KEY IDEAS
As you read this section, keep these questions in mind:
• What are some ways to measure and compare waves?
• How can you calculate the speed of a wave?
• What is the Doppler effect?

How Can You Describe a Wave’s Properties?
If you have spent time at the beach or on a boat, you have probably noticed many properties of waves. Sometimes the waves are very large. At other times they are smaller. Sometimes they arrive close together. Other times they come farther apart. Scientists use special terms to describe these properties of waves.

AMPLITUDE
One property of a wave is how much it moves particles as it passes them. The largest distance that a wave displaces particles from their resting position is called the amplitude of the wave. In a transverse wave, for example, the amplitude is the distance between the resting position and the wave’s crest or trough. The figure below illustrates the amplitude of a transverse wave.

Simple transverse waves have similar shapes, no matter how large they are or what medium they travel through. These waves are shaped like a sine curve. A sine curve looks like an S lying on its side. Waves with the shape of sine curves, like the one above, are called sine waves. Although many waves are not perfect sine waves, a sine curve is a good estimate of their shapes.

Describe After you read this section, make a chart comparing amplitude, frequency, wavelength, and period. In your chart, define each quantity and give the units used to measure it.

1. Compare How does the distance between the resting position and the crest compare with the distance between the resting position and the trough?
WAVELENGTH

The crests of ocean waves lapping up on the beach may be several meters apart. In contrast, ripples on a pond may be separated by only a few centimeters. In transverse waves, the distance between one crest and the next, or one trough and the next, is the wavelength. In a longitudinal wave, the wavelength is the distance between two neighboring compressions or rarefactions.

Generally, the wavelength is the distance between any two neighboring identical parts of a wave. The figure below shows the wavelengths of a transverse wave and a longitudinal wave.

Not all waves have an obvious wavelength. Most sound waves have a complicated shape. That makes it difficult to determine their wavelengths.

Scientists use the Greek letter lambda, \( \lambda \), to represent wavelengths in equations. Wavelength is measured in units of length, such as meters or centimeters.

AMPLITUDE, WAVELENGTH, AND ENERGY

Remember that waves carry energy. There is a relationship between the amplitude of a wave and the amount of energy it carries. A wave with a large amplitude carries more energy than the same kind of wave with a smaller amplitude.

There is also a relationship between wavelength and energy. A wave with a large wavelength carries less energy than the same kind of wave with a smaller wavelength.
PERIOD

Imagine floating in an inner tube away from the shore of the ocean, as shown below. As waves pass you on their way to the shore, your body rises and falls. If you had a stopwatch, you could count the number of seconds between one crest or trough and the next. You would be measuring the period of the wave. The period of a wave is the time it takes for one full wavelength of the wave to pass a specific point.

It takes 2 s for a full wavelength of this wave to pass the person. Therefore, the wave’s period is 2 s.

Scientists use the letter $T$ to represent the period in equations. Period is measured in units of time, such as seconds.

FREQUENCY

The period of a wave is how long it takes for a full wavelength of the wave to pass a point. Suppose you were to measure the number of wavelengths that passed the point in a certain amount of time. Then, you would be measuring the frequency of the wave.

The symbol for frequency is $f$. Its SI unit is the hertz (Hz). Hertz units measure the number of vibrations per second. One vibration per second is 1 Hz, and two vibrations per second is 2 Hz. The average person can hear sounds with frequencies as low as 20 Hz and as high as 20,000 Hz.

There is a relationship between the frequency of a wave and its period. The equation below describes this relationship:

$$f = \frac{1}{T}$$
How Can You Measure Wave Speed?

Remember that you can describe the speed of a moving object using units such as meters per second. The speed describes how long it takes the object to move a certain distance. In a similar way, you can describe the speed of a wave. The speed of a wave is the time it takes for one part of the wave to travel a certain distance.

You can calculate the speed of a wave in two different ways. One way is divide the wave’s wavelength by its period:

\[
\text{speed} = \frac{\text{wavelength}}{\text{period}}
\]

\[v = \frac{\lambda}{T}\]

Because frequency equals \(1 \div T\), you can also calculate the speed of a wave by multiplying its wavelength by its frequency:

\[
\text{speed} = \text{wavelength} \times \text{frequency}
\]

\[v = \lambda f\]

Let’s look at an example of calculating the speed of a wave. A piano string vibrates to produce a note. The sound waves the string produces have a frequency of 262 Hz and a wavelength of 1.30 m. What is the speed of the sound waves?

**Math Skills**

8. Calculate An ocean wave has a wavelength of 15.0 m. Its period is 10 s. What is the speed of the wave? Show your work.

<table>
<thead>
<tr>
<th>Step 1: List the given and unknown values.</th>
<th>Given: frequency, (f = 262) Hz wavelength, (\lambda = 1.30) m</th>
<th>Unknown: speed, (v)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Step 2: Write the equation. (v = f\lambda)</td>
<td>(v = (262) Hz (\times (1.30) m)</td>
<td>(v = 341) m/s</td>
</tr>
<tr>
<td>Step 3: Insert the known values and solve for the unknown value.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

So, the wave’s speed is 341 m/s. This means that, in one second, a certain point on the wave travels 341 m.

Do Waves Travel at the Same Speed in Every Medium?

A wave’s speed depends on the medium through which the wave travels. In any particular medium, however, the speed of waves stays the same. The speed does not depend on the waves’ frequencies. The table on the next page shows the speed of sound in different mediums.
### Characteristics of Waves continued

#### Speed of Sound in Different Mediums

<table>
<thead>
<tr>
<th>Medium</th>
<th>Speed of sound (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air at 25 °C</td>
<td>$3.46 \times 10^2$</td>
</tr>
<tr>
<td>Water at 25 °C</td>
<td>$1.49 \times 10^3$</td>
</tr>
<tr>
<td>Gold</td>
<td>$3 \times 10^3$</td>
</tr>
</tbody>
</table>

#### DIFFERENCES IN WAVE SPEED

The arrangement of molecules in a medium determines how quickly waves travel through the medium. In gases, the molecules are far apart and move randomly. In a gas, a molecule must travel through a lot of empty space before it bumps into another molecule. As a result, gas molecules have few chances to transfer energy to other molecules. Therefore, waves generally travel slowly in gases.

In liquids such as water, the molecules are much closer than they are in gases. They can easily collide with each other and transfer their energy. Molecules in liquids act like masses on springs. They transfer vibrations from one molecule to the next. As a result, waves travel faster in liquids than in gases.

Molecules in solids are even closer to each other. They are also bound tightly to each other. You can imagine molecules in solids as masses that are glued together. When one mass starts to vibrate, all the others start to vibrate almost immediately. As a result, waves travel very quickly through most solids.

### How Fast Do Light Waves Travel?

When you flip a light switch, light seems to fill the room instantly. However, like all waves, light waves take time to travel from place to place. All electromagnetic waves travel at the same speed in a given medium. In a vacuum, this speed is $3.00 \times 10^8$ m/s, or 186,000 miles per second. This value of the speed of light in empty space is a constant. Scientists give it the symbol $c$.

Light doesn’t always travel at the speed that $c$ represents. When light travels through a medium, such as air or water, it moves more slowly than in empty space. For example, light travels at $2.25 \times 10^8$ m/s in water.

#### Looking Closer

9. **Identify** In which substance does sound move the fastest?

#### Critical Thinking

10. **Infer** The speed of a wave in a medium changes depending on the temperature of the medium. What do you think is the reason for this? (Hint: Remember what temperature describes.)
THE ELECTROMAGNETIC SPECTRUM

Remember that visible light is just one kind of electromagnetic wave. There are many different forms of electromagnetic waves. All travel at the same speed, but they have different wavelengths. For example, the wavelength of visible light varies from about $7.0 \times 10^{-7}$ m to about $4.0 \times 10^{-7}$ m. The different wavelengths of visible light correspond to the different colors we see.

<table>
<thead>
<tr>
<th>Color of visible light</th>
<th>Wavelength (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blue</td>
<td>$4.75 \times 10^{-7}$</td>
</tr>
<tr>
<td>Yellow</td>
<td>$5.70 \times 10^{-7}$</td>
</tr>
<tr>
<td>Red</td>
<td>$6.80 \times 10^{-7}$</td>
</tr>
</tbody>
</table>

Some forms of electromagnetic radiation, such as gamma rays and X rays, have shorter wavelengths than visible light. Other forms, such as radio waves and microwaves, have longer wavelengths than visible light. The full range of wavelengths of all electromagnetic waves is called the electromagnetic spectrum.

How Can Motion Affect the Properties of Waves?

Imagine that you are standing on a corner as an ambulance rushes by. As the ambulance passes, the sound of its siren changes. This happens because the ambulance is moving.

The pitch of a sound describes how high or low the sound is. High sounds, such as a bird singing, have a high pitch. Pitch is determined by the frequency or wavelength of a sound. The higher the frequency of a sound, the higher the pitch.

Suppose you could see the sound waves from the ambulance, as in the figure on the next page. When the ambulance stands still, sound waves from its siren spread out evenly in all directions. The pitch of the sound is the same no matter where you stand.

As the ambulance travels toward you, the waves are squeezed into a smaller space. When it is moving away, the waves are stretched. This squeezing and stretching affects the pitch of the sound you hear. If the ambulance is moving toward you, the pitch sounds higher. If it is moving away from you, the pitch sounds lower.
When the ambulance is not moving, the sound waves have the same frequency everywhere. No matter where you stand, the siren sounds the same.

When the ambulance is moving, the sound waves are stretched or compressed. Observer A hears a higher-pitched siren than Observer B.

Consider the situation in which the ambulance is moving toward you. Between the time when the siren emits one sound wave and the next one, the ambulance moves forward. The movement shortens the distance between wave fronts. As a result, the sound waves reach your ear at a higher frequency than normal. They sound higher-pitched than they would if the ambulance were parked.

The opposite happens if the ambulance is moving away from you. The movement lengthens the distance between wave fronts. The sound waves reach your ear at a lower than normal frequency. So, you hear the siren at a lower pitch than you would if the ambulance stayed still.

This change in the observed wavelength of a wave when the source and observer are moving relative to one another is called the Doppler effect. The Doppler effect happens any time the source and the observer are moving relative to each other. The effect occurs for all types of waves, including light and radio waves.

Scientists use the Doppler effect in several different ways. For example, meteorologists use the effect to help them track storms. Astronomers rely on the Doppler effect to measure the speeds at which galaxies are moving away from Earth.
Section 2 Review

SECTION VOCABULARY

<table>
<thead>
<tr>
<th><strong>amplitude</strong></th>
<th>the maximum distance that the particles of a wave’s medium vibrate from their rest position</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Doppler effect</strong></td>
<td>an observed change in the frequency of a wave when the source or observer is moving</td>
</tr>
<tr>
<td><strong>frequency</strong></td>
<td>the number of cycles or vibrations per unit of time; also the number of waves produced in a given amount of time</td>
</tr>
<tr>
<td><strong>period</strong></td>
<td>in physics, the time that it takes a complete cycle or wave oscillation to occur</td>
</tr>
<tr>
<td><strong>wavelength</strong></td>
<td>the distance from any point on a wave to an identical point on the next wave</td>
</tr>
</tbody>
</table>

1. **Identify**  On the figure below, label the amplitude and wavelength of the wave.

![Wave Diagram]

2. **Calculate**  Green light has a wavelength of $5.20 \times 10^{-7}$ m. The speed of light is $3.00 \times 10^8$ m/s. What is the frequency of green light waves? Show your work. (Hint: $1 \text{ m/s} \div 1 \text{ m} = 1 \text{ Hz}$.)

3. **Explain**  A scientist strikes a long metal bar with a hammer. The energy produces waves that travel through the bar and through the air. Which will reach the end of the bar first, the wave traveling through the bar or the one traveling through the air? Explain your answer.

4. **Describe**  As the frequency of a wave increases, what happens to its period and wavelength if its speed stays the same?