7.1 What Is Light?

Off the Wall

Light from the Sun is produced by nuclear fusion of hydrogen particles. The Sun is composed of about 70 percent hydrogen. When hydrogen particles fuse (combine), they form another particle called helium. During this process, an enormous amount of energy is released as heat and light. The temperature inside the Sun is about 16 000 000°C!

In the simplest terms, **light** is the form of energy that you can see. The Sun is a **natural light source**, the most abundant and least expensive light source in the world. Fire is another natural source of light (see Figure 7.1).

The Sun is a star; all stars in the universe are sources of light. Light spreads out, or **radiates**, from the Sun and other stars, in all directions, like the spokes of a bicycle wheel. This type of energy transfer does not require matter; it is known as **radiation**. Energy such as light that travels by radiation is often called **radiant energy**.

Less than one tenth of one millionth of a percent of the Sun's energy actually reaches Earth, but our lives are totally dependent upon this energy. Plants, people, and other animals could not live without light from the Sun. Because sunlight is not always available, people have developed light-producing technologies, or artificial lights. A light bulb is an example of an **artificial light source**. Like the Sun, light from a bulb radiates in all directions.

What else can produce light? Think about what happens when you strike a match. Chemicals on the tip of the match react to produce heat and light. Once the chemical energy is used up, the match is no longer useful. Like the match, all other sources of light require energy. Flashlights use electrical energy from batteries. Light bulbs glow when you switch on electricity. The light that leaves the Sun is formed through a process called *nuclear fusion*.

Figure 7.1 Besides the Sun and the stars, flames and sparks are natural sources of light.

Find Out **ACTIVITY**

Is Light Energetic?

It takes energy to do work. Just getting out of bed some mornings takes what seems like a lot of energy! It takes energy to produce light, as well. Do you think light, like other forms of energy, can cause a change in an object?

What You Need

solar-powered calculator
2 identical black film canisters
aluminum foil
bright light source, such as a 100 W bulb

What to Do

1. Find the solar cells on a calculator. Enter some digits, then completely cover the solar cells with your finger to block the light. What happens to the digits? If nothing happens, the calculator has "dual power." What do you think this means?

2. Wrap one of the film canisters with a single layer of aluminum foil, shinier side out. Place both canisters in a bright light, such as sunlight or light from a 100 W bulb. Wait a few minutes, then remove the top of each canister and feel the inside surface of the containers.

What Did You Find Out?

1. What happened when you prevented the light from reaching the solar cells on the calculator?

2. What difference did you observe between the two film canisters?

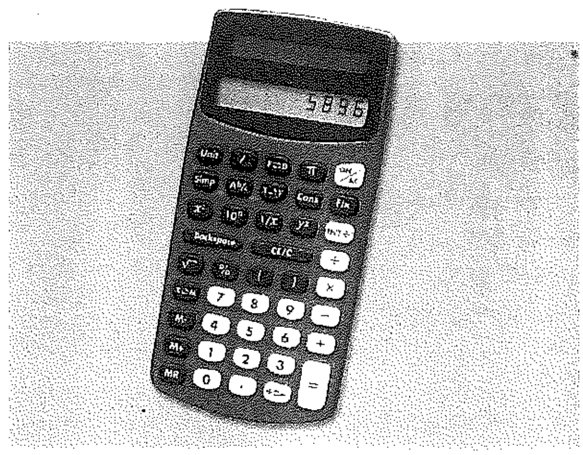
3. What evidence do you have that light caused a change in both steps 1 and 2 of "What to Do"?

Extensions

4. When light energy is absorbed by solar cells, into what form of energy does it change so that the calculator can use the energy?

5. In your notebook, complete the following sentence: "Light can be changed into energy forms such as...."

6. In step 2 of "What to Do," what is the independent variable? What is the dependent variable? What variables should be controlled to get meaningful results?



The First Basic Property of Light

You have seen that light is a form of energy. This is the first basic property of light. When light is absorbed by a surface, it can be transformed into several different forms of energy. Light can be transformed into thermal energy, electrical energy, or chemical energy. For example, the absorption of sunlight by a black sweater causes the garment to gain thermal energy. Solar cells change light into electricity. Trees in your neighbourhood absorb sunlight to make chemical energy (sugars).

Did You Know?

Satellites use solar cells to power their electronic equipment. Someday, we might all use sunlight to produce the electrical energy we need. In 1987, the Sunraycer, a test car covered with solar cell panels, drove across Australia powered only by energy from the Sun.

Figure 7.2 Sunlight is absorbed by the pavement on this runway and transformed into thermal energy. You can see heated air rising from the pavement on a road or a runway on a hot, sunny summer day.

The brightness, or **intensity**, of light indicates how much energy a surface will receive. A surface can absorb more energy if the brightness of the light intensifies. For instance, pavement may feel hot to the touch on a sunny summer day (see Figure 7.2). However, the pavement will feel only warm if the clouds block out the sunlight. In the activity below, explore further the concepts of light, intensity, and radiant energy.

At Home **ACTIVITY**

Reading with Intensity

Light intensity is determined by how much energy is received on a unit of area. In this activity, you will observe how distance affects the intensity (brightness) of light striking an object.

What You Need

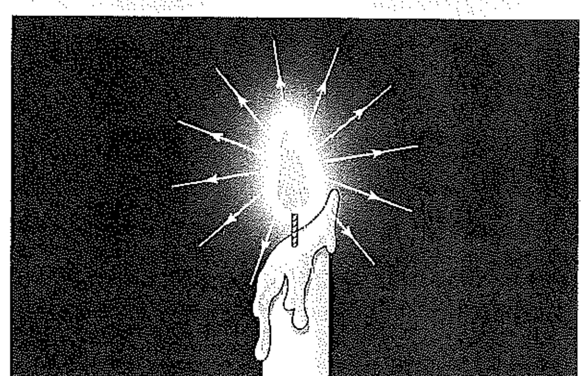
book
lamp with the shade removed
60 W bulb
100 W bulb
measuring tape

What to Do

1. Ask an adult to place a 60 W bulb in the lamp. **CAUTION:** Turn off the electricity before the bulb is changed.
2. Darken the room. Turn on the lamp and stand about 60 cm away from it while holding this book. Read a sentence from the book at this distance.
3. Move about 3 m from the lamp. Read a sentence from the book at this distance.
4. Repeat steps 1 to 3 using a 100 W bulb.

What Did You Find Out?

1. How does increasing the distance from the bulb affect the intensity of the light striking the book's pages?
2. Describe the difference between reading the book using the 60 W bulb and reading the book using the 100 W bulb.
3. Draw two diagrams, one showing light leaving the 60 W bulb and one showing light leaving the 100 W bulb. Think of a way to represent the amount of energy striking the book at each distance you measured. You might try drawing different numbers of lines to represent different intensities of light. Remember that light radiates in all directions from the bulb, just as it radiates from the candle flame shown in the diagram below.



Sources of Light

How would your life be different if the Sun and stars were the only sources of light available to you? You would probably go to bed very early, especially in the winter, because there would not be much that you could do after dark. Without artificial sources of light, there would be no television, no lamps for reading, no computers. All the rooms in buildings would probably have windows or skylights.

We are lucky to have many sources of light available to us. In earlier times, once the Sun had set, people found their way around outside with the aid of torches and lanterns. Candles and oil lamps were commonly used indoors. Imagine trying to study by the light of a candle!

Today, we have so much light in our cities that light pollution can wash out our view of the skies at night. That is why many observatories, such as the one shown in Figure 7.3, are located far from urban areas. However, some communities are taking steps to conserve light energy. For example, new types of streetlights are designed to direct their light downward, so that they illuminate the ground or the street and not the sky. In addition, these lights are comparatively energy-efficient. For example, the yellow sodium vapour lights shown in Figure 7.4 on the next page are much more efficient than white lights. The following sections will examine and compare different types of light sources, both natural and artificial.

Pause & Reflect

In your Science Log, describe several ways in which plants and animals respond to changes in the intensity of light. For example, how do your eyes react to a bright light? How do roosters behave when the Sun rises? What do you think birds do during an eclipse of the Sun?

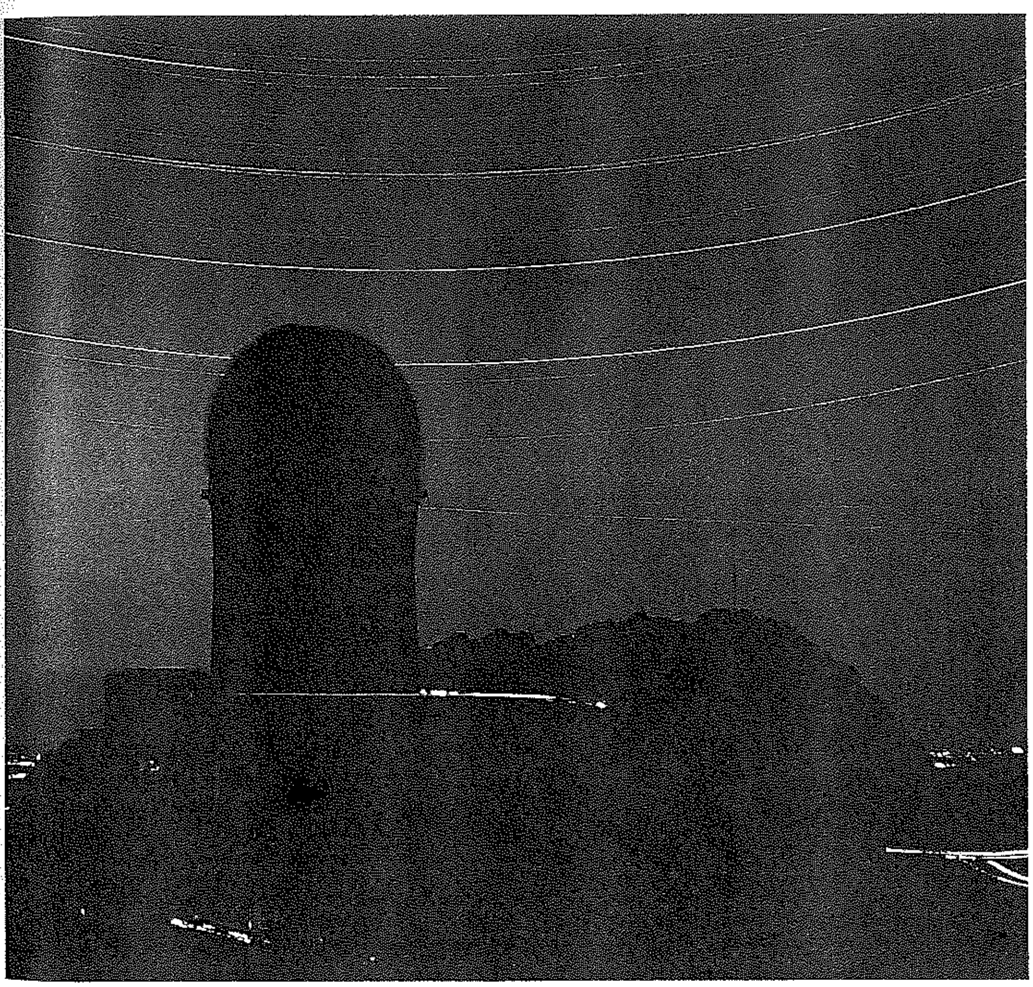


Figure 7.3 This photograph is a time exposure image of star trails over the dome of the Mayall telescope at the Kitt Peak National Observatory in Arizona, USA. The telescope's high-altitude location (over 2000 m) and the clear desert skies reduce atmospheric interference to incoming light.

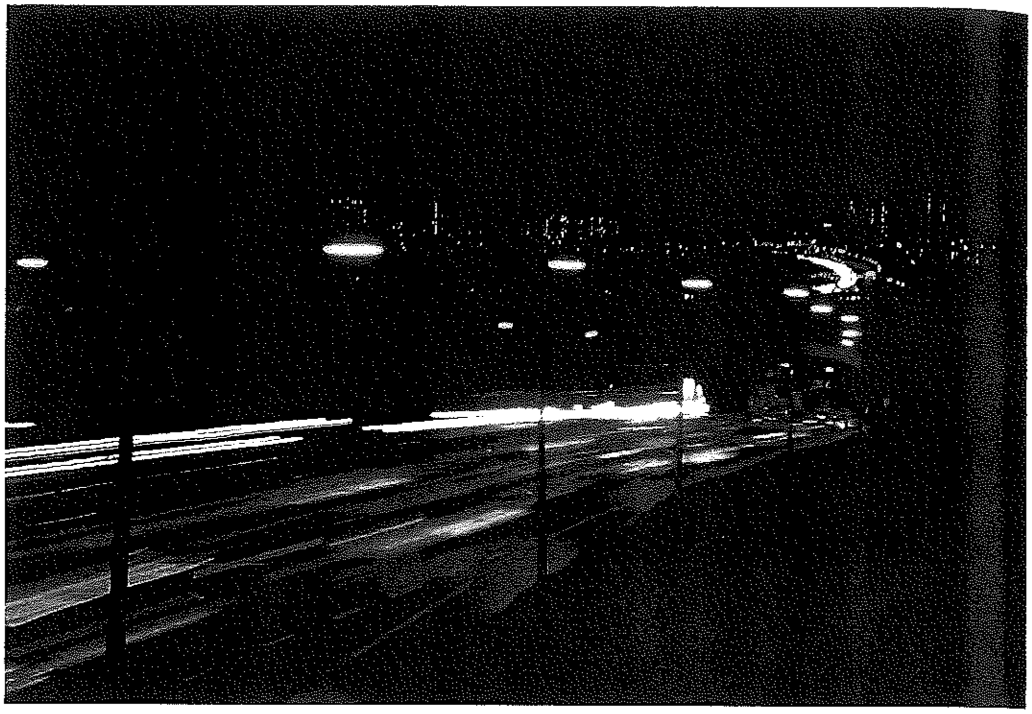


Figure 7.4 These bright yellow lights contain sodium vapour. Electricity makes the gas glow, producing a very intense yellow light.

Incandescent Sources

An object can be heated to such a high temperature that it emits visible light. Such an object is called an **incandescent source** of light. The emission of visible light by a hot object is called **incandescence**. Both candle flames and light bulbs are examples of incandescent sources. As you saw in the Starting Point Activity, in the light bulbs used most commonly in our homes, electricity heats a metal wire filament in the bulb (see Figure 7.5). This filament becomes so hot that it glows white. The change from electrical energy to visible light energy involves the following energy transformation:

Electrical energy → Thermal energy → Visible light energy

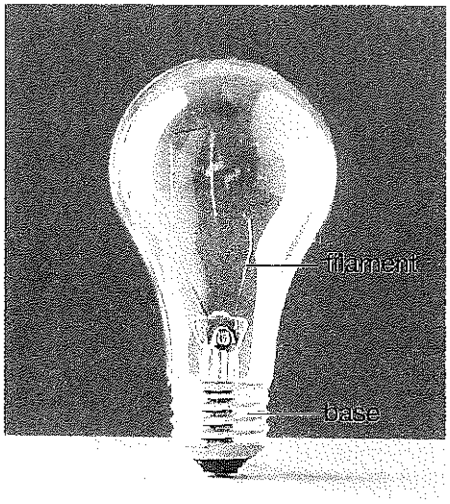


Figure 7.5 An incandescent light bulb

Have you ever touched an incandescent bulb right after you turned off the light? If so, you probably burned your fingers! About 95 percent of the energy given off by incandescent light bulbs is released as heat. In a way, an incandescent source of light is like having a small electric heater in the room.

DidYou**Know**?

The filament in an incandescent light bulb is usually made of the element tungsten.

Fluorescent Sources

You may have noticed that when you stand under a so-called "black light," some of your clothing glows, especially white socks! In this process, high-energy, invisible ultraviolet light is absorbed by the particles in the fabric. (You will learn more about ultraviolet light in Chapter 9.) These particles then emit some of this energy as light that you can see, making the clothing glow. This glow is called **fluorescence**. You can summarize this energy transformation as follows:

Ultraviolet light energy → Energy absorbed by particles → Visible light energy

A **fluorescent source** of light makes use of this energy transformation. Figure 7.6 shows the typical parts of a fluorescent tube. An electric current from the lead-in wires and electrodes cause the mercury vapour inside the tube to give off ultraviolet radiation. A phosphor coating on the inside of the tube absorbs the ultraviolet energy. This causes the coating to glow, thus producing light that you can see. The energy pathway for a fluorescent source is summarized as follows:

Electrical energy → Energy absorbed by mercury particles →

Ultraviolet light energy → Energy absorbed by phosphor particles → Visible light energy

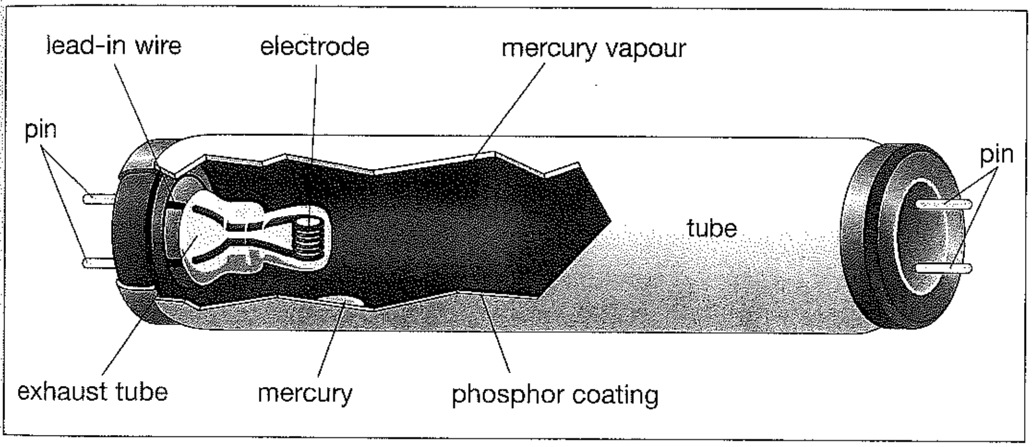


Figure 7.6 A fluorescent tube

Fluorescent tubes have a few disadvantages compared to incandescent light bulbs. They are much more expensive to manufacture and more difficult to dispose of than incandescent bulbs. Also, both the phosphor coating and the mercury vapour of fluorescent tubes are toxic.

However, if you compare the energy pathways for the fluorescent tube and the incandescent light bulb, you will notice a definite advantage for fluorescent sources. Thermal energy is not involved in the operation of a fluorescent light source. You can even touch the tubes when they are lit. As a result, fluorescent lighting wastes much less energy as heat than incandescent lighting. In other words, fluorescent lighting is more energy-efficient. Most schools and businesses use fluorescent tubes rather than incandescent bulbs to conserve energy and thus save money.

DidYouKnow?

Ultraviolet light can cause eye damage. Never stare directly at an ultraviolet light source.

DidYouKnow?

Fluorescent tubes use a device called a ballast resistor. One function of this device is to limit the amount of electricity flowing to the tube. After a few years of use, parts of this device can become loose and begin to vibrate. These vibrating parts cause the annoying hum that you sometimes hear in your classroom.

Phosphorescent Sources

A **phosphorescent source** of light is similar to a fluorescent source. Light energy is absorbed by certain particles that can store this energy for a while. The stored energy is later released as visible light. The original light energy may be either in the form of high-energy ultraviolet light (as in fluorescent tubes) or in the form of visible light. The persistent emission of light following exposure to and removal of a source of radiation is known as **phosphorescence**.

The main difference between a fluorescent source and a phosphorescent source is that particles in the fluorescent source release their light energy immediately. Phosphorescent particles take longer to emit light, and they continue to glow for a while after the energy source has been removed (see Figure 7.7).

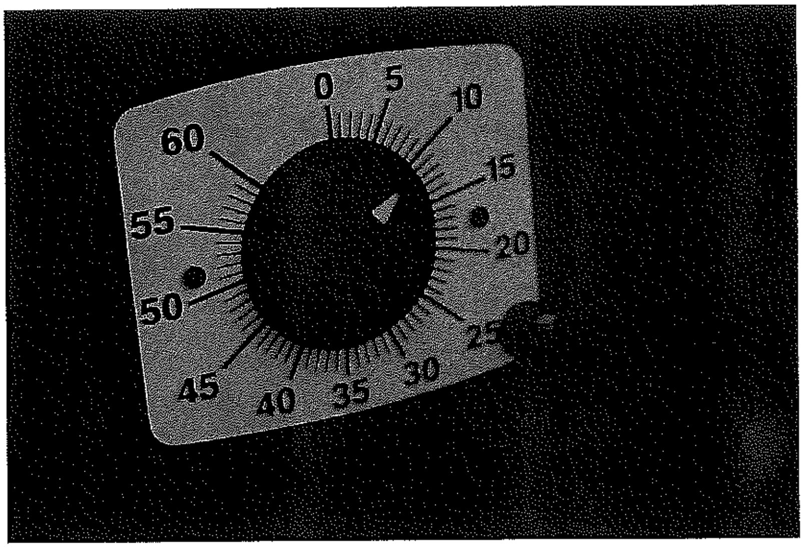


Figure 7.7 Phosphorescent materials are often used in photographic darkrooms. This phosphorescent dial on a darkroom timer glows to indicate how long a photograph should remain in various solutions.

Find Out ACTIVITY

Recycling Fluorescent Tubes

Disposal of fluorescent tubes poses a challenge. The mercury vapour and the phosphor coating in these tubes are toxic, so we cannot simply throw the tubes away. Is there a way to recycle fluorescent tubes?

What to Do

Conduct research on how fluorescent tubes should be recycled. You might contact a lighting store and arrange to speak to a salesperson or a manager. You could also speak to your school board's health and safety officer. Make sure you write down your questions ahead of time. Another research strategy would be to search the Internet using key terms such as "fluorescent lighting" and "disposal."

What Did You Find Out?

Present your findings to your class in a question-and-answer format. (Use visual aids if possible.) Include your recommendations for the safe disposal of fluorescent tubes.

Chemiluminescent Sources

Light can also result from the energy released in chemical reactions. The chemical reaction produces particles that give off visible light energy. This process is called **chemiluminescence**. The energy pathway for a **chemiluminescent source** can be represented as follows:

Chemical energy → Visible light energy

Glow sticks, often used as emergency signal lights, produce light by chemiluminescence. In a glow stick, a breakable barrier separates two liquids. Bending the stick causes the barrier to break. The liquids mix and cause a chemical reaction that releases light, as shown in Figure 7.8.

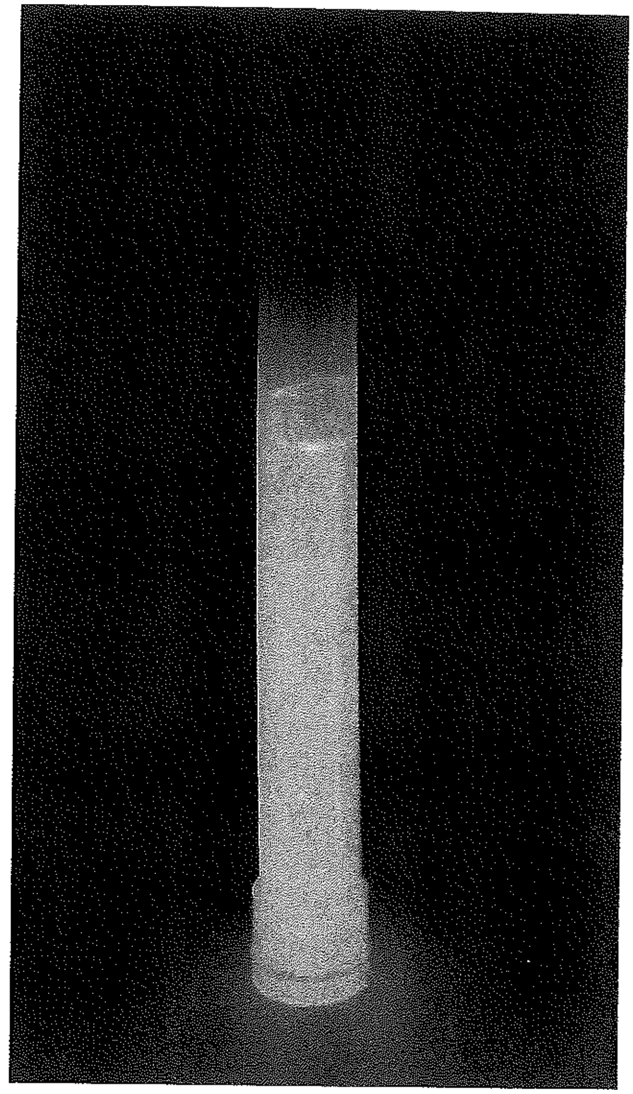


Figure 7.8 A mixture of chemicals releases light when a glow stick is bent. The stick will glow for several hours until the chemical energy is used up.

Bioluminescent Sources

If you were moving through the darkest depths of the ocean in a research submarine, you might be surprised to see glowing creatures swimming past your porthole (see Figure 7.9). These animals cannot be incandescent or fluorescent sources. Instead, they rely on chemical reactions inside their bodies to provide the energy for light. This special type of light produced in living creatures is called **bioluminescence**, and the result is known as a **bioluminescent source** of light. Many organisms that live deep in the ocean use bioluminescence because so little sunlight reaches far below the surface. Some fish produce bioluminescence to attract prey. Certain fungi in caves also produce bioluminescence, as do fireflies. Fireflies glow to attract mates.

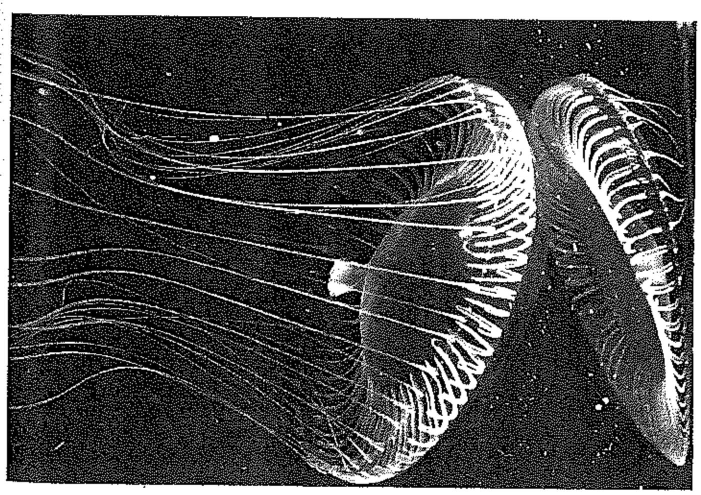


Figure 7.9 How might bioluminescence be helpful to these jellyfish?

Pause& Reflect

In your Science Log, record the various sources of light you encounter in the next few days. Make a table and classify the light sources as incandescent, fluorescent, phosphorescent, chemiluminescent, or bioluminescent. If possible, and if it is safe to do so, bring an unusual light source to class and explain how it works.

The Cost of Lighting

So far, you have looked at how various light sources produce light. Now consider the cost of using different sources of light. Since incandescent and fluorescent sources are the most common around the home, you can compare their costs.

Electrical energy costs about eight cents per kilowatt hour. A **watt** is a unit of electrical power. A **kilowatt hour** is one thousand watts of electrical power operating for one hour. The symbol for watt is W and the symbol for kilowatt hour is kW•h. To understand how to calculate the cost of lighting, look at the following example.

Example: How much will it cost to leave a 60 W bulb on for 10 h if electrical energy costs 8¢/kW•h?

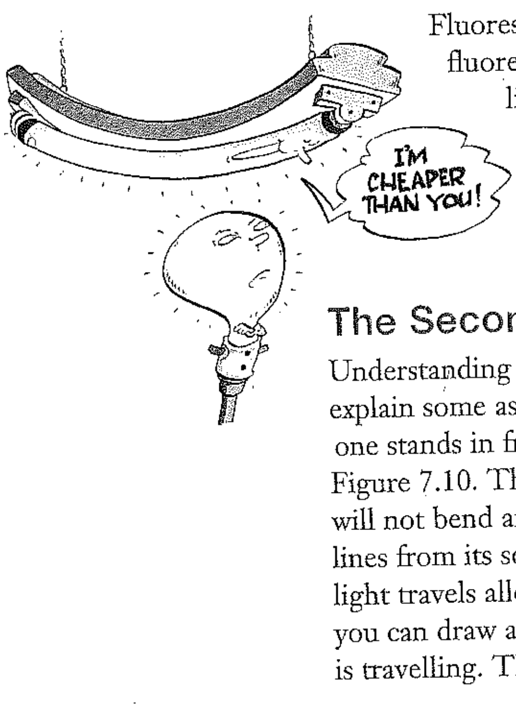
Solution:

1. Convert 60 W to kilowatts by dividing by 1000.
   $60\ W \div 1000 = 0.06\ kW$

2. Calculate the number of kilowatt hours by multiplying the power (in kW) by the number of hours.
   Number of kW•h = $0.06\ kW \times 10\ h = 0.6$ kW•h

3. Calculate the cost of leaving the light on for 10 h by multiplying the number of kilowatt hours by the cost per kilowatt hour.
   Cost (in cents) = Amount of energy (in kW•h) × Unit price (in ¢/kW•h)
   Cost = 0.6 kW•h × 8¢/kW•h = 4.8¢

   Therefore, the cost of leaving the light on for 10 h is 4.8¢.



Fluorescent tubes are more energy-efficient than incandescent bulbs. A fluorescent tube with a power of 12 W can produce the same amount of light as a 60 W incandescent bulb. The cost of operating the 12 W fluorescent tube for 10 h would be 0.96¢. This is only one fifth the cost of operating the 60 W incandescent bulb for the same amount of time!

The Second Basic Property of Light

Understanding the first basic property of light — that light is energy — helps explain some aspects of light. However, it does not explain everything. When someone stands in front of you during a movie, part of your view is blocked, as shown in Figure 7.10. This hints at another basic property of light. The light from the screen will not bend around the person to reach your eyes because light travels in straight lines from its source. This is the second basic property of light. Knowledge of how light travels allows us to predict how light will behave. To show the path of light, you can draw a straight line with an arrowhead to show the direction in which light is travelling. This type of drawing is called a **ray diagram** (see Figure 7.11).

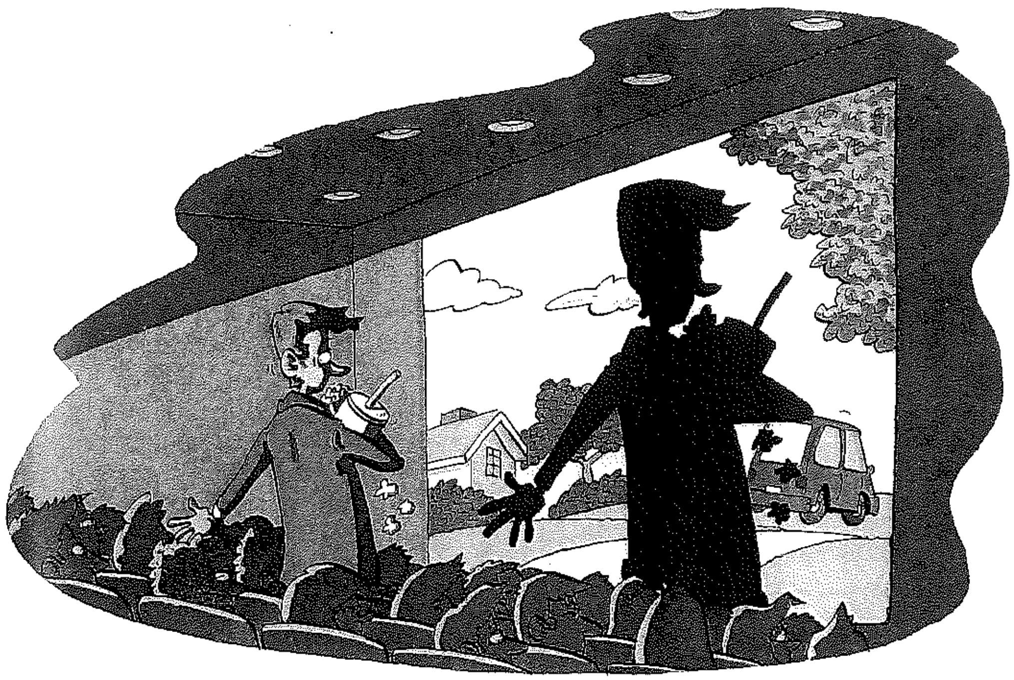


Figure 7.10 A shadow results because light travels in straight lines from its source and does not bend around objects.

Until light strikes something, it will continue to travel in straight lines away from the source, as shown in Figure 7.11. When light strikes clear substances such as air and water, it passes through them. These media are **transparent**. Window glass is transparent, and so are the lenses in your eyes. You can look through a transparent surface to see the light source clearly on the other side. Other substances let some light pass through them, but the light is scattered from its straight path. These substances are **translucent**. Wax paper is translucent. You can sometimes see the source of light on the other side of a translucent surface, but the image is not clear. Many materials will not allow any light to pass through them. These materials are **opaque** — they block the path of light. A book is opaque, for example. As you learned in previous science studies, opaque objects produce shadows when light strikes them.

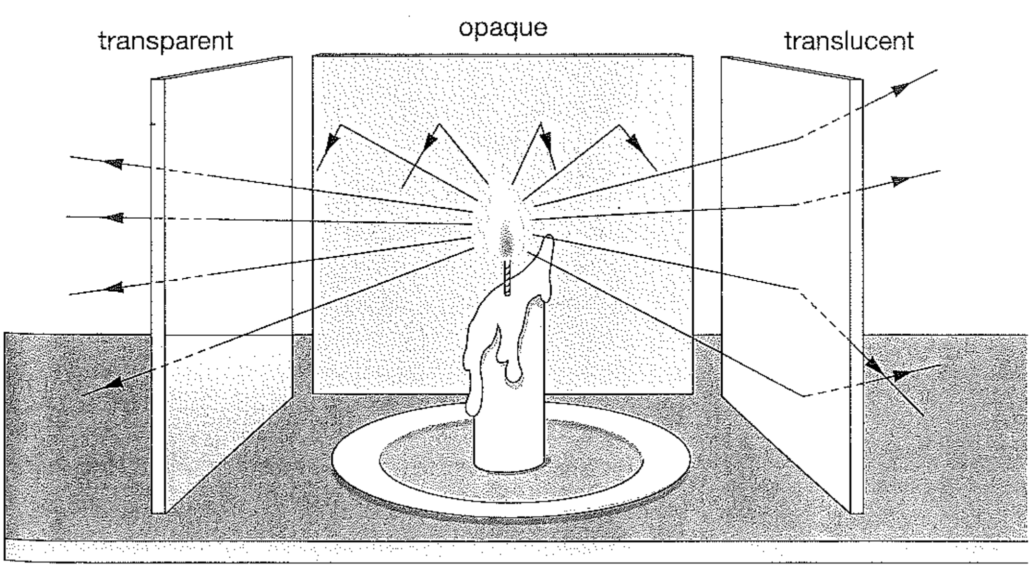


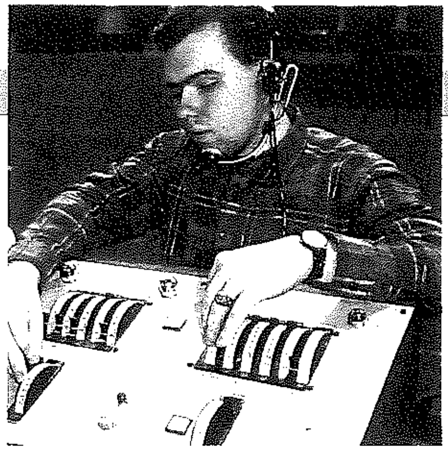
Figure 7.11 Light will travel in straight lines until it strikes something.

Career CONNECT

Stage Lighting

Have you ever watched a play in a theatre? Did you notice how lighting can change the mood of a scene on stage? Bright lights shining from all sides create a warm, relaxed atmosphere. Dim lights and shadows create an atmosphere of danger and suspense.

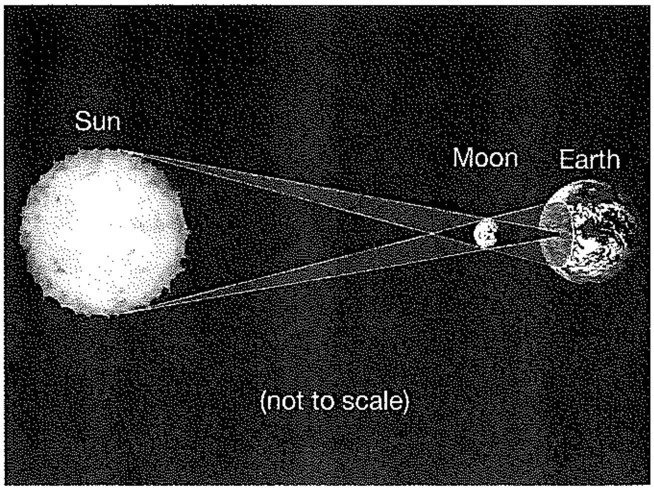
The lighting technician in the theatre must know which of the many lights needs to be lit for each scene and just how quickly or slowly the lights should fade out or come on. In the past, the job often required two people: one to make each lighting change on cue and another to set the switches in preparation for the change. Now, most large theatres have a computerized lighting board. The technician can program the lighting changes for the show ahead of time. During the show, only one person is needed to shift from one lighting cue to the next. The equipment is more complicated, but it allows the show to run more smoothly, with fewer errors.



Ask your teacher's permission to interview a person in a light-related career, such as a photographer, home-security installer, photo-lab manager, or videographer. Ask about the technological changes that have taken place in the industry and how these changes affect the work the person does. What changes are likely to take place in the future? Write a report comparing and contrasting past methods of doing the job with today's methods.

Check Your Understanding

1. What is light?
2. Write the energy pathway for
   (a) an incandescent source
   (b) a fluorescent source
   (c) a chemiluminescent source
3. State one advantage that incandescent bulbs have over fluorescent tubes.
4. State one advantage that fluorescent tubes have over incandescent bulbs.
5. If electrical energy costs 7¢/kW•h, calculate the cost of running a 15 W scanner for 10 min. (You will need to convert 10 min into hours.)
6. Describe what happens when light strikes a translucent surface, a transparent surface, and an opaque surface. Give one specific example of an object that has each type of surface.
7. What would happen to the intensity of sunlight if Earth were twice as far from the Sun?
8. **Apply** The diagram on the right shows the relative positions of Earth, Moon, and Sun during a solar eclipse, as well as the path of the light during an eclipse. Is much of Earth's surface in complete shadow? Use the idea that light travels in straight lines to explain how a solar eclipse occurs. (The motions of Earth and Moon are factors, as well.)



Pause & Reflect

Start a list of careers that require knowledge of the behaviour of light. Share what you have written with at least two class members. Add to your list of careers as you learn more about light in this chapter.