chapter 9

# Introduction to Waves

## section 2 Wave Properties

## Before You Read

Have you ever sat high in the stadium at a baseball game and heard the sound of a ball being hit by a bat? Did you notice that you heard the sound after you saw the ball being hit? Explain why you think this happened.

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### What You'll Learn

- what wavelength, frequency, period, and amplitude are
- how frequency and wavelength are related
- how a wave's energy and amplitude are related
- how to calculate wave speed

## Read to Learn

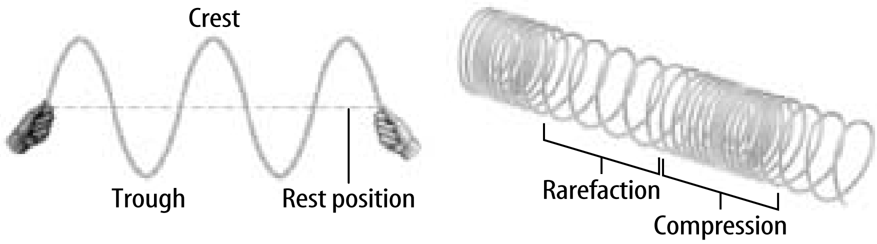
Mark the Text

**Underline** As you read this section, look for important information about the properties of waves. Underline all of the ideas that you think are important to understand and remember.

### The Parts of a Wave

How are sound waves, water waves, and seismic waves different? Some waves have more energy than others. Some travel faster than others. There are other ways that waves are different.

Remember that transverse and longitudinal waves act differently as they travel through a medium. The first figure below shows a transverse wave. Notice that the medium (the rope) has alternating high points and low points. A **crest** is the high point of a transverse wave. A **trough** is the low point of a transverse wave. The second figure shows a longitudinal wave in a coiled spring. It does not have crests or troughs. Instead, the wave creates areas where the coils are close together. This area is called a **compression**. In other areas, the coils are spread apart. A **rarefaction** (RAYR uh fak shun) is the area in a longitudinal wave where the medium is most spread out.




### Picture This

1. **Describe** the pattern shown in the medium by the transverse wave.

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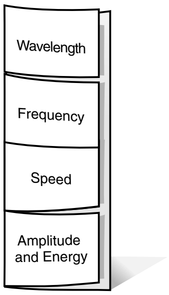
FOLDABLES™

**B Summarize** Make a Foldable to record the differences among wavelength, frequency, speed, and amplitude and energy.

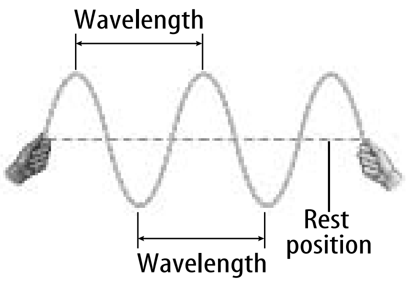


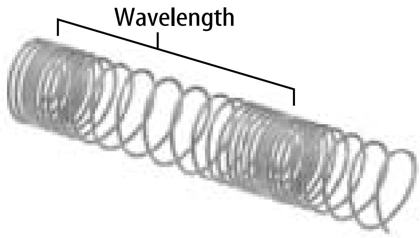

## Wavelength

Another way to describe a wave is by its wavelength. A **wavelength** is the distance between one point on a wave and the nearest point just like it. The first figure below shows a transverse wave. Commonly the wavelength is measured from the top of one crest to the top of the next crest. You could also measure the wavelength from the bottom of one trough to the bottom of the next trough.

The second figure below shows a compressional wave. The wavelength is the distance from the center of one compression to the center of the next compression. You could also measure the wavelength from the center of one rarefaction to the center of the next rarefaction.

Humans cannot hear all sounds. You can hear sounds that have wavelengths between a few centimeters and about 15 m. The highest-pitched sounds you hear have wavelengths that are smaller than a few centimeters. The deepest sounds you hear have wavelengths that are about 15 m.




### Picture This

**2. Analyze** In the figure showing the transverse wave, how do the sizes of the wavelengths compare?

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## Frequency and Period

Have you ever heard someone use the word *frequency*? It usually refers to how often something happens in a given period of time. Frequency has a similar meaning when referring to waves. The **frequency** of a wave is the number of wavelengths that pass a point each second. To find the frequency of a transverse wave, count the number of crests or troughs that pass by a point each second. In the same way, to find the frequency of a compressional wave, count the number of compressions or rarefactions that pass by a point each second.

When you tune a radio to a certain station, you are choosing radio waves of a certain frequency. Frequency is expressed in hertz (Hz). A frequency of 1 Hz means that one wavelength passes per second. In SI units, 1 Hz is the same as 1/s.

Reading Check

**3. Explain** How is the frequency of a wave measured

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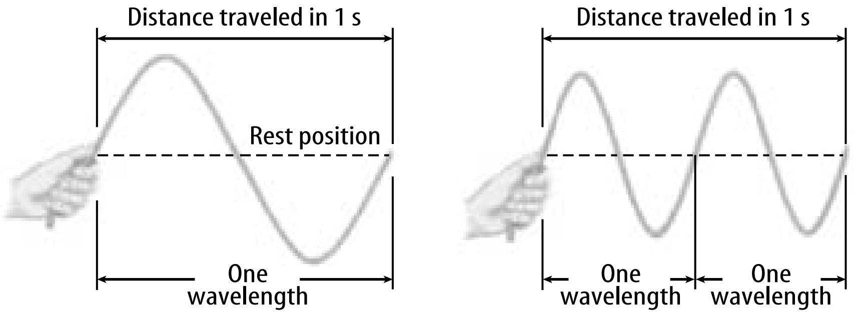
**Wave Periods** The **period** of a wave is the amount of time it takes one wavelength to pass a point. Periods are measured in units of seconds. The period of an ocean wave is two seconds if it takes that long for two consecutive crests to pass a point.

## How are frequency and wavelength related?

There is a relationship between frequency and wavelength. If you make transverse waves with a rope, you can increase the frequency by moving the rope up and down faster. The frequency increases because more crests or troughs pass by a point in one second. Moving the rope faster also makes the wavelength shorter. The distance from crest to crest or trough to trough is shorter. This relationship is always true: as frequency increases, wavelength decreases.

Look at the two figures below. The waves in the ropes show that as the frequency of waves increases, their wavelengths decrease. The first figure shows one wavelength passing by in one second. The frequency of the first wave is 1 Hz. The second figure shows two wavelengths passing by in one second. The frequency of the second wave is 2 Hz. As more wavelengths pass by in one second, the wavelengths get shorter. In the two figures, the frequency increases from 1 Hz to 2 Hz, so the wavelengths decrease. If you move a rope up and down five times in 1 s, the frequency of the wave is 5 Hz. However, the wavelengths would be shorter than for the rope with a frequency of 2 Hz.




## Wave Speed

Look back at the question at the beginning of this section. It asks if you have ever sat up high in the stadium at a baseball game, heard the sound of a ball being hit by a bat, and realized that you heard the sound after you saw the ball being hit. You saw the baseball being hit before you heard it because light waves travel through gases much faster than sound waves. Air is a gas. The light waves reflected from the ball reached your eyes before the sound waves created by the bat hitting the ball reached your ears.

### Picture This

4. **Identify** What kind of waves are shown in the figure?

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### Think it Over

5. **Explain** if you are watching fireworks from a distance, why do you see fireworks explode before you hear the noise?

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Reading Check

6. **Determine** Do light waves or sound waves travel faster through gases?

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Applying Math

7. **Calculate** What is the speed of a sound wave that has a frequency of 150 Hz and a wavelength of 0.00002 mm? Show your work.

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## What determines wave speed?

The speed of a wave depends on the medium it is traveling through. Light waves travel faster than sound waves through gases. Sound waves usually travel faster than light waves through liquids and solids. Sound waves are longitudinal waves. Longitudinal waves travel faster in liquids and solids than they do in gases. Also, sound waves usually travel faster in a material when the temperature of the material is increased. For example, sound waves travel faster in air at 20°C than in air at 0°C.

## How do you calculate wave speed?

You can calculate the speed of any wave by multiplying its frequency times its wavelength. The Greek letter *lambda* ($\lambda$) represents the wavelength, $f$ represents the frequency, and $v$ represents the speed of the wave. The wave speed equation is:

**speed** (in m/s) = **frequency** (in Hz) × **wavelength** (in m)

$$v = f\lambda$$

Why does multiplying the frequency unit (Hz) by the distance unit (m) result in the unit for speed (m/s)? Recall that the SI unit Hz is the same as 1/s. So multiplying m × Hz equals m × 1/s, which equals m/s.

Using the equation, you can calculate the speed of a wave traveling in water. If the wave has a frequency of 500 Hz and a wavelength of 3 m, what is the speed of the wave?

Step 1 What do you know?
$f = 500.0$ Hz
$\lambda = 3.0$ m

Step 2 Write the equation and put in the known numbers.
$v = f\lambda$
$v = 500.0 \text{ Hz} \times 3.0 \text{ m}$

Step 3 Solve the equation.
$v = 1{,}500.0$ m/s
The speed of the wave is 1,500 m/s.

# Amplitude and Energy

Why do some earthquakes cause terrible damage, while others hardly are felt? This is because waves can carry different amounts of energy. **Amplitude** is a measure of the energy that a wave carries. The greater a wave's amplitude, the more energy the wave carries. Amplitude is measured differently for longitudinal and transverse waves.

## How is amplitude measured for compressional waves?

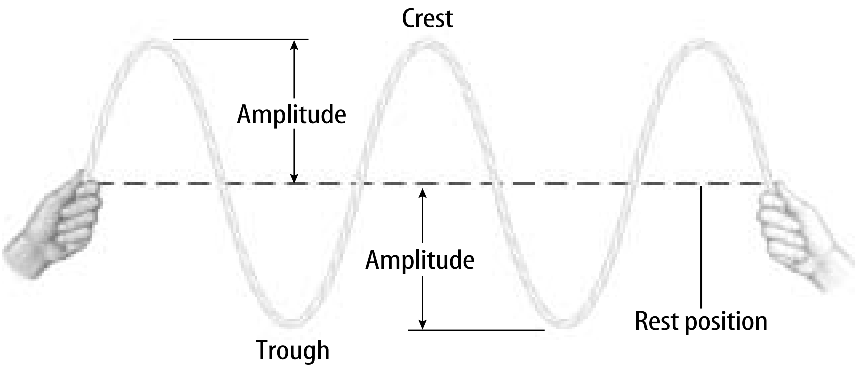
The amplitude of a longitudinal wave depends on how tightly the medium is pushed together at the compressions. The tighter the medium is pushed together at the compressions, the greater its amplitude. The greater the amplitude is, the more energy the wave carries. Think of a coiled-spring toy. It takes more energy to push the coils tightly together than it does to barely move them.

Compare the compression in the figure on the left with the compressions in the figure on the right. The coils in the compressions of the figure on the right are closer together. The second wave has greater amplitude and more energy compared to the first wave.

Look at the rarefactions in the two springs. The closer the coils are in the compression, the farther apart they are in the rarefaction. So the less dense a medium is at the rarefactions, the more energy the wave carries.

## How is amplitude measured for transverse waves?

Have you ever been knocked over by an ocean wave? If so, you know that higher waves carry more energy than shorter waves do. Remember that the greater a wave's amplitude, the more energy the wave carries. So a tall ocean wave has a greater amplitude than a short ocean wave. The amplitude of a transverse wave is measured differently than the amplitude of a compressional wave. The figure below shows that the amplitude of a transverse wave is the distance from the crest or trough of the wave to the rest position. The greater this distance is, the greater the amplitude is.




### Picture This

**8. Identify** In the figure on the right, are the coils in the rarefactions closer together or farther apart than in the figure on the left?

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### Picture This

**9. Draw** Using the same rest position, draw a wave with a greater amplitude than the one shown. Then draw a wave with a smaller amplitude.

# After You Read

## Mini Glossary

**amplitude:** the measure of the energy that a wave carries
**crest:** the high point of a transverse wave
**compression:** the more dense region of a longitudinal wave
**frequency:** the number of wavelengths that pass a fixed point in 1 s
**period:** the amount of time it takes one wavelength to pass a fixed point
**rarefaction:** the section in a compressional wave where the material is less crowded and more spread out
**trough:** the low point of a transverse wave
**wavelength:** the distance between one point on a wave and the nearest point just like it

1. Review the terms and their definitions in the Mini Glossary above. Explain how a transverse wave's wavelength is different from its amplitude.

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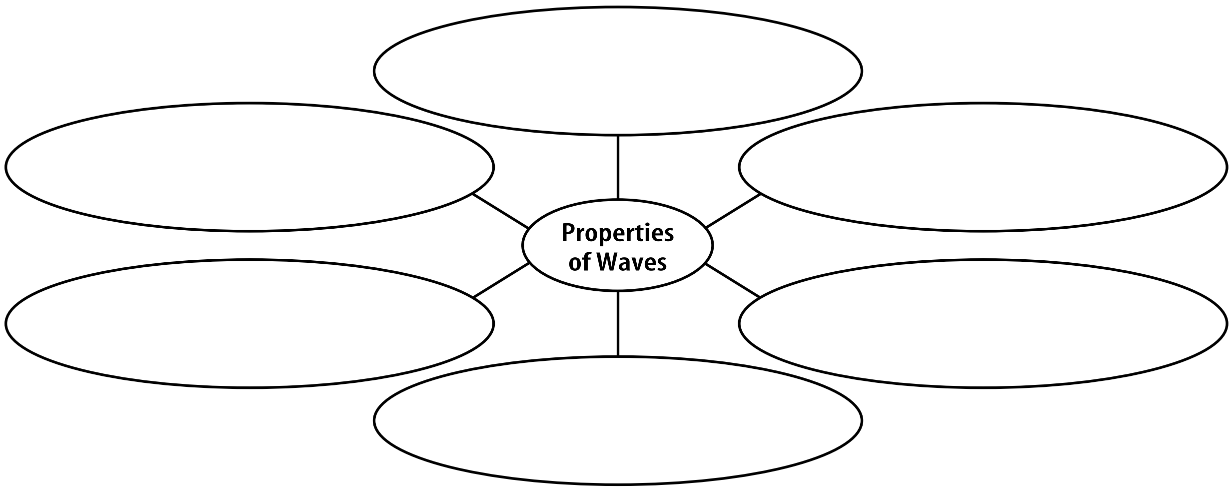
2. Complete the concept map below to list the properties of waves that you learned about in this section.




3. **Mark the Text** Look back at the important ideas you underlined about wave properties. How did underlining these ideas help you learn the information?

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**End of Section**