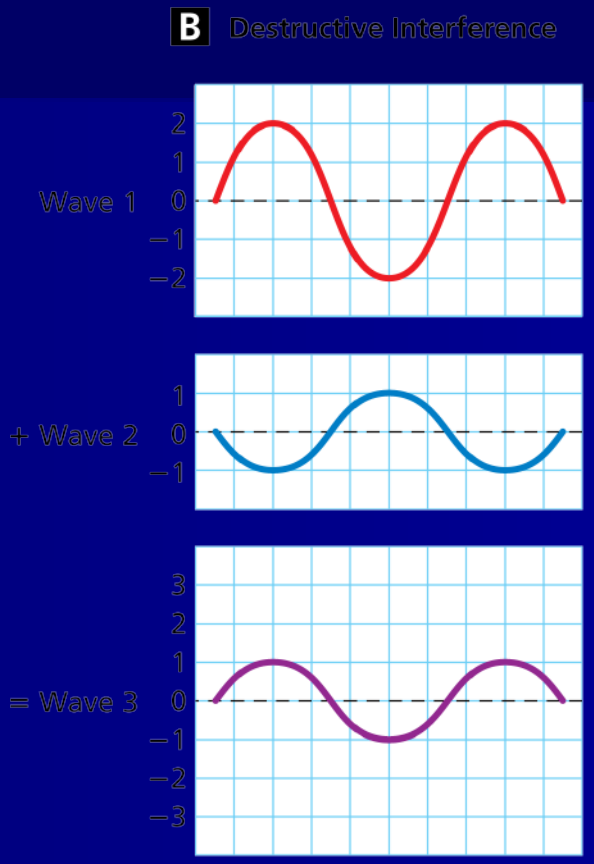


Interference

Destructive Interference

Two waves with equal frequencies travel in opposite directions.

When a crest meets a trough, the result is a wave with a reduced amplitude.



Standing Waves

A standing wave is a wave that appears to stay in one place—it does not seem to move through the medium.

A standing wave forms only if half a wavelength or a multiple of half a wavelength fits exactly into the length of a vibrating cord.

Standing Waves

Interference occurs as the incoming waves pass through the reflected waves.

At certain frequencies, interference between a wave and its reflection can produce a standing wave.

Standing Waves

A node is a point on a standing wave that has no displacement from the rest position. At the nodes, there is complete *destructive interference* between the incoming and reflected waves.

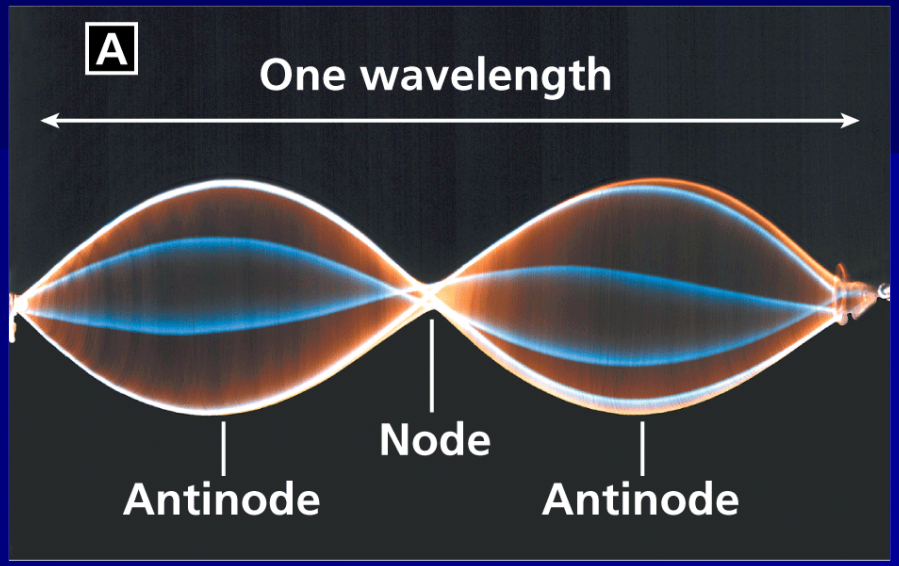
An antinode is a point where a crest or trough occurs midway between two nodes.

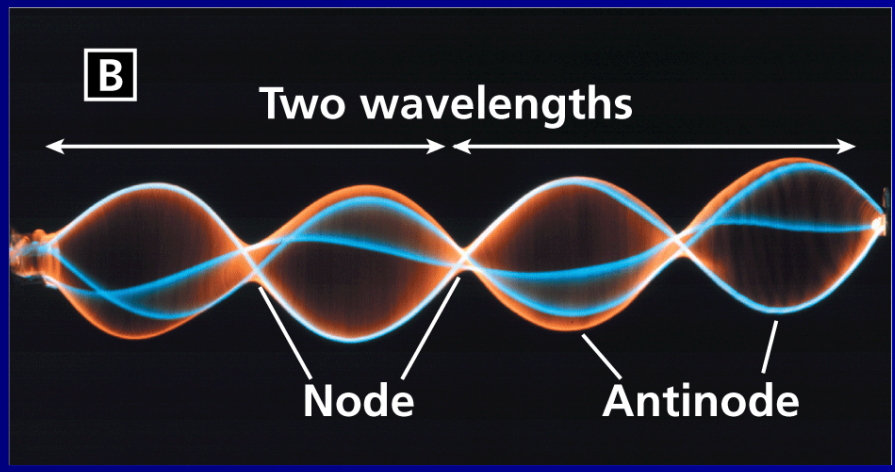
Standing Waves

These photos show standing waves for two different frequencies.

A. One wavelength equals the length of the cord.

B. Two wavelengths equal the length of the cord.





Assessment Questions

1. **The property of waves bending as they pass through a narrow opening is called**

   a. reflection.

   b. refraction.

   c. diffraction.

   d. destructive interference.

Assessment Questions

1. **The property of waves bending as they pass through a narrow opening is called**

   a. **reflection.**

   b. **refraction.**

   c. **diffraction.**

   d. **destructive interference.**

Assessment Questions

2. **When does refraction of a wave occur?**
   a. **The wave cannot enter the new medium.**
   b. **The wave enters a new medium at any angle.**
   c. **The wave enters a new medium at any angle except 90°.**
   d. **Part of the wave enters a new medium and part is reflected.**

Assessment Questions

2. When does refraction of a wave occur?
   a. The wave cannot enter the new medium.
   b. **The wave enters a new medium at any angle.**
   c. The wave enters a new medium at any angle except 90°.
   d. Part of the wave enters a new medium and part is reflected.

Assessment Questions

3. **A 6-meter rope is tied to a hook in the wall. Which of the following wavelengths can produce a standing wave?**

   a. **1.5 m**

   b. **2.5 m**

   c. **3.5 m**

   d. **4.5 m**

Assessment Questions

3. **A 6-meter rope is tied to a hook in the wall. Which of the following wavelengths can produce a standing wave?**

   a. **1.5 m**

   b. **2.5 m**

   c. **3.5 m**

   d. **4.5 m**

Assessment Questions

4. The amount of diffraction of a wave increases as the size of the obstacle causing the diffraction decreases.

   True
   False

Critical Thinking

- If you drop a perfectly transparent piece of glass into perfectly clear water, you can still see the glass. Why?

Chapter 17: Mechanical Waves and Sound

17.4 Sound and Hearing

Properties of Sound Waves

Many behaviors of sound can be explained using a few properties—speed, intensity and loudness, and frequency and pitch.

Properties of Sound Waves

Sound waves are longitudinal waves—compressions and rarefactions that travel through a medium.

Properties of Sound Waves

Speed

It takes time for sound to travel from place to place.

The speed of sound varies in different media. In dry air at 20°C, the speed of sound is 342 meters per second.

Properties of Sound Waves

Speed of Sound	
Medium (at 1 atm)	**Speed (m/s)**
Dry air, 0°C	331
Dry air, 20°C	342
Fresh water, 0°C	1401
Fresh water, 30°C	1509
Salt water, 0°C	1449
Salt water, 30°C	1546
Lead, 25°C	1210
Cast iron, 25°C	4480
Aluminum, 25°C	5000
Borosilicate glass, 25°C	5170

Properties of Sound Waves

In general, sound waves travel fastest in solids, slower in liquids, and slowest in gases.

- **The speed of sound depends on many factors, including the density of the medium and how elastic the medium is.**

Properties of Sound Waves

Intensity and Loudness

Intensity is the rate at which a wave's energy flows through a given area.

- **Sound intensity depends on both the wave's amplitude and the distance from the sound source.**
- **The decibel (dB) is a unit that compares the intensity of different sounds.**

Properties of Sound Waves

Lengthy exposure to sounds more intense than 90 decibels can cause hearing damage.

Sound Intensity Level	
Sound	**Intensity Level (decibels)**
Threshold of human hearing	0
Whisper	15–20
Normal conversation	40–50
Street noise	60–70
Inside a bus	90–100
Operating heavy machinery	80–120
Rock concert (in audience)	110–120
Threshold of pain	120
Jet plane (taking off)	120–160

Properties of Sound Waves

Loudness is a physical response to the intensity of sound, modified by physical factors.

- **The loudness depends on sound intensity.**
- **Loudness also depends on factors such as the health of your ears and how your brain interprets sound waves.**

Properties of Sound Waves

Frequency and Pitch

The frequency of a sound wave depends on how fast the source of the sound is vibrating.

The air in the tubing of brass instruments forms a standing wave. Longer tubing makes a standing wave with a longer wavelength and a lower frequency.

Properties of Sound Waves

The French horn can produce lower notes than the trumpet because it can make a longer tube for a standing wave.

French Horn

Trumpet

Properties of Sound Waves

Pitch is the frequency of a sound as you perceive it.

- **High-frequency sounds have a high pitch, and low-frequency sounds have a low pitch.**

Ultrasound

Ultrasound is used in a variety of applications, including sonar and ultrasound imaging.

Ultrasound

Most people hear sounds between 20 hertz and 20,000 hertz.

- **<u>Infrasound</u> : frequencies lower than most people can hear.**
- **<u>Ultrasound</u> :frequencies higher than most people hear.**

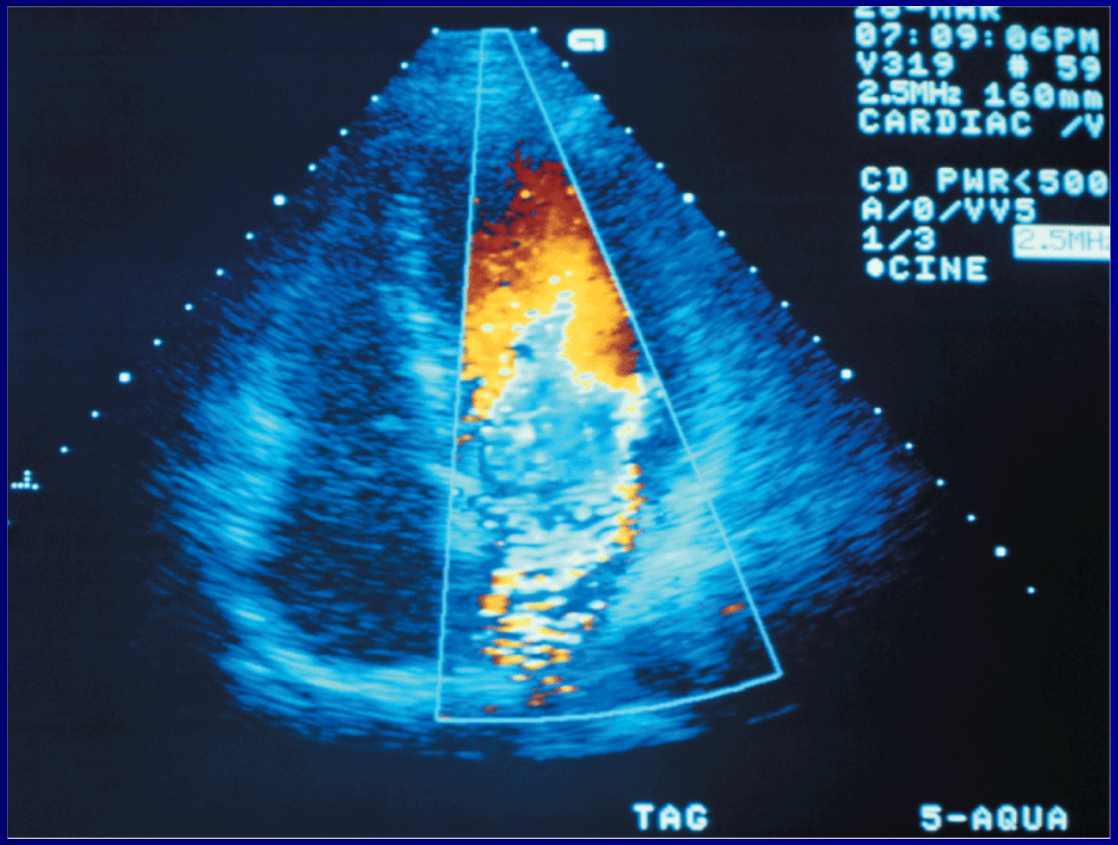
Ultrasound

Sonar is a technique for determining the distance to an object under water.

Ultrasound imaging is an important medical technique. Computer software uses reflected pulses of ultrasound to make a detailed map of structures and organs inside the body.

Ultrasound

Ultrasound can be used to make images of the heart.



The Doppler Effect

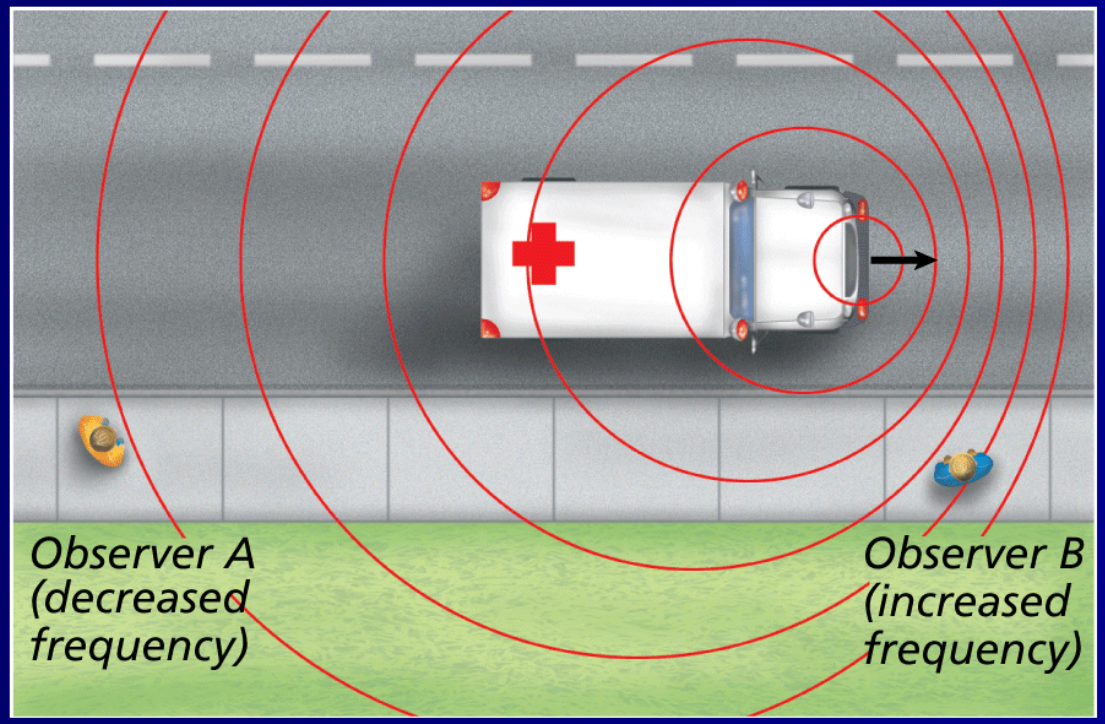
As a source of sound approaches, an observer hears a higher frequency. When the sound source moves away, the observer hears a lower frequency.

The Doppler Effect

The Doppler effect is a change in sound frequency caused by motion of the sound source, motion of the listener, or both.

The Doppler Effect

Observer A hears a lower-pitch sound than observer B because the wave fronts are farther apart for observer A.



Hearing and the Ear

What are the functions of the three main regions of the ear?

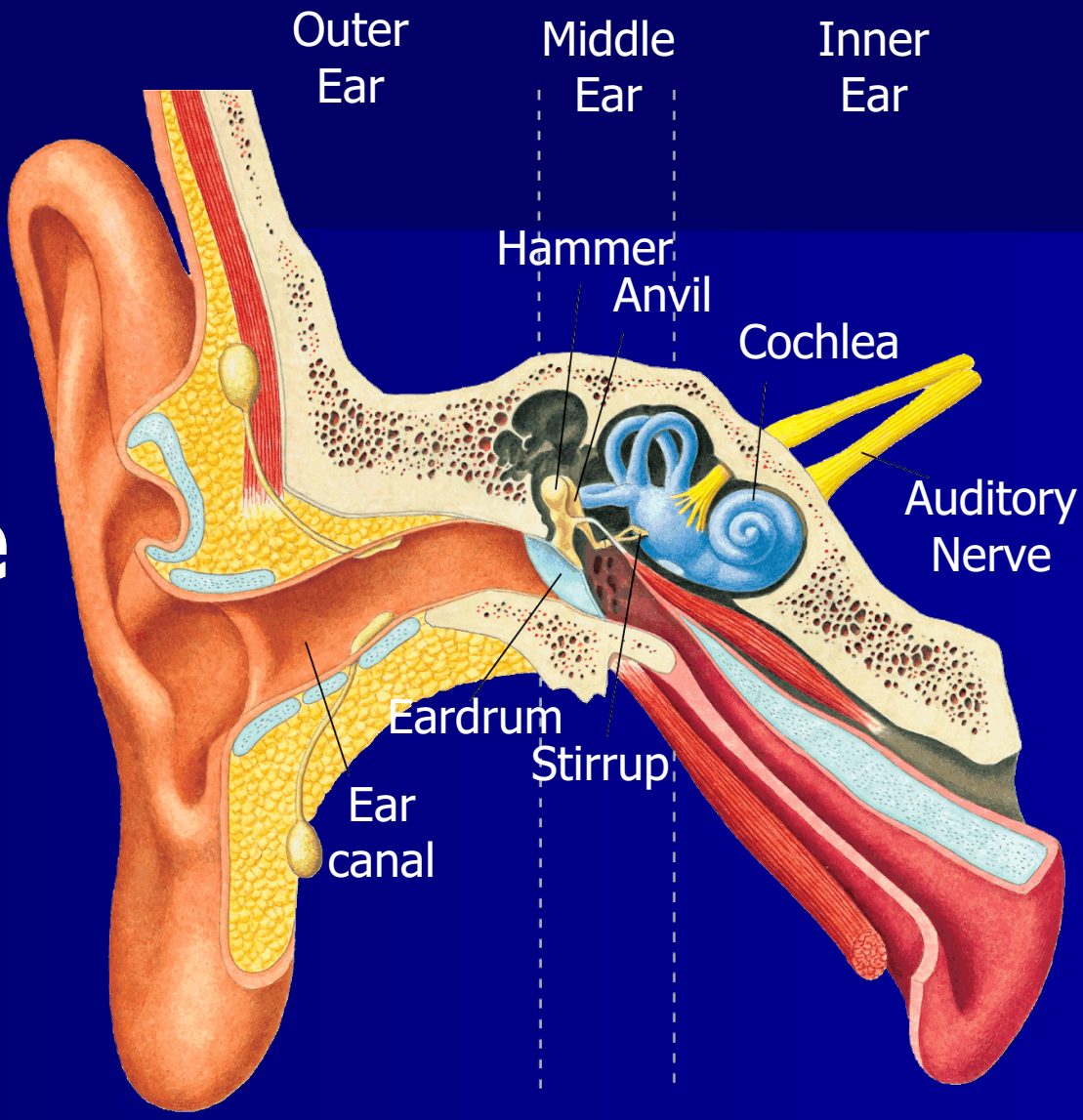
The outer ear: gathers and focuses sound

middle ear: receives and amplifies the vibrations

inner ear: uses nerve endings to sense vibrations and send signals to the brain.

Hearing and the Ear

Your ear consists of three main regions—the outer ear, the middle ear, and the inner ear.



How Sound Is Reproduced

How is sound recorded?

Sound is recorded by converting sound waves into electronic signals that can be processed and stored. Sound is reproduced by converting electronic signals back into sound waves.

How do musical instruments vary pitch?

Most musical instruments vary pitch by changing the frequency of standing waves.

Music

Resonance is the response of a standing wave to another wave of the same frequency. Musical instruments often use resonance to amplify sound.

- **One wave can "push" another wave to a higher amplitude.**
- **Resonance can produce a dramatic increase in amplitude.**

Music

Sound-absorbing tiles in this auditorium reduce unwanted reflections. The curved reflecting panels above the stage help gather and direct sound waves toward the audience.

Sound Question

- The speed of sound in ocean water is 1530 m/s. If it takes 3 s for a sound wave to make a round trip from a sonar device, what is the distance to the reflecting object?

Assessment Questions

1. The intensity of sound waves is measured in units of
   a. hertz (Hz).
   b. decibels (dB).
   c. joules (J).
   d. meters (m).

Assessment Questions

2. Most musical instruments vary pitch by
   a. changing the amplitude of sound waves.
   b. reflecting sound from surfaces in a room.
   c. changing the frequency of a standing wave.
   d. using the Doppler effect.

Assessment Questions

3. The Doppler effect is
   a. a change in sound frequency caused by motion of the sound source relative to the listener.
   b. used in a variety of applications including sonar and ultrasound imaging.
   c. a technique for determining the distance to an object under water.
   d. the rate at which a wave's energy flows through a given area.