UNIT 2

Optics

An astronomical telescope can detect light from the depths of space.

Key Ideas

4 Many properties of light can be understood using a wave model of light.

5 Optical systems make use of mirrors and lenses.

6 Human vision can be corrected and extended using optical systems.

Getting Started

An aerobatics team produces colourful vapour trails.

High-performance jets fly low in front of a crowd. The jets are at high speed and in tight formation, moving at 300 km/h and holding steady at a separation of just 3 m from wing tip to wing tip. On a radio command, each pilot squeezes a trigger, releasing billowing clouds of red, white, and green. The spectators see the sky fill with brightly coloured clouds. A thunderous roar rips through the air as the jets scream by. As the jets move off, the clouds begin to mix and break up.

A performance like an air show depends on many things, including the effective use of light. The pilots produced the coloured clouds at the same instant using radio transmissions to communicate. Radio communication, colours, cameras, binoculars, eyeglasses, and our own human vision system all depend on predictable properties of light.

Ancient societies used light energy from fire and sunlight. In our modern society we also use laser light, radio waves, infrared light, and other forms of light energy. In this unit, you will learn about how we see and use visible light as well as invisible kinds of radiation. You will learn about optics—the branch of physics that studies the properties of light and vision.


A laser light show

internet connect

Four main types of light sources are incandescence, electrical discharge, fluorescence, and phosphorescence. Find out how each of these processes produces light. Start your search at **www.bcscience8.ca**.

Word Connect

Light comes from the Greek word *leukos,* which means white, and later from a German word that means to shine.

Light Is Energy

Find Out ACTIVITY

Solar calculators use light from a light source such as a light in the room or the Sun to operate without batteries. In this activity, you can observe evidence that light is a form of energy.

Materials

- calculator with solar panel that does not use batteries

What to Do

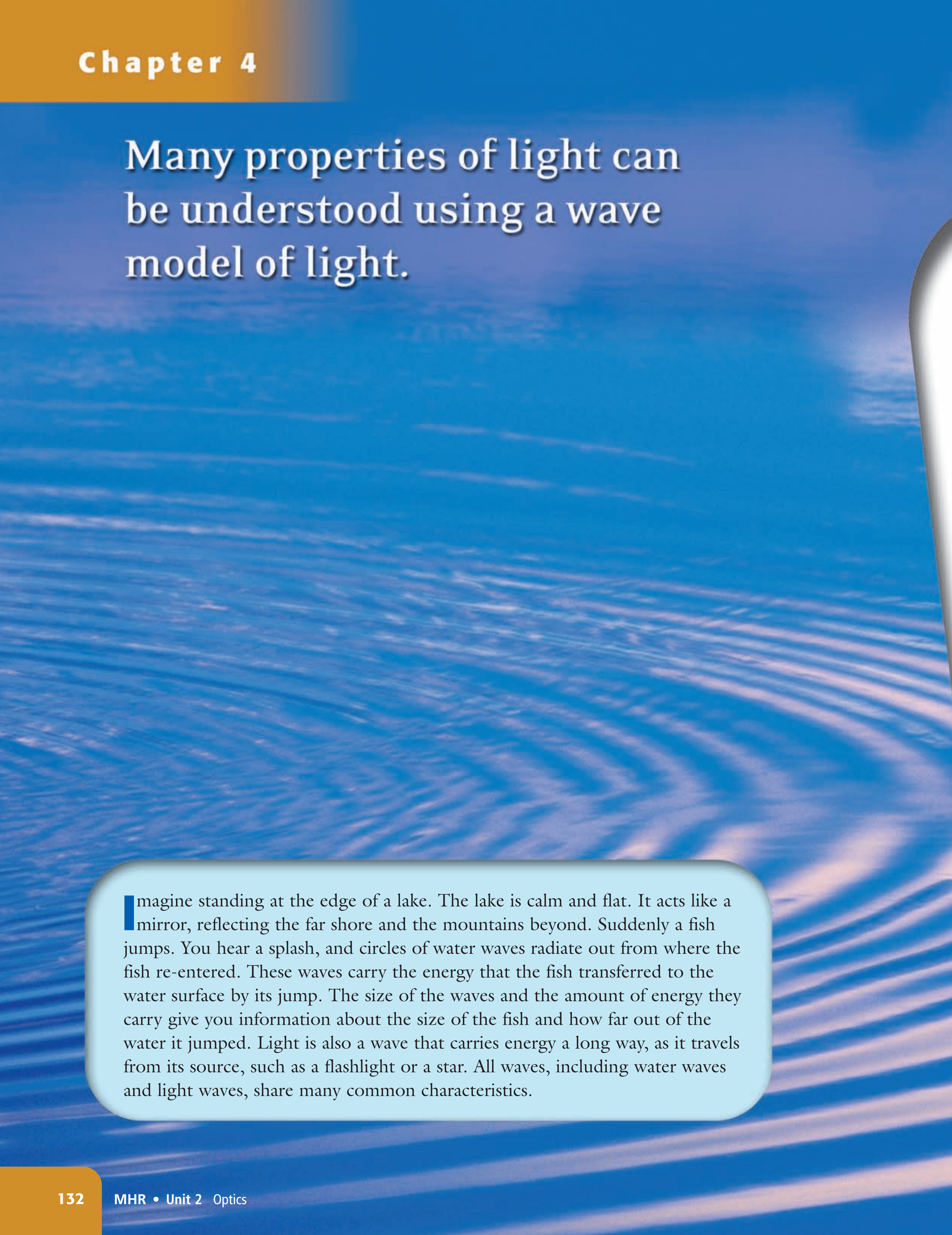
1. Enter some numbers into the calculator and then block any light from getting to the solar panel. Note the result.
2. Uncover the panel and look again at the display. Note the result.

What Did You Find Out?

1. What happened to the display when light was prevented from reaching the solar panel?
2. Was the calculator able to retain the numbers that were entered before the solar panel was covered? Explain.
3. How would you explain to a younger student how this experiment does or does not show that light is energy?

Chapter 4

Many properties of light can be understood using a wave model of light.



Imagine standing at the edge of a lake. The lake is calm and flat. It acts like a mirror, reflecting the far shore and the mountains beyond. Suddenly a fish jumps. You hear a splash, and circles of water waves radiate out from where the fish re-entered. These waves carry the energy that the fish transferred to the water surface by its jump. The size of the waves and the amount of energy they carry give you information about the size of the fish and how far out of the water it jumped. Light is also a wave that carries energy a long way, as it travels from its source, such as a flashlight or a star. All waves, including water waves and light waves, share many common characteristics.

What You Will Learn

In this chapter, you will
- **recognize** that waves carry energy
- **describe** ways in which water waves can explain properties of light
- **explain** why a prism separates white light into different colours
- **describe** properties and uses of electromagnetic waves

Why It Is Important

You can see and hear the world around you because of the energy carried by waves. Waves with different properties can be used in different ways. Electromagnetic waves can be used to make different kinds of images of the world around us.

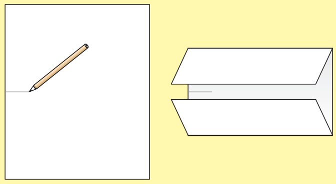
Skills You Will Use

In this chapter, you will
- **observe** how light can be separated into colours
- **model** the properties of light
- **communicate** using diagrams and colours

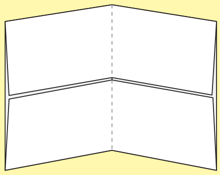
FOLDABLES™
Reading & Study Skills

Make the following Foldable to guide your study of the wave model of light.

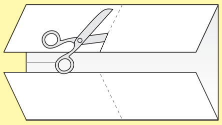
STEP 1 **Draw** a mark at the midpoint of a sheet of paper along the side edge. Then **fold** the top and bottom edges in to touch the midpoint. (If you are using notebook paper, use the centre of the middle hole to mark the midpoint.)



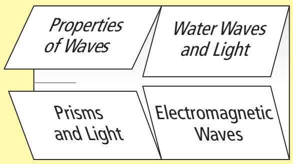
STEP 2 **Fold** in half from side to side.



STEP 3 **Open** and cut along the inside fold lines to form four tabs.



STEP 4 **Label** each tab as shown.



Read and Write As you read the chapter, record notes under the appropriate tabs.

4.1 Properties of Waves

Waves transfer energy through matter or space. Amplitude is the height of a wave crest or depth of a wave trough, as measured from its rest position. A wavelength is the distance over which the wave repeats. As the wavelength decreases, the frequency increases. Waves can differ in how much energy they carry and in how fast they travel.

Key Terms

amplitude
crest
energy
frequency
trough
wave
wavelength

A surfer bobs in the ocean waiting for the perfect wave (Figure 4.1), microwaves warm up your leftover pizza, and sound waves from your CD player bring music to your ears. These and other types of waves have many properties in common.

Figure 4.1 Waiting for a wave. A wave transfers energy through matter or space.

4-1 Watching Water Waves

Find Out ACTIVITY

You do not need to visit the ocean to make waves. In this activity, you can make waves right in your classroom.

Materials

- pie plate or wide pan
- water
- pencil

What to Do

1. Fill a pie plate or other wide pan with water about 2 cm deep.
2. Lightly tap the bottom of a pencil once in the middle of the surface of the water. Observe the waves that form.
3. Lightly tap your pencil once per second on the surface of the water. Observe the spacing of the water waves.
4. Increase the rate of your tapping. Observe the spacing of the water waves.
5. Clean up and put away the equipment you have used.

What Did You Find Out?

1. In what direction did the waves travel when you tapped the water lightly with your pencil?
2. How did the spacing of the water waves change when the rate of tapping increased?

Features of a Wave

A **wave** is a disturbance or movement that transfers energy through matter or space, without causing any permanent displacement. Sound waves disturb the air and transfer energy through it. Ocean waves disturb the water and transfer energy through it. **Energy** is the capacity to apply a force over a distance. A **force** is a push or pull on an object.

To visualize the features of a wave, examine Figure 4.2. The dotted line shows the equilibrium or rest position. The rest position is the level of the water when there are no waves. Notice the labels in the illustration. A **crest** is the highest point in a wave. A **trough** is the lowest point in a wave.

Did You Know?

Sound waves can be used to make an image of an unborn child during an ultrasound procedure. Sound waves can also be used for cleaning lenses and other optical equipment, dental instruments, and surgical instruments.

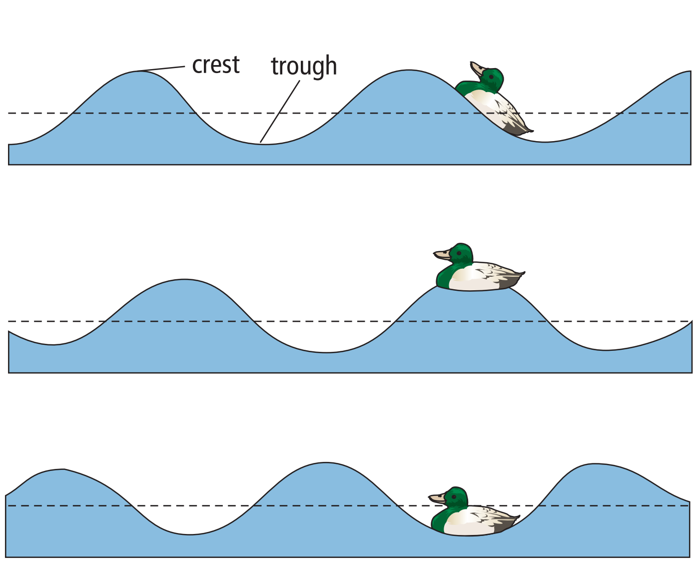


Figure 4.2 The wave is moving from left to right.

Wavelength

The **wavelength** is the distance from crest to crest or from trough to trough. You can also think of a wavelength as the distance covered by one complete crest plus one complete trough (see Figure 4.3). Wavelength is measured in metres.

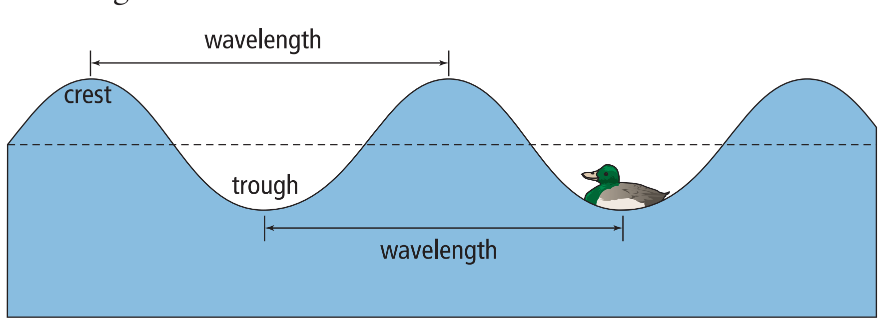


Figure 4.3 A wavelength is the distance over which the wave repeats.

Amplitude

If a breeze picks up on the lake where the duck is sitting, the height of the waves can increase. This means that the duck floats higher and lower as the crests rise and the troughs deepen. When the crests are high and the troughs are low, we say the wave has a larger amplitude. The **amplitude** is the height of a wave crest or depth of a wave trough, as measured from its rest position (see Figure 4.4).

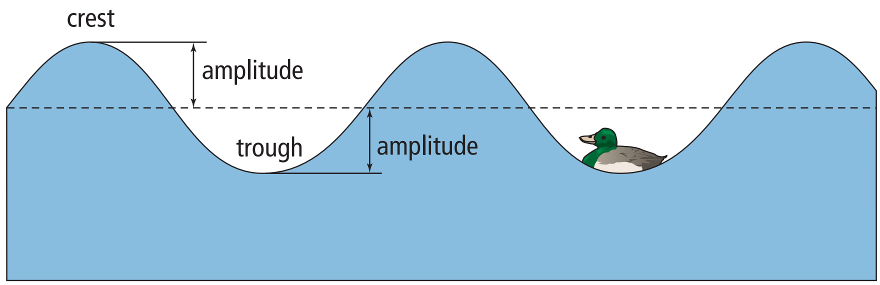


Figure 4.4 The amplitude of the wave crest equals the amplitude of the wave trough.

The amplitude is related to the amount of energy carried by the wave. The larger the amplitude, the greater the energy transported. A light wave that has a large amplitude carries more energy and is very bright. A dim light has a lower amplitude and carries less energy. The next time you lower the brightness of a light using a dimmer switch, think of the switch as a light wave amplitude adjuster.

internet connect

With sound waves, frequency is related to musical pitch. Find out more about the frequencies of musical notes. Start your search at **www.bcscience8.ca**.

Frequency

As the wavelength decreases, the duck and the water move up and down more frequently. Every cycle of bobbing up and down is called an oscillation or a vibration. **Frequency** is the number of repetitive motions, or oscillations, that occur in a given time. Frequency is usually measured in **hertz** (Hz), or cycles per second. In our example, it is the number of times per second the duck bobs from crest to crest. For example, if two wave crests were to pass under the duck every second, then the duck is said to be vibrating or oscillating at a frequency of 2 Hz.

When the duck is sitting in water waves with short wavelengths, it will bob up and down frequently. When the duck is sitting in waves with long wavelengths, it will bob up and down less frequently. The shorter the wavelength, the greater the frequency (see Figure 4.5). When one value increases as the other decreases, scientists call this an *inverse relationship*.

Suggested Activities

Find Out Activity 4-2 on page 138
Find Out Activity 4-3 on page 139

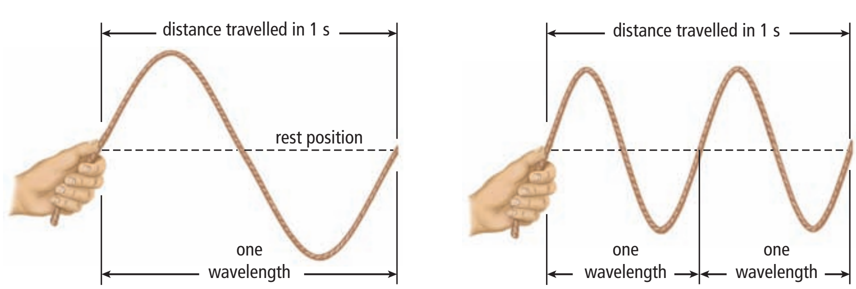


Figure 4.5 The wavelength of a wave decreases as the frequency increases. All waves share this property.

A Water Wave Moves Energy, Not Water

A water wave does not carry water along with it. Only the energy carried by the water wave moves forward (see Figure 4.6). Many important types of waves share this property—they carry energy without transporting matter. Think of being out in the middle of a lake and bobbing straight up and down as the wave passes underneath. Only the energy in the wave moves forward toward the shore. You do not move forward and neither does the water. Once the waves have passed, the water returns to its original, or rest, position.

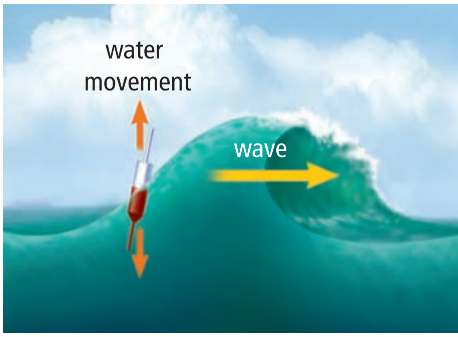


Figure 4.6 The energy carried by the wave moves forward. The water moves up and down.

Two Types of Waves

Waves can differ in how much energy they carry and in how fast they travel. Waves also have other characteristics that make them different from each other.

Sound waves travel through the air to reach your ears. Ocean waves move through water to reach the shore. In both cases, the matter the waves travel through is called a **medium**. The medium can be a solid, liquid, or gas, or a combination of these. For sound waves, the medium is air, and for ocean waves the medium is water. The two types of waves that travel through a medium are transverse waves and compression waves.

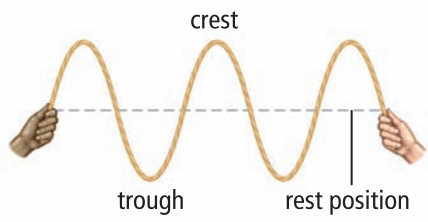


Figure 4.7 A transverse wave travels horizontally along the rope, and the rope moves up and down.

Transverse waves

In a **transverse wave**, matter in the medium moves up and down perpendicular to the direction that the wave travels (see Figure 4.7). When you shake one end of a rope while your friend holds the other end, you are making transverse waves. The wave and its energy travel from you to your friend as the rope moves up and down.

Compression waves

Sound waves are compression waves. In a **compression wave**, matter in the medium moves back and forth along the same direction that the wave travels. You can model compression waves with a coiled spring with a piece of string tied on a coil (see Figure 4.8). Squeeze several coils together at one end of the spring. Then let go of the coils, still holding onto the other end of the spring. A wave will travel along the spring. As the wave moves, it looks as if the whole coil spring is moving toward one end. The string moves back and forth as the wave passes, and then stops moving after the wave has passed. The wave carries energy, but not matter, forward along the spring.

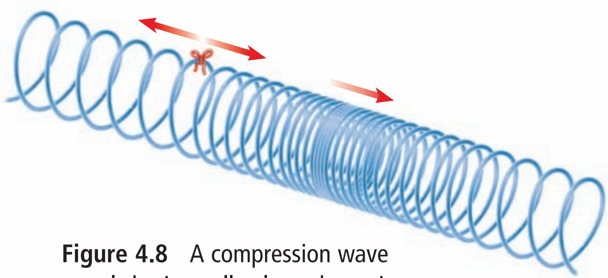


Figure 4.8 A compression wave travels horizontally along the spring, and the coils in the spring move back and forth horizontally.

Explore More

Traffic waves are a form of traffic jam on highways that can occur when cars are more densely packed in some places and less densely packed in others. A traffic wave can move through a lane of cars causing the whole lane to slow down. Find out what causes these waves and what can be done to prevent them. Start your search at **www.bcscience8.ca**.

Suggested Activity

Conduct an Investigation 4-4 on page 140

Water waves and seismic (earthquake) waves are a combination of transverse and compression waves. Seismic waves can travel through Earth and along Earth's surface. When objects on Earth's surface absorb some of the energy carried by seismic waves, the objects move and shake.

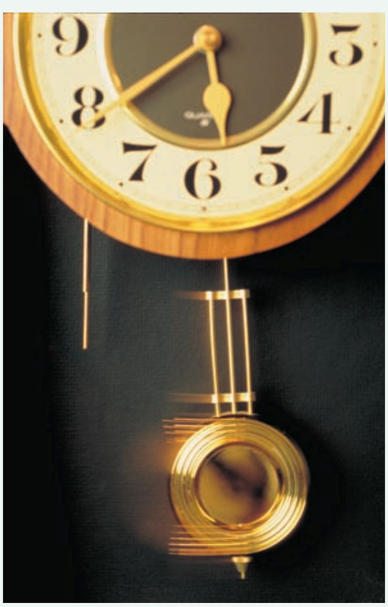
Not all waves need a medium to travel through. Some waves, such as visible light waves and radio waves, can travel through space where there is no material.

Reading Check

1. What is the difference between a crest and a trough?
2. What are three ways to measure wavelength?
3. What property of a wave is measured in hertz?
4. How are the wavelength and frequency of a wave related?
5. What is the difference between a transverse wave and a compression wave?

4-2 Frequency Formula — Think About It

Examples of frequency exist all around you. In this activity, you can calculate frequency by using the number of cycles, the time, and an equation.



The pendulum on a grandfather clock

What to Do

1. Use the following equation to calculate frequency (in hertz) for each of the examples below. The first example is done for you.

   frequency = cycles ÷ seconds

   (a) pendulum: 24 swings in 6 s
   frequency = cycles/s
   = 24 swings/6 s
   = 4 Hz

   (b) merry-go-round: 12 revolutions per 2 min

   (c) flashing red light at an intersection: 30 flashes in 0.5 min

   (d) heart rate: 18 beats per 20 s

   (e) car drive shaft: 2000 rpm (revolutions per min)

What Did You Find Out?

1. In order to calculate frequency measured in hertz, what must be done with the time unit before dividing?

4-3 Catch a Waveform

Find Out ACTIVITY

A waveform is a visual record of waves. In this activity, you will make a waveform using the motion of a vibrating metre stick.

Materials

- felt pen
- metre stick
- C clamp
- cardboard or manila card stock
- masking tape

What to Do

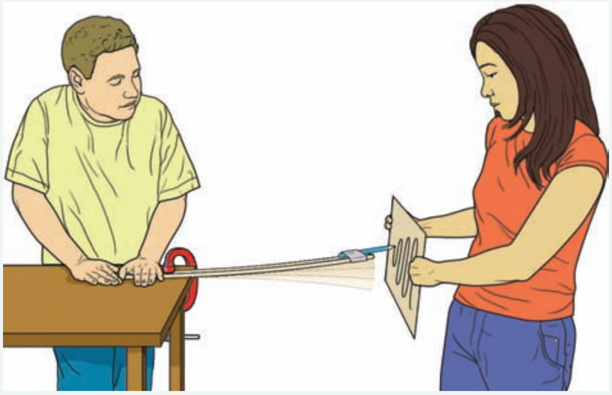
1. Tape the felt pen to the end of the metre stick.

Part 1

2. Clamp the metre stick to a desk with 40 cm of the metre stick (and the pen) extending out from the desk. Hold the end firmly in place on the desk.
3. Gently press down on the metre stick and let it go so that it can vibrate gently.
4. Have a partner hold the cardboard and walk slowly next to the vibrating pen. The waveform should be recorded on the cardboard. Make sure that several waves are recorded. You may need to practise this several times to get it right. Your partner can follow a masking tape line on the floor in front of the desk to make it easier to walk in a straight line.

Part 2

5. Make a new waveform on a new piece of cardboard by repeating steps 3 and 4.
   This time, increase the length that the metre stick extends out from the desk to 60 cm.
6. Label each waveform with crest, trough, and wavelength.
7. Clean up and put away the equipment you have used.



Part 1, step 4

What Did You Find Out?

1. What did you observe about the sound of the metre stick vibrating?
2. Measure the distance between two adjacent crests on each waveform. Which trial produced waves with the longest wavelengths?
3. Which trial produced the most vibrations?
4. As the wavelength increases, what happens to the frequency?
5. What is the relationship between wavelength and frequency?
6. Is it possible for the wave with the greatest wavelength to also have the greatest frequency? Explain.

4-4 Wire Waves

Skill Check
- Observing
- Classifying
- Communicating
- Modelling

A coiled metal spring can be stretched along the floor and moved back and forth to generate waves. When you make compression waves in a coiled spring, a compression is the region where the coils are close together. The less-dense region of a compression wave is called a rarefaction.

Question

How can a coiled metal spring be used to investigate amplitude, wavelength, and frequency?

Safety

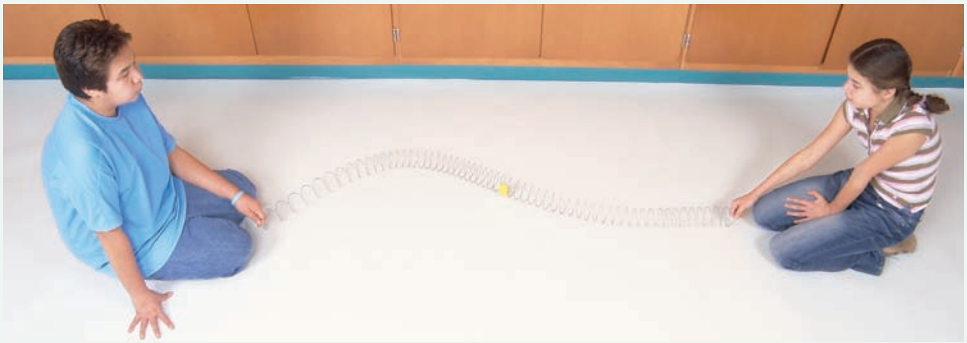
- Do not let go of the spring when it is stretched out.
- The end of the spring might be sharp.

Materials

- coiled metal spring or Slinky®
- piece of masking tape or string

Step 1 Attach tape or string to the spring.

Step 2 Carefully stretch the spring out on the floor.



Step 3 Hold each end of the spring firmly.

Procedure

1. Work with a partner. Attach a piece of tape or string at about the halfway mark of the spring.
2. Stretch the spring out on the floor, with you and your partner each holding an end. Be very careful not to overstretch the spring, as it is easily damaged. Also, be careful not to allow the spring to get knotted up. Always keep the spring on the floor when generating waves.
3. Hold one end of the spring firmly in place as your partner moves the other end slowly from side to side. Observe and draw a diagram of the wave that results. Label it "low frequency wave," and indicate its wavelength. Use arrows to show the directions in which the marked coil moves. Note whether you feel a side-to-side force as you hold the spring firmly in place.
4. Repeat step 3 but have your partner move the end of the spring quickly from side to side to provide a higher frequency. There will be more places on the spring that do not move very much, and other places that move a lot. What has happened to the frequency? Observe and draw a diagram of the resulting wave. Indicate the wavelength. Label this diagram.
5. Try to do the following. Draw and label a diagram for each of your results.
   (a) Increase the amplitude of the wave.
   (b) Make a low frequency, high amplitude wave.
   (c) Make a high frequency, high amplitude wave.
   (d) Make a low frequency and low amplitude wave.

Analyze

1. How did the wavelength in the spring change as it moved from side to side more quickly?
2. How did the marked coil move in each of your waves?
3. (a) How are the frequency and amplitude of a wave related?
   (b) Can a low frequency wave sometimes have a large amplitude, and sometimes have a small amplitude? Explain.

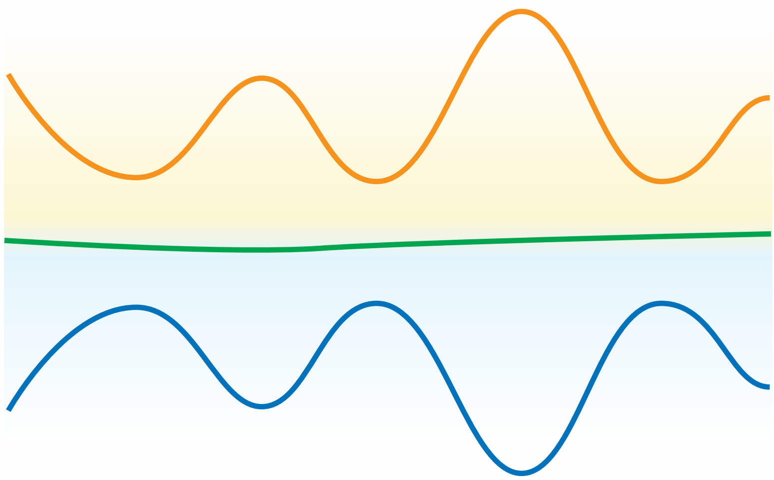
Conclude and Apply

1. (a) Draw a diagram to illustrate:
      (i) a wave with a high frequency, a short wavelength, and a large amplitude
      (ii) a wave with a low frequency, a long wavelength, and a small amplitude
   (b) Use labels to show crests, troughs, wavelength, and amplitude on both diagrams you drew in (a).
2. The amount of energy transferred by the spring changes with frequency, and also with wavelength.
   (a) What happens to the amount of energy transferred through the spring as the frequency increases?
   (b) What happens to the amount of energy transferred through the spring as the wavelength increases?

Wild, Weird, Wonderful

www Science

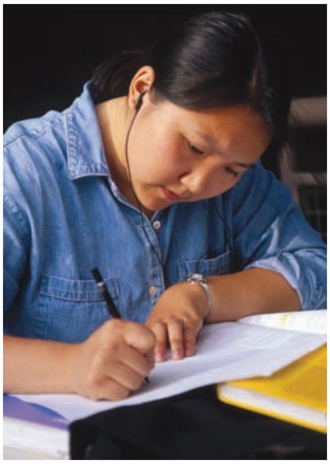
Noise Cancellation Headphones



The positive and negative sound waves cancel each other in noise cancellation headphones.

Have you ever tried to listen to music on a noisy bus? Earphone plugs help to keep out the background noise, while larger headphones have foam pads that help block noise. Noise cancellation headphones, also called noise reduction headphones, use properties of sound waves to reduce noise by cancelling out unwanted waves. Noise cancellation headphones work best against constant noise, such as the sounds of a school cafeteria or an aircraft engine.

Sound is carried by a series of high and low pressure waves that move from the source of the sound to your eardrum. The changing pressures cause your eardrum to vibrate. Sound waves have a particular shape that is determined by their wavelength and amplitude. The wave-length determines the pitch of the sound and the amplitude determines how loud the sound is.



Noise cancellation headphones can help you study when you are in a noisy place.

Noise cancellation headphones have tiny microphones mounted into the headsets that detect the background noise. The background noise is called the positive sound, because it is the sound that is normally heard. A digital signal processor analyzes the shape of the positive sound wave and then generates another sound wave that has the exact opposite shape. This cancellation wave is called the negative sound. The negative sound is then amplified and played through the headphones. The positive and negative sound waves combine and effectively cancel each other out.

Some people use noise cancellation headphones simply to listen to silence. Others use them to listen to music. Using noise cancellation allows you to listen to music at a lower volume than you would otherwise be able to.

Noise cancellation does not remove all sounds that you might hear—which is a good thing, because you want to be able to hear the approach of the school bus you are waiting for!

Check Your Understanding

Checking Concepts

1. Draw a wave with a wavelength of 4 cm and an amplitude of 1 cm. Label the crest, the trough, the amplitude, and the wavelength.
2. (a) A buzzer vibrates 900 times in 1 s. What is its frequency?
   (b) A guitar string vibrates 880 times in 2 s. What is its frequency?
   (c) A ball bounces on the floor 10 times in 50 s. What is its frequency?
3. (a) Draw a transverse wave and a compression wave.
   (b) Give an example of each type of wave.
4. A speedboat zips by on a lake and sends a series of waves toward a dock. The frequency of the waves is 5 Hz. How many wave crests will pass by the dock in 8 s?

Understanding Key Concepts

5. You can make a wave by shaking the end of a long rope up and down.
   (a) Explain how you would shake the end of the rope to make the wavelength shorter.
   (b) State two different ways you could shake the rope to increase the energy carried by the wave.
6. Explain why water waves travelling under a raft do not move the raft horizontally.
7. A wave in the open ocean between Prince Rupert and Haida Gwaii has an amplitude of 15 m in a large storm. The wavelength is 1000 m.
   (a) How high will the crest of the wave be above a boat that is in the trough?
   (b) If the wave travels at a speed of 10 km per hour, how often will a wave pass under the boat?
8. A student performs a frequency experiment on three different pendulums and obtains the following results:

Pendulum	Number of Swings	Time to Complete All the Swings (s)
A	32	8 s
B	72	9 s
C	210	1 min 20 s

   (a) Calculate the frequency of each pendulum in Hz.
   (b) Rank the pendulums from lowest to highest frequency.
9. A female soprano sings at a higher frequency (higher pitch) than a male baritone.
   (a) Which singer is producing waves of longer wavelength? Explain your answer.
   (b) If both singers sing at an equal volume, which singer is sending more energy out through his or her voice? Or are they both sending out the same energy? Explain your answer.

Pause and Reflect

Write a paragraph or develop a table to explain how a wave with a length of 6 cm and a frequency of two waves per second changes when the frequency is changed to four waves per second.