As you read this section, keep these questions in mind:

• What is a wave?
• How do waves form?
• How are transverse and longitudinal waves different?

What Is a Wave?

Imagine a leaf floating on water when a wave passes by. First, the leaf bobs up. Then, it drops back to its original position, as shown in the figure below. In the same way, the water molecules in the pond rise up and fall back as the wave passes. Both the leaf and the molecules end in nearly their original positions. In other words, their displacement is almost zero.

If the wave does not move any matter, what does move with the wave? The answer is energy. A wave is a disturbance that carries energy through matter or space. Waves in a pond are disturbances that carry energy through water. Sounds are disturbances that carry energy through the air. The energy released by an earthquake is carried by waves within Earth.

Many waves, such as water waves, sound waves, and earthquake waves, can travel only through matter. The matter through which the wave travels is called the medium. Water is the medium for water waves. Earth is the medium for earthquake waves.

Waves that can travel only through a medium are called mechanical waves. Most waves, including water waves, sound waves, and earthquake waves, are mechanical waves. Electromagnetic waves are the most common kind of nonmechanical waves.
What Are Electromagnetic Waves?

Electromagnetic waves consist of changing electric and magnetic fields in space. Light is an electromagnetic wave. Electromagnetic waves can travel through a medium, but they do not have to travel through a medium. For example, light from the sun travels to Earth through empty space, and can also travel through the air.

There are many different kinds of electromagnetic waves. Visible light is one kind. Ultraviolet rays, X rays, and radio waves are also electromagnetic waves.

What Happens to Energy as a Wave Travels?

If you stand next to the speakers at a rock concert, the sound waves may damage your ears. However, if you stand 100 m away, the sound will cause no harm. This is because the energy of a wave spreads out as the wave travels.

Imagine throwing a stone into a pond. When the stone hits the water, energy is transferred from the stone to the water. The energy produces water waves in the pond. The waves start at the place where the stone hits the water. The waves spread out in circles, or wave fronts, that get wider as the waves move farther from the center.

Remember that energy cannot be created or destroyed. Therefore, no matter how big each wave front gets, it has the same amount of energy. In the larger circles, the energy is spread out over a larger area. Therefore, the energy at each point in the wave gets smaller as the wave fronts get larger.

Each wave front has the same amount of energy. The bigger the wave front, the more spread out the energy is.

When sound waves travel in air, they spread out in spheres. As the waves move outward, the spherical wave fronts get bigger. The energy spreads out over a larger volume. This is why noises sound fainter when you move farther from their source.
What Produces Waves?
When a singer sings a note, the vocal chords in the singer’s throat move back and forth. That motion makes the air in his throat vibrate. These vibrations travel through the air as sound waves and eventually reach your ears. Vibration of the air in your ears causes your eardrums to vibrate. The motion of your eardrums produces signals that travel through your nerves to your brain.

Waves are related to vibrations. Most mechanical waves, such as sound waves, are produced by vibrating objects. For example, the singer’s vibrating vocal chords create sound waves. As a mechanical wave travels through a medium, the particles in the medium vibrate. Vibrations can also produce electromagnetic waves: vibrating charged particles can produce electromagnetic waves.

Vibrating Masses on Springs
Look at the mass hanging on a spring in the figure below. If you pull the mass down and let it go, it will move up and down around its original position. The spring exerts a force that causes the mass to vibrate up and down. The movements involve different types of energy.

As the mass vibrates, its energy changes form.

When you pull the mass down, the mass and spring gain potential energy. As the spring pulls the mass up to its original position, the potential energy becomes kinetic energy. When the spring rises above its original position, kinetic energy again becomes potential energy. However, the total amount of mechanical energy does not change, except for energy that is lost to friction. This type of vibration is called simple harmonic motion.

Talk About It
Discuss In a small group, think of 10 different kinds of waves. For each wave, identify what vibrations produce the wave.

Looking Closer
6. Identify Name three kinds of energy that the spring can have as it vibrates.
How Do Waves Transfer Energy?

The figure below shows a series of masses and springs tied together in a row. If you pull down on the mass at the end of the row and then let go, that mass will start to vibrate. As it vibrates, it pulls on the mass next to it. It causes that mass to vibrate. Each mass in the row vibrates in turn as the mass next to it pulls on it.

Because these masses are linked together, pulling on one of them causes the others to move.

The connected masses in the figure show how energy can move through a medium. Each mass is connected to the next mass. Therefore, energy can move from one mass to the next. Over time, the energy from the first mass moves to other masses in the line. In a similar way, energy moves from one particle to another in a medium. Eventually, the energy of the wave moves from one side of the medium to the other.

If the first mass were not connected to the other masses, it would keep vibrating on its own. Because it transfers some energy to the second mass, it starts to slow down. It returns to its resting position faster than it would have if it were alone. Scientists have a name for a vibration that gets smaller as energy is lost to friction or is transferred to other objects. They call it damped harmonic motion.

** LOOKING CLOSER **

7. Predict Consequences
Suppose the five masses in the figure were not connected by the small springs. What would happen to the other four springs when the person pulled on the first spring?

** READING CHECK **

8. Define What is damped harmonic motion?

<table>
<thead>
<tr>
<th>Type of motion</th>
<th>Description</th>
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</thead>
<tbody>
<tr>
<td>Simple harmonic motion</td>
<td>• masses move independently&lt;br&gt;• masses do not lose energy</td>
</tr>
<tr>
<td>Damped harmonic motion</td>
<td>• masses are linked together&lt;br&gt;• masses lose energy to other masses or to friction</td>
</tr>
</tbody>
</table>
In What Ways Do Waves Move Particles?

When a mechanical wave travels through a medium, the particles in the medium vibrate. Different kinds of waves cause the particles to vibrate in different ways. Scientists classify mechanical waves based on how the waves cause the particles to move.

**TRANSVERSE WAVES**

Look at the rope in the figure below. As the person moves the end of the rope, energy travels through the rope as a wave. The energy (and the wave) moves from left to right in the rope. However, the particles in the rope move up and down. The direction of motion of the rope is perpendicular to the direction of motion of the wave. The rope is an example of a transverse wave. In a transverse wave, the particles in the medium move perpendicular to the direction the wave is traveling.

In a transverse wave, particles vibrate perpendicular to the direction the wave travels.

**LONGITUDINAL WAVES**

Imagine stretching out a long, flexible spring, such as the one shown on the next page. If you move one end forward and backward, you will see a wave move along the spring. The coils in the spring move forward and backward, just like the wave. In other words, the particles in the medium vibrate parallel to the direction in which the wave moves. This is an example of a longitudinal wave.

Sound waves are longitudinal waves. As a sound wave moves through the air, air molecules move closer together and farther apart.

**READING CHECK**

9. Describe How do scientists classify mechanical waves?

10. Apply Concepts If the wave in the rope were traveling from right to left, which way could the particles vibrate?
The points along the spring move left and right.

The wave moves from left to right.

In a longitudinal wave, particles vibrate parallel to the direction the wave travels.

**LOOKING CLOSER**

11. **Compare** How does the direction of motion of the particles in the spring compare with the direction of motion of the wave?

**DEscribing Waves**

Scientists use different words to describe the parts of transverse and longitudinal waves. The figure below shows a transverse wave. Notice that parts of the wave are higher than the rest of the wave. Other parts are lower than the rest of the wave. The high points in a transverse wave are called *crests*. The low points are called *troughs*.

Compare the transverse wave above with the longitudinal wave in the figure below. The longitudinal wave does not have crests and troughs. As the wave moves through the medium, the particles in some areas move closer together. The particles in other areas move farther apart. Places where the particles are closer together are called *compressions*. Places where the particles are farther apart are called *rarefactions*.

**LOOKING CLOSER**

12. **Describe** Draw and label arrows on the figure to show the directions of motion of the wave and of the particles in the medium the wave is traveling through.

13. **Identify** What happens to particles in a medium when a rarefaction moves through them?
What Are Surface Waves?

Waves on the ocean or a swimming pool are not simple transverse or longitudinal waves. Instead, they cause particles to move both parallel and perpendicular to the direction the wave is moving. These waves are surface waves. Surface waves form at the boundary between two different mediums, such as air and water.

Look at the movements of the beach ball below as a surface wave passes it. The ball starts in a trough, or low point. As the crest, or high point, approaches, the ball moves to the left, parallel to the wave. It also moves up, perpendicular to the wave. When the ball is near the crest, it starts to move to the right. When the crest has passed, the ball starts to fall back downward and then to the left. The up-and-down motions combine with the side-to-side motions to give the ball a circular motion overall.

Particles in surface waves move just like the beach ball, in an ellipse. (A circle is a special type of ellipse.) The motion of the beach ball shows the motion of the water molecules that are particles in surface waves.
Section 1 Review

SECTION VOCABULARY

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>crest</td>
<td>the highest point of a wave</td>
</tr>
<tr>
<td>electromagnetic wave</td>
<td>a wave that consists of oscillating electric and magnetic fields, which radiate outward at the speed of light</td>
</tr>
<tr>
<td>longitudinal wave</td>
<td>a wave in which the particles of the medium vibrate parallel to the direction of wave motion</td>
</tr>
<tr>
<td>mechanical wave</td>
<td>a wave that requires a medium through which to travel</td>
</tr>
<tr>
<td>medium</td>
<td>a physical environment in which phenomena occur</td>
</tr>
<tr>
<td>transverse wave</td>
<td>a wave in which the particles of the medium move perpendicularly to the direction the wave is traveling</td>
</tr>
<tr>
<td>trough</td>
<td>the lowest point of a wave</td>
</tr>
</tbody>
</table>

1. **Compare**  Give two similarities and one difference between mechanical waves and electromagnetic waves.

2. **Apply Concepts**  Why can light travel through outer space, but sound cannot?

3. **Compare**  What is the difference between how transverse waves and longitudinal waves move particles?

4. **Identify Problems**  A student is describing a longitudinal wave in his notebook. He writes down “The distance between crests is 3 cm.” What is wrong with what the student recorded?

5. **Explain**  Why does a noise sound fainter as you move away from its source?