CHAPTER 10

Sources and Properties of Light

KEY IDEAS

- Light is produced by a variety of sources, both natural and artificial.
- Light may be reflected, transmitted, or absorbed, depending on the material that it strikes.
- Visible light is a part of the energy that comes from the Sun.
- The visible and invisible parts of radiation from the Sun make up the electromagnetic spectrum.

LEARNING TIP

Before reading this chapter, make a note of the headings and subheadings. Ask yourself, "What do I already know about this topic? What questions do I have about this topic?"

The rising and setting of the Sun are regular occurrences that we often take for granted. Most of our daily activities occur between sunrise and sunset so we can use light from the Sun. After sunset, we use other sources of light for our activities.

The Sun is so bright that it is dangerous to look at, yet it is the most important source of light for everything on Earth. Thinking about the Sun reveals a lot about the behaviour of light. Sunlight produces shadows in a forest and a city. Sunlight shines through the atmosphere and through windows, but not through bricks or wood. Sunlight reflects brightly off mirrors and water but not off asphalt. Why does sunlight, and all other light, behave in these ways?

In this chapter, you will explore the sources, properties, and characteristics of light. As well, you will learn how light from the Sun is used as a source of energy.

Light Energy and Its Sources

10.1

What is light? Light is not something you can touch or taste. It does not have any mass. But you can see light, and you can observe its effects on matter. For example, a penny put in sunlight will get warmer than a penny placed in the shade. The penny put in sunlight gains energy from the light. Based on this observation, we can define **light** as a form of energy that can be detected by the human eye.

You can learn more about light by looking carefully around you. In a room lit by electric light, for example, you can see the light energy that travels directly from the electric light to your eyes. What about other objects in the room? How can you see them? The light energy from the electric light must spread throughout the room. Some of it bounces off objects and then travels to your eyes, enabling you to see objects and people in the room. **Figure 1** shows how light reaches your eyes.

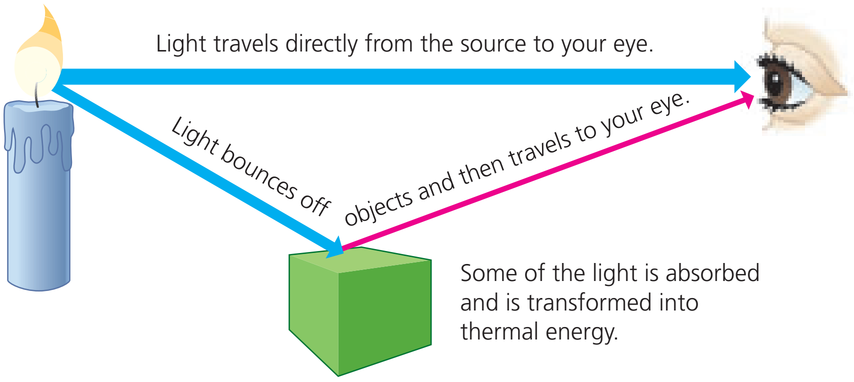


Figure 1
Light energy travels directly and indirectly to your eyes.

LEARNING TIP

Identifying key words helps readers determine the most important concepts in a chapter. To help you determine key words, look for words that are highlighted, repeated, and used in headings.

Sources of Light and Reflectors of Light

Light energy comes from many different sources, both natural and artificial. The Sun is the most important natural source of light. Artificial sources of light are created by people. Objects that emit (give off) energy in the form of light are said to be **luminous**. For example, the Sun is luminous, and so is a burning candle. Objects that do not emit light, but only reflect light from other sources, are said to be **nonluminous**. Most things—this book, your desk, your classmates—are nonluminous. Even the Moon is nonluminous—it does not emit light. We see the Moon because it reflects light from the Sun.

LEARNING TIP

Active readers pose questions to guide their reading. Read this section and try to answer these questions: "Which light sources are efficient sources of light? Which light sources are inefficient sources of light?"

In luminous objects, the input energy transforms into light energy. Common forms of input energy are chemical energy, electrical energy, nuclear energy, and thermal energy.

When designing a light source, engineers consider not only the brightness, location, attractiveness, and cost of the light source. They also consider how effectively the light source transforms the input energy into light energy.

Light from Incandescence

Things that are extremely hot become luminous. At high temperatures, they begin to emit light. The process of emitting light because of high temperatures is called **incandescence**. In incandescent light sources, a large amount of the input energy becomes thermal energy. Therefore, these light sources are not efficient.

In an incandescent light bulb, electrical energy transforms into heat and light energy (**Figure 2**). Electricity passing through a fine metal wire (the tungsten filament) makes the wire very hot when the bulb is turned on.

A kerosene lamp can provide enough light to read by (**Figure 3**). The chemical energy in the kerosene fuel transforms into heat and light energy.

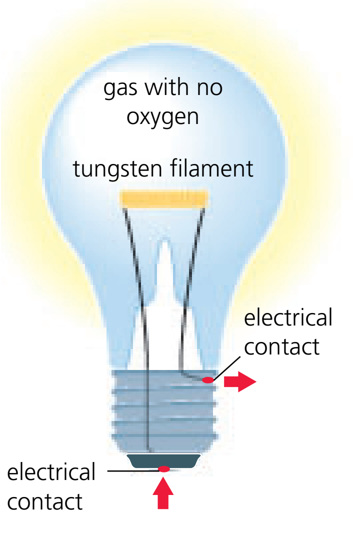


Figure 2
In an incandescent light bulb, electricity passes through a fine metal wire. The wire becomes very hot when the bulb is turned on. (The direction of the electricity is shown by the arrows.)

Figure 3
The chemical energy in kerosene fuel transforms into heat and light energy.

Thermal energy can heat a metal to such a high temperature that it emits light. This light ranges from dull red to yellow to white and blue-white as the metal gets hotter. The colour of the emitted light indicates when the molten metal is ready to be poured.

Light from Phosphorescence

Certain materials, called phosphors, give off light for a short time after you shine a light on them. They store the energy and then release it gradually as light energy. The process of emitting light for a short time after receiving energy from another source is called **phosphorescence**. The colour of the light and the length of time it lasts depend on the material used. This is a good way to make light switches that glow in the dark. **Figure 4** shows a phosphorescent light source.

Figure 4
The painted luminous dials on some watches and clocks are phosphorescent.

Light from Electric Discharge

When electricity passes through a gas, the gas particles can emit light. The process of emitting light because of electricity passing through a gas is called **electric discharge**.

Lightning is an example of electric discharge in nature. The electricity discharges through the air, from one cloud to another or from a cloud to Earth. Some artificial light sources make use of electric discharge. Electricity is passed through tubes filled with gases, such as neon. The electricity causes the gases to emit light (**Figure 5**). Neon gas gives off a reddish-orange light. Sodium vapour gives off a yellowish light. Other gases emit other colours of light.

Figure 5
This artificial light source works because of electric discharge.

Light from Fluorescence

Fluorescence is the process of emitting light while receiving energy from another source. Fluorescent tubes are used in schools, offices, and homes. Fluorescent tubes use electric discharge and phosphorescence (**Figure 6**). Electricity passing along the tube causes particles of mercury vapour to emit ultraviolet (UV) energy. Since UV energy is invisible, however, it does not help you see. The UV energy is absorbed by a phosphor coating on the inside of the tube. The coating emits light that you can see. After the light is turned off, the phosphors emit light for a very brief time, much less than a second.

LEARNING TIP

Diagrams are important to reader comprehension. Study **Figure 6** and make connections to the information provided in the text.

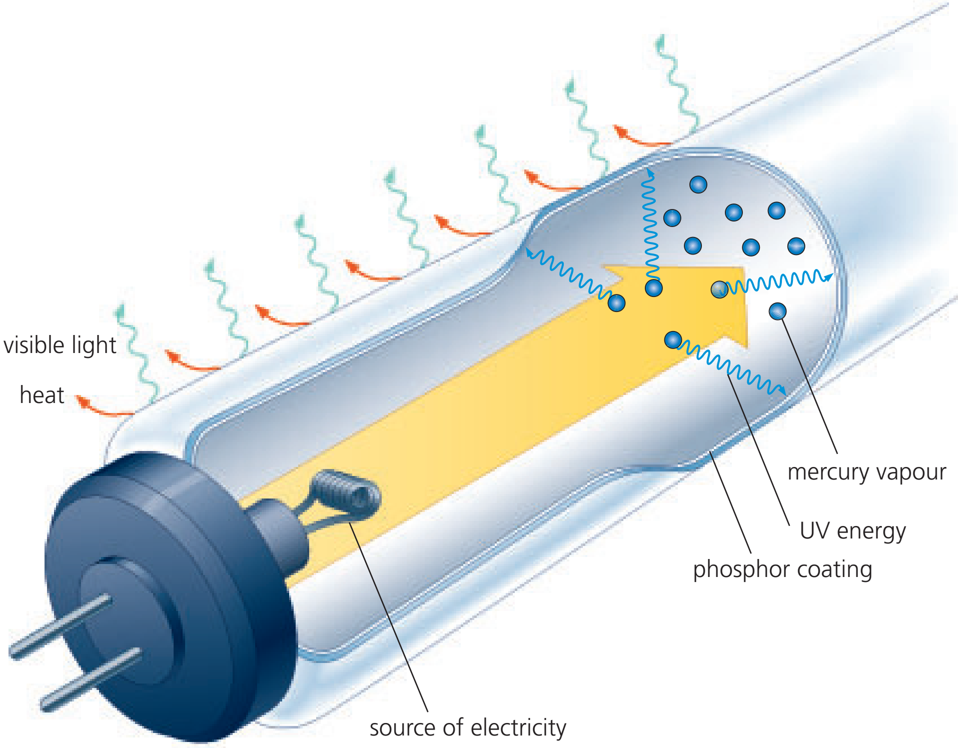


Figure 6
A fluorescent light source. Fluorescent tubes do not produce as much heat as incandescent light bulbs.

Light from Chemiluminescence

LEARNING TIP

Pause and think. What conclusions did you draw about light sources that are efficient sources of light, and those that are inefficient sources of light?

Chemiluminescence is the process of changing chemical energy into light energy with little or no change in temperature.

Safety lights, often called glowsticks or light sticks, produce light by chemiluminescence. In these lights, a thin wall separates two chemicals (**Figure 7**). When the wall is broken, the chemicals mix and react to produce a light until the chemicals are used up.

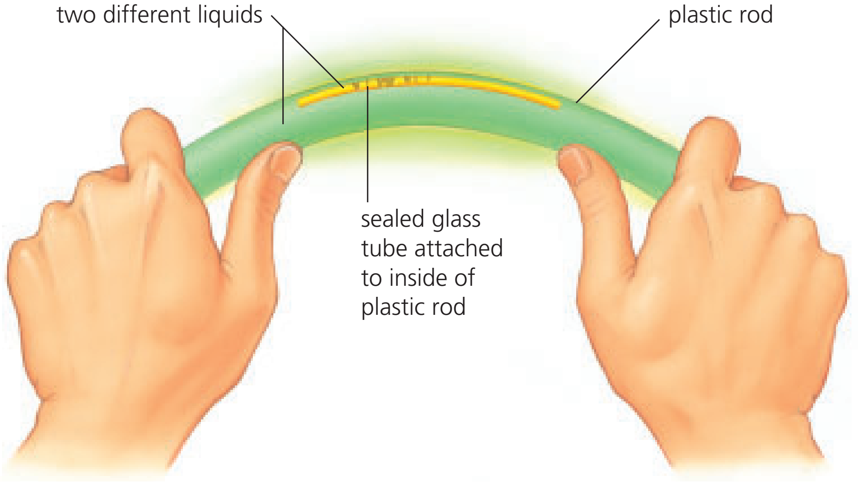


Figure 7
Light sticks are chemiluminescent light sources.

Light from Bioluminescence

Some living things, such as the fish in **Figure 8**, can make themselves luminous using a chemical reaction similar to chemiluminescence. This reaction is called **bioluminescence**. Fireflies and glow-worms are bioluminescent, as are some types of fish, squid, bacteria, and fungi.

Figure 8
Many organisms that live deep in the ocean are bioluminescent. Scientists are not sure why so many species glow. Perhaps it allows members of the same species to find each other.

DID YOU KNOW?

Firefly Chemistry

The "fire" of a firefly is bioluminescence. It is caused by a chemical reaction between oxygen and several other chemicals in special cells called photocytes. (A similar type of reaction is used to produce the chemiluminescence in glowsticks.) The flashing of fireflies is a mating signal between males and females. The males fly around and flash, while the females sit in trees and flash back.

10.1 CHECK YOUR UNDERSTANDING

1. Which of the following are luminous?
   (a) a campfire
   (b) the Moon
   (c) a hot toaster filament

2. Make flow charts to illustrate the process that each luminous object uses to emit light and the type of energy that is transformed into light energy.
   (a) the lights in your home
   (b) a lit match
   (c) car headlights
   (d) Day-Glo paints and fabrics

3. Explain, in your own words, the difference between a phosphorescent light source and a fluorescent light source.

4. Describe how a flashlight can be luminous. Describe how it can also be nonluminous.

5. While cycling, your body's efficiency is about 20 %. This means that your body uses about 20 % of its available energy for cycling. The remaining 80 % becomes heat. Incandescent bulbs have an efficiency of about 5 %, fluorescent tubes about 20 %.
   (a) Why does a bright incandescent bulb get much hotter than a bright fluorescent tube?
   (b) Why do people not always use the most energy-efficient type of lighting? What other factors could affect their choice of lighting?

6. What kind of light source would be safest to use in buildings or mines that might be filled with explosive gas?

PERFORMANCE TASK

What source(s) of light might be used in the optical device you chose for the Performance Task? What source of light is best for this device?

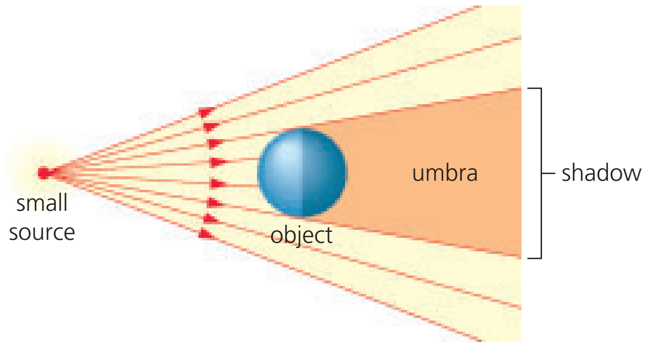
10.2 Inquiry Investigation

INQUIRY SKILLS

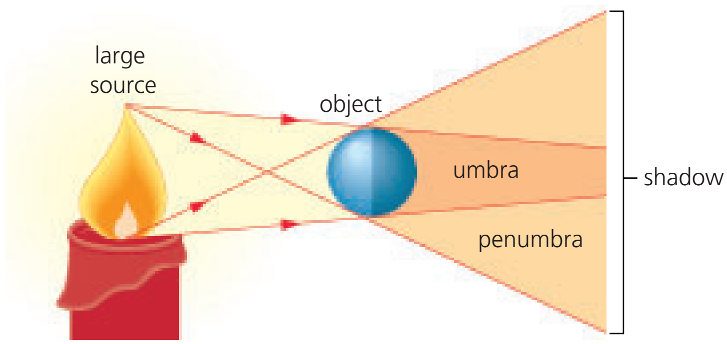
- ○ Questioning
- ● Hypothesizing
- ○ Predicting
- ○ Planning
- ● Conducting
- ● Recording
- ● Analyzing
- ○ Evaluating
- ● Communicating

Watching Light Travel

Have you ever tried to escape from the heat of direct sunlight on a summer day? One way is to find shade under a tree or to step into the shadow of a building. A **shadow** is an area where light has been blocked by a solid object (**Figure 1**). The dark part of a shadow is called the **umbra**; no light from the source reaches there. The lighter part of a shadow is called the **penumbra**; some light from the source reaches there. In this Investigation, you will use the umbra and the penumbra to reveal an important property of light.



(a) Light from a small source spreads out in all directions. The object blocks some of the light to produce a shadow.



(b) If the light source is larger, or there is more than one light source, the shadow will have both an umbra and a penumbra.

Figure 1

Question

What property of light allows shadows to form?

Hypothesis

(a) Create a hypothesis that answers the question.

LEARNING TIP

For help with writing a hypothesis, see "Hypothesizing" in the Skills Handbook section **Conducting an Investigation**.

Experimental Design

Using light and a solid object, you will explore shadow formation. You will create diagrams that include rays. A ray is how we represent the path taken by light energy. A ray is a line with an arrow at one end to show the direction that light is travelling. Light does not really travel in rays, but rays help us understand some of the properties of light.

Do not touch the light bulb in a ray box or look directly into the light.

Materials

- rubber stopper
- paper
- pencil
- ruler
- 2 ray boxes

Procedure

1. Put a rubber stopper on a piece of paper. Draw a line around the stopper on the paper. Place the ray box 5 cm away from the stopper, and aim a wide light ray toward the stopper. The ray must travel on both sides of the stopper.

Step 1

2. Use a pencil and a ruler to draw the outside edges of the shadow behind the stopper, and the source of the light. Remove the stopper, and turn off the ray box.

Step 2

3. Shade the area of your diagram where the shadow was. Label the light source, stopper, and umbra on your diagram.

4. Repeat steps 1 to 3 using a new piece of paper and moving the ray box to 10 cm from the stopper. How is this diagram different from your first diagram?

Step 4

5. Using another piece of paper, set up the stopper again as in step 4. Aim light rays from two ray boxes toward the stopper. Make sure that each light ray travels on both sides of the stopper.

Step 5

6. Use a ruler and a pencil to outline the umbra and the penumbra. Use darker shading for the umbra than for the penumbra. Label the light sources, stopper, umbra, and penumbra on your diagram.

Analysis

(b) Add arrows to the pencil lines in your diagrams to show the direction in which the light was travelling.

(c) What can you conclude about the property of light that causes shadows to form?

(d) Explain how the property of light illustrated in this Investigation also prevents us from seeing around corners.

(e) Compare **Figure 1** with your ray diagrams. Does a wide light ray from a single ray box act like light from a small source or from a large source?

PERFORMANCE TASK

How are shadows important in the optical device you chose for the Performance Task? Are shadows desirable or undesirable?

10.3 Getting in Light's Way

Imagine a world without glass. Your school would be very different—and very dark. When choosing materials, designers and engineers need to consider which materials block light and which materials, such as glass, let light pass through. **Transparency** is a measure of how much light can pass through a material. Materials are classified as transparent, translucent, or opaque.

Plastic wrap is transparent (**Figure 1**). Particles in a **transparent** material let light pass through easily. A clear image can be seen through the material. Plate glass, air, and shallow, clear water are examples of transparent materials.

LEARNING TIP

Check your understanding of transparent, translucent, and opaque materials by explaining **Figures 1** to **3** to a partner.

Skin is a translucent material (**Figure 2**). Particles in a **translucent** material transmit light, but also reflect some, so a clear image cannot be seen through the material. Frosted glass, clouds, and your fingernails are translucent materials.

A glass of milk is opaque (**Figure 3**). Particles in an **opaque** material do not allow any light to pass through. All the light energy is either absorbed or reflected. Most materials are opaque. For example, building materials, such as wood, stone, and brick, are opaque.

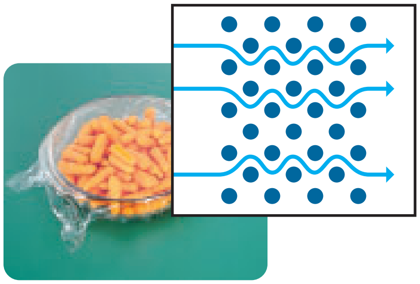


Figure 1
Transparent materials allow all light to pass through.

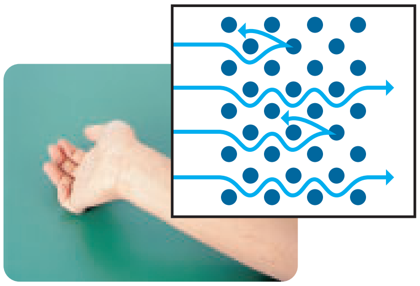


Figure 2
Translucent materials allow some light to pass through.

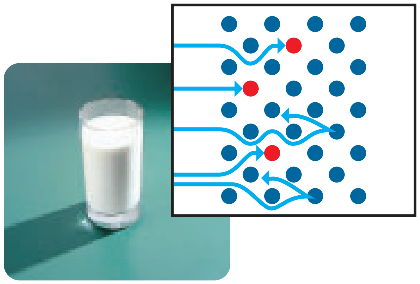


Figure 3
Opaque materials allow no light to pass through.

Classifying materials for transparency can be tricky. For example, a glass of water is transparent. However, you may have noticed that you cannot see the bottom of a deep lake, no matter how clear the water is. Water actually absorbs and reflects light slightly. As a result, small amounts of water are transparent, larger amounts are translucent, and very large amounts are opaque. This is true of all transparent materials. It is also true in reverse. If you cut an opaque material, such as a rock, into very thin slices, the slices will be translucent rather than opaque. Small amounts of an opaque material cannot absorb or reflect all the light.

TRY THIS: *Comparing Surfaces*

Skills Focus: predicting, controlling variables, observing

You can test how surfaces absorb and reflect light using a flashlight as a light source and a piece of white cardboard as a screen. You will also need a small flat mirror, another piece of white cardboard, and a piece of dull, black cardboard.

Handle mirrors carefully to avoid breakage.

(a) Before testing each surface, predict how strong the reflection will be.

1. In a dark room, shine the flashlight onto the mirror, as shown in **Figure 4**. Observe the effect on the white cardboard you are using as a screen.

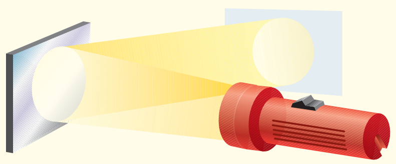


Figure 4

2. Replace the mirror with the second piece of white cardboard, and observe the effect on the screen.

3. Replace the second piece of white cardboard with the black one. Shine the flashlight on the black cardboard and observe the effect on the screen.

4. Try other surfaces—some rough, some smooth, some dark, and some light.

(b) Did your observations confirm your predictions? Explain.

Absorbing and Reflecting Light

When light strikes an opaque material, no light is transmitted (passes through). Some of the light energy is absorbed by the material and is converted into thermal energy. On a warm, sunny day, for example, asphalt absorbs light energy and converts it into thermal energy, becoming hot. Some of the light energy is not absorbed, but is reflected from the opaque material. This allows us to see the asphalt.

Colour, sheen (shininess), and texture are three properties that describe the amount of light energy that is absorbed or reflected. Black and dark-coloured materials absorb more light energy than white and light-coloured materials. This is one reason why builders often use dark shingles on Canadian homes. Similarly, dull materials, such as

LEARNING TIP

When you come across a word in brackets, think about how you can use it to figure out the meaning of words that you are unsure of.

wood, absorb more energy than shiny materials, such as aluminum siding. A material with a rough surface, such as stucco, absorbs more light energy than a smooth surface, such as plaster. Can you decide which materials in **Figure 5** absorb more light energy?

Figure 5
These two buildings are made with different construction materials. Architects choose certain materials for hot, sunny areas, and different materials for cool areas, based on the ability of the materials to transmit, absorb, or reflect light energy.

These properties of materials are also important in the design of posters, magazines, clothing, and solar heating panels. If you were designing a poster, for example, you might use some materials that absorb light and other materials that reflect light, so the contrast would allow the printing or artwork to be easily seen from far away. You might also want to avoid using shiny materials that would cause glare.

10.3 CHECK YOUR UNDERSTANDING

1. Classify the following materials as transparent, translucent, or opaque: milk, apple juice, wax paper, aluminum foil, plastic wrap, mirror, helium, ice cube, smoky air, writing paper, newspaper, cardboard, clear Plexiglas, coloured Plexiglas, silk, rubber, copper plate.
2. Explain how climate is an important factor in deciding what type of building materials to use when constructing a house.
3. Why does fall and winter clothing usually come in darker colours, while spring and summer clothing usually comes in lighter colours?

PERFORMANCE TASK

What parts of your optical device will need to be transparent, translucent, and opaque? Are absorption and reflection of light important?

The Visible Spectrum 10.4

You have investigated and studied several properties of light. You know that light is a form of energy; it travels in straight lines and it can be reflected, absorbed, and transmitted. None of these properties, however, explains an important fact—we can see colours.

You have probably seen a rainbow like the one in **Figure 1**. A rainbow gives an important clue to help explain colour. The band of colours you can see in a rainbow is called the **visible spectrum**. The visible spectrum has six main colours, called the spectral colours. Starting at the top, the spectral colours are red, orange, yellow, green, blue, and violet.

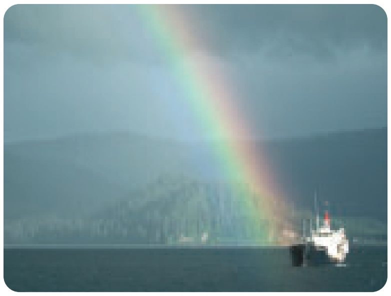


Figure 1
For you to see a rainbow, the Sun must be behind you and the water droplets (in the rain and the clouds) must be in front of you.

TRY THIS: Viewing the Visible Spectrum

Skills Focus: creating models, communicating

In this activity, you will create your own mini-rainbow. You will need two solid triangular prisms (blocks of acrylic) and a ray box or similar light source.

1. Place one prism on a sheet of white paper, and trace around it.

2. With the room lights dim, aim a ray of white light from the ray box toward the prism (**Figure 2**). Move the ray box to adjust the position of the ray until you obtain the brightest possible spectrum.

(a) Draw a diagram of your observations. Include the white light ray and the colours.

3. Position the second prism as shown in **Figure 3**, and aim the ray as you did earlier.

(b) Draw a diagram of what you observe.

4. Predict what you would observe if you aimed red light at the triangular prism instead of white light.

Do not touch the light bulb in the ray box or look directly into the light.

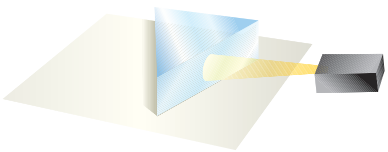


Figure 2

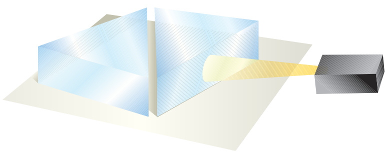


Figure 3

The Discovery of the Composition of White Light

Hundreds of years ago, scientists thought they could see the colours of objects because the objects added colour to white light. Then, in 1666, an important discovery was made. A scientist named Isaac Newton hypothesized that light from the Sun might be made up of several colours. To test his hypothesis, he passed a beam of sunlight through a triangular glass prism, as in **Figure 2**. Newton discovered that white light is made up of the spectral colours red through violet.

Those people who opposed Newton's explanation were quick to argue that the different colours were produced by the prism. They reasoned that the colours must be inside the glass. The light just allowed the colours to escape.

To end the controversy, Newton decided to collect the separate colours of light with a second prism, (**Figure 3**). As he had predicted, the light became white again when the six colours were added together.

Newton's experiments provided evidence that white light is composed of colours, and that each colour acts differently inside a prism. Many years after Newton's discovery, scientists found that the colours of light actually travel at different speeds inside a prism. This causes each colour to change direction a slightly different amount when the light reaches the surface of the glass. The colour that changes direction the most (violet) slows down the most.

Why We See the Colour of Objects

When white light strikes an opaque object three things can happen: the light may be reflected, the light may be absorbed, or, most often, some of the light is reflected and some of it is absorbed. Different spectral colours are reflected and absorbed depending on the characteristics of the object's material. This is why we see the object as a specific colour. For example, if an object reflects the blue part of the visible spectrum, we see the object as blue. If an object reflects the red part of the visible spectrum, we see it as red. If all of the parts of the visible spectrum are reflected we see the object as white, and if none of the parts of the visible spectrum are reflected we see the object as black.

PERFORMANCE TASK

Does your chosen optical device rely on white light or only on some of the spectral colours? Does it function better with some colours than with others?

10.4 CHECK YOUR UNDERSTANDING

1. Which statement do you think is correct? Explain.
   A: White light is made up of the spectral colours. The rainbow colours appear when light passes through water droplets.
   B: Water droplets add colour to white light to produce the rainbow.
2. Which colour of light changes direction the most when it leaves the triangular prism? Which colour of light changes direction the least?
3. Briefly describe three places where you have seen the visible spectrum.
4. Why can we see the colour of objects?

The Electromagnetic Spectrum

10.5

Light is a form of radiant energy you can see. The visible spectrum you saw through the prism, however, is only a small part of the range of radiant energies. Other radiant energies you may have heard about include ultraviolet (UV) radiation, X-rays, and microwaves. These radiant energies are invisible to our eyes, but they are the same kind of energy as light. The entire range of radiant energies is called the **electromagnetic spectrum**.

Radiation in Space

We know that light from the Sun and other stars reaches us after travelling great distances, mostly through the vacuum of space. Other parts of the electromagnetic spectrum can also travel through space. One important property of all electromagnetic radiation is that it can travel through a vacuum—no substance is needed to transmit it.

Light and other parts of the electromagnetic spectrum travel at an extremely high speed. In a vacuum, this speed is 300 000 km/s. At this speed, light takes about 1.3 s to travel from Earth to the Moon. Light from the Sun takes about 8 min to reach Earth. Light from the nearest star beyond the solar system takes over four years to reach us, even at its high speed.

Properties of Waves

A wave is the result of a vibration that transfers energy from one location to another. In most cases, the vibration that causes a wave is a regular repeated motion that produces a regular wave pattern. A wave can be created by stretching out a length of rope (or a spring) and vibrating one end back and forth (**Figure 1**).

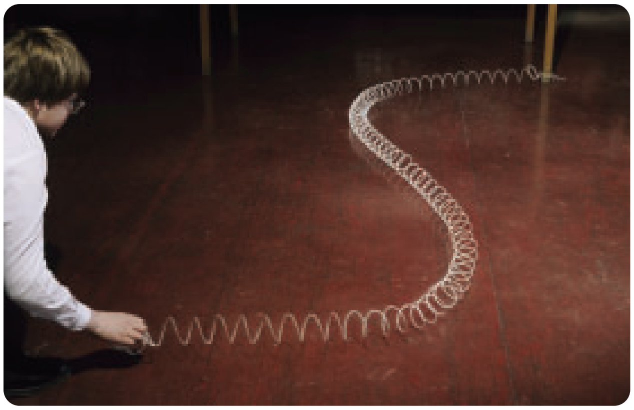


Figure 1
Creating a wave using a long spring

Waves in a piece of rope transfer mechanical energy. Light behaves in a way similar to mechanical waves. It reflects off surfaces or changes directions when passing through different materials. Radiant energies like light can be described as electromagnetic waves. Electromagnetic waves transfer electromagnetic energy through space and transparent materials.

Waves have characteristics that can be used to describe them and to distinguish one wave from another. It is helpful to demonstrate the characteristics of a wave on a graph (**Figure 2**). Imagine that the line on the graph is a piece of rope that has been vibrated to produce the wave. The resting position is represented by the *x*-axis. The rope vibrates above and below the resting position. The farthest point above the resting position is called the **crest.** The farthest point below the resting position is called the **trough.** The **wavelength** is the distance between two adjacent crests or two adjacent troughs (recall Section 8.6).

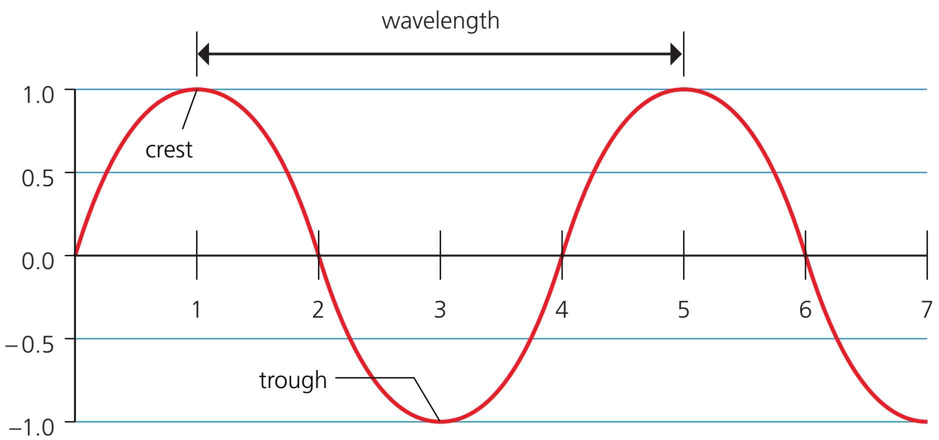


Figure 1
The features of a typical wave

The maximum distance above or below the resting position is referred to as the **amplitude.** The amplitude determines the amount of energy that is transferred. Think of an ocean wave; the higher the wave, the more energy it has and the more dangerous it can be. In sound waves, the greater the amplitude, the louder the sound. Likewise, with light, the greater the amplitude, the greater the energy transferred and the brighter the resulting light. **Figure 2** illustrates two waves of different amplitudes.

LEARNING TIP

Vocabulary are often illustrated. When you come across a term you do not know, examine the illustrations along with the captions.

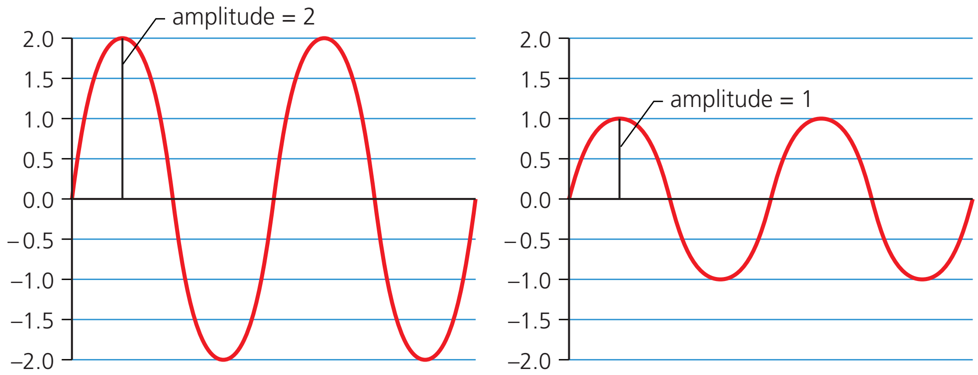


Figure 2
The amplitude of a wave is the amount of displacement from the resting position. The amplitude indicates the amount of energy that is transferred by the wave.

Some objects vibrate quickly and others vibrate more slowly, depending on the source of the energy that starts the vibrations. The **frequency** of a vibration is the number of cycles in a period of time. For waves, a cycle is a complete wavelength. The frequency of a wave is normally indicated in **hertz** (Hz), or cycles per second. The greater the number of wavelengths passing a point in a specific time, the greater the frequency is. Because many waves have frequencies that are large numbers, prefixes are used with the unit hertz. For example, 1000 Hz is a kilohertz (kHz), 1 million hertz is a megahertz (MHz), and 1 billion hertz is a gigahertz (GHz). **Figure 3** shows two waves that have different frequencies.

DID YOU KNOW?

Sensitive Hearing

A healthy young person can hear sounds in the frequency range of 20 Hz to 20 000 Hz. Dogs can hear sounds that have much higher frequencies—as high as 50 000 Hz. Dog whistles produce high frequency sounds that cannot be heard by humans but can be heard by dogs.

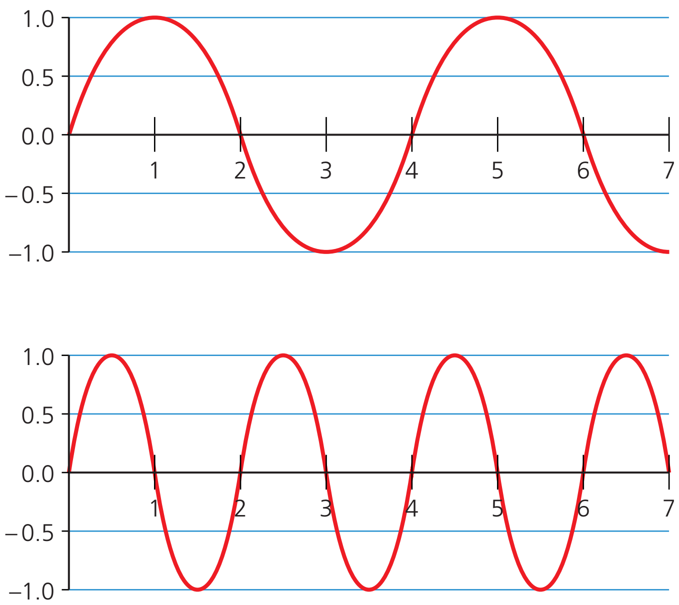


Figure 3
These two graphs represent the same time period. The frequency of the bottom wave is twice as great as the frequency of the top wave. Note that the bottom wave has twice as many wavelengths in the same time period.

LEARNING TIP

Tables help readers identify specific information quickly. As you study **Table 1**, look at the headings. The headings will help you focus on what is important in the table.

Waves, Energy, and the Electromagnetic Spectrum

The different parts of the electromagnetic spectrum have common properties, such as their high speed and their ability to travel through a vacuum. They also have different properties, related to their wavelength, frequency, and energy. The electromagnetic spectrum represents a very wide range of frequencies (**Table 1**).

very long wavelengths
very low frequencies
very low energy

very short wavelengths
very high frequencies
very high energy

Table 1 Segments of the Electromagnetic Spectrum

Type of wave	Description of wave	Uses
radio	• AM radio waves are about 1 km long • research is being done to determine the effects of cell phone frequencies on the human brain	• ship and boat communication • AM and RM radio stations • cellular telephones • television
microwaves	• one wave can fit into about 1 cm	• microwave ovens • communication
infrared radiation (IR)	• about 1000 waves can fit into about 1 cm • can be detected by the skin as heat • emitted by living things and warm objects	• thermal photographs of houses and diseased areas on the surface of the human body • remote control for televisions
visible light	• up to 500 000 waves can fit into 1 cm • red has the longest wavelength, lowest frequency, and lowest energy • violet has the shortest wavelength, highest frequency, and highest energy	• artificial light • lasers
ultraviolet radiation (UV)	• 1 million waves can fit into 1 cm • can cause sunburns, skin cancer, and cataracts in the eye • can be detected by the skin and special instruments	• suntanning • "black lights" in shows
X-rays	• 100 million waves can fit into 1 cm • can pass through skin, but not through bones • can damage body cells	• X-ray photographs of parts of the human body • measurement of thickness in manufacturing
gamma rays	• 10 billion waves can fit into 1 cm • dangerous energy given off by radioactive materials	• study of what makes up matter • study of unusual events in distant galaxies

The low frequency radio waves have frequencies in the range of 3 GHz or 3 000 000 000 Hz. The high frequency gamma rays have frequencies that are greater than 30 000 000 000 000 000 000 Hz. The higher frequency parts of the electromagnetic spectrum (for example, X-rays and gamma rays) have even higher energy and are more dangerous than the lower frequency parts. The ultraviolet part of the spectrum presents a potential risk to human health because it can cause sunburns and skin cancer.

Scientists use their knowledge of the different properties of the electromagnetic spectrum to invent uses for each part of the spectrum.

TRY THIS: Observing and Using Waves

Skills Focus: creating models, observing

Making waves with a rope will help you understand how the parts of the electromagnetic spectrum travel.

1. With a partner holding one end of the rope, stretch the rope tightly along the floor. To create waves with the rope, move your hand back and forth sideways.

2. Stand a folded piece of paper beside the rope, between you and your partner. Use the rope to knock over the paper.

(a) It took energy to knock over the paper. Where did the energy come from?

(b) How did the energy get to the paper?

(c) What would you have to do to increase the amplitude of the wave? What would this increase in amplitude represent?

3. Move your hand back and forth slowly, at a constant speed. (This represents a low, constant frequency.) Now gradually move your hand faster. (You are increasing the frequency of vibration.)

(d) What happened to the wavelength of the waves as the frequency increased? Use diagrams to illustrate your answer.

10.5 CHECK YOUR UNDERSTANDING

1. Use simple sketches of waves to illustrate the meanings of the terms *wavelength*, *amplitude*, and *frequency*.
2. Assuming that the speed of a wave is constant, explain the relationship between wavelength and frequency.
3. Place these electromagnetic waves in order from lowest energy to highest energy: blue light, microwaves, X-rays, orange light, infrared radiation.
4. List the electromagnetic waves you have experienced in the past year and where they are found in the electromagnetic spectrum.

PERFORMANCE TASK

UV radiation from a "black light" causes some substances to gain energy and emit visible light. Does your optical device detect or emit UV radiation or other forms of invisible radiation?

10.6 Explore an Issue

DECISION-MAKING SKILLS

○ Defining the Issue	● Researching
○ Identifying Alternatives	● Analyzing the Issue
● Defending a Decision	● Communicating
○ Evaluating	

Solar Panels

Since energy comes from the Sun, why can you not leave a computer, television, or toaster in sunlight to make it work? Unfortunately, it is not that simple. Sunlight must be changed into electrical energy before it can be used to operate electrical devices.

The Issue: A Solar School

A new school is being planned for your community. A meeting is going to be held to discuss possible sources of electricity for the new school. Four specialists will give presentations about solar power.

Background to the Issue

A **solar cell** is a device that converts light energy into electrical energy. Light energy strikes crystals causing electricity to flow. Wires coming from the crystals are connected to the appliance.

Solar cell technology was developed in the 1950s. To obtain more electricity, scientists created **solar panels**, which are collections of solar cells (**Figure 1**).

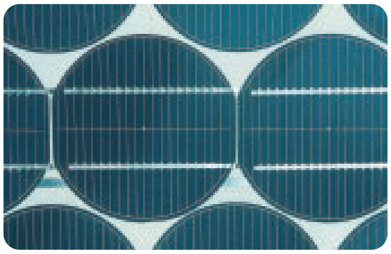


Figure 1
Solar cells are packed close together in this solar panel.

Solar Panel Technology

Solar panels can be installed on a roof to provide power (**Figure 2**). Because the Sun is not always available, energy collected during sunny periods must be stored for use during dull or dark periods. Rechargeable batteries can be used for this purpose.

Figure 2
These solar panels are installed on a south-facing roof. A tracking system allows light energy from the Sun to hit the solar cells as directly as possible.

Three main factors affect the technological design of solar panels:

- the efficiency of the solar cells
- the amount of solar energy that strikes the cells in the panel
- the capacity of the rechargeable batteries

Currently, the efficiency of solar cells is about 18 %. The Sun's rays must hit the solar cells directly all day long, so an expensive tracking system must be used. Rechargeable batteries to store electrical energy are constantly being improved.

Advantages of using solar panels	Disadvantages of using solar panels
• As solar cell technology improves, a complete system will cost less to install than the costs of purchasing electricity from power companies. • Using more solar energy will put less demand on non-renewable sources of energy, such as fossil fuels and uranium. • A school with solar panels would not be affected by electric power outages caused by failures in external power lines or generators.	• The cost of installing a solar panel system is about $10 000 for a typical home. Rechargeable batteries last for about 10 years, and their replacement cost is about $1500. • Repairs may be costly if part of the system, such as the Sun tracker, fails. • Heavy snowfall could block the panels or overload the Sun tracker; in some regions, especially in winter, there may not be enough sunlight to produce the needed power.

Take a Position

You will assume the role of one of the specialists. Prepare for your role by considering the advantages and disadvantages of solar panels given here. Conduct research to help improve your arguments.

The Roles

- an environmentalist who thinks that installing a solar panel system will help to protect the environment
- a manager from a power utility who thinks that using solar power will reduce the need for electricity and cause job losses
- a school board official who is determined to keep construction costs of the new school to a minimum
- a solar panel manufacturer who says that, over several years, the money saved by using solar energy will pay for the installation

Communicate Your Position

Prepare a presentation that represents the role you assumed. When preparing your presentation, consider the following questions:

- What arguments support your opinion?
- Will your ideas be appropriate in the long term? In the short term?
- How can you justify your suggestions to the community?

Make your presentation to the "concerned citizens" in your class. Be prepared to answer questions.

10.6 CHECK YOUR UNDERSTANDING

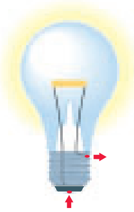
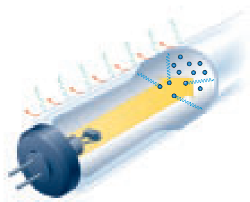
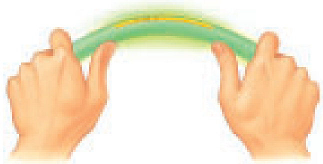
1. What are the names and functions of the parts of a solar-panel system?
2. Assume that a solar panel has an efficiency of 18 %. Also assume that solar energy hits the panel at a rate of 1000 W (watts) in full sunlight.
   (a) What is the output of the panel?
   (b) How many 60 W light bulbs can be operated using the panel?

CHAPTER 10 *Review* Sources and Properties of Light

Key Ideas

Light is produced by a variety of sources, both natural and artificial.

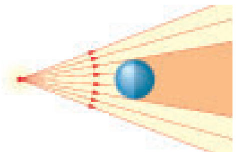
- Light is a form of energy that can be detected by the human eye.
- Light is produced by luminous objects when some of their energy is transformed into light energy.
- The Sun is the most common luminous object and the most important source of natural light.
- Light can be produced by a variety of processes: incandescence, phosphorescence, fluorescence, electric discharge, chemiluminescence, and bioluminescence.
- Light sources that produce a lot of heat energy along with light energy are not as efficient as light sources that produce little heat energy.

Light may be reflected, transmitted, or absorbed depending on the material that it strikes.

- Opaque materials allow no light to be transmitted. Translucent materials allow some light to be transmitted. Transparent materials allow all light to be transmitted.
- Shadows are produced when light shines on an opaque object because light cannot pass through the object.



Vocabulary

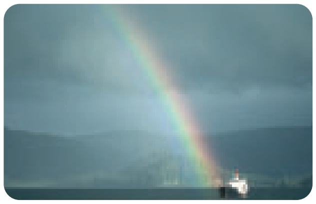
light, p. 289
luminous, p. 289
nonluminous, p. 289
incandescence, p. 290
phosphorescence, p. 291
electric discharge, p. 291
fluorescence, p. 291
chemiluminescence, p. 292
bioluminescence, p. 293
shadow, p. 294
umbra, p. 294
penumbra, p. 294
transparency, p. 296
transparent, p. 296
translucent, p. 296
opaque, p. 296
visible spectrum, p. 299
electromagnetic spectrum, p. 301
crest, p. 302
trough, p. 302
wavelength, p. 302
amplitude, p. 302

Visible light is a part of the energy that comes from the Sun.

- The Sun is the major source of energy for Earth. Part of this energy, known as the visible spectrum, is in the form of light. Other parts of this energy are invisible.
- The light in the visible spectrum can be split into six colours—red, orange, yellow, green, blue, and violet.
- Different materials will absorb some parts of the visible spectrum and reflect other parts. We see the reflected part of the spectrum as the colour of an object.

The visible and invisible parts of radiation from the Sun make up the electromagnetic spectrum.

- Electromagnetic radiation behaves like waves. Different parts of the electromagnetic spectrum have different wavelengths and frequencies.
- The invisible parts of the electromagnetic spectrum consist of radiation with longer wavelengths (radio waves, microwaves, and infrared radiation) and radiation with shorter wavelengths (ultraviolet radiation, X-rays, and gamma rays) than the visible part of the spectrum.
- The energy of the different parts of the electromagnetic spectrum depends on the wavelength or frequency. Long wavelength, low frequency radiation has low energy; short wavelength, high frequency radiation has high energy.
- Each part of the electromagnetic spectrum is used for specific purposes.



frequency, p. 303

hertz, p. 303

solar cell, p. 306

solar panels, p. 306

Review Key Ideas and Vocabulary

1. Fluorescent lighting is preferable over incandescent lighting because
   (a) fluorescent tubes are cheaper than incandescent bulbs
   (b) fluorescent lighting is more efficient at converting electrical energy into light energy
   (c) incandescent lighting is more efficient at converting electrical energy into light energy
   (d) fluorescent lighting is safer
   (e) fluorescent lighting is brighter
2. A T-shirt has a logo that glows in the dark. This is an example of
   (a) incandescence
   (b) phosphorescence
   (c) fluorescence
   (d) chemiluminescence
   (e) bioluminescence
3. A shadow is formed because
   (a) the object causing the shadow is luminous
   (b) the object causing the shadow is nonluminous
   (c) the object causing the shadow is transparent
   (c) light is a form of radiant energy
   (e) light travels in a straight line
4. Which of the following is NOT an example of an optical device?
   (a) window
   (b) eye
   (c) camera
   (d) projector
   (e) microscope
5. A solar cell converts sunlight into
   (a) electric energy
   (b) heat energy
   (c) solar energy
   (d) solar panel
   (e) electromagnetic radiation
6. Name the energy changes that occur to produce light in
   (a) an incandescent electric light bulb
   (b) a fluorescent tube
   (c) a phosphorescent dial on a clock
7. How can you judge the efficiency of a device or system that transforms energy into light energy?
8. Describe factors that affect the amount of light absorbed by or reflected from an object.
9. The position of the Sun in the sky changes during the day.
   (a) Draw three diagrams to show the shadows cast by a building at three different times of day.
   (b) Every species of plant requires different amounts of sunlight. Some species need full sunlight all day, some need it part of the day, and some grow only in shade. On your diagrams, indicate where these different types of species will grow best around the building.
10. (a) What properties does visible light have in common with the rest of the electromagnetic spectrum?
   (b) What properties are different?

Use What You've Learned

11. Describe and give an example of a material that
   (a) transmits light easily
   (b) absorbs most incident light
   (c) reflects most incident light

12. You are asked to put on a "light show" to demonstrate that light travels in a straight line. Describe how would you do this.

13. A manufacturing company has hired you to design lamps that have a special feature: the on/off switch must be visible in the dark, and it must not consume any electrical energy directly.
(a) What design would you use?
(b) How would you test your design to check its effectiveness?

14. Meteoroids are nonluminous chunks of rocky material that travel through space. Meteoroids that fall into Earth's atmosphere become meteors, or "shooting stars." Why are meteors luminous?

15. How are transparent and translucent materials used in practical applications? Identify home, school, transport, clothing, packaging, and sports products. Which of the uses you identified are for appearance and which are functional?

16. **Figure 1** shows a gobo, a disc that is placed in front of a stage light to cast a shadow on the stage. Design a gobo that could be placed in front of a ray box or a flashlight. Cut it out and try it.

Figure 1
This gobo would project the shadow of a palm tree on the stage.

17. Many homes and other buildings use special glass for windows called low-emissivity glass. Use print and electronic resources to find out why.

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18. Explain how coloured light can be produced from white light. Speculate on what you would observe if white light was passed through coloured filters.

Think Critically

19. Which part of the electromagnetic spectrum do you think is most dangerous? Explain why.

20. An image can be either real or virtual, but not both at the same time. In games with virtual reality, computer-controlled images appear to be real. Do you think virtual reality is a good name for images? Explain why or why not on the basis of what you have learned so far.

Reflect on Your Learning

21. List ways in which light energy is important in your life. What sources of light do you use?

22. Write a short creative essay entitled "Light and Me." Express your feelings about light and shadows. Ask yourself the following questions. How does light affect my mood or my emotions? Am I a morning person or a night person? How do shadows make me feel? Do I like dark nights or bright moonlit nights? If I could control the daylight, what would I do?

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