The Nature of Waves

READING WARM-UP

Objectives

- Describe how waves transfer energy without transferring matter.
- Distinguish between waves that require a medium and waves that do not.
- Explain the difference between transverse and longitudinal waves.

Terms to Learn

wave	transverse wave
medium	longitudinal wave

READING STRATEGY

Discussion Read this section silently. Write down questions that you have about this section. Discuss your questions in a small group.

Imagine that your family has just returned home from a day at the beach. You had fun playing in the ocean under a hot sun. You put some cold pizza in the microwave for dinner, and you turn on the radio. Just then, the phone rings. It's your friend calling to ask about homework.

In the events described above, how many different waves were present? Believe it or not, there were at least five! Can you name them? Here's a hint: A **wave** is any disturbance that transmits energy through matter or empty space. Okay, here are the answers: water waves in the ocean; light waves from the sun; microwaves inside the microwave oven; radio waves transmitted to the radio; and sound waves from the radio, telephone, and voices. Don't worry if you didn't get very many. You will be able to name them all after you read this section.

Reading Check What do all waves have in common? *(See the Appendix for answers to Reading Checks.)*

Wave Energy

Energy can be carried away from its source by a wave. You can observe an example of a wave if you drop a rock in a pond. Waves from the rock's splash carry energy away from the splash. However, the material through which the wave travels does not move with the energy. Look at **Figure 1.** Can you move a leaf on a pond if you are standing on the shore? You can make the leaf bob up and down by making waves that carry enough energy through the water. But you would not make the leaf move in the same direction as the wave.

wave: a periodic disturbance in a solid, liquid, or gas as energy is transmitted through a medium

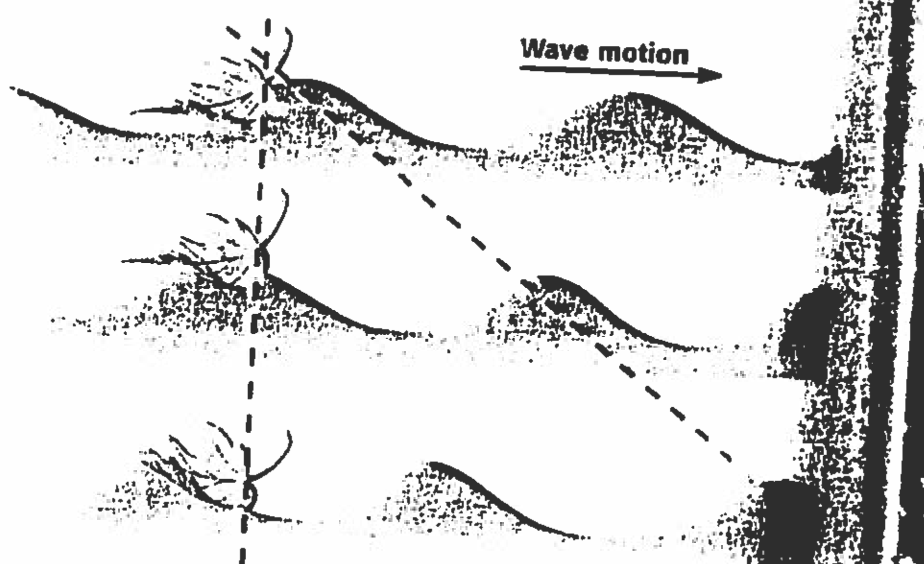


Figure 1 *Waves on a pond move toward the shore, but the water and the leaf floating on the surface only bob up and down.*

Waves and Work

As a wave travels, it does work on everything in its path. The waves in a pond do work on the water to make it move up and down. The waves also do work on anything floating on the water's surface. For example, boats and ducks bob up and down with waves. The fact that these objects move tells you that the waves are transferring energy.

Energy Transfer Through a Medium

Most waves transfer energy by the vibration of particles in a medium. A **medium** is a substance through which a wave can travel. A medium can be a solid, a liquid, or a gas. The plural of *medium* is *media*.

When a particle vibrates (moves back and forth, as in **Figure 2**), it can pass its energy to a particle next to it. The second particle will vibrate like the first particle does. In this way, energy is transmitted through a medium.

Sound waves need a medium. Sound energy travels by the vibration of particles in liquids, solids, and gases. If there are no particles to vibrate, no sound is possible. If you put an alarm clock inside a jar and remove all the air from the jar to create a vacuum, you will not be able to hear the alarm.

Other waves that need a medium include ocean waves, which move through water, and waves that are carried on guitar and cello strings when they vibrate. Waves that need a medium are called *mechanical waves*. **Figure 3** shows the effect of a mechanical wave in Earth's crust: an earthquake.

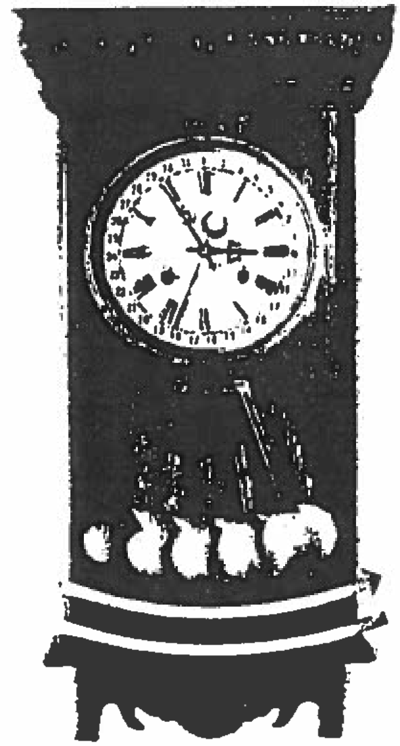


Figure 2 *A vibration is one complete back-and-forth motion of an object.*

medium a physical environment in which phenomena occur

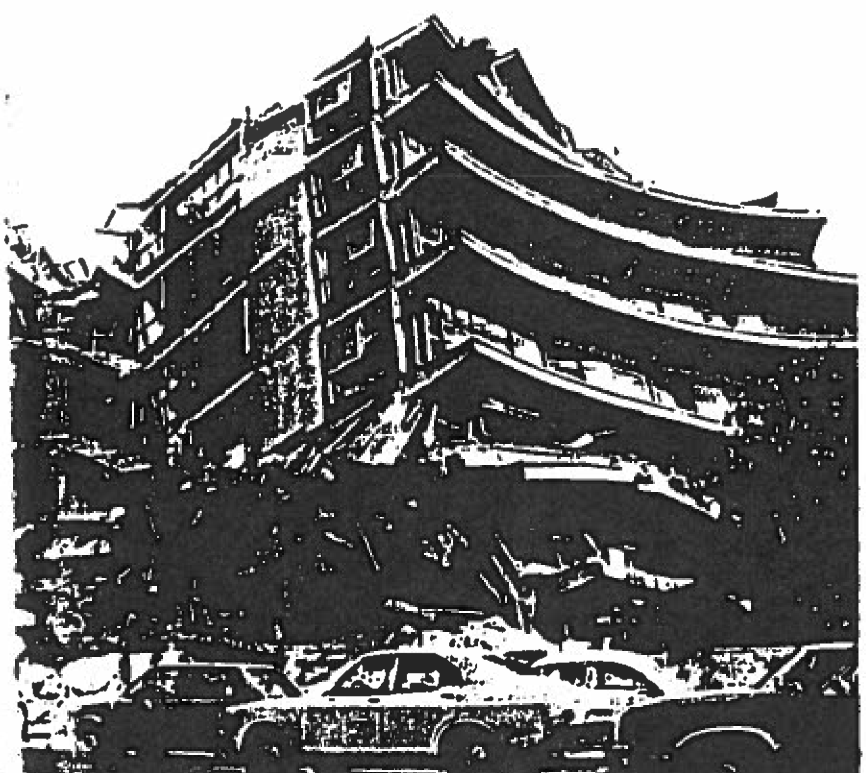


Figure 3 *Earthquakes cause seismic waves to travel through Earth's crust. The energy they carry can be very destructive to anything on the ground.*

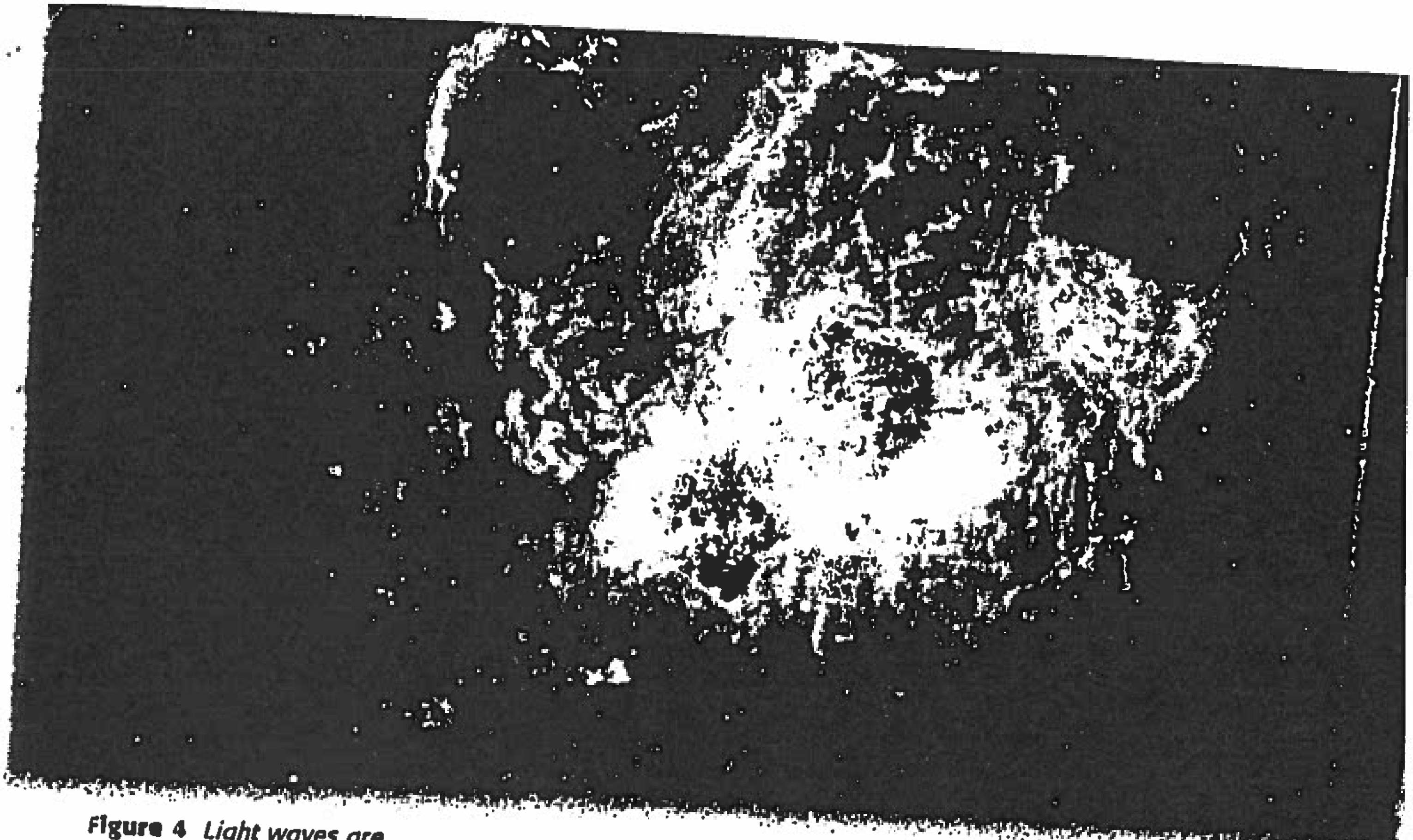


Figure 4 *Light waves are electromagnetic waves, which do not need a medium. Light waves from the Crab nebula, shown here, travel through the vacuum of space billions of miles to Earth, where they can be detected with a telescope.*

Energy Transfer Without a Medium

Some waves can transfer energy without going through a medium. Visible light is one example. Other examples include microwaves made by microwave ovens, TV and radio signals, and X rays used by dentists and doctors. These waves are *electromagnetic waves.*

Although electromagnetic waves do not need a medium, they can go through matter, such as air, water, and glass. The energy that reaches Earth from the sun comes through electromagnetic waves, which go through space. As shown in **Figure 4,** you can see light from stars because electromagnetic waves travel through space to Earth. Light is an electromagnetic wave that your eyes can see.

Reading Check **How do electromagnetic waves differ from mechanical waves?**

CONNECTION TO Astronomy

Light Speed Light waves from stars and galaxies travel great distances that are best expressed in light-years. A light-year is the distance a ray of light can travel in one year. Some of the light waves from these stars have traveled billions of light-years before reaching Earth. Do the following calculation in your **science journal:** If light travels at a speed of 300,000,000 m/s, what distance is a light-minute? (Hint: There are 60 s in a minute.)

ACTIVITY

All waves transfer energy by repeated vibrations. However, waves can differ in many ways. Waves can be classified based on the direction in which the particles of the medium vibrate compared with the direction in which the waves move. The two main types of waves are *transverse waves* and *longitudinal* (LAHN juh TOOD'n uhl) *waves*. Sometimes, a transverse wave and a longitudinal wave can combine to form another kind of wave called a *surface wave*.

INTERNET ACTIVITY

For another activity related to this chapter, go to **go.hrw.com** and type in the keyword **HP5WAVW.**

Transverse Waves

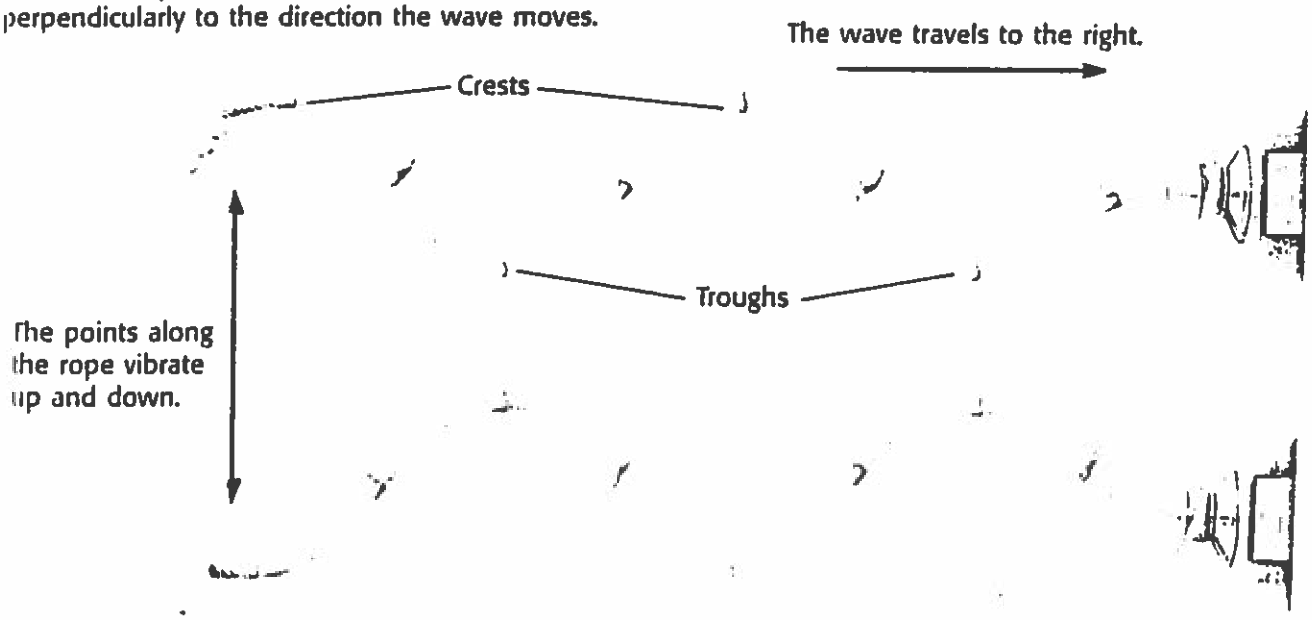
Waves in which the particles vibrate in an up-and-down motion are called **transverse waves.** *Transverse* means "moving across." The particles in this kind of wave move across, or perpendicularly to, the direction that the wave is going. To be *perpendicular* means to be "at right angles."

transverse wave a wave in which the particles of the medium move perpendicularly to the direction the wave is traveling

A wave moving on a rope is an example of a transverse wave. In **Figure 5,** you can see that the points along the rope vibrate perpendicularly to the direction the wave is going. The highest point of a transverse wave is called a *crest,* and the lowest point between each crest is called a *trough* (TRAWF). Although electromagnetic waves do not travel by vibrating particles in a medium, all electromagnetic waves are considered transverse waves. The reason is that the waves are made of vibrations that are perpendicular to the direction of motion.

Figure 5 **Motion of a Transverse Wave**

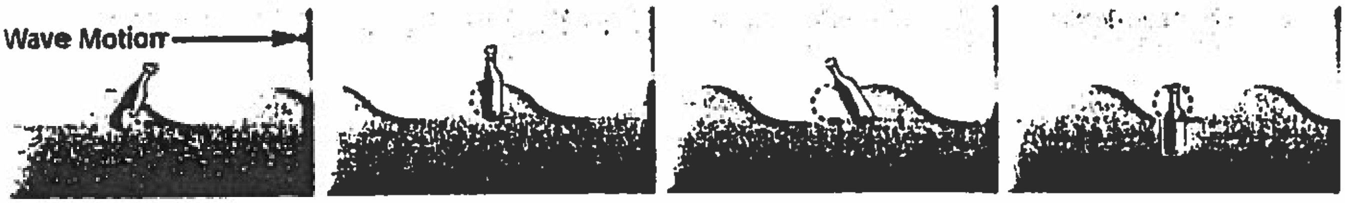
A wave on a rope is a transverse wave because the particles of the medium vibrate perpendicularly to the direction the wave moves.



Combinations of Waves

When waves form at or near the boundary between two media, a transverse wave and a longitudinal wave can combine to form a *surface wave.* An example is shown in **Figure 8.** Surface waves look like transverse waves, but the particles of the medium in a surface wave move in circles rather than up and down. The particles move forward at the crest of each wave and move backward at the trough.

***Figure 8** Ocean waves are surface waves. A floating bottle shows the circular motion of particles in a surface wave.*



SECTION Review

Summary

- A wave is a disturbance that transmits energy.
- The particles of a medium do not travel with the wave.
- Mechanical waves require a medium, but electromagnetic waves do not.
- Particles in a transverse wave vibrate perpendicularly to the direction the wave travels.
- Particles in a longitudinal wave vibrate parallel to the direction that the wave travels.

Using Key Terms

Complete each of the following sentences by choosing the correct term from the word bank.

transverse wave	wave
longitudinal wave	medium

1. In a ___, the particles vibrate parallel to the direction that the wave travels.
2. Mechanical waves require a ___ through which to travel.
3. Any ___ transmits energy through vibrations.
4. In a ___, the particles vibrate perpendicularly to the direction that the wave travels.

Understanding Key Ideas

5. Waves transfer
   - a. matter.
   - b. energy.
   - c. particles.
   - d. water.
6. Name a kind of wave that does not require a medium.

Critical Thinking

7. **Applying Concepts** Sometimes, people at a sports event do "the wave." Is this a real example of a wave? Why or why not?
8. **Making Inferences** Why can supernova explosions in space be seen but not heard on Earth?

Interpreting Graphics

9. Look at the figure below. Which part of the wave is the crest? Which part of the wave is the trough?

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For a variety of links related to this chapter, go to www.scilinks.org

Topic: The Nature of Waves; Types of Waves

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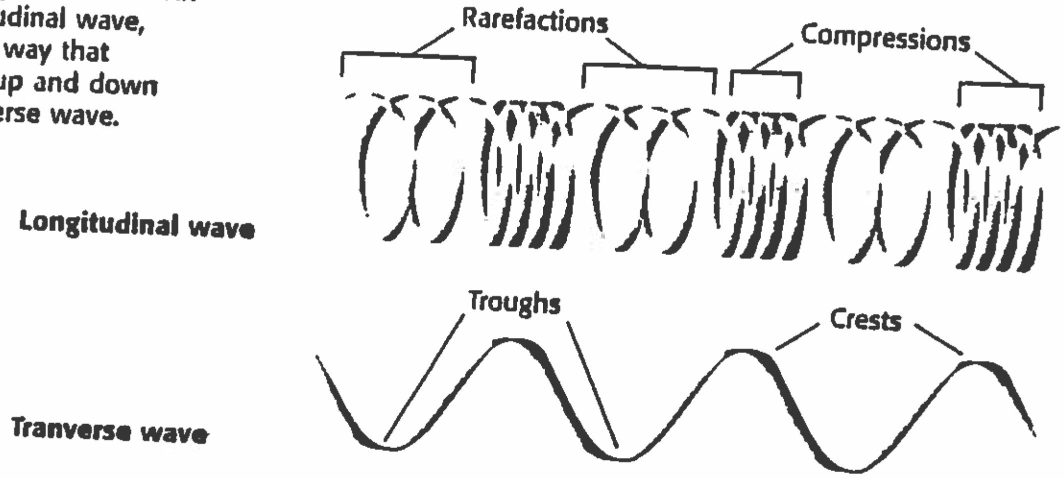
Figure 6 **Comparing Longitudinal and Transverse Waves**

Pushing a spring back and forth creates a longitudinal wave, much the same way that shaking a rope up and down creates a transverse wave.



longitudinal wave a wave in which the particles of the medium vibrate parallel to the direction of wave motion

Longitudinal Waves

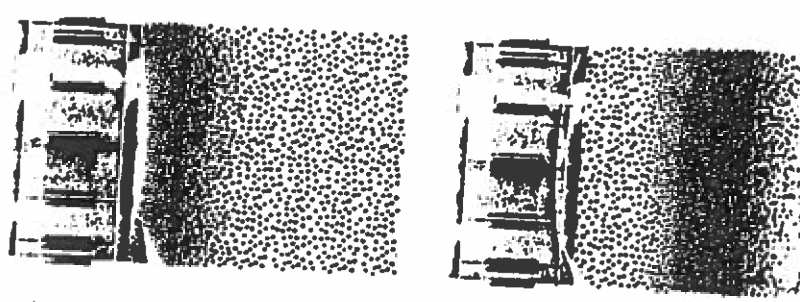
In a **longitudinal wave**, the particles of the medium vibrate back and forth along the path that the wave moves. You can make a longitudinal wave on a spring. When you push on the end of the spring, the coils of the spring crowd together. A part of a longitudinal wave where the particles are crowded together is called a *compression*. When you pull back on the end of the spring, the coils are pulled apart. A part where the particles are spread apart is a *rarefaction* (RER uh FAK shuhn). Compressions and rarefactions are like the crests and troughs of a transverse wave, as shown in **Figure 6.**

Sound Waves

A sound wave is an example of a longitudinal wave. Sound waves travel by compressions and rarefactions of air particles. **Figure 7** shows how a vibrating drum forms compressions and rarefactions in the air around it.

Reading Check What kind of wave is a sound wave?

Figure 7 *Sound energy is carried away from a drum by a longitudinal wave through the air.*



When the drumhead moves out after being hit, a compression is created in the air particles.

When the drumhead moves back in, a rarefaction is created.

SECTION 2

Properties of Waves

You are in a swimming pool, floating on your air mattress, enjoying a gentle breeze. Your friend does a "cannonball" from the high dive nearby. Suddenly, your mattress is rocking wildly on the waves generated by the huge splash.

READING WARM-UP

Objectives

- Identify and describe four wave properties.
- Explain how frequency and wavelength are related to the speed of a wave.

Terms to Learn

amplitude, frequency, wavelength, wave speed

READING STRATEGY

Mnemonics As you read this section, create a mnemonic device to help you remember the wave equation.

The breeze generates waves in the water as well, but they are very different from the waves created by your diving friend. The waves made by the breeze are shallow and close together, while the waves from your friend's splash are tall and widely spaced. Properties of waves, such as the height of the waves and the distance between crests, are useful for comparing and describing waves.

Amplitude

If you tie one end of a rope to the back of a chair, you can create waves by moving the free end up and down. If you shake the rope a little, you will make a shallow wave. If you shake the rope hard, you will make a tall wave.

The **amplitude** of a wave is related to its height. A wave's amplitude is the maximum distance that the particles of a medium vibrate from their rest position. The rest position is the point where the particles of a medium stay when there are no disturbances. The larger the amplitude is, the taller the wave is. **Figure 1** shows how the amplitude of a transverse wave may be measured.

amplitude the maximum distance that the particles of a wave's medium vibrate from their rest position

Larger Amplitude—More Energy

When using a rope to make waves, you have to work harder to create a wave with a large amplitude than to create one with a small amplitude. The reason is that it takes more energy to move the rope farther from its rest position. Therefore, a wave with a large amplitude carries more energy than a wave with a small amplitude does.

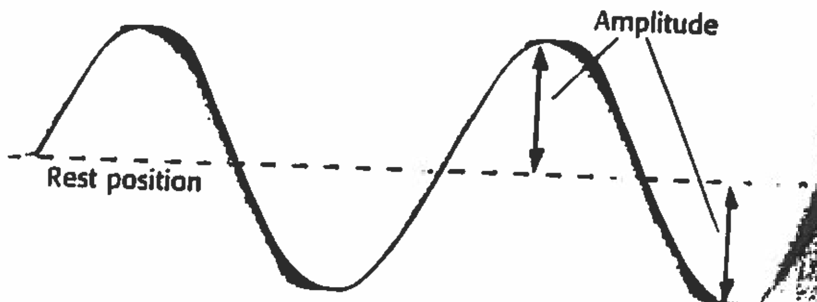


Figure 1 *The amplitude of a transverse wave is measured from the rest position to the crest or to the trough of the wave.*

Wavelength

Another property of waves is wavelength. A **wavelength** is the distance between any two crests or compressions next to each other in a wave. The distance between two troughs or rarefactions next to each other is also a wavelength. In fact, the wavelength can be measured from any point on a wave to the next corresponding point on the wave. Wavelength is measured the same way in both a longitudinal wave and a transverse wave, as shown in **Figure 2.**

wavelength the distance from any point on a wave to an identical point on the next wave

Shorter Wavelength—More Energy

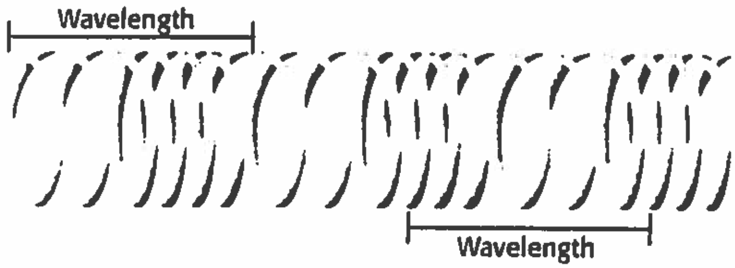
If you are making waves on either a spring or a rope, the rate at which you shake it will determine whether the wavelength is short or long. If you shake it rapidly back and forth, the wavelength will be shorter. If you are shaking it rapidly, you are putting more energy into it than if you were shaking it more slowly. So, a wave with a shorter wavelength carries more energy than a wave with a longer wavelength does.

Reading Check **How does shaking a rope at different rates affect the wavelength of the wave that moves through the rope?** (*See the Appendix for answers to Reading Checks.*)

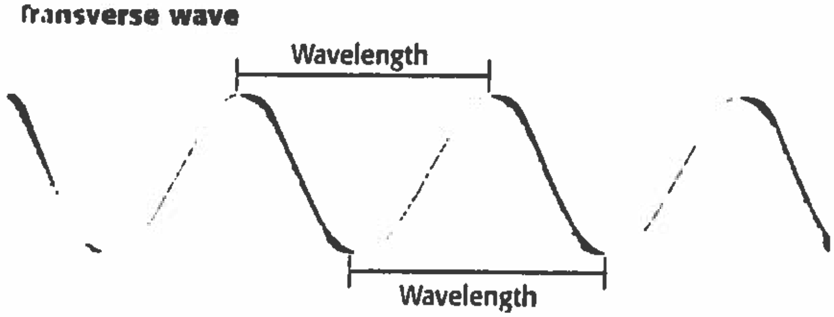
Figure 2 **Measuring Wavelengths**

Wavelength can be measured from any two corresponding points that are adjacent on a wave.

Longitudinal wave



Transverse wave



Quick Lab

Springy Waves

1. Hold a coiled **spring toy** on the floor between you and a classmate so that the spring is straight. This is the rest position.
2. Move one end of the spring back and forth at a constant rate. Note the wavelength of the wave you create.
3. Increase the amplitude of the waves. What did you have to do? How did the change in amplitude affect the wavelength?
4. Now, shake the spring back and forth about twice as fast as you did before. What happens to the wavelength? Record your observations.

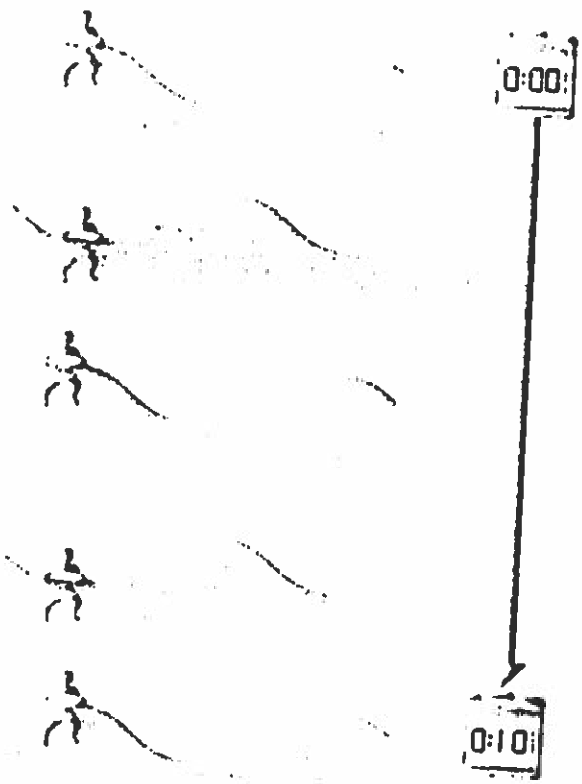


Figure 3 *Frequency can be measured by counting how many waves pass by in a certain amount of time. Here, two waves went by in 10 s, so the frequency is 2/10 s = 0.2 Hz.*

Frequency

Think about making rope waves again. The number of waves that you can make in 1 s depends on how quickly you move the rope. If you move the rope slowly, you make only a small number of waves each second. If you move it quickly, you make a large number of waves. The number of waves produced in a given amount of time is the **frequency** of the wave. Frequency is usually expressed in *hertz* (Hz). For waves, one hertz equals one wave per second (1 Hz = 1/s). **Figure 3** shows a wave with a frequency of 0.2 Hz.

Reading Check **If you make three rope waves per second, what is the frequency of the wave?**

Higher Frequency—More Energy

To make high-frequency waves in a rope, you must shake the rope quickly back and forth. To shake a rope quickly takes more energy than to shake it slowly. Therefore, if the amplitudes are equal, high-frequency waves carry more energy than low-frequency waves.

Wave Speed

Wave speed is the speed at which a wave travels. Wave speed (v) can be calculated using wavelength (λ, the Greek letter *lambda*) and frequency (f) by using the *wave equation,* which is shown below:

$$v = \lambda \times f$$

MATH FOCUS

Wave Calculations Determine the wave speed of a wave that has a wavelength of 5 m and a frequency of 4 Hz.

Step 1: Write the equation for wave speed.

$$v = \lambda \times f$$

Step 2: Replace the λ and f with the values given in the problem, and solve.

$$v = 5\ \text{m} \times 4\ \text{Hz} = 20\ \text{m/s}$$

The equation for wave speed can also be rearranged to determine wavelength or frequency, as shown at top right.

$\lambda = \frac{v}{f}$ (Rearranged by dividing by f.)

$f = \frac{v}{\lambda}$ (Rearranged by dividing by λ.)

Now It's Your Turn

1. What is the frequency of a wave if the wave has a speed of 12 cm/s and a wavelength of 3 cm?
2. A wave has a frequency of 5 Hz and a wave speed of 18 m/s. What is its wavelength?

·requency ·and ·Wavelength ·Relationship

Three of the basic properties of a wave are related to one another in the wave equation—wave speed, frequency, and wavelength. If you know any two of these properties of a wave, you can use the wave equation to find the third.

One of the things the wave equation tells you is the relationship between frequency and wavelength. If a wave is traveling ı certain speed and you double its frequency, its wavelength will be cut in half. Or if you were to cut its frequency in half, the wavelength would be double what it was before. So, you can say that frequency and wavelength are *inversely* related. Think of a sound wave, traveling underwater at 1,440 m/s, given off by the sonar of a submarine like the one shown in **Figure 4.** If the sound wave has a frequency of 360 Hz, it will have a wavelength of 4.0 m. If the sound wave has twice that frequency, the wavelength will be 2.0 m, half as big.

The wave speed of a wave in a certain medium is the same no matter what the wavelength is. So, the wavelength and frequency of a wave depend on the wave speed, not the other way around.

Figure 4 *Submarines use sonar, sound waves in water, to locate underwater objects.*

frequency the number of waves produced in a given amount of time

wave speed the speed at which a wave travels through a medium

SECTION Review

Summary

- Amplitude is the maximum distance the particles of a medium vibrate from their rest position.
- Wavelength is the distance between two adjacent corresponding parts of a wave.
- Frequency is the number of waves that pass a given point in a given amount of time.
- Wave speed can be calculated by multiplying the wave's wavelength by the frequency.

Using Key Terms

1. In your own words, write a definition for each of the following terms: *amplitude*, *frequency*, and *wavelength*.

Understanding Key Ideas

2. Which of the following results in more energy in a wave?
   a. a smaller wavelength
   b. a lower frequency
   c. a shallower amplitude
   d. a lower speed
3. Draw a transverse wave, and label how the amplitude and wavelength are measured.

Math Skills

4. What is the speed (v) of a wave that has a wavelength (λ) of 2 m and a frequency (f) of 6 Hz?

Critical Thinking

5. **Making Inferences** A wave has a low speed but a high frequency. What can you infer about its wavelength?
6. **Analyzing Processes** Two friends blow two whistles at the same time. The first whistle makes a sound whose frequency is twice that of the sound made by the other whistle. Which sound will reach you first?

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