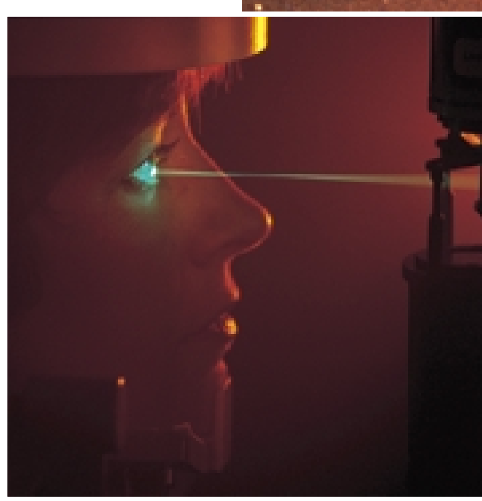
UNIT
3

Light and Optical Systems

What is light? You know it allows you to see, but do you know how? Do you know what causes the shimmering colours in the northern lights shown here? Why do we see in colour? For centuries, scientists around the world have tried to find answers to questions such as these. They developed models to try to explain their observations about light. Some early scientists thought that light might consist of particles that enter our eyes and make us see. However, when light shines on an object, the object's mass does not increase. Therefore, light must be a form of energy, but what form?



After hundreds of years of observations and experiments, scientists have not found one simple model that explains all of the characteristics of light. One helpful model is the ray model. A ray is an imaginary line that represents the direction in which light energy travels. While it explains how light forms images in a mirror and shadows on the wall, the ray model cannot explain colours or the way that light behaves when it travels through a very tiny slit. The wave model explains these characteristics.

In this unit, you will learn how to use these models to develop an understanding of how light works. You will also learn how we can use light technologies to assist us in everyday life. For example, an understanding of light has made it possible to develop advanced technologies such as lasers (used in eye surgery) and fibre optics (used in communications).

Unit Contents

UNIT 3

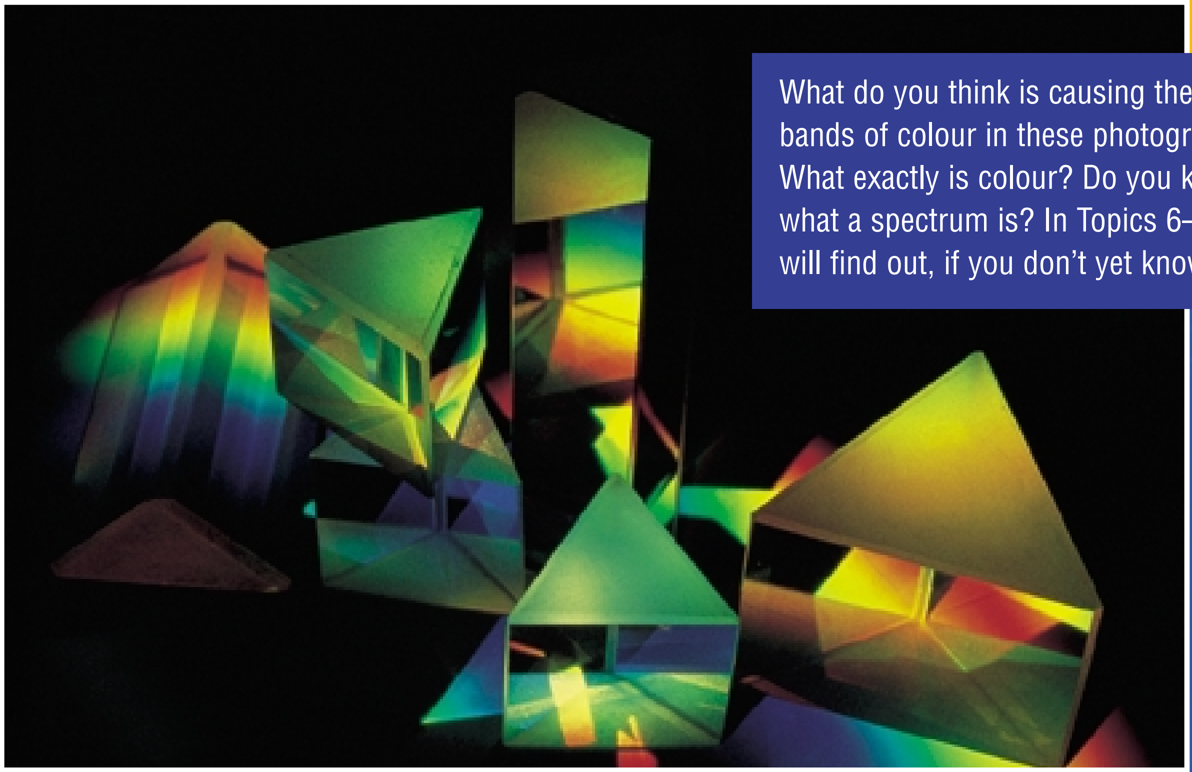
Preview

Focussing Questions

- What is light?
- What inventions use light?
- What do these inventions reveal about the nature of light?

In how many different ways have you used light today? How often have you used a mirror or seen reflections off a shiny surface? In Topics 1–3, you will learn just what light is and how it behaves in predictable ways.

We have opened up the universe to our eyes. How? With the help of powerful telescopes, astronomers can study the birth of stars, such as the Orion Nebula shown here. In Topics 4–5, you will investigate some fantastic technologies that extend human vision in ways unimaginable even a few decades ago.



What do you think is causing the bands of colour in these photographs? What exactly is colour? Do you know what a spectrum is? In Topics 6–8, you will find out, if you don't yet know…

Looking Ahead

Read pages 260–261, "Design Your Own Investigation." Here is a chance to display your skills in designing controlled experiments. You can start planning your investigation well in advance…

- Start sharing ideas with your teammates. Save all your ideas in an "Experiment Planning File."
- Begin collecting the materials you will need for your experiment.
- Think about how you might present your experimental results in a multimedia presentation.

TOPIC 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**. It is the source of the most abundant and least expensive light in the world. Fire is another natural source of light (see Figure 3.1).

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. Nonetheless, 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*.

> **Science Log**
>
> Look around the room. List all the items you can that either give off or reflect light. You will discover a great deal about how light behaves as you study this unit.

Figure 3.1 Besides the Sun and the stars, flames and sparks are natural sources of light.

Find Out ACTIVITY

Is Light Energetic?

In the introduction, you read that light is a form of energy. Scientists often tell us that energy has no matter but you can tell that it exists because it can cause changes in matter. Can you use this concept to show that light is a form of energy?

Materials

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

Procedure

1. Find the solar cells on a calculator. Enter some digits, then completely cover the solar cells with your finger to block the light. Observe what happens to the digits.

2. Feel the inside wall of the canister. Replace the lid of the canister and place it in a bright light, such as sunlight or light from a 100 W bulb. Wait a few minutes, then remove the lid of the canister and feel the inside surface.

What Did You Find Out?

1. What happened to the digits when you prevented the light from reaching the solar cells on the calculator? Some solar calculators have a second source of power, such as a battery. What can you infer from your observations, about the power source of the calculator you tested?

2. What change did you notice about the canister after it had been exposed to a bright light?

3. Analyzing and Interpreting What evidence do you have that light caused a change in both steps 1 and 2 of the procedure?

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 the procedure, what is the manipulated variable? What is the responding variable? What variables should be controlled to obtain meaningful results?

7. Repeat procedure step 2 with two canisters. Before placing the canisters in a bright light, cover one of the canisters with aluminum foil (shiny side out). What can you infer about the effect of the foil?

The First Basic Principle of Light

You have seen that light is a form of energy. This is the first basic principle 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).

DidYouKnow?

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 3.2 Sunlight is absorbed by the pavement on this runway and transformed into thermal energy. You can see the effect of 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 3.2). 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.

Find Out ACTIVITY

Reading with Intensity

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

Safety Precautions

Materials

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

Procedure

1. Ask an adult to place a 60 W bulb in the lamp. CAUTION Turn off the electricity before the bulb is changed. Remember, bulbs become hot when they are turned on.

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. Performing and Recording Move about 3 m from the lamp. Read a sentence from the book at this distance. Record how your observations compare with those in step 2.

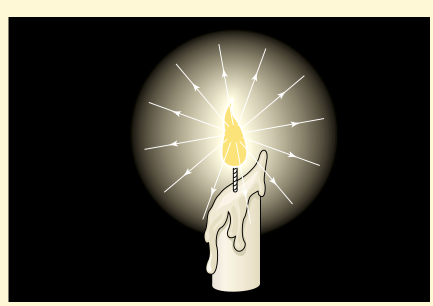
4. Repeat steps 1 to 3 using a 100 W bulb.

What Did You Find Out? Analyzing and Interpreting

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 3.3, 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 3.4 on the next page are much more efficient than typical white lights. The following pages will compare different types of light sources, both natural and artificial.

Figure 3.3 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.

Pause & Reflect

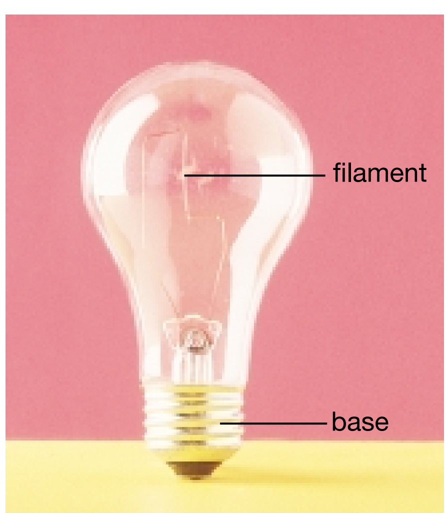
In your Science Log, describe several ways in which plants and animals respond to changes in the intensity of light. For example, how do your eyes react to a bright light? How do roosters behave when the Sun rises? What do you think birds do during an eclipse of the Sun?

Figure 3.4 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. In the light bulbs used most commonly in our homes, electricity heats a metal wire filament in the bulb (see Figure 3.5). 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



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.

Figure 3.5 An incandescent light bulb

DidYouKnow?

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 Topic 8.) 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 process. Figure 3.6 shows the typical parts of a fluorescent tube. An electric current from the lead-in wires and electrodes causes 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

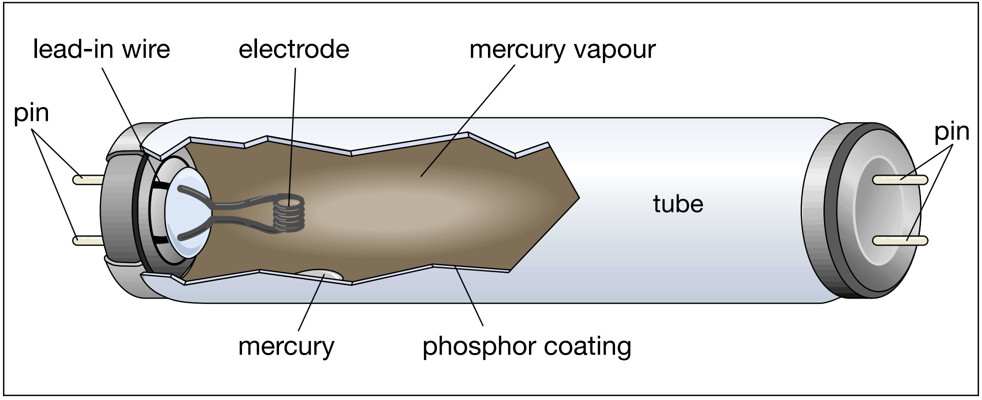


Figure 3.6 A fluorescent tube

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 as much 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.

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.

Looking Ahead

Are there other light sources that you should consider for your end-of-unit investigation? We know that our skin needs protection from ultraviolet light, but do we also need to protect ourselves from other sources of light such as fluorescent and phosphorescent light? Research the Internet and other sources to find more information about the different sources of light that you are learning about in this unit.

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. They also continue to glow for a while after the energy source has been removed (see Figure 3.7).

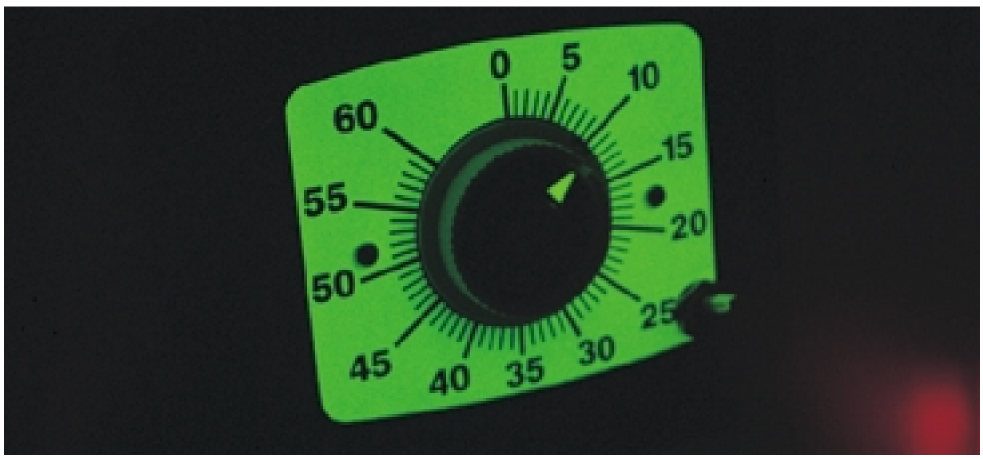


Figure 3.7 The inner surface of television and computer screens is coated with phosphors. Phosphorescent materials are also often used in photographic darkrooms. This phosphorescent dial on a darkroom timer glows to indicate how long a photograph should remain in various solutions.

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 and picture tubes from discarded television sets and computer monitors?

Procedure ✶ Initiating and Planning

Conduct research on how these 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" or "picture tubes" and "disposal."

What Did You Find Out? ✶ Analyzing and Interpreting

Present your findings to your class in a question-and-answer format. (Use visual aids or multimedia 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 energetic 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 3.8.

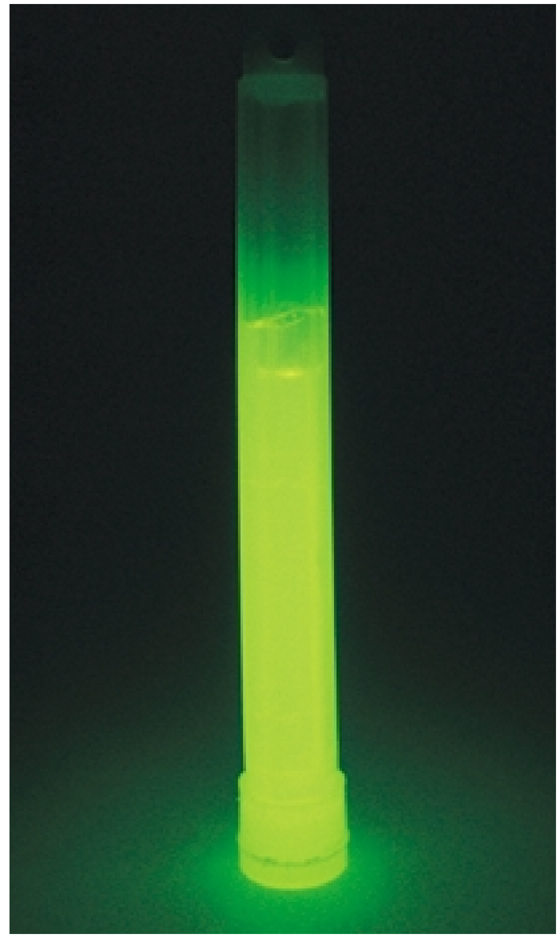


Figure 3.8 A mixture of chemicals releases light when a glow stick is bent. The stick will glow for several hours until the chemical energy is used up.

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 3.9). 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**. 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.

All objects that emit light are called **luminous**. How can you see **non-luminous** objects, objects that do not emit light? The next Topic will answer that question.

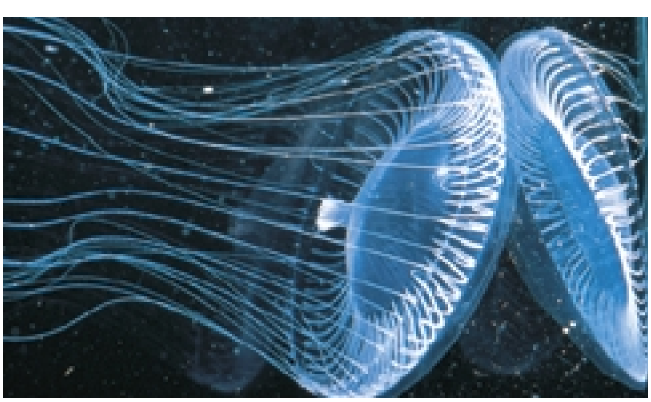


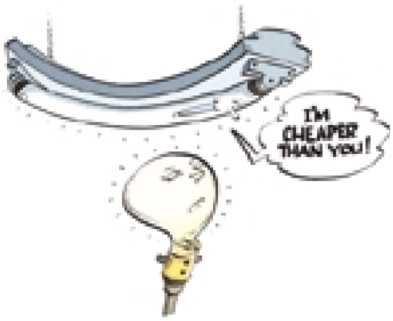
Figure 3.9 How might bioluminescence be helpful to these jellyfish?

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.



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 ÷ 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 × 10h = 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¢.

DidYouKnow?

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 Ray Model of Light

Fig. 3.10 A shadow results because light travels in straight lines from its source and does not bend around objects.

The idea that light is a form of energy cannot explain certain properties of light. For example, how can this energy make shadows? When someone passes the screen during a movie, a shadow is cast over the screen, as shown in Figure 3.10. Light from the projector cannot bend around the person to reach the screen. Observations such as this tell us that light travels in straight lines. The **ray model** of light is based on such observations. A **ray** is a straight line that represents the path of a beam of light. You can use the ray model to predict where shadows will form and how large they will be. The **ray diagram** in Figure 3.11 shows you how to use the ray model. Light beams travel out in all directions from a source but you need to draw only a few rays to predict the size and location of shadows. Notice, in the diagram, that you always draw the ray that travels closest to the object that is blocking the light.

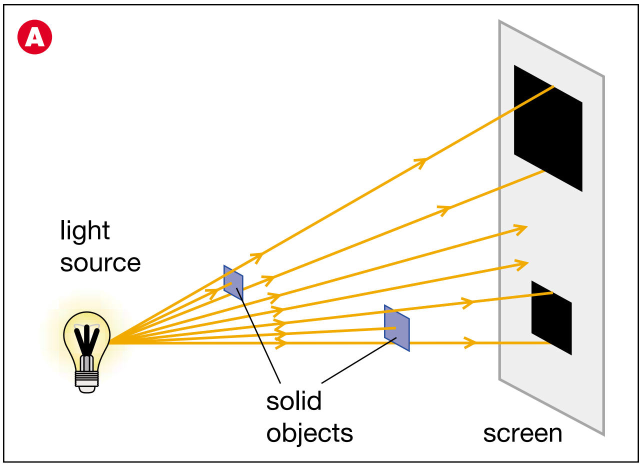


Figure 3.11A The ray diagram shows you how the distance from the light source affects the size of a shadow that an object makes. The smaller object casts the larger shadow because it is closer to the light source.

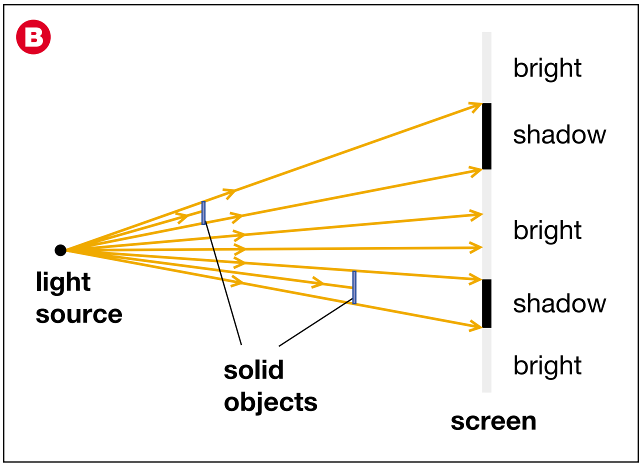


Figure 3.11B To make ray diagrams easier to draw and to visualize, you usually draw them as though you were looking at the objects directly from the side. You would also represent the light source with a dot.

The ray model can also help you understand what happens when light energy reaches different types of materials (see Figure 3.12). When light passes through clear substances, the rays continue along their straight path. We say that these clear substances are **transparent**. For example, air, water, window glass, and the lenses of your eyes are transparent.

When you hold a piece of paper in front of a light source, you can see light coming from the other side. However, you cannot see images because the paper scatters the light. The paper bends the light rays. Some of the rays bounce back off the paper. Substances such as paper are said to be **translucent**. Some types of glass and plastic are translucent.

Many materials totally block the light and prevent any of it from passing through. We call these materials **opaque**. This book, your desk, and you are opaque. Opaque materials cast shadows.

Word **CONNECT**

A ray is an imaginary line showing the direction in which light is travelling. How do you think a ray of light differs from a beam of light? In your notebook, write a definition for a beam of light. (If you wish, you can use a dictionary.)

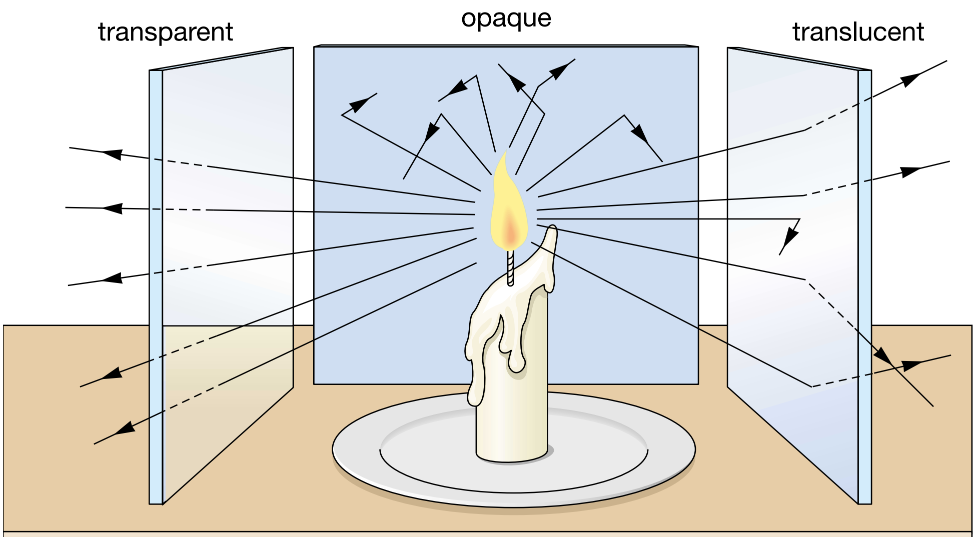


Figure 3.12 Light will travel in straight lines until it strikes something.

Find Out ACTIVITY

Make a Large Pinhole Camera

To see for yourself that light travels in straight lines, try making a large pinhole camera.

Safety Precaution

Materials

sharp knife

large cardboard box, about twice as large as your head

aluminum foil

bright object, such as a light bulb or brightly lit window

masking tape

Procedure

1. The box will serve as a camera body. Cut a 3 cm square hole in one side of the box, 2–3 cm from the closed end of the box. CAUTION Be careful when using sharp objects such as scissors.
2. Fold a 5 cm square piece of aluminum foil in half. Cut a semicircle 1 cm wide into the fold.
3. Unfold the foil and tape it over the square opening in the box. The hole will let light into your camera.
4. Turn your back on the bright object (light bulb). Lower the box over your head with the hole behind you.
5. Fold the flaps of the box against your neck and head to make the inside of the box as dark as possible. Slowly move the box around until you can see a bright patch of light on the inside of the box.
6. Observe the patch of light at several distances from the bright object.

CAUTION Have a partner move the object for you. Do not walk while wearing the box on your head.

What Did You Find Out?

1. What happens to the brightness of the image when an object is closer to the camera?
2. What happens to the size of the image when an object is closer to the camera?
3. What happens to the sharpness of the image when an object is closer to the camera?
4. Analyzing and Interpreting What evidence have you observed that light travels in straight lines?

Extension

Initiating and Planning

Try a similar activity using a tissue box with a small hole at one end of the box and wax paper (as the screen) taped to the other end.

Career CONNECT

Stage Lighting

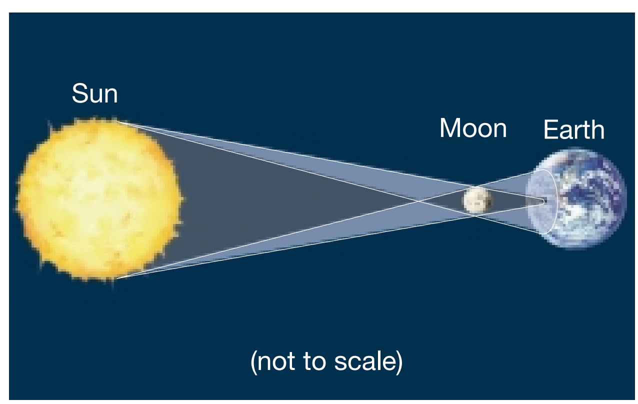
Have you ever watched a play in a theatre? Did you notice how lighting can change the mood of a scene on stage? Bright lights shining from all sides create a warm, relaxed atmosphere. Dim lights and shadows create an atmosphere of danger and suspense.

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. Examples include a photographer, home-security installer, photo-lab manager, or videographer. Ask about the technological changes that have taken place in the industry. How have these changes affected 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.

TOPIC 1 Review

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 translucent material, a transparent material, and opaque material. 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 geometric ray model — 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 unit.

TOPIC 2 Reflection

Figure 3.13 In order for you to see such a clear image in the mirror, reflected light must follow a very precise pattern.

When you read the word "reflection" you probably think of looking in a mirror as the student in the photograph is doing. **Reflection** is the process in which light strikes a surface and bounces back off that surface. Light reflecting from a mirror allows you to see an image of yourself. Did you realize that, as you read this page, you are also seeing reflected light? How can the same process cause such different results? Is reflection from a printed page the same process as reflection from a mirror or are they different altogether? Can we find one model for reflection that can explain both situations? The answer is yes, one model can explain both situations.

The difference between seeing your own image and seeing a printed page is determined by the surface from which light reflects. The surface of paper is actually very rough when compared with the extremely smooth surface of a mirror, as shown in Figure 3.14. The ink on this page also changes the surface.

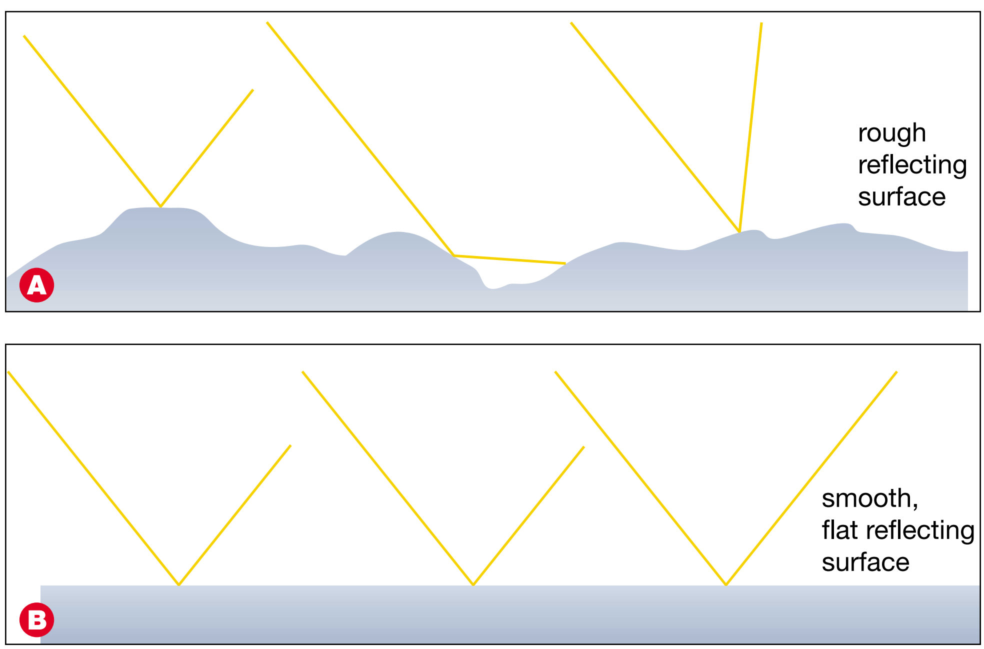


Figure 3.14 If you look at the surface of paper (A) and a mirror (B) with a magnifying glass, you see that the paper is quite rough while the mirror is very smooth.

To analyze the process of reflection, shown in Figure 3.15, imagine a mirror surface or a very tiny part of the paper surface that is flat. The ray that comes from a light source and strikes the surface is the **incident ray**. The ray that bounces off the surface is the **reflected ray**.

To describe the direction of these rays, you define certain angles. First, you draw a line that is perpendicular to (makes an angle of 90° with) the reflecting surface at the point where the incident ray strikes the surface. This line is called the **normal** line. The angle between the incident ray and the normal line is the **angle of incidence**, *i*. The angle between the normal line and the reflected ray is the **angle of reflection**, *r*.

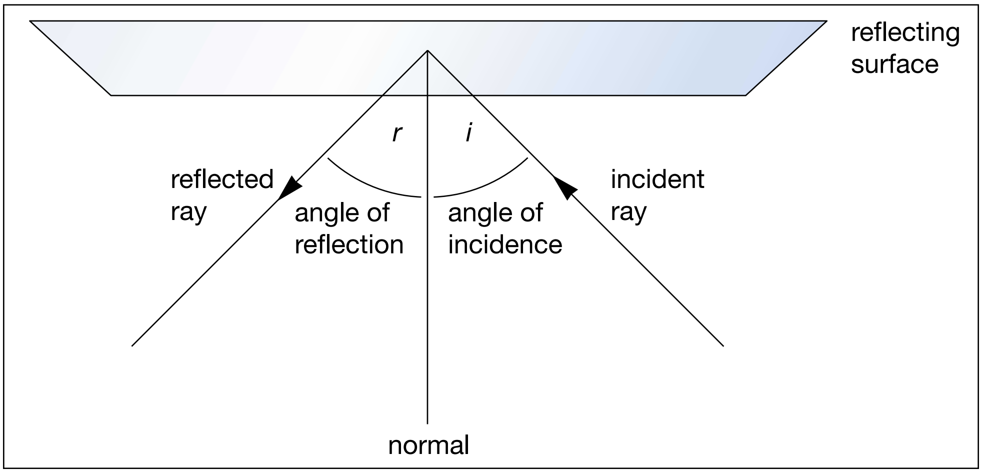


Figure 3.15 The normal is a reference line that is drawn perpendicular to the reflecting surface. It is drawn at the point where an incident ray strikes a reflecting surface. The angle of incidence, i, is the angle between the normal and the incident ray. The angle of reflection, r, is the angle between the normal and the reflected ray.

Now you have the tools to experiment with reflection. In the next investigation, you will discover the laws of reflection. You will use a **plane mirror** (one that has a flat surface) for a reflecting surface because it will give uniform results. In the following investigation, you will use another, very smooth surface and apply the laws that you discovered.

Figure 3.16 The surface of a lake can be so smooth that it provides a near-perfect mirror image of the scenery around it.

Word CONNECT

In science and mathematics, words sometimes have a very different meaning than they do in everyday language. Look up the word normal. Find the origin of the word. Can you find any connection between the common meaning and the mathematical meaning of normal?

SKILLCHECK
- Initiating and Planning
- Performing and Recording
- Analyzing and Interpreting
- Communication and Teamwork

Inferring the Law of Reflection

When you look in your bathroom mirror, light reflects off your face in all directions. Some of this light reflects off the mirror into your eyes. This light must follow a consistent pattern because you always see the same image of your face in a mirror.

In this activity, you will be guided through the process of making a ray diagram. When your diagram is complete, you will analyze the relationship between incident and reflected rays. From these data, you will be able to infer the fundamental law of reflection.

Question

How does light behave when it reflects off a flat surface?

Hypothesis

What is the relationship between the angle of incidence and the angle of reflection? Make a hypothesis and test it.

Safety Precaution

The edges of the mirror may be sharp. Be careful not to cut yourself.

Apparatus

ray box
plane mirror (about 5 cm × 15 cm) with support stand
small object with a pointed end such as a short pencil or a nail (the object should be shorter than the mirror)
protractor
ruler
pencil (for drawing)

Materials

sheet of blank paper (letter size)

Skill FOCUS

For tips on making tables, turn to Skill Focus 10.

Procedure

1. Near the middle of the blank sheet of paper, draw a straight line to represent the reflecting surface of the plane mirror. (This is usually the back surface of the mirror because the front surface is a sheet of protective glass.) Label the line "plane mirror."

2. Lay the small object on the paper. Place it about 5–10 cm in front of the line representing the plane mirror. Trace the shape of the object. Label the pointed end *P* and the blunt end *O*.

3. Remove the object. Draw two different straight lines from point *P* to the line labelled "plane mirror." On each line, draw an arrowhead pointing toward the mirror. These lines represent the paths of two incident light rays that travel from the object to the mirror.

4. Carefully place the mirror in its stand on the sheet of paper. Make sure the mirror's reflecting surface is exactly along the line you drew in step 1.

5. Use the ray box to shine a thin beam of light along one of the incident rays that you drew from point *P*. Mark the reflected ray with a series of dots along the path of the reflected light.

6. Remove the mirror and the ray box. Locate the reflected ray by drawing a line through the dots and ending at the mirror. On this line draw an arrowhead pointing away from the mirror to indicate that this is a reflected ray.

7. At the point where the incident ray and its corresponding reflected ray meet the mirror, draw a line at 90° to the mirror. Label this line the "normal."

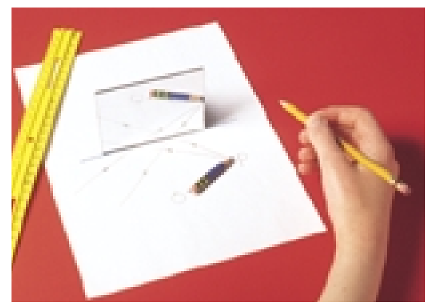
8. **Measure and record** the angle of incidence (the angle between the normal and the incident ray).

9. **Measure and record** the angle of reflection (the angle between the normal and the reflected ray).

10. Repeat steps 4–9 for the second incident ray from point *P*.

11. If time permits, repeat steps 3–9 for point *O*.

12. Place the mirror and the object back on the sheet of paper. **Observe** the image of the object and the reflected rays that you drew. From what point do the reflected rays seem to come?



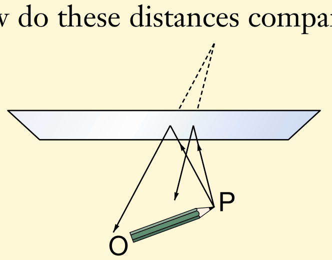
Analyze

1. You drew two rays from point *P* to the mirror. If you had enough time, how many rays could you have drawn between point *P* and the mirror? Don't try drawing them all, just think about the question.

2. How does the angle of reflection compare to the corresponding angle of incidence?

3. Extend each reflected ray behind the mirror, using a dotted line. Label the point where these two dotted lines meet as *P*. This is the location of the image of point *P*. **Measure** the perpendicular distance between
   - point *P* (the object) and the mirror
   - point *P* (the image) and the mirror

   How do these distances compare?



Conclude and Apply

4. From your data table, **describe** the pattern relating the angle of incidence and the angle of reflection. Does this pattern agree with your hypothesis? In science, a **law** is a statement of a pattern that has been observed again and again, with no exceptions. You have just demonstrated the first law of reflection. Do other groups in your class agree with your conclusions?

5. You were able to draw the incident ray, the reflected ray, and the normal all on the surface of a flat piece of paper. What name is given to a flat surface? Make up a statement that describes this relationship mathematically.

6. Based upon your measurements, how does the distance from the image to the mirror compare with the distance from the object to the mirror?

INQUIRY

INVESTIGATION 3-B

SKILLCHECK

Initiating and Planning

Performing and Recording

Analyzing and Interpreting

Communication and Teamwork

When Light Reflects

You have just followed detailed directions for making a ray diagram. Now use your knowledge to make your own diagram. In this investigation, your reflecting surface will not be a mirror. It will be the surface of water.

Hypothesis

Does light reflect off liquid surfaces according to the same principles that it reflects off a solid, mirror surface? Make a hypothesis to answer this question, and test it.

Apparatus

clear plastic cup
wooden pencil
ruler

Materials

water
paper

Procedure

1. Fill the cup about three quarters full of water. Place the cup of water on a level surface.

2. **Observe** the surface of the water. Move your head around until you can see a reflection of the lights overhead, or a reflection of a window.

3. Make a simple ray diagram to record the direction in which light travels before it reaches your eye. Show and label the positions of the light source, the surface of the water, and your eye. This drawing should show the situation as someone would observe it from the side.

Skill FOCUS

For tips on scientific drawing, turn to Skill Focus 11.

4 Move the cup of water to the edge of the desk or table. Wait until the water stops jiggling. Crouch down so that you can look up at the bottom of the water's surface.

5 Slide a pencil across the desk, toward the cup and your eye.

6 Move the pencil along the desk surface until you can see a reflection of the pencil in the lower surface of the water. Make a simple ray diagram to record the path of the light from the pencil to your eye.

7 Look at the reflection of the pencil as you did in step 6, but now gently tap on the rim of the glass. **Record your observations.** Wipe up any spills as wet floors are slippery.

Analyze

1. In steps 4 and 6, what happened to some of the light that struck the lower flat surface between the air and the water? What common device depends on this behaviour of light?

2. In step 7, what change occurred in the surface of the water when you tapped on the glass? Could you still see a reflection of the pencil?

Conclude and Apply

3. During reflection, what happens to the direction in which light travels?

4. Did your observations support or refute your hypothesis? Explain.

Forming an Image

Did you discover, in the last two investigations, that the angle of reflection was the same as the angle of incidence? This relationship has been observed for all types of surfaces with no exceptions. Therefore, it is considered a law. You can state the **law of reflection** as "*the angle of reflection equals the angle of incidence*." For example, if the angle of incidence, *i*, is 60° then the angle of reflection, *r*, will be 60°. Another important relationship that you probably observed is that the incident ray, the normal line, and the reflected ray lie in the same **plane** (an imaginary flat surface).

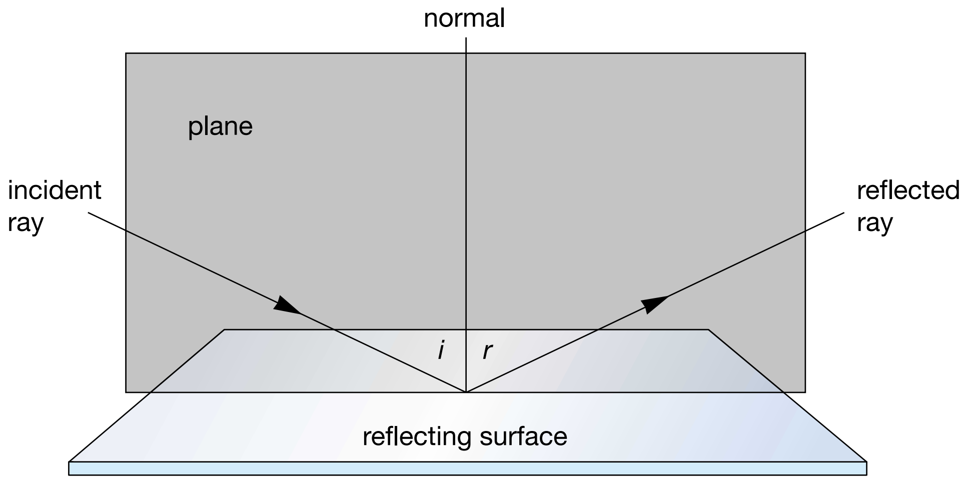


Figure 3.17 The angle of reflection, *r*, is always equal to the angle of incidence, *i*. The incident ray, the normal, and the reflected ray are always in the same plane.

How do reflected rays form an image that you can see in a mirror? Study Figure 3.18 to answer this question. Light from some luminous source shines on an object, a blueberry. This light reflects off all points on the blueberry in all directions. In the figure, only the rays coming from one point are shown. All of the rays from the blueberry that strike

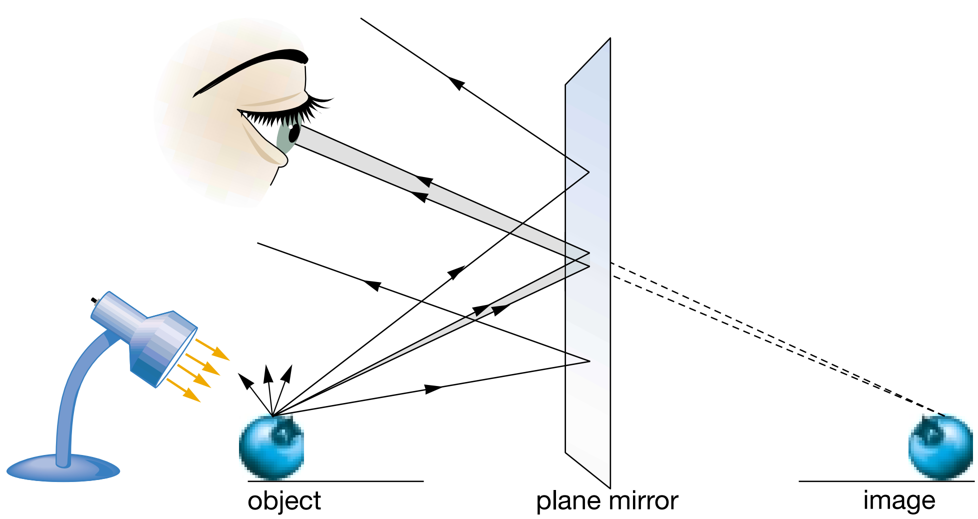


Figure 3.18 Only a small fraction of the light reflecting from an object enters your eyes.

the mirror reflect according to the law of reflection. The rays that reach your eye appear to be coming from a point behind the mirror. The same process occurs for every point on the blueberry. Your brain "knows" that light travels in straight lines. Therefore, your brain interprets the pattern of light that reaches your eye as an image of a blueberry behind the mirror.

Another important feature of images in mirrors is demonstrated in Figure 3.19. Rays are shown coming from three different points on the bird. These rays reflect off the mirror and back to the bird's eye. Notice where the points appear to be coming from behind the mirror. Each point appears to be coming from a point that is as far behind the mirror as the real point is in front of the mirror. Also notice that the three points are exactly the same distance apart in the image as they are on the object, the bird. These observations explain why an image in a mirror is the same size as the object and appears to be the same distance from the mirror as the object. These results are true only for plane (flat) mirrors. What happens when mirrors are curved?

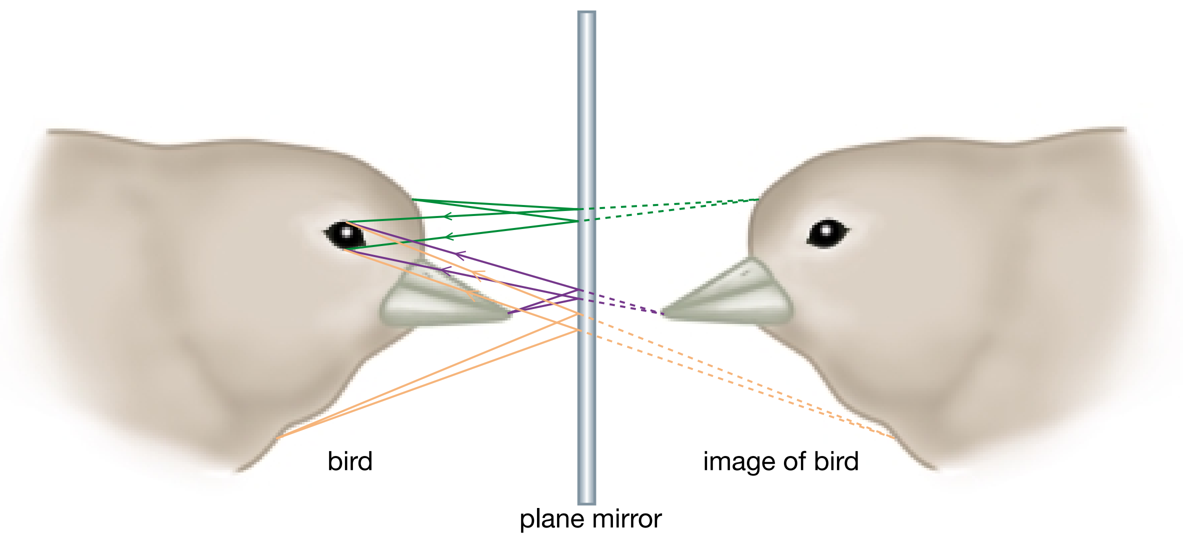


Figure 3.19 We know that what we see in a mirror is just an image. However, a pet bird will chatter for hours to a "friend" in the mirror.

Curved Mirrors

In stores or on buses, you have probably seen mirrors that bulge out. These are **convex** mirrors. Some makeup mirrors are caved in. They are **concave** mirrors. Learn more about curved mirrors by completing the following activity.

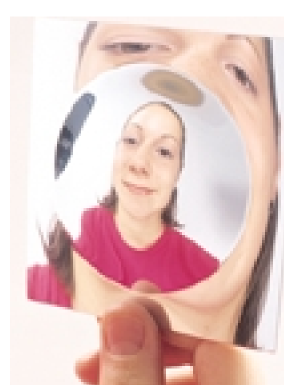


Figure 3.20A A convex mirror bulges outward like the surface of a shiny, helium-filled party balloon.

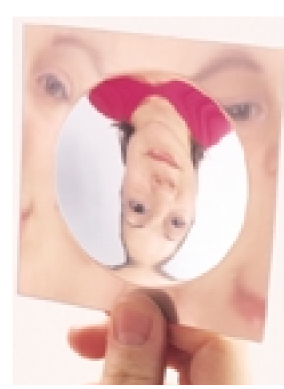


Figure 3.20B A concave mirror is curved like the inside of a shiny bowl.

Out of the Looking Glass

Find Out ACTIVITY

Compare the images formed by curved mirrors with the images you see in plane (flat) mirrors.

Materials

concave mirror
convex mirror
white cardboard or Bristol board (about 20 cm × 30 cm)

Procedure ✷ Performing and Recording

1. Stand near a window and aim the concave mirror toward the outside. Hold the cardboard screen in front of the mirror but a bit off to the side.

2. Angle the mirror so that the reflected light strikes the screen. Move the screen back and forth until you see a sharp image. Describe the image.

3. Hold the mirror close to your face and look at yourself. Describe the image.

4. Repeat steps 1 to 4 with the convex mirror.

What Did You Find Out? ✷ Analyzing and Interpreting

1. How are the images formed by a concave mirror different from the ones you see in a plane mirror? Describe any similarities you observe between concave mirror images and plane mirror images.

2. How are the images formed by a convex mirror different from the ones you see in a plane mirror? Describe any similarities you observe between convex mirror images and plane mirror images.

Did you discover that you could focus an image onto a screen with a concave mirror? Could you find any place to position the screen where a convex mirror would focus an image on it? When a mirror cannot focus an image on a screen but you can see an image when you look in the mirror, that image is called a **virtual** image.

Convex mirrors form images that appear much smaller and farther away than the object. However, they can reflect light from a large area. Therefore, convex mirrors are often used as security mirrors in stores as shown in Figure 3.21A. Often, one clerk in a small convenience store can see everyone in the store in the mirror. For the same reason, convex mirrors are sometimes used on the passenger side of cars and trucks as shown in Figure 3.21B. Although the image is a little distorted, the driver can see many of the vehicles that are behind the car.

Figure 3.21A Convex mirrors are useful security devices.

Figure 3.21B Why do these mirrors have labels saying "Objects may be closer than they appear"?

Rough Surfaces

Near the beginning of this Topic, you read that the one model of reflection could explain both the images you see in mirrors and the image of the page that you are reading. Study Figure 3.22 to see what happens when light strikes a rough image. Figure 3.22 is the same as Figure 3.14 with normal lines and rays added. As you have seen, smooth surfaces reflect light very uniformly. If you pick out several tiny, flat areas on a rough surface you will see that the normal lines go in many different directions. Each light ray that strikes the surface will reflect according to the law of reflection. However, since the normal lines all point in different directions, the reflected rays will go in different directions. The result appears as though the reflected rays were scattered randomly. They cannot form an image.

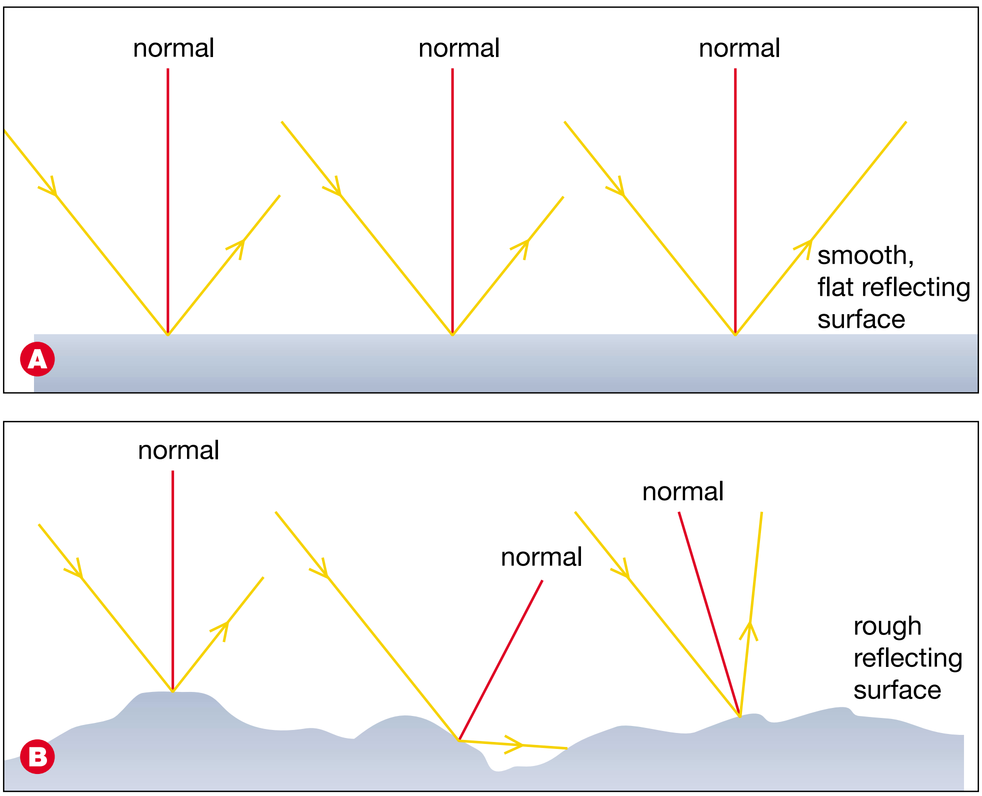


Figure 3.22 (A) Smooth surfaces reflect all light uniformly. (B) Rough surfaces appear to reflect light randomly.

Figure 3.23 shows you how this seemingly scattered light creates the image of the print on the page. Light hitting the white paper reflects in all directions. Some of that light reaches your eyes. Since there is no pattern, your eyes just see white light. The ink on the paper absorbs light. None of the light that strikes the ink is reflected. Since no light reaches your eyes from the ink, your eyes see it as black. In Topic 6, you will learn why some types of ink and other objects have colour.

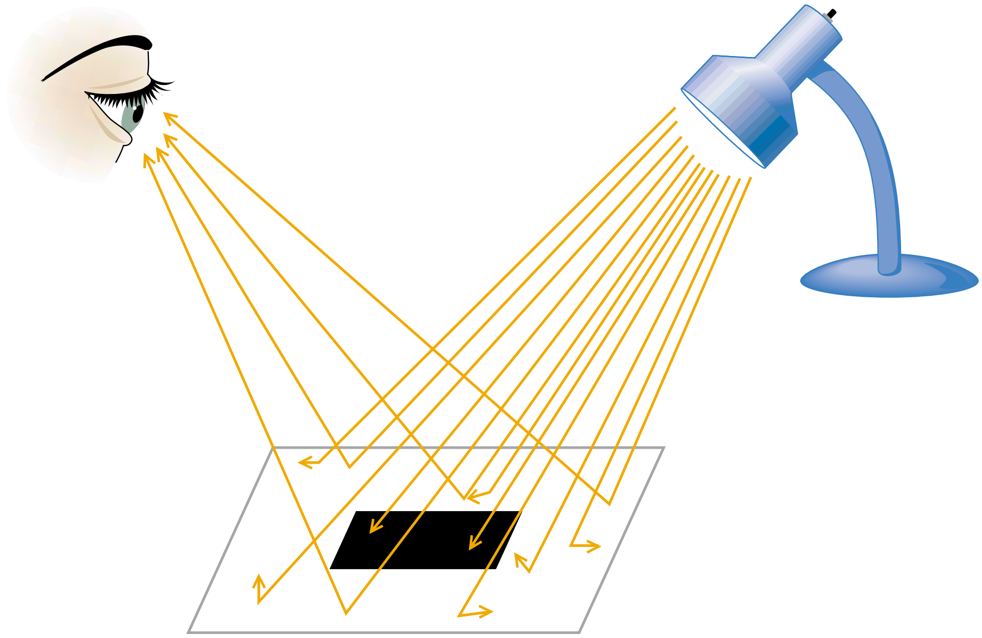


Figure 3.23 A rough surface that reflects all light that strikes it will appear white. A rough surface covered with ink will absorb the light. Since it reflects no light, it appears black.

Astronauts have placed corner reflectors on the Moon. Scientists on Earth then aimed pulses of laser light at these reflectors. By measuring the time it took for the light to return to Earth, the scientists determined the distance to the Moon's surface to within a few centimetres!

Using Reflections

Cars and bicycles have reflectors to make these vehicles visible at night. Figure 3.24 shows a reflector in which hundreds of tiny, flat reflecting surfaces are arranged at 90° to one another. These many small surfaces are packed side by side to make the reflector. When light from another vehicle hits the reflector, the light bounces off the many tiny surfaces back toward the source of the light. The driver in the other vehicle sees the reflection and realizes that something is ahead.

Figure 3.24 A bicycle reflector

Pool players can use the law of reflection to improve their game. Like a light ray, a pool ball travels in a straight line until it strikes something. In a "bank shot," the white cue ball bounces off a cushion before it strikes the target ball. To decide where to aim the cue ball against the cushion, the player chooses a spot that is the same distance behind the cushion as the target ball is in front (see Figure 3.25). This spot is the "image" of the target ball. The player now shoots the cue ball toward the image. Because the ball bounces off the cushion at the same angle at which it strikes the cushion, the cue ball bounces off the cushion and strikes the target ball.

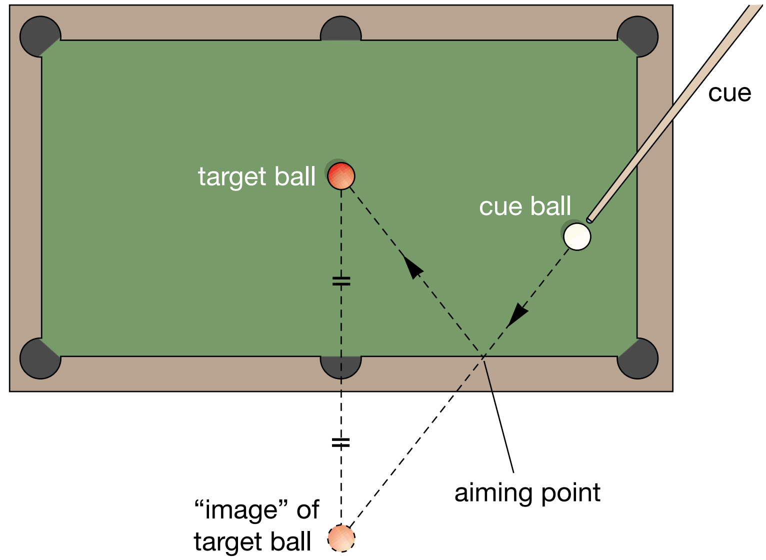
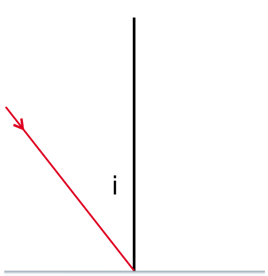


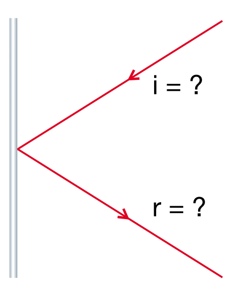
Figure 3.25 You can improve your pool game by applying the law of reflection.

TOPIC 2 Review

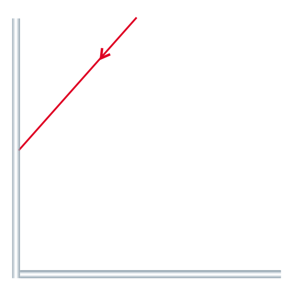
1. Make a simple, accurate drawing in which you show and label: an incident ray, a reflected ray, the normal, the angle of incidence, and the angle of reflection. Write a definition for each term.
2. State the law of reflection.
3. When you see the reflection of the tip of your nose in a plane mirror, from where do the reflected rays of light appear to be coming? If you move twice as far away from the mirror, what happens to the position of the image of your nose?
4. In your notebook, trace each ray diagram below. Make the measurements and draw the missing parts.



r = ?
Draw the reflected ray.



Draw the normal.



Draw the two reflected rays. Compare the directions of the light striking and bouncing off the mirror.

TOPIC 3 Refraction

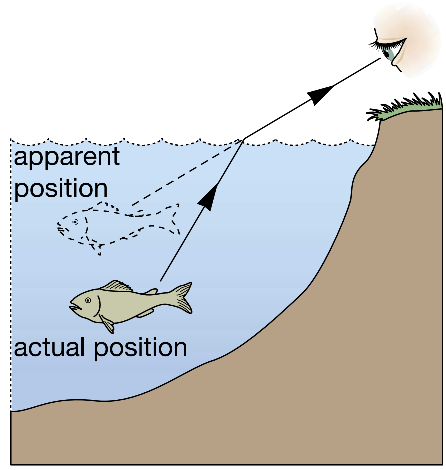


Figure 3.26 The bending of light can make it difficult to see where an object is located in the water.

You know that reflection occurs when light rays bounce off objects, and you can now accurately predict the direction in which reflected light rays travel by using the law of reflection. You can also predict where an image will be located in a plane mirror.

What happens when light moves from air into a medium such as water? If you have ever stood on the side of a pool and tried to dive for an object on the bottom, you may have been surprised that the object was not where you expected it to be. **Refraction** is the bending of light when it travels from one medium to another. Light bends because it changes speed when it moves between materials that have different densities. Light usually travels more slowly in comparatively dense material. The bending of light makes the object's image appear to be in a different position from where the object really is (see Figure 3.26). Explore refraction in the next two investigations.

DidYouKnow?

In air, light travels at 300 000 km/s. It slows down to 200 000 km/s in glass and 165 000 km/s in diamond.

The Re-appearing Coin

Find Out ACTIVITY

How does bending of light rays affect the apparent location of an object?

Materials

cup or bowl with opaque sides

water

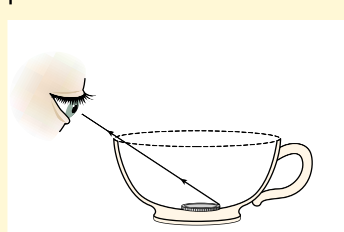
coin

Procedure ✷ Communication and Teamwork

1. Work with a partner. Place the coin in the middle of the empty cup or bowl. Look down on the coin with one eye. Then lower your head until the edge of the cup blocks your view of the coin. Do not move your head.
2. Your partner now slowly pours water into the cup until you can see the coin again. If the coin moves because of the flow of water, start again. Use a pencil to temporarily hold the coin in place.
3. Wipe up any spills and wash your hands after this activity.

What Did You Find Out? ✷ Analyzing and Interpreting

When water was poured into the cup, you could see the coin, even though the straight-line path of the light was blocked by the cup. Copy the diagram below. Indicate the water line and draw rays to show the light's path. What happened to the rays of light when light passed from air to water?



INQUIRY

INVESTIGATION 3-C

When Light Refracts

Observe how refraction affects light travelling through different materials.

Question

What happens to light when it travels from one medium into another?

Apparatus

clear plastic cup, three quarters full of water

wooden pencil

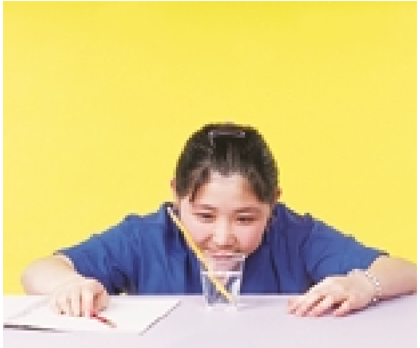
ruler

pencil (for drawing)

Materials

water

paper



Procedure

1. Lay the pencil on the desk so that the middle of the pencil touches the back edge of the cup. **Observe** the pencil through the front of the cup. Draw what you see.

2. Lean the pencil, pointed end down, in the cup of water. Lower your eyes so that they are level with the surface of the water. When you look at the pencil from the side, **observe** what seems to happen to it at the surface of the water. Draw what you see.

3. Look straight down along the pencil that is standing in the water. **Observe** what seems to happen to the pencil at the surface between the water and the air. Move your head slightly to the side. Draw the pencil as it appears to you. Wipe up any spills after this investigation.

Analyze

1. In step 1, through what medium did light from the ends of the pencil travel before reaching your eyes? Through what medium did light from the middle of the pencil have to travel? Did this light travel in a straight line all the way? How do you know?

2. In steps 2 and 3, through what medium does the light from the bottom part of the pencil travel before reaching your eyes? Did this light travel in a straight line all the way? What happens to the path of the light when it moves from the water to the air?

Conclude and Apply

3. Through how many different media does light travel during refraction in this activity?

4. What can happen to the path of light during refraction? What can happen to the image you see, compared with the real object?

INQUIRY

INVESTIGATION 3-D

SKILLCHECK

- Initiating and Planning
- Performing and Recording
- Analyzing and Interpreting
- Communication and Teamwork

Follow That Refracted Ray!

Your class will work in groups to design an investigation to study the behaviour of light as it passes through different materials. When you examined the path of light rays that reflected off a plane mirror, you discovered a pattern. The angle of reflection always equals the angle of incidence. Understanding this pattern helps you predict how light reflects off a flat surface. Does refracted light behave according to a consistent pattern as well?

Question

Is there a pattern that describes the path of light during refraction?

Hypothesis

With your group, agree upon a hypothesis about the effect of different materials on light.

Safety Precautions

Apparatus

ray box (placed on the edge of a sheet of white paper)

transparent plastic, watertight tray (box top from greeting cards, candies, etc.)

ruler and protractor

Materials

sheet of blank white paper (letter size)

water

liquid other than water (vegetable oil, liquid soap, etc.)

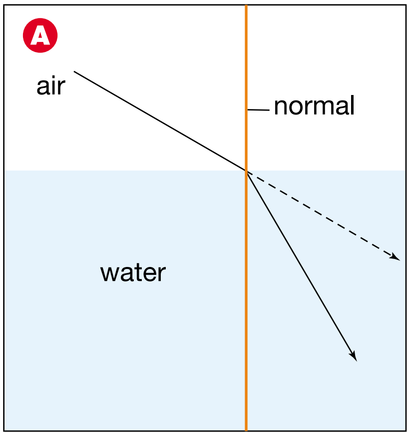
Skill FOCUS

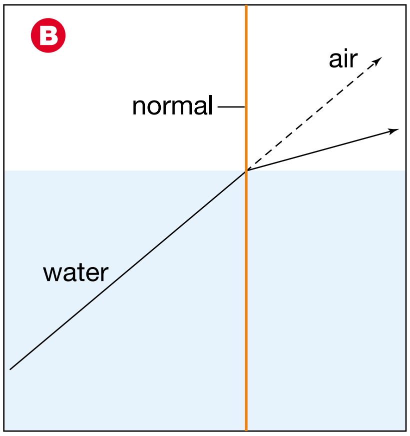
For tips on designing your own experiment, turn to Skill Focus 6.

Procedure

1. With your group, **design a procedure** that will allow you to **observe** and then trace the paths of light rays entering and leaving a transparent, watertight tray.
2. Write a brief description of the procedure you plan to follow. Have your teacher approve your procedure.
3. After conducting your investigation, prepare actual-size diagrams on which you can **record your observations**.

4. Each of your diagrams should show the following:
   - **(a)** the path of a light ray going from the air, through the empty tray, and back into the air through the opposite side of the tray, for at least two different angles of incidence
   - **(b)** the path of the same incident rays when there is water in the tray
   - **(c)** the path of light that travels through one corner of the tray, through the water, and out the adjacent side of the tray back into the air
   - **(d)** the paths of light travelling through some liquid other than water for the same incident rays you used in (a) and (b)
5. If necessary, you can refer to the diagrams on this page as a guide.
6. Wipe up any spills as wet floors are slippery.
7. Wash your hands after this investigation.





Analyze

1. What were the manipulated and responding variables in this investigation? What was your controlled variable?
2. On your diagrams, draw the normal at each point where a light ray travels from one medium into another.
3. **Measure** and **record** the size of each angle on your diagrams. Record the angles using the symbols i and r.

Conclude and Apply

4. Does light bend toward or away from the normal when it travels from air into another medium such as water? Did your results support your hypothesis? Did other groups get similar results using their procedures?
5. What happens to the size of the angle at which the light bends when the angle of incidence increases?
6. What happens to the size of the angle at which the light bends when a liquid other than water is used and the angle of incidence is the same?
7. Does light move toward or away from the normal when it travels from a medium such as water into air?
8. Is there an angle of incidence for which there is no change in the direction of the light? Draw a diagram for this situation for light travelling through a rectangular shape.
9. Write a statement that answers the question on page 202.

Around a Bend with Light

When light travels from one medium into a denser one — for example, when it moves from air into water — it will bend *toward* the normal. When light exits a denser medium, its direction of travel bends *away from* the normal. How much bending occurs depends on the type of material through which the light travels. The new direction of the light is called the **angle of refraction**, *R* (see Figure 3.27). When the angle of incidence, *i*, increases, the angle of refraction, *R*, also increases. However, doubling the angle of incidence does not mean that the angle of refraction also doubles.

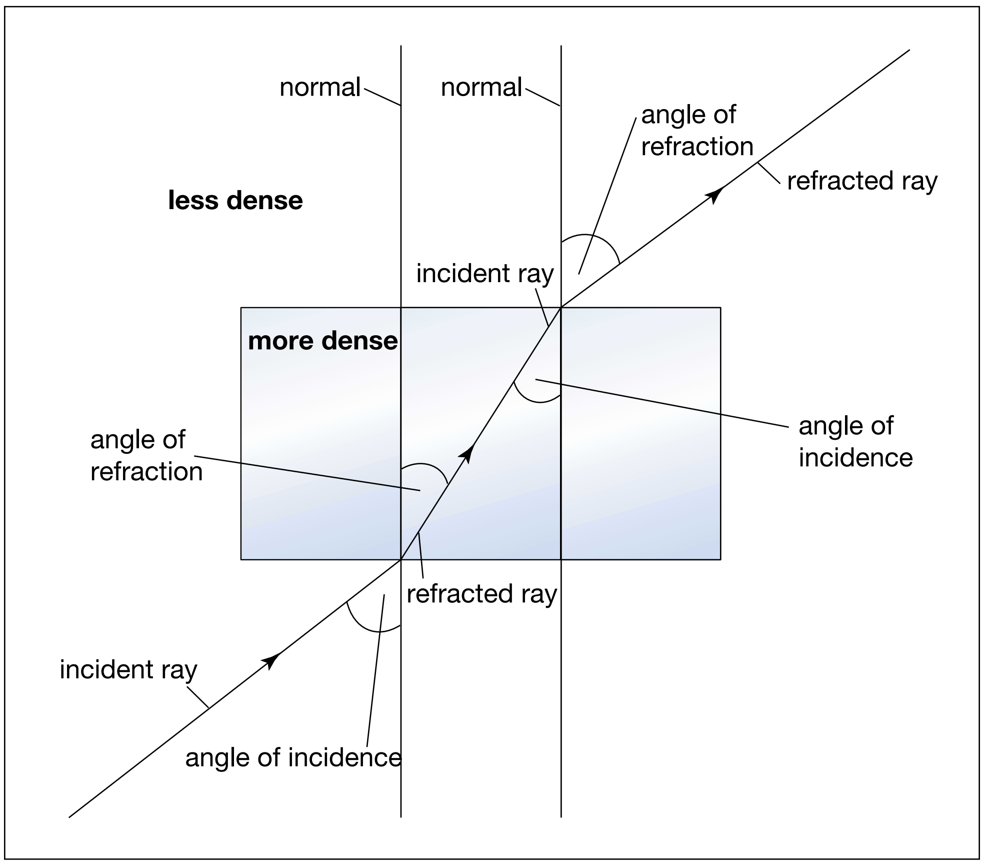


Figure 3.27 Light is refracted as it passes through one medium into a denser medium.

Refraction can also occur when light travels through air at different temperatures. Warm air is less dense than cold air. Light bends as it travels through different densities of air. The refraction of light through air can result in a mirage. Have you ever been driving along a highway on a hot summer day and noticed what looked like pools of water lying ahead? However, when you got close to the pools, they mysteriously disappeared. You were seeing a mirage. The air close to the ground is hotter and less dense than air higher up. As a result, light from the sky directed at the ground is bent upward as it enters the less dense air. The "pools of water" were actually images of the sky refracted by warm air near the ground (see Figure 3.28).

Figure 3.28 Refracted light is responsible for creating mirages. When air near the ground warms up, the light from objects at a distance is refracted into a curved path. This causes the illusion of a water surface, which is really an image of the sky refracted by warm air near the ground.

Is That All There Is to Light?

Table 3.1 summarizes what happens to light when it strikes different surfaces. Sometimes all three light behaviours happen at once. Light from the Sun can reflect off the still surface of a lake to produce a mirrorlike reflection. At the same time, the water can absorb light, transforming the light energy into thermal energy. The water warms during the day and cools off at night. If you are looking down into the water from shore, you might be uncertain about the location of objects on the bottom. This happens because light is refracted as it travels from water into the air.

Table 3.1 What Happens When Light Strikes a Surface?

Type of behaviour	What happens to light striking a surface?	Nature of surface	What else happens?
Absorption	Changes into some other kind of energy.	Occurs mostly on rough, dark, opaque surfaces.	Some light is usually reflected off the surface.
Reflection	Bounces off the surface and travels in a new direction.	Occurs best when light hits a smooth, shiny surface.	Some light is usually absorbed.
Refraction	Travels through the surface, often in a new direction.	Occurs when light strikes a different, transparent medium.	Some light is usually reflected off the surface.

Ask an Expert

Solar energy can be changed into electrical energy for homes, farms, and recreational vehicles. To meet someone whose company makes solar energy systems, turn to page 258. There, you can read an interview with Judy Kitto, a solar systems designer.

TOPIC 3 Review

1. Distinguish between reflection and refraction.

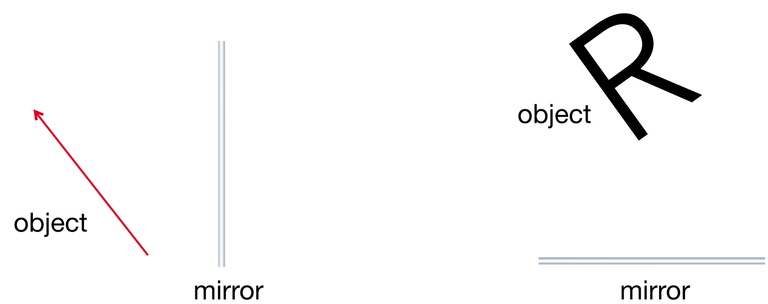
2. Give two specific examples of materials that mostly refract light. Is light also reflected or absorbed by these materials?

3. What happens to light when it is refracted?

4. Using the normal as a reference line, describe the change in direction of a light ray that travels from
   (a) air into glass
   (b) water into air

5. **Apply** A student chops a piece of ice out of a frozen lake and holds its smooth, parallel sides tilted toward the Sun. Show the path of a ray of sunlight through the ice. (Hint: Light travels more slowly in ice than in air.)

6. Use a ruler to trace the following diagrams. Use the law of reflection to locate and draw the image. Measure accurately.



7. **Thinking Critically** What if light behaved differently from what you have learned? Describe the changes you would notice if
   (a) black surfaces and white surfaces reflected the same amount of light (that is, the incident light falling on both surfaces is the same)
   (b) human skin absorbed all the visible light that struck it
   (c) instead of travelling at 300 000 km/s in air, light travelled only at the speed of a car on a highway, about 0.03 km/s

8. **Design Your Own** Make a hypothesis about how various liquids will refract light. Design an investigation to test your hypothesis. What will your manipulated variables be? What will your responding variable be? What will your controlled variable be? (If you need help designing your experiment, turn to Skill Focus 6.) Carry out your investigation (with your teacher's approval). Describe the angle of refraction for each liquid.

9. **Thinking Critically** Formulate your own question about the behaviour of light and explore possible answers and solutions.

Wrap-up TOPICS 1-3

If you need to check an item, Topic numbers are provided in brackets below.

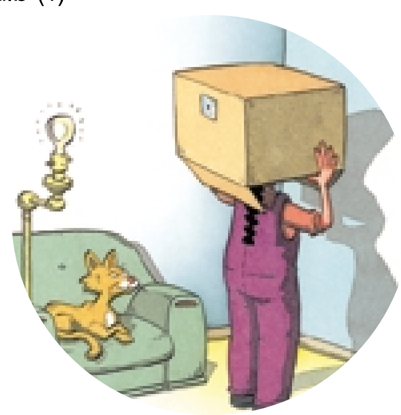
Key Terms

image	incandescence	translucent	angle of incidence
light	fluorescence	opaque	angle of reflection
natural light source	phosphorescence	luminous	plane mirror
radiates	chemiluminescence	non-luminous	law of reflection
radiation	bioluminescence	reflection	plane
radiant energy	ray	incident ray	refraction
artificial light source	ray diagram	reflected ray	angle of refraction
incandescent source	transparent	normal	

Reviewing Key Terms

1. In your notebook, match the description in column A with the correct term in column B.

A	B
• the bending of light as it passes from one medium to another	• incandescent bulb (1)
• can be transformed into chemical energy, electrical energy, or thermal energy	• light (1)
• allowing no light to pass through	• image (1)
• an artificial light source	• refraction (3)
• a type of diagram explaining how light travels	• plane (2)
• occurs when light bounces off a surface	• ray diagram (1)
• describes objects that produce their own light	• opaque (1)
	• luminous (2)
	• reflection (2)



Understanding Key Concepts

2. What are some things you could say or do to convince a younger sibling that light is a form of energy that travels in straight lines? (1)

3. Name the sources of light that you have learned about in these Topics, and give an example of each. (1)

4. Make a drawing to show how a plane mirror produces an image that is the same size as the reflected object. (2)

5. State the law of reflection. Draw a simple diagram that shows this law. (2)

6. Describe a situation in which each of the following could occur:

(a) Almost all of the light energy that strikes a surface is absorbed. (1)

(b) Very little light is absorbed by the surface. Most of the light energy is reflected to produce images. (2)

7. Explain what causes refraction of light rays. (3)

8. Give some factors that can affect the angle of refraction of a light ray. (3)

TOPIC 4

Lenses and Vision

Types of Lenses

Knowing how light rays bend when going from air into a more dense medium can help you understand how lenses affect light rays. A **lens** is a curved piece of transparent material, such as glass or plastic. Light refracts as it passes through a lens, causing the rays to bend.

A double **concave lens** is thinner and flatter in the middle than around the edges (see Figure 3.29). Light passing through the thicker, more curved areas of the lens will bend more than light passing through flatter areas. This causes rays of light to spread out, or diverge, after passing through the lens.

A double **convex lens**, also shown in Figure 3.29, is thicker in the middle than around the edges. This causes the refracting light rays to come together, or converge.

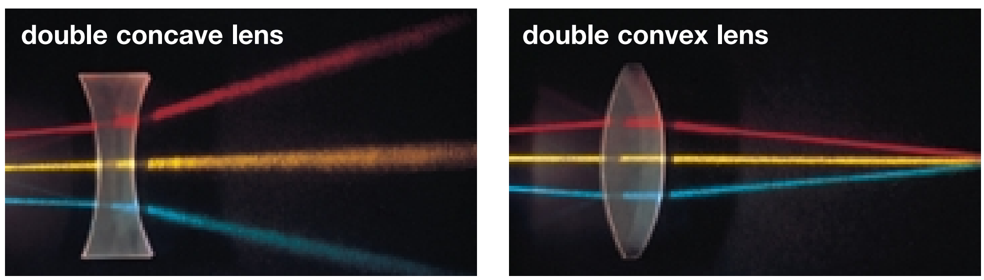


Figure 3.29 Light refracts when it travels through lenses. The double concave lens on the left causes light rays to spread out. The double convex lens on the right brings light rays close together.

Find Out ACTIVITY

See for Yourself!

Using simple materials, you can observe how concave and convex lenses work.

Materials

flashlight
comb
concave lens
convex lens
piece of plastic wrap (5 cm x 5 cm)
water

Procedure — Performing and Recording

1. In a dark room, shine the flashlight through the teeth of the comb. **Observe** the shadows of the teeth on a table.
2. Now place a concave lens just beyond the comb and repeat step 1. What difference in the shadows do you **observe**? **Record** your observations.
3. Replace the concave lens with a convex lens and repeat step 1. **Observe** any differences in the shadows.
4. Place a single drop of water on the piece of plastic wrap and hold the wrap over some words in your textbook. The water drop forms a simple convex lens. **Observe** whether the appearance of the words changes.

What Did You Find Out? — Analyzing and Interpreting

1. Based on your observations, predict what kind of lens is used to make a magnifying glass.
2. **Apply** List some possible uses for (a) a concave lens and a light beam, and (b) a convex lens and a light beam.

Lenses and Images

Lenses are probably the most useful and important of all optical devices. Eyeglasses, for example, were made from lenses as early as the thirteenth century.

An image forms where light rays from an object converge. The light rays spread out from points on the object. A convex lens refracts these rays so that they come back together (see Figure 3.30).

However, the lens directs light from the left portion of the object to the right portion of the image. Similarly, light from the top of the object is directed to the bottom of the image (see Figure 3.31). Thus, an image formed by a double convex lens is sometimes inverted rather than upright. Both film projectors and overhead projectors use a double convex lens to create images. Since you see upright images on the screen, how must the images on the film be placed in the projector?

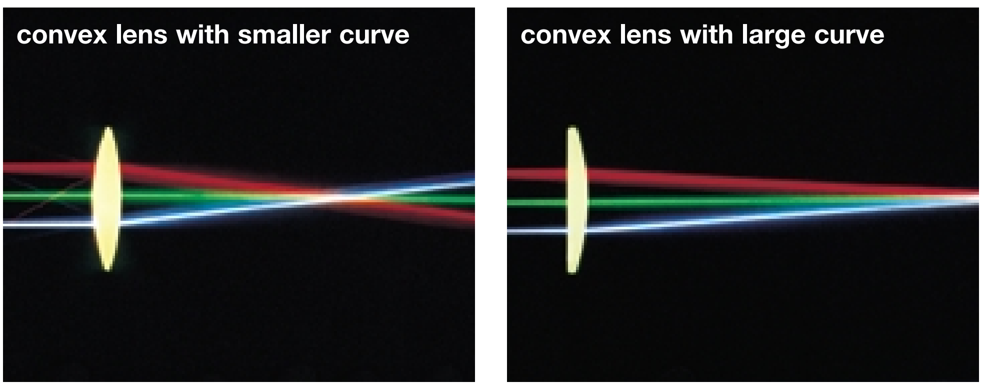


Figure 3.30 A convex lens causes parallel rays to converge. Why do the rays from the lens on the right converge farther from the lens compared to the rays on the left?

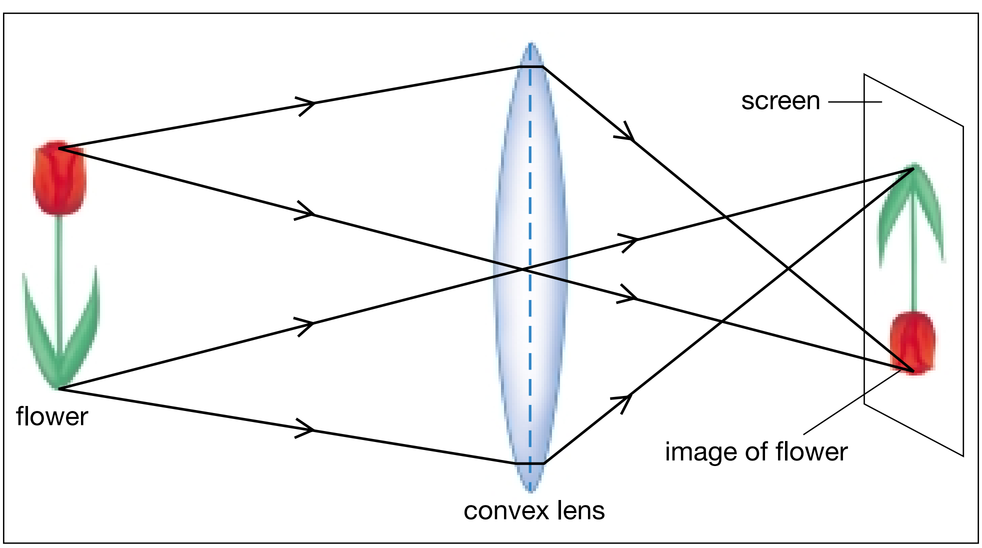


Figure 3.31 Images formed by a convex lens are inverted, or upside down.

Eye Spy

The lens in the human eye is a convex lens. This lens takes light rays from objects and, by refraction, **focusses** them, or brings them back to a point. This focussing of light rays allows us to see objects. In a normal eye, light refracts through the lens onto a light-sensitive area at the back of the eye called the **retina**. The image you see is formed on the retina (see Figure 3.32A).

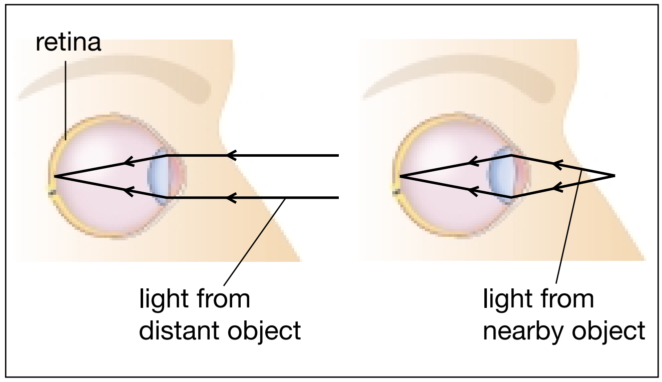


Figure 3.32A These diagrams show how the lens in a normal human eye focusses light rays onto the retina.

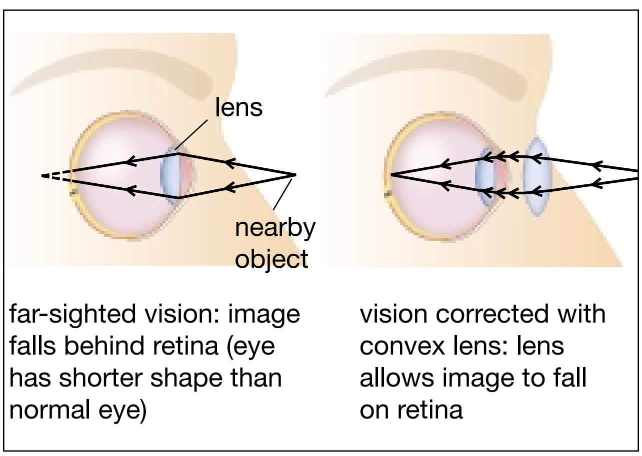


Figure 3.32B How a convex lens in eyeglasses corrects far-sightedness

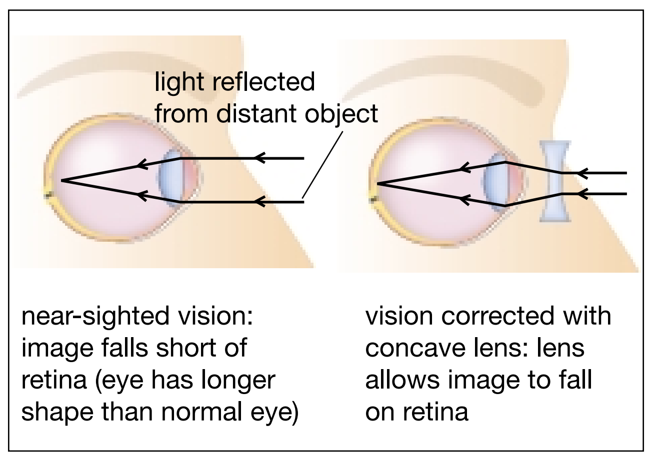


Figure 3.32C How a concave lens in eyeglasses corrects near-sightedness

Some people, however, have eyes that are too long. As a result, the image forms *in front of* the retina (see Figure 3.32C). These people are **near-sighted** — they have trouble seeing distant objects. Other people have eyes that are too short. Consequently the image has not formed by the time the light reaches the retina. These people are **far-sighted** — they have trouble seeing objects that are close to them.

Knowledge of how light behaves when it travels through lenses helps eye specialists to correct vision problems. As Figure 3.32B shows, a convex lens placed in front of a far-sighted eye helps bend the light rays so that the image appears on the retina. As Figure 3.32C shows, a concave lens placed in front of a near-sighted eye moves the image back so that, again, it forms on the retina.

Comparing the Eye and the Camera

There are many similarities between the human eye and the camera (see Figure 3.33). You already know that you see objects when light from an object focusses on your retina. In a camera, the lens refracts the light and the film senses the light. Explore how a camera works in the next investigation. Then read the pages that follow for a more detailed comparison of the eye and the camera.

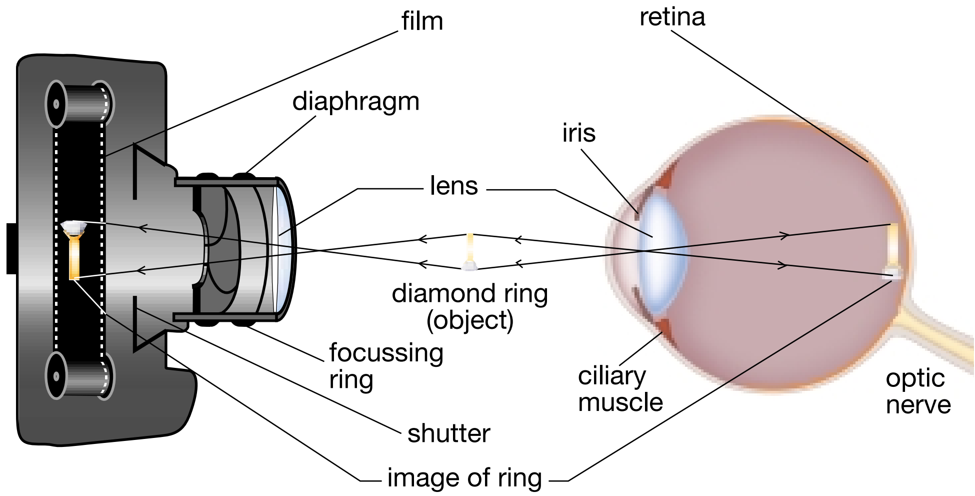


Figure 3.33A A comparison of the camera and the human eye. Study this diagram and try to infer the function of each part of the camera and the eye.

Figure 3.33B By focussing the camera, you can see what the camera "sees" so that the image you take will be crisp and clear.

Word CONNECT

The word "optics" has not been defined in this unit, even though nearly everything you have learned so far has been related to optics. Think about what you have been learning. Then write a definition for optics.

INQUIRY

INVESTIGATION 3-E

SKILLCHECK

Initiating and Planning

Performing and Recording

Analyzing and Interpreting

Communication and Teamwork

The Camera

A basic camera is a rather simple device. To make a camera, all you need is a convex lens, film, a box to keep the light out, and a shutter to let the light in when you wish. Why, then, are photos sometimes too dark or out of focus? To find out why, you will examine two processes in this investigation:

1. what happens when you focus a camera
2. how to adjust the brightness of the photograph

Question

How are the brightness and the sharpness of the image in a camera controlled?

Prediction

If a camera is focussed on an object and the object moves, must the lens move to keep the image in focus? Predict what you think will happen, and test your prediction.

Safety Precautions

- Exercise extreme caution when dealing with open flames.
- Keep skin, clothing, and hair well away from the flames. Tie back long hair.
- If a fire does start, dowse it with water or smother it with a coat or fire blanket. Alert your teacher immediately.
- Be careful when using sharp objects such as scissors.

Apparatus

convex lens

candle and matches

dish large enough for the candle to sit on

mathematical compass

book

scissors

metre-stick

Materials

masking tape

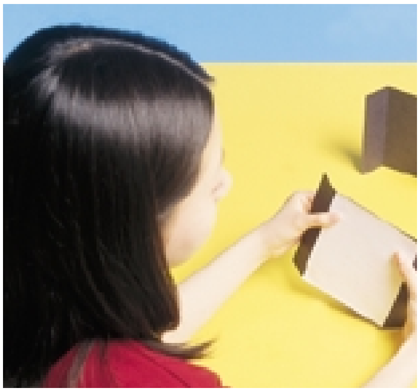
3 pieces of black Bristol board (about 20 cm × 15 cm)

piece of white paper (about 15 cm × 13 cm)

Procedure

Part 1

Getting Ready



1. Fold two pieces of black Bristol board as shown, to make two optics stands. Cover the front of one of the stands with white paper to make a screen. In this investigation, the white paper will represent the film in the camera.

2. Draw a circle 10 cm from the bottom of the second stand. The circle should be slightly smaller than the diameter of the convex lens. Cut out the circle. Tape the lens securely over the back of the hole. Make sure that the tape covers just the edge of the lens. This lens will represent the camera lens.

3 Take the third piece of Bristol board and mark a point about 6 cm from the top of the piece and midway between the sides. Using that mark as the centre, draw a circle with a diameter of 1 cm. Cut out the circle.

(a) Cut out a second circle with a diameter of 2 cm about 6 cm from the bottom of the Bristol board, just below the first circle.

(b) In your notebook, **make a table** with three columns. The headings for the columns should be “Object distance (cm),” “Image distance (cm),” and “Image size.” Give your table a suitable title.

(c) Your teacher will light the candle, drip some wax onto the dish, and set the candle upright in the melted wax, holding it there until the wax has solidified.

Part 2

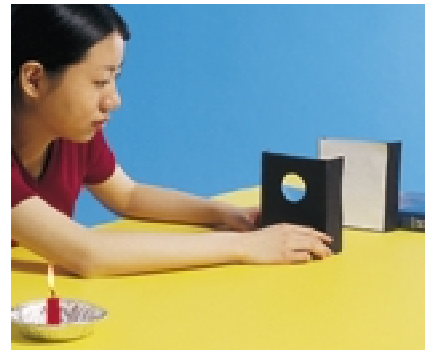
Setting Up the Camera

When you take a photograph, you usually hold the back of the camera firmly against your face. Because the film is found just inside the back of the camera, the film is also held firmly in place.

1 Place the book near one edge of the table. It will represent your face. Then place the screen against the book. The black Bristol board represents the back of the camera. The white paper represents the film. Do not move the screen during this investigation.

Skill FOCUS

For tips on making tables, turn to Skill Focus 10.



2 Your teacher will place the lighted candle 1 m from the screen. The candle flame will be the object upon which the camera is being focussed.

Now place the lens (of the camera) between the candle and the white film. Darken the room. Move the lens back and forth until you see a sharp image on the “film.”

(a) **Measure** the distance from the lens to the object (object distance). Then measure the distance from the lens to the film (image distance). **Record** these values in your table. Also **record** how the size of the image compares to the size of the object. Note whether it is larger, smaller, or the same size.

(b) Repeat steps 2 and 2(a), but move the candle 10 cm closer to the film. **Record** your observations.

(c) Continue moving the candle closer to the film, 10 cm at a time, until it is impossible to form a sharp image on the film.

CONTINUED

Computer CONNECT

Enter the data from Inquiry Investigation 3-E into a spreadsheet. Make a graph of the data using a graphing program.

Math CONNECT

In Inquiry Investigation 3-E, you changed the brightness of the image using two openings. Light comes in through the area of the opening. Try calculating the area of each opening. Then divide the larger area by the smaller area. According to your calculations, how should the brightness of the images compare?

3. Move the candle back to a distance of 1 m from the film. Move the lens until you have focussed a sharp image on the film. Place the 2 cm hole in front of the lens and **observe** the brightness of the image.
   - **(a)** Now place the 1 cm hole in front of the lens. **Record** how the brightness changes.
   - **(b)** **Record** whether you see all or only part of the image.

Analyze

1. Make a line graph of your observations. Place the object distance on the horizontal axis (x-axis) and the image distance on the vertical axis (y-axis). Choose a suitable title for your graph. On your graph, mark the following:
   - **(a)** the region in which the image is smaller than the object
   - **(b)** the region in which the image is larger than the object
   - **(c)** the point where the object and image are closest to being the same size

Conclude and Apply

2. As the object moves toward the "camera," which way must the lens move to keep the image focussed on the film?
3. What happens to the image distance as the object distance decreases?
4. How do the distances compare when the object and the image are the same size?
5. What happens to the brightness of the image when you reduce the diameter of the opening into the camera by half? Do you see less of the image?

Cool Tools

Many cameras today are digital. Instead of using film, these cameras store the image as a series of electrical charges across a silicon chip. The brighter the image at a point, the greater the electrical charge. This charge is then measured, and the value is converted into a binary number. (In the binary system, information is expressed by combinations of the digits 0 and 1.) Using binary numbers is the basis of all digital technology. Do some library research or use the Internet to find out some ways in which a digital camera can be superior to a regular camera.

Putting It in Focus

In a camera, if an object moves closer to the film, the lens must move farther from the film to keep the image in focus. This is what you do when you focus the camera. In the human eye, you cannot move the lens farther away from the retina. Instead, the ciliary muscles change the shape of the lens. (Refer back to Figure 3.32 on page 210.) If the object you are looking at comes closer to you, these muscles make the lens bulge in the middle. This keeps the object in focus on the retina without having to stretch the eyeball.

The process of changing the shape of the lens to adjust for different object distances is called **accommodation**. As people become older, the lens stiffens and loses its ability to change shape. It can no longer become thick enough to focus on close objects. As a result, many people wear convex lenses as reading glasses.

The shortest distance at which an object is in focus is called the **near point** of the eye. The longest distance is the **far point** of the eye. For the average adult human eye, the near point is about 25 cm away (see Figure 3.34A). However, babies can focus on objects only about 7 cm away (see Figure 3.34B). The far point is said to be infinity. After all, a person with normal vision can see the stars and they can be many thousands of light years away.

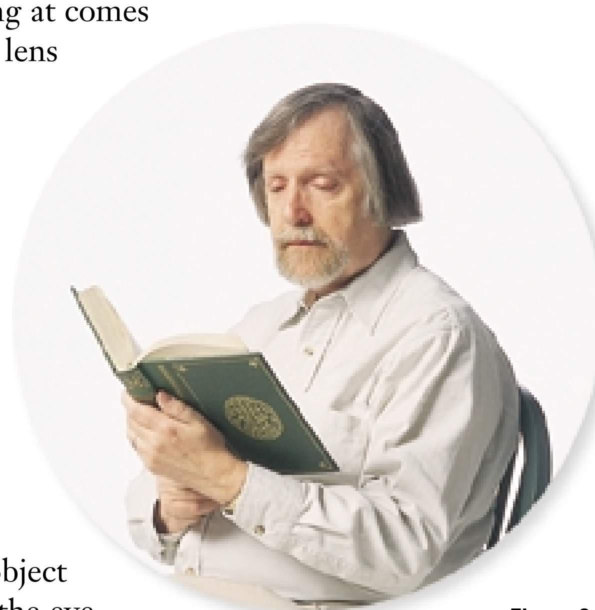


Figure 3.34A Most adults can focus on objects that are about 25 cm away.

Figure 3.34B Most babies can focus easily on objects that are very close.

Bringing in the Light

If you are photographing a scene and a cloud suddenly covers the Sun, the brightness of the scene decreases. As a result, the amount of light reaching the film decreases. If the light is too dim, the film will not receive enough light to record the image clearly. In this case, the camera's diaphragm and shutter can be adjusted to allow the correct amount of light to reach the film. The **diaphragm** is a device that controls the **aperture** (the opening) of a lens or optical system. The **shutter** is a device that limits the passage of light. The aperture in the diaphragm can let more light into the camera by being opened wider, as shown in Figure 3.35. The shutter can let in more light by staying open longer.

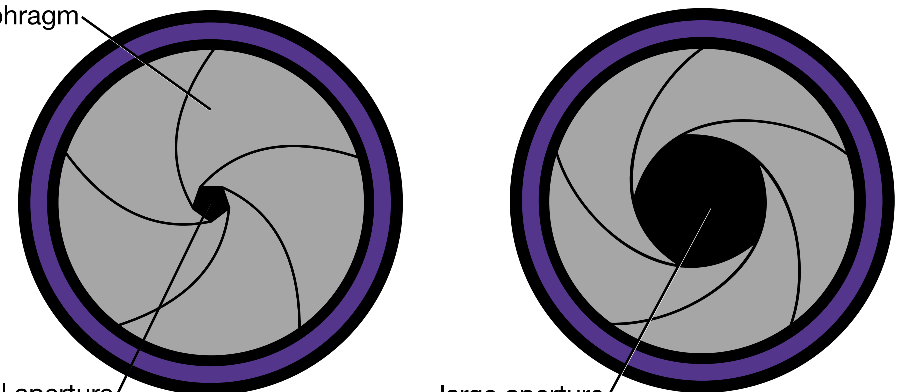


Figure 3.35 The diaphragm controls the amount of light that enters a camera. The opening in the diaphragm is called the aperture.

In the human eye, the **iris**, which is the coloured ring, functions like the diaphragm of a camera (see Figure 3.36). If the light is dim, the iris increases the size of the eye's opening to let in more light. This opening is called the **pupil**, which appears as the dark centre of your eye.

Did You Know?

Frogs' eyes are eight times more sensitive to light than human eyes.

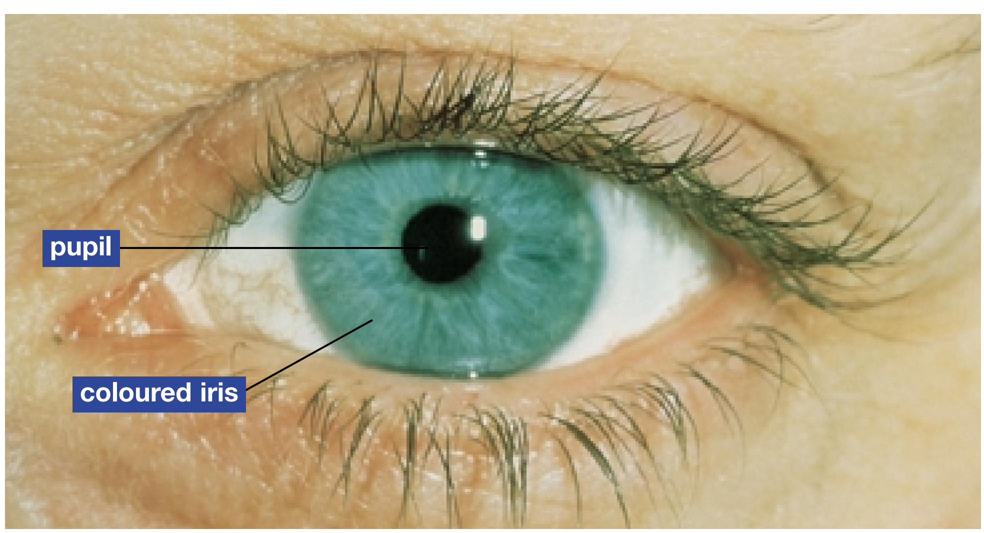
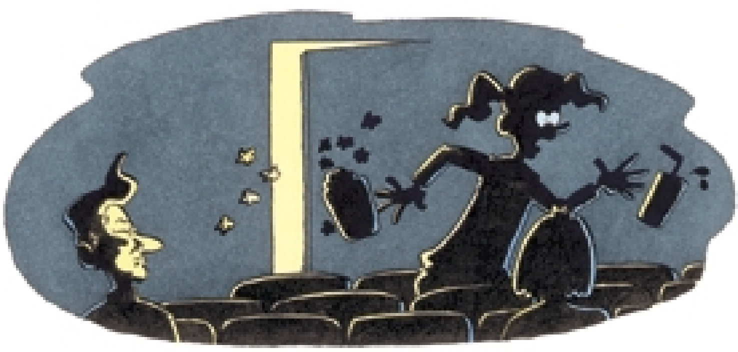


Figure 3.36 The iris controls how much light enters the human eye.

The natural adjustment in the size of the pupils is called the **iris reflex**. You are generally unaware of this reflex, which is extremely rapid. What happens when you first walk into a dark movie theatre on a bright, sunny day? You are probably unable to see anything at first. The split-second iris reflex is the first in a series of adjustments the eye makes to enable you to see the interior of the theatre.

When you leave the theatre and walk into bright sunlight, the opposite reaction occurs. The daylight glare makes your eyes feel uncomfortable. However, the iris reflex quickly shrinks the size of the pupils, less light enters the eyes, and other adjustments take place so that your eyes feel comfortable again.



Looking Ahead

Have you ever wondered why some people's skin gets sunburned more quickly than others? For many people, using a sunscreen with a high SPF is a necessity. Do some research and find out why people's skin reacts differently to ultraviolet light. Include this information in your "Experiment Planning File" for the end-of-unit investigation. Once you've completed the *Design Your Own Investigation Testing SPF*, make a recommendation for sunscreen use for different skin types.

Seeing the Image

At the back of the camera, you will find the film. The image is focussed onto this light-sensitive material. The light energy causes chemical changes in the film to record the image.

In the human eye, the retina senses the light. When the cells in the retina detect light, they produce small electrical impulses that travel from the retina to the brain through the **optic nerve**. The point where the optic nerve enters the retina does not have any light-sensing cells. This point is known as the **blind spot.** You can easily demonstrate the presence of your blind spot by following the steps outlined in Figure 3.37. Note that each eye sees what the other misses because the blind spots are not in the same place.

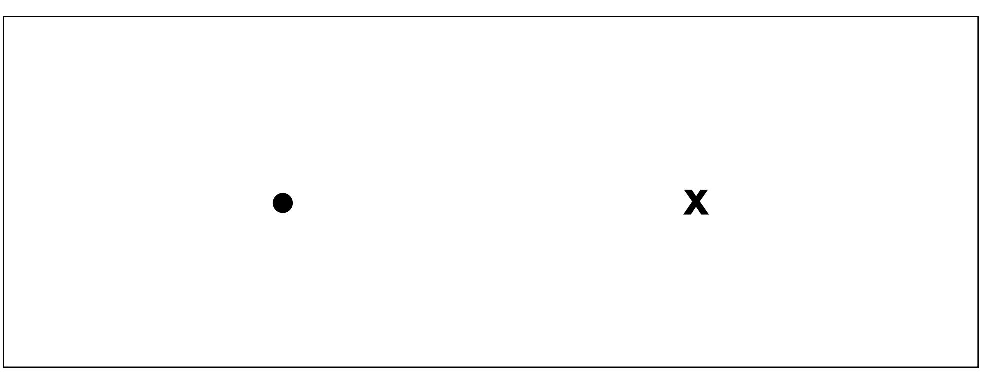


Figure 3.37 Locating your blind spot. Hold this book at arm's length. Cover your right eye with your hand. Stare at the X while you move the book slowly toward yourself. The dot should disappear and then reappear as its image moves onto your blind spot and then off again.

The parts of a camera are contained in a rigid, lightproof box (see Figure 3.38). In the eyes, layers of tissue hold the different parts together. In order to keep the eye from collapsing, the eyeball is filled with fluids called humours (see Figure 3.39). In addition to keeping the eye rigid, humours help refract the light that enters the eye. The next investigation will reinforce what you have learned about the parts of the eye and the camera.

Figure 3.38 Cameras differ in size and complexity, but the parts of all cameras are housed in a rigid, lightproof box.

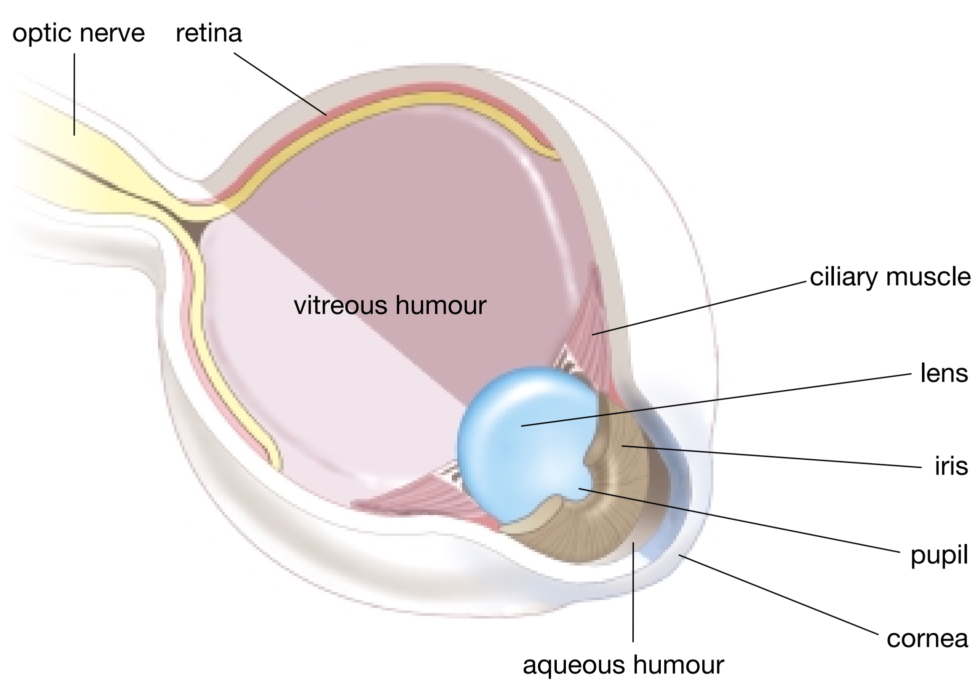


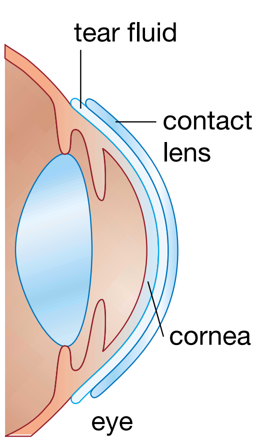
Figure 3.39 The human eye is an almost spherical object that is filled with fluids.

Word CONNECT

It may seem strange that the fluids in the eye are called "humours." However, *humour* is an old word for bodily fluids. At one time it was thought that a person's moods were governed by these fluids. You could be in good humour, out of humour, or in foul humour, and it was all thought to be due to imbalances in these bodily fluids. Explain how you think today's common meaning of humour was derived from these original meanings.

DidYouKnow?

Contact lenses are very thin lenses placed directly on the cornea of the eye. A thin layer of tears between the cornea and the contact lens keeps the lens in place. Most of the refraction occurs at the air-lens surface.



INVESTIGATION 3-F

SKILLCHECK
- Initiating and Planning
- Performing and Recording
- Analyzing and Interpreting
- Communication and Teamwork

What an Eyeful!

Think About It

You have seen how the structure and function of the human eye compare to the structure and function of a camera. It is also interesting to compare a human eye (or the eye of another mammal) to the eyes of other species.

As with all characteristics of living creatures, eyes must meet the organism's needs. For example, humans once needed to be able to hunt or gather food on land. This required eyes that can focus on both close and distant objects. Hunting/gathering also required eyes that are positioned for three-dimensional viewing. It is not surprising that other mammals such as apes share these features.

Insects such as grasshoppers have less need for good distance vision. Instead, they need a type of eye that will allow them to detect nearby motion. Their compound eyes are well designed to do this. Obviously, too, the eyes of aquatic creatures must differ in structure and function from ours.

What to Do

1. Work in groups of three or four. Choose a species that has eyes that are different from your own eye, for example, a frog; a flounder or a salmon; a flatworm; a lobster; a shellfish such as an oyster, clam, or scallop; an insect such as a housefly; a squid or an octopus; a species of your choice.
2. Using library resources or the Internet, research the type of eye that you have chosen.
3. Develop and give a 5 min presentation in class based upon your research. If possible, prepare a multimedia presentation. If you wish, create a model of the eye that you chose to research, and include it in your presentation.

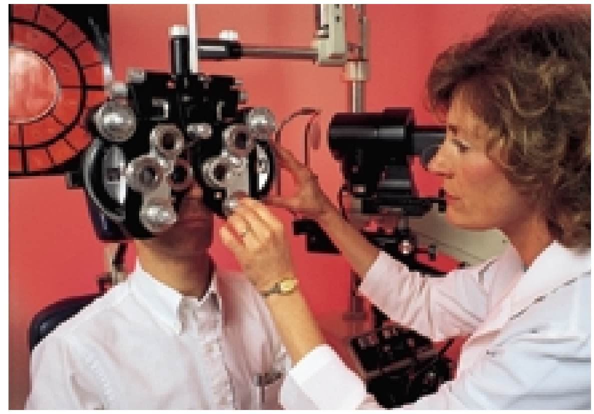
Analyze

Based upon the information provided in the presentations:

1. What features do all of these eyes have in common?
2. Which eye was the most different from your own eye? In what ways did it differ from yours?
3. Describe how the eye structure of a particular species enables that species to live in a particular environment. How do the function and structure of the organism's eyes help it to meet its needs?

Career CONNECT

An Eye on Education



If you are having trouble with your vision, you visit an optometrist. This is a specialist trained to examine patients' eyes for defects and then prescribe lenses or exercises to correct the problem. How might you become an optometrist?

First, you would need to complete two or three years of university courses in many different sciences. After completing these courses, you would apply to one of the two schools of optometry in Canada, at either the University of Waterloo or l'Université de Montréal. If accepted, you would spend the next four years learning about the physics of light and lenses and the anatomy of the human eye. You would learn how to set up your own practice and spend time dealing with patients in clinics. If you studied hard, after four years, you could be one of the 100 optometrists in all of Canada to graduate each year. You must then pass a provincial examination before getting your optometrist's licence and opening an office.

Six or seven years of preparing for a career might seem like a long time. However, these years of study would lead to a very rewarding career. Deciding what amount of education is ideal for you is an important step in choosing a career path. Would you like to enter the work force right after high school? Are you interested in receiving a one-, two-, or three-year college diploma, or a three- or four-year university degree? Do you plan to invest more than four years in education and training for a career? Do some research to identify careers that require the amount of education you think is right for you.

TOPIC 4 Review

1. As an object comes closer to a convex lens, what happens to
   (a) the size of the image?
   (b) the attitude of the image?
   (c) the location of the image?
2. Draw a diagram to show what happens when light passes through
   (a) a concave lens (b) a convex lens
3. Make labelled drawings to show how the lens in a pair of eyeglasses can be used to correct
   (a) far-sightedness (b) near-sightedness
4. State which part of the human eye corresponds to each of the following parts of a camera, and explain why:
   (a) the film
   (b) the diaphragm
   (c) the aperture
   (d) the lens
5. Make labelled drawings to show differences in the structure and function of the eye of a mammal compared to the eye of a completely different species. Are there any similarities in the structure and function of the two types of eyes? If so, describe them.
6. **Thinking Critically** In Topic 4, you have seen a number of ways in which the camera and the eye are similar. Describe three ways in which the camera and the eye are dissimilar.

INTERNET CONNECT

www.school.mcgrawhill.ca/resources/

Would you like to learn more about careers involving light-based technologies? Visit the above web site. Go to **Science Resources**, then to **SCIENCEFOCUS 8** to find out where to go next. Choose one that interests you and find out how to follow that career path.

TOPIC 5 Extending Human Vision

Human knowledge about our planet and the universe was very limited until we developed tools to extend our vision. We now have the ability to peer into the tiny world of micro-organisms and out into the vast reaches of outer space. The tools we use for these inquiries seem quite different from each other, but they are based on the same understandings of light, mirrors, and lenses.

Did You Know?

The first telescope may have been invented by Hans Lippershey, a Dutch optician. In 1608, Lippershey was testing some lenses and discovered their magnifying power by accident. The following year, the Italian scientist Galileo Galilei developed a telescope that could see mountains on the Moon, sunspots, stars in the Milky Way, and moons around Jupiter.

Telescopes

Telescopes like the one shown in Figure 3.40 help us see distant objects more clearly. In a **refracting telescope**, light from a distant object is collected and focussed by a convex lens called the **objective lens**. A second lens, called the **eyepiece lens**, works as a magnifying glass to enlarge the image (see Figure 3.41A). A **reflecting telescope** uses a concave mirror to collect rays of light from a distant object. The mirror is called the primary or **objective mirror**. It forms a real image, which is then magnified by the eyepiece lens (see Figure 3.41B on the next page).

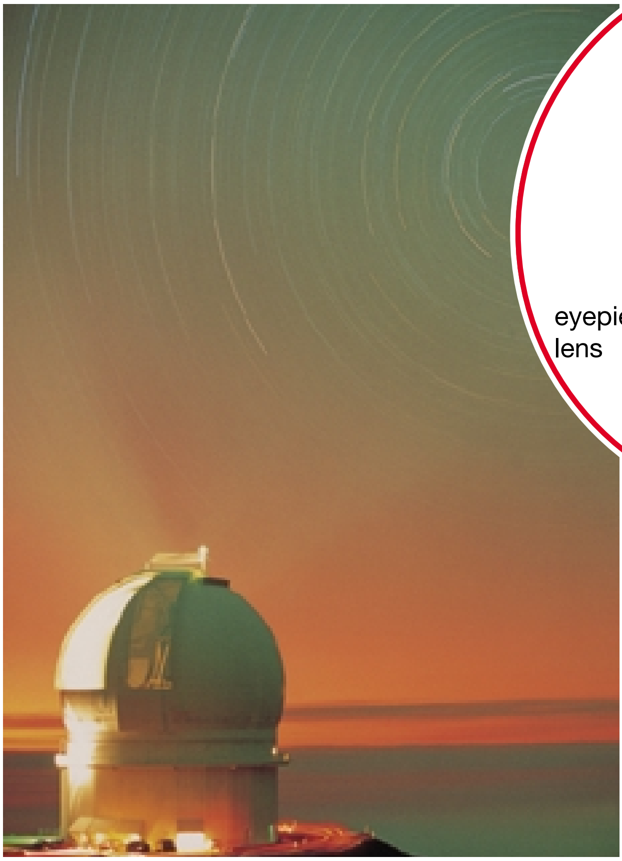


Figure 3.40 The Canada France Hawaii Telescope (CFHT) is located near the summit of Mauna Kea, an extinct volcano in Hawaii. It uses a concave mirror that measures 3.6 m in diameter. What does a concave mirror do to light?

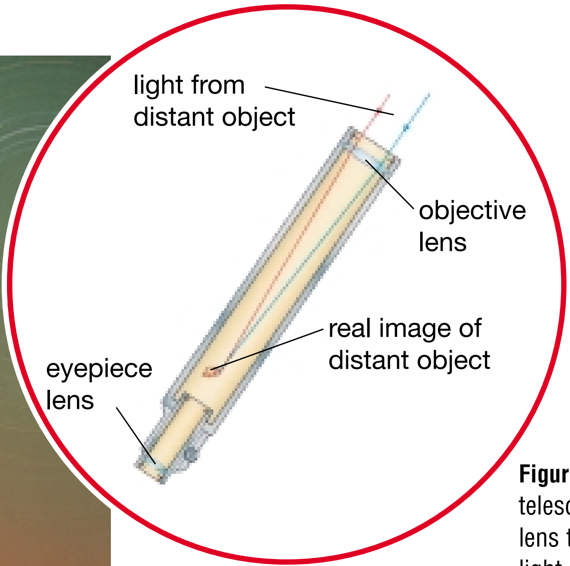


Figure 3.41A A refracting telescope uses a convex lens to gather and focus light.

INTERNET CONNECT

www.school.mcgrawhill.ca/resources/

Search the Internet to find images from the Hubble Space Telescope. Visit the above web site. Go to **Science Resources**, then to **SCIENCEFOCUS 8** to find out where to go next. Create a poster or your own web page describing the achievements of the Hubble Telescope.

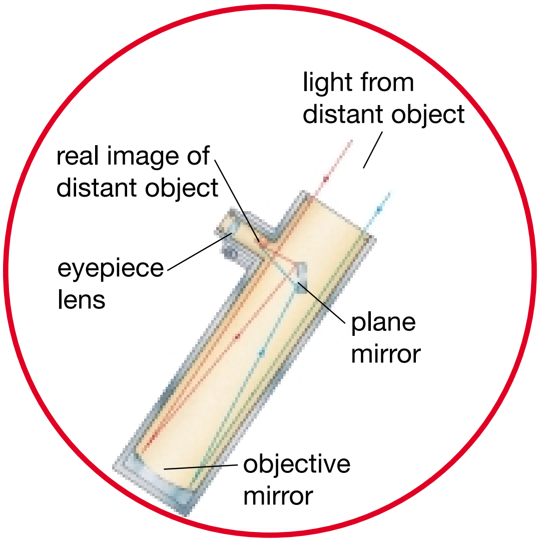


Figure 3.41B A reflecting telescope uses a concave mirror to gather and focus light.

The lens in a refracting telescope and the mirror in a reflecting telescope both act as a collector of light. Reflecting and refracting telescopes must have a large collector (either a lens or a mirror) in order to gather as much light as possible from the distant object. The collector then focusses the light into an image. As you learned in Inquiry Investigation 3-E, the farther the image is from the lens, the greater the magnification. Similarly, the farther the image is from the mirror in a reflecting telescope, the greater the magnification. For the greatest magnification, the telescope needs to have as large a distance as possible between the object being viewed — a star or a planet, for example — and its image. This explains why some telescopes are so enormous.

Find Out ACTIVITY

Make Your Own Refracting Telescope

In this activity, you will make a simple refracting telescope using two lenses.

Materials

2 mounted convex lenses of the same diameter (one having a smaller curve than the other)

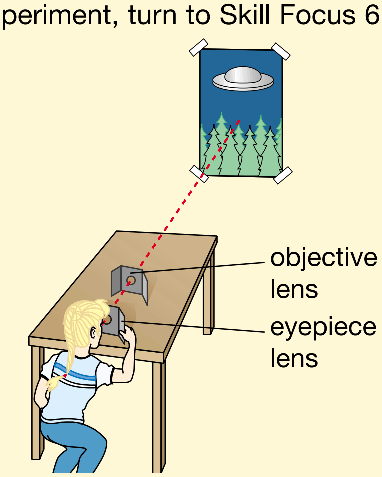
Procedure

Performing and Recording

1. Place the mounted lenses on a table and look in a straight line through both lenses.
2. Find out which combination of lenses will let you see a magnified image of a distant object. This object could be a poster on the far wall of the classroom, for example. You may have to move the objective lens back and forth until you can see a clear image.
3. Choose a specific area of the image. Estimate how much larger that part of the image is when viewed through the lens, compared with its size when viewed with the unaided eye.
4. Make a diagram showing the arrangement of the far object, the two lenses, and your eye. Label the objective and eyepiece lenses.

What Did You Find Out?

1. How many times larger does the image appear to be?
2. What is the attitude of the image?
3. In a refracting telescope, which lens has the greater curve?
4. **Design Your Own** How could you use a piece of waxed paper to find out whether the image between the lenses is real or virtual? Design your own experiment to find out. (If you need help designing an experiment, turn to Skill Focus 6.)



Binoculars

Binoculars are actually two reflecting telescopes mounted side by side. You can imagine how difficult it would be to hold up two long telescopes. In binoculars, the telescopes are shortened by placing glass blocks inside. These glass blocks, called **prisms**, serve as plane mirrors. Rather than travelling down the long tube of a telescope, light in binoculars is reflected back and forth inside a short tube, as you can see in Figure 3.42.

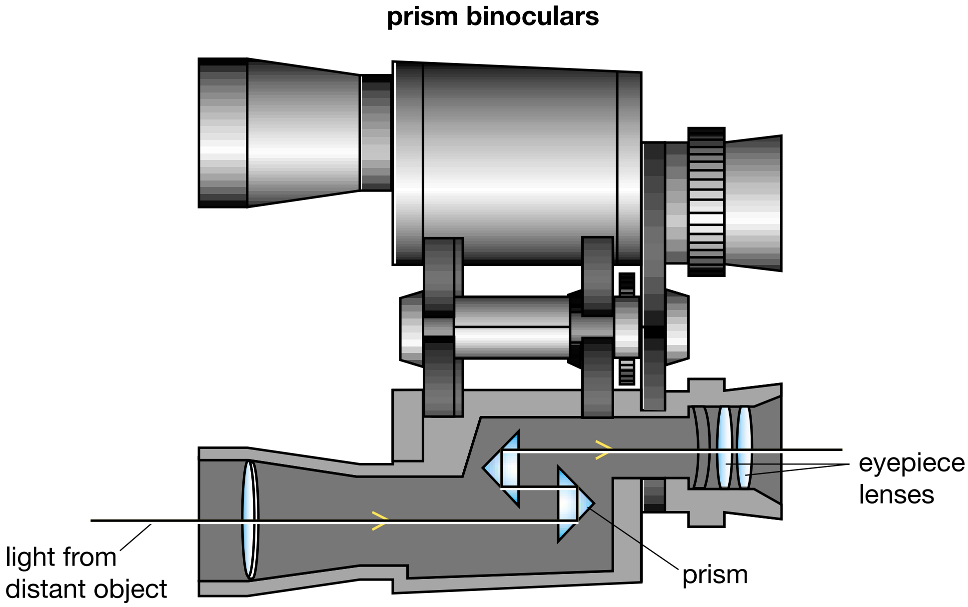
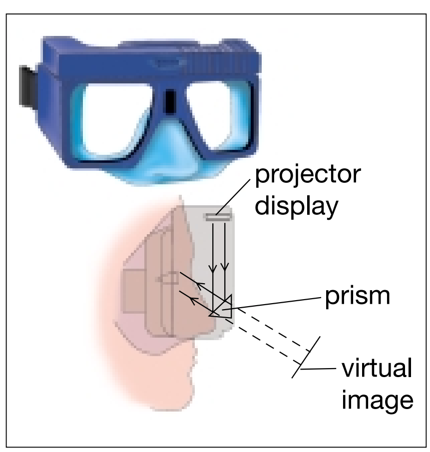


Figure 3.42 Binoculars use prisms to reflect light.

Cool Tools

Prisms are used to reflect light in an optical device known as a "Heads Up Display" or HUD. Light reflects through prisms to make an image appear in front of a person's eyes. This device helps airline pilots, who need to check air speed and altitude while at the same time looking out the plane's windshield. Pilots can monitor the glowing displays projected in front of them as they watch the approaching runway.

HUDs have also been developed for scuba divers. The device is positioned inside the diver's mask. The diver can check depth, water pressure, and air consumption by examining an image of this data projected directly in front of the diver. This spares the person the inconvenience of having to check the readings on separate gauges. These gauges indicate depth, pressure, and the amount of air left in the diver's tanks. Where else do you think HUDs could be useful?



DidYouKnow?

By means of a telescope, a French physicist named Armand Hippolyte Louis Fizeau obtained the first accurate value for the speed of light. Thus, a device that employs light was used to discover one of its most fundamental properties. This discovery led eventually to Einstein's theories of relativity.

Microscopes, Telescopes, and Scientific Knowledge

As you learned in Unit 1, a magnifying glass is a simple kind of microscope. Generally, magnifying glasses are used for magnifications up to about ten times actual size. In 1676, however, Dutch scientist Anton van Leeuwenhoek was able to see bacteria by using a single convex lens. The magnification required for this feat was 280×. Modern compound light microscopes can magnify objects up to 2000×.

Compound microscopes have an objective lens that forms a real image of the object. Then an eyepiece lens magnifies the image further. As you learned in Unit 1, compound microscopes use more than one lens in the objective and in the eyepiece to improve the sharpness of the image (see Figure 3.43).

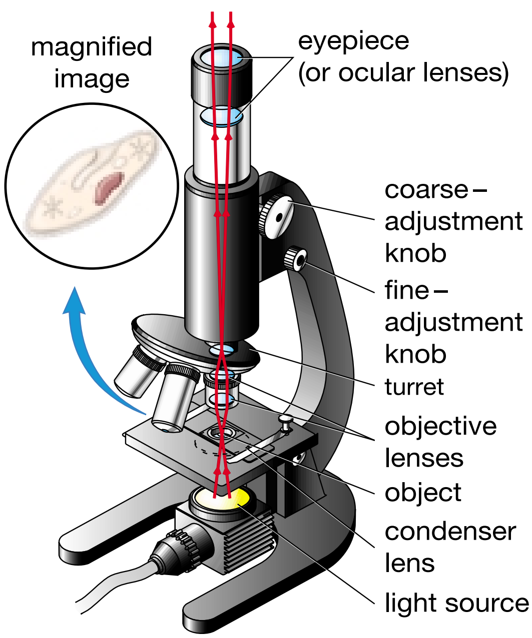


Figure 3.43 A compound light microscope uses several lenses to magnify an object.

New Discoveries

By means of microscopes, scientists learned that all living tissues consist of cells. They saw how these cells functioned and reproduced. They also saw how cells grew wild when they became cancerous, and how they were destroyed by viruses. Now scientists are using microscopes to study the genetic make-up of cells.

Similarly, the development of telescopes in the seventeenth century triggered an explosion of scientific knowledge about the universe. No longer were planets just wandering points of light in the dark sky. They became worlds of their own. For astronomers, the starry sky became an expanding cosmos of galaxies linked in truly gigantic formations.

Telescopes and microscopes have limits in terms of their magnification and their ability to reveal the difference between one large object and two smaller ones. These limits reveal the nature of light itself. You will learn more about this subject in Topics 6–8.

Figure 3.45 The planet Saturn.

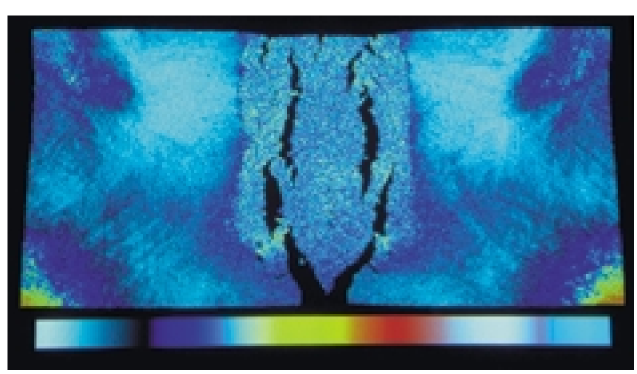


Figure 3.44 Metallurgists use microscopes to see how the size and shape of tiny crystals in metals affect their strength and hardness. This micrograph shows stress cracks in a metal. From microscopic observations of metals came the high-strength alloys in vehicles that protect us when we drive and fly.

INVESTIGATION 3-G

SKILLCHECK
- Initiating and Planning
- Performing and Recording
- Analyzing and Interpreting
- Communication and Teamwork

Microscopes on the Job

Think About It

In previous studies, you have seen how biologists use microscopes. However, they are not the only people who need microscopes in their daily work. Find out how microscopes are used in several occupations that are quite different from one another. Share your findings in a brief research presentation.

What to Do

1. Work in groups of two or three. In your group, select an occupation in which a microscope is used, for example:
   - medical laboratory technician
   - minerologist (someone who studies minerals)
   - forensic laboratory technician (someone who studies evidence related to crimes)
   - gemologist (someone who studies precious stones known as gems)
   - metallurgist (someone who studies the properties of metals)
   - petrologist (a geologist who studies the origin and composition of rocks)

2. Research the type of work done by a person in the occupation you have selected. You can find information in the library and on the Internet. Find answers to the following questions:
   (a) For what purpose does the person use the microscope?
   (b) Does the person use a special type of microscope?
   (c) What can be seen through the microscope? (In your research presentation, include a typical view. Show this in a circle to represent the field of view of the microscope. Include the magnification, if possible.)
   (d) What does the person do with the information obtained by using a microscope? How does using a microscope assist the person at work?

This technician is using a microscope to study thin sections of rock samples. These samples can indicate potential sites of new oil and gas resources.

3. Create a presentation based on the occupation you have selected. Make sure you include information on all the questions that you researched. Use appropriate support materials, for example, a pamphlet, poster, overhead transparencies, video, computer, or web site. If possible, produce a multimedia presentation.

Analyze

Based on the information in the presentations:

1. List those occupations that make similar uses of the microscope.
2. Identify which occupation uses the microscope in the greatest number of different ways.
3. Decide if one of these occupations is of interest to you. If so, what do you find interesting about the occupation?
4. Describe how your group's presentation could have been improved.

Find Out ACTIVITY

Making a Microscope

Because a microscope, like a telescope, uses two lenses to magnify an object, you should be able to make a simple microscope out of the same two lenses used in the telescope activity.

Procedure ✷ Performing and Recording

1. Find out which combination of lenses will let you see a magnified image of a near object. You should not place the object too close to the objective lens or you will not get any image at all!

2. Estimate how much larger the image is than the object. To do this, keep both eyes open and compare the same parts of the image and the object.

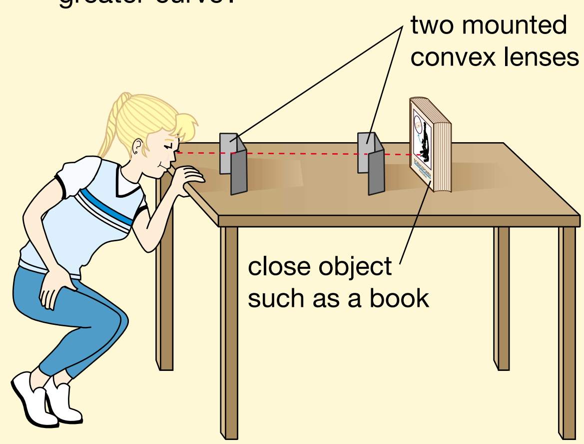
3. Draw a diagram showing the arrangement of the near object, the two lenses, and your eye. Label the lenses.

What Did You Find Out? ✷ Performing and Recording

1. How many times larger than the object is the image?

2. What is the attitude of the image?

3. In a microscope, which lens has the greater curve?



TOPIC 5 Review

1. State the function of a telescope's
   (a) objective lens or mirror
   (b) eyepiece lens

2. Name the lens that has the greater curve in
   (a) a refracting telescope
   (b) a compound microscope

3. What role do prisms play in a pair of binoculars?

4. How have optical systems such as the microscope and the telescope contributed to scientific knowledge? Give some examples.

5. Name some occupations in which microscopes are used, and describe how microscopes benefit those occupations.

Wrap-up TOPICS 4-5

If you need to check an item, Topic numbers are provided in brackets below.

Key Terms

attitude	retina	aperture	refracting telescope
concave	near-sighted	shutter	objective lens
convex	far-sighted	iris	eyepiece lens
lens	accommodation	pupil	reflecting telescope
concave lens	near point	iris reflex	objective mirror
convex lens	far point	optic nerve	prisms
focusses	diaphragm	blind spot	

Reviewing Key Terms

1. In your notebook, match the description in column A with the correct term in column B.

A	B
• the point where the optic nerve enters the retina	• objective lens (5)
• attitude of the image in a microscope	• optic nerve (4)
• controls the size of the pupil	• iris (4)
• largest lens in a refracting telescope	• retina (5)
• path from the retina to the brain	• inverted (4)
• corresponds to the film in a camera	• blind spot (4)

Understanding Key Concepts

2. Describe how the distance between the object and the convex lens affects the characteristics of the image. (4)

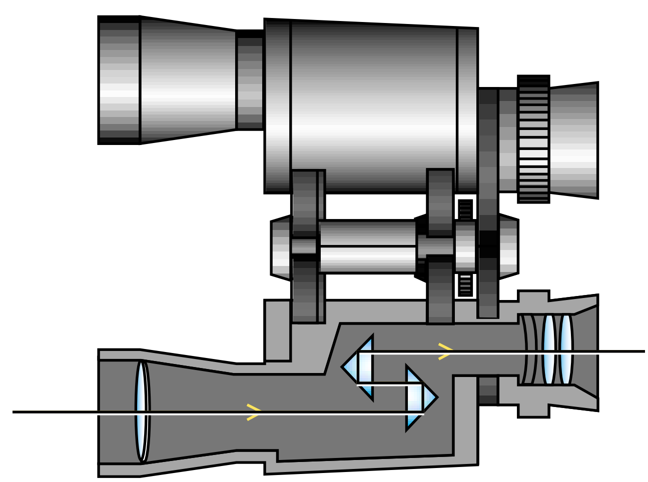
3. Compare the structure and function of the eye of a mammal to the structure and function of the eyes of several different species. (4)

4. How are convex lenses and concave mirrors used in telescopes? (5)

5. Describe how convex lenses are used in microscopes. (5)

6. Give some examples of how optical devices have furthered scientific knowledge. (5)

7. Look at the diagram on the right and explain how binoculars work. (5)



TOPIC 6 The Source of Colours

At one time, people believed that colour was something added to light. When white light struck a green leaf, people believed the leaf was adding green to the light. Is colour picked up when light strikes a coloured object? Or does light itself contain colour? Find answers to these questions in the activity below.

Figure 3.46 Trembling aspens in Sheep River Wildlife Sanctuary, Alberta. Where does the green colour in the leaves come from?

Find Out ACTIVITY

A Shower of Colour

How is colour related to light?

Safety Precautions

Materials

sharp pencil

overhead projector

piece of cardboard large enough to cover the stage of the overhead projector

equilateral prism

sheet of white paper

Procedure Performing and Recording

1. Use a sharp pencil to punch a hole in the middle of the cardboard. CAUTION Be careful when punching the hole.

2. Place the cardboard on the stage of the overhead projector so that a beam of light passes through the hole.

3. Shine the light beam from the overhead projector onto one side of the prism.

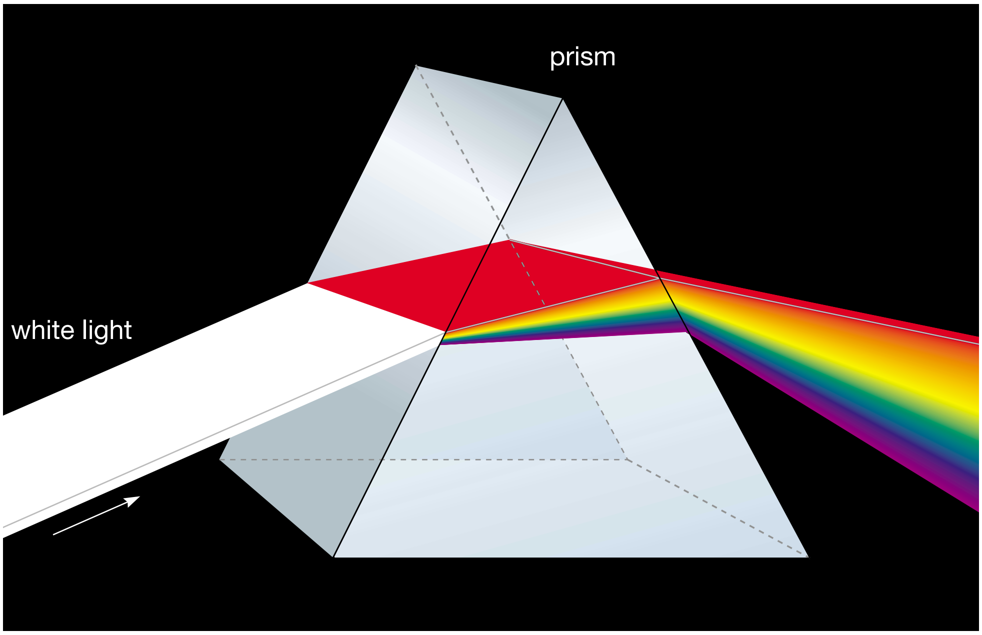
4. Using the sheet of white paper, locate the area where the light exits the prism. List the sequence of colours you see. Then compare your list with the lists your classmates made.

What Did You Find Out? Analyzing and Interpreting

1. You allowed white light to refract through a prism, and you observed colours emerge. Where did the colours come from?

2. Do all colours refract the same amount? Give a reason for your answer.

3. What do you think you would see if you were able to put all the colours back together again?



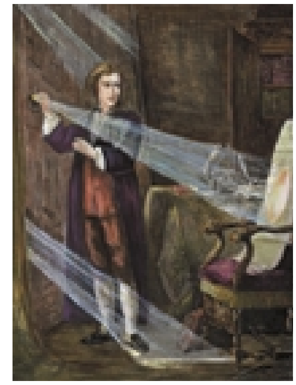


Figure 3.47A Sir Isaac Newton observed that a prism refracted light into different colours.

In the seventeenth century, English scientist Sir Isaac Newton (shown right) conducted a famous experiment. He placed a prism so that a thin beam of white light could pass through it. When white light travelled through the prism, Newton saw bands of colour emerge. He observed that each band of colour was refracted at a different angle. This produced a rainbow effect (see Figure 3.47A). Newton concluded that the prism was not the source of the colours. The different colours must have been present already in the white light.

Next, Newton passed these colours through a reversed prism. This time, only white light emerged, as shown in Figure 3.47B. In this way, Newton showed that colour was a property of visible light. He proposed that white light such as sunlight is the result of mixing together all the different colours of light.

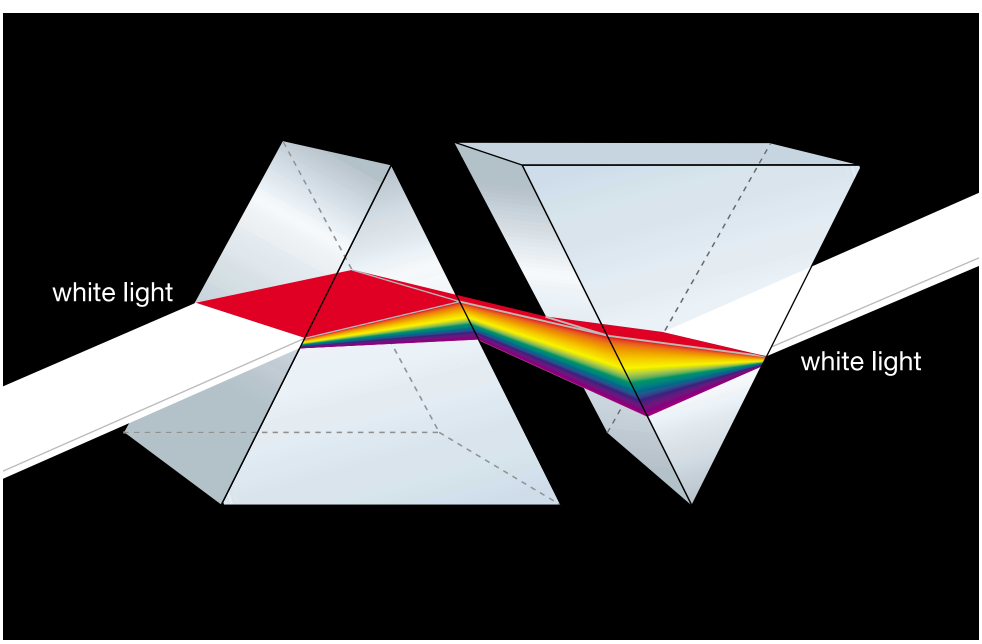


Figure 3.47B When passed through a second prism, the refracted light combined to form white light once again.

The Spectrum

When white light is refracted into different colours, the resulting pattern is called a **spectrum**. For sunlight, the colours range from red through orange, yellow, green, blue, indigo, and violet. This pattern is called the **solar spectrum**. You can remember the order of the seven colours in the solar spectrum by means of a memory aid: the name ROY G. BIV. The "R" stands for red, "O" for orange, and so on. Make up a memory aid of your own to help you remember the order of the colours in the spectrum. A rainbow is an example of a spectrum (see Figure 3.48).

Figure 3.48 A rainbow arches over the Trans-Canada Highway near Banff, Alberta.

When light strikes an object, the light may be reflected off the object, absorbed by the object, or transmitted through the object. When white light passes through a blue bottle, the glass absorbs all the colours of light except the blue (see Figure 3.49). Only the blue light is reflected or transmitted. This explains why the bottle appears blue.

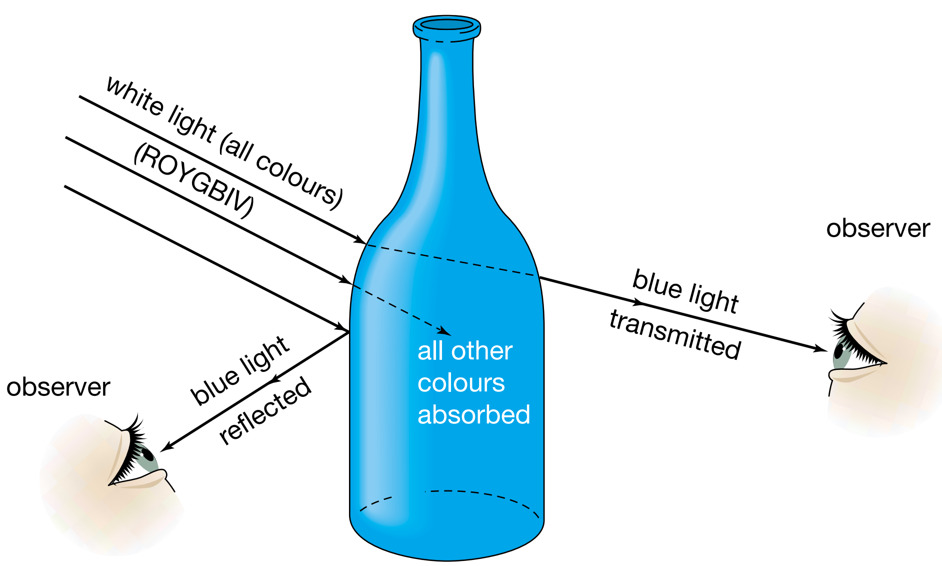


Figure 3.49 All the colours of light except blue are absorbed by a blue bottle. Only the blue light is reflected or transmitted.

Word CONNECT

The word *spectrum* comes from Latin and means "spectre" or "apparition." These words are also synonyms for the word "ghost." The plural of spectrum is spectra. In a dictionary, look up another word with the root "spectre" and use it in a sentence.

Pause & Reflect

You have seen that a prism can break up light into the colours of the spectrum. What do you think is serving as a prism in the case of a rainbow? Answer this question in your Science Log. Use the word "refract" or "refraction" in your answer.

Did You Know?

The passing of light rays through a medium is known as "transmission." The opposite of transmission is "absorption"—the complete retention of light rays without transmission or reflection.

Seeing Red

The colour you see when light strikes an opaque object depends on which colours are reflected and which ones are absorbed. The paper on this page reflects all colours. Thus, you see the paper as white. The print on the page absorbs all colours. Therefore, you see the print as black. Any colours you see in coloured photographs depend on the colour of light reflected from the photographs.

Examine Figure 3.50. A tomato under white light looks red. Why? It is reflecting only red light to your eyes, as shown in photograph A. What happens to all the other colours if only red light is reflected? The other colours have been absorbed by the skin of the tomato. In photograph B, you see the tomato under red light. The tomato still appears red because red light is not absorbed by the tomato. However, in photograph C, the tomato is illuminated by only blue light. Blue light is almost completely absorbed by the tomato. Very little light can reflect back. Thus, the tomato looks black, with just a hint of blue.

Did You Know?

Many animals such as cows, deer, and dogs, cannot see colours. They see the world in only black and white.

A tomato under white light

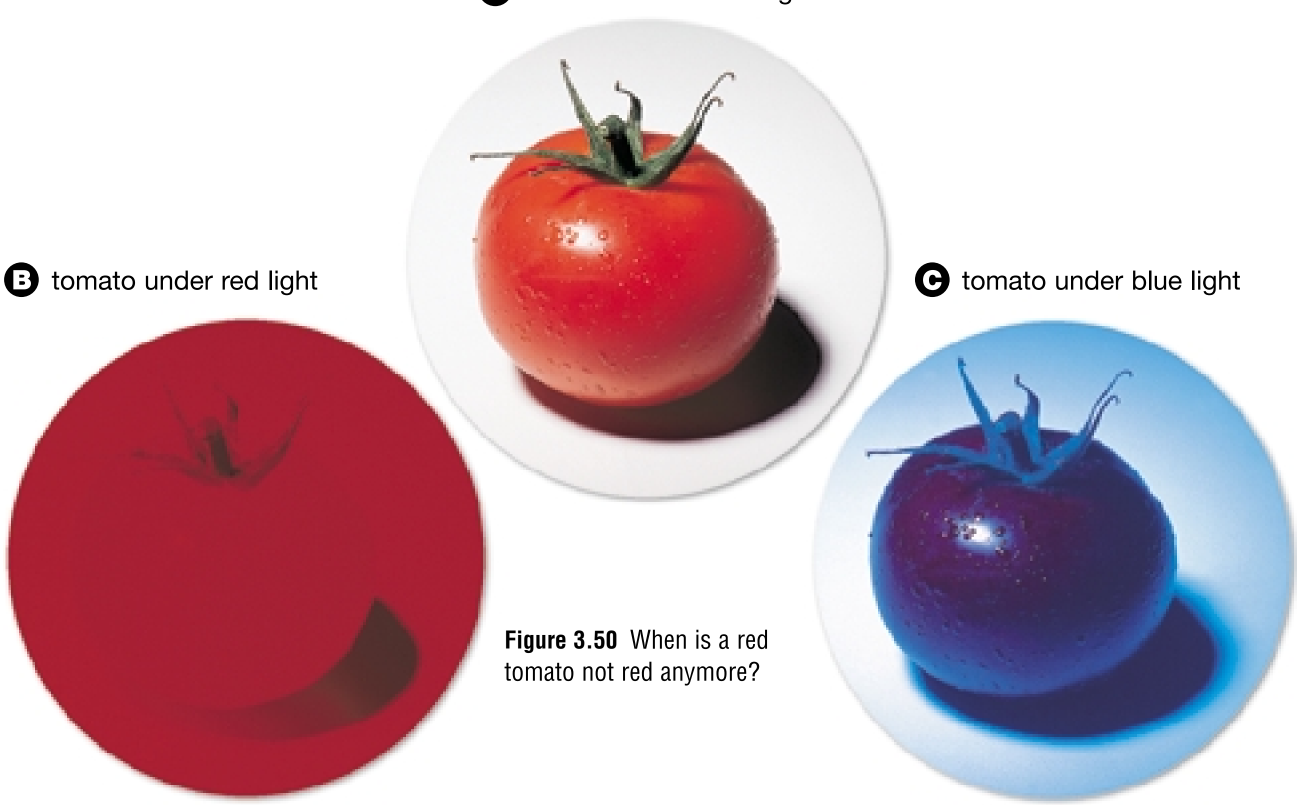


Figure 3.50 When is a red tomato not red anymore?

Pause & Reflect

Colours are reflected light that we can see. What happens when we see no reflected light? Close your eyes and cover them with your hands. You should see only black. Now look at something black, such as a pair of shoes. The shoes appear black because they have absorbed all the colours in the light. Black objects do not reflect any light. In your Science Log, write a definition of the colour "black."

INQUIRY

INVESTIGATION 3-H

SKILLCHECK

- Initiating and Planning
- Performing and Recording
- Analyzing and Interpreting
- Communication and Teamwork

Spotlight on Colour

You have seen that white light is a mixture of red, orange, yellow, green, blue, indigo, and violet light. However, do you need all these colours to make white light? Is it possible to trick the human eye into thinking that all the colours are present when some are missing? You will find out in this investigation.

Question

How can you produce the effect of white light using fewer than the seven colours of the solar spectrum?

Safety Precautions

Apparatus

3 floodlights (1 red, 1 green, 1 blue) mounted on separate stands, all facing a screen or a light-coloured wall

Procedure

1. Darken the room as much as possible. Turn on all three floodlights. Try to produce a glowing patch of white light. You can change the brightness of each colour by moving the floodlights closer to the screen or farther away from it.
   (a) Turn off the red floodlight and **identify** the colour.
   (b) Turn on the red floodlight and turn off the green. **Identify** the colour.
   (c) Turn on the green floodlight and turn off the blue. **Identify** the colour.
2. Turn on all the floodlights. Hold up your hand about 10–15 cm from the screen. **Observe** the shadows and try to name their colours.

Analyze

1. How close did you get to producing white light using just red, green, and blue light?
2. Name the colour that is produced by combining
   (a) green and blue
   (b) red and blue
   (c) red and green

Conclude and Apply

3. Try to explain the colours that you saw in the shadows of your hand.
4. How might a stage lighting technician use the information that you just gained?

Additive Primary Colours

The three colours red, green, and blue are called the **additive primary colours**. They are called additive colours because adding all three together in the proper amounts will make white light, as shown in Figure 3.51. The light of two additive primary colours will produce a secondary colour. The three **secondary colours** are yellow, cyan, and magenta.

Did You Know?

An *electron* is a negatively charged particle orbiting the nucleus of an atom. You will learn more about atoms and electrons in later science studies.

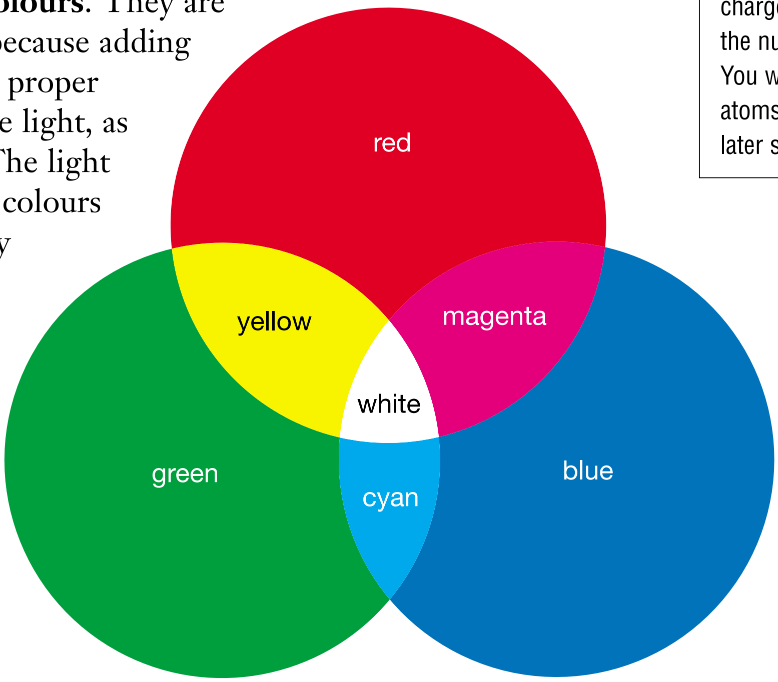


Figure 3.51 Combining the additive primary colours red, green, and blue produces white light.

Television screens use additive primary colours. The screen contains many groups of three tiny phosphor dots (see Figure 3.52). Each dot glows with a different colour when it receives energy from the electrons inside the picture tube of the television set. In each group, one dot glows red, a second glows green, and the third glows blue. If all three dots glow brightly, you see white light.

The phosphor dots on a television screen are too tiny to be seen from a distance. Thus, you see sections of colour rather than individual dots. A section on the screen will look yellow if the red and green dots in the section glow. If the red and blue dots glow, you will see magenta. What combination of glowing dots produces cyan? All other colours can be created by varying the intensities of the three primary colours.

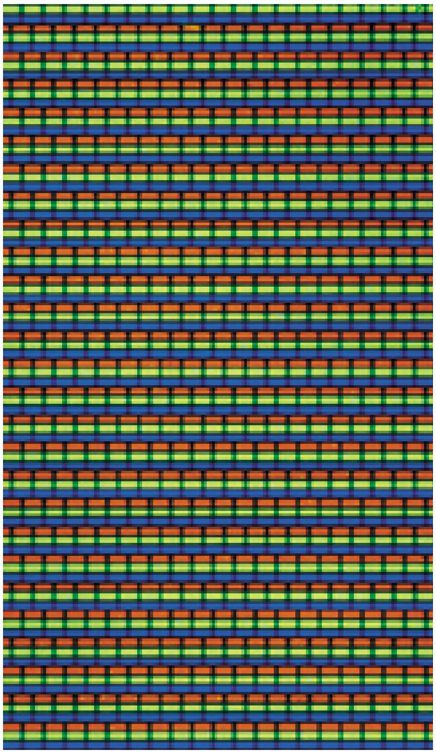


Figure 3.52 All colours on a television screen are composed of various combinations and intensities of red, green, and blue light.

How We See Colour

The retina of the human eye contains two types of cells that respond to light (see Figure 3.53). Some cells look like tiny cylinders. These cells are called **rods**. They detect the presence of light. The other cells are called **cones**, again because of their shape. The cones detect colour. There are three types of cones. Each type of cone responds to a different colour.

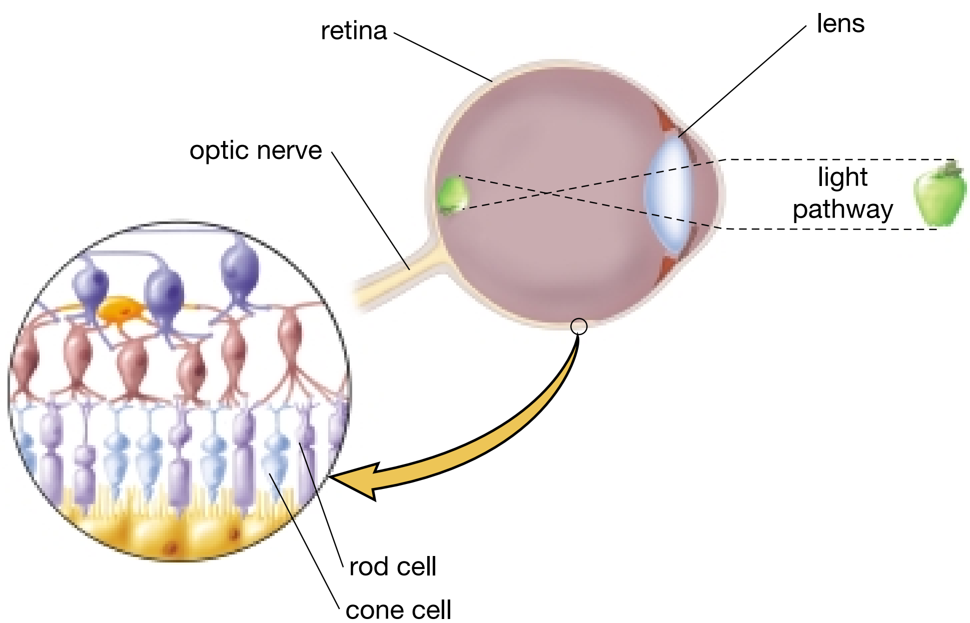


Figure 3.53 Rods and cones are the two types of light-detecting nerve cells in the retinas of your eyes.

Think again about the spectrum produced by a prism. Recall that white light contains red, orange, yellow, green, blue, indigo, and violet light. However, cones in the human eye respond mainly to red, green, and blue light. This is why the eye can be tricked into thinking that a beam of light is white when it contains only those three colours. This is also why all other colours are seen by the eye in terms of the relative amounts of red, green, and blue light sensed by the cones.

Signals from all three types of cone cells and the rod cells travel along the optic nerve to your brain. Your brain then interprets the shape and colour of the object that you see.

Off the Wall

Almost no mammals except primates — for example, apes, monkeys, and humans — possess colour vision. In those mammals that do have colour vision, it is very basic. However, many other animals have an excellent sense of colour. It is highly developed in birds and fish. Insects such as bees see a broader spectrum and probably a greater variety of colours than humans can. To a bee, vegetation we see as basic green would appear as a range of hues. Birds have the best developed colour sense of any species of animal. They see an enormous variety of colours compared to humans!

The cone cells in some people's eyes are unable to detect certain colours. This condition is known as **colour blindness**. A simple test for colour blindness is shown in Figure 3.54.

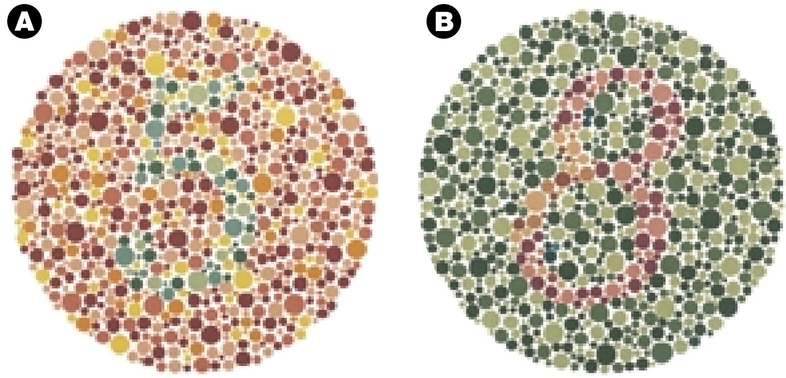


Figure 3.54 Some people cannot detect the difference between green and yellow. They cannot see the "5" in picture A. Other people cannot detect the difference between red and green. They see the "8" as a "3" in picture B. People with total colour blindness cannot read either number.

Find Out ACTIVITY

Making a Colour Wheel

You can see how the additive primary colours blend together in this simple activity.

Safety Precautions

Materials

circular piece of cardboard (about the size of the lid of a yogurt or margarine container)

white paper the same size and shape as the cardboard circle

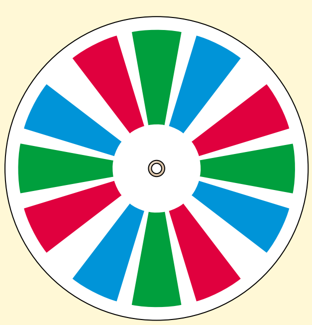
red, green, and blue markers or paints

sharp pencil

tape or glue

Procedure ✷ Performing and Recording

1. Colour the paper using red, green, and blue markers. Your paper circle should look like the one below.



2. Attach the paper to the cardboard.
3. Using a sharp pencil, punch a hole through the middle of the disk. **CAUTION** Use care when punching the hole. Push the pencil through the hole and spin the disk rapidly. (For best results, do this outdoors in bright sunlight.) **Record** your observations.

What Did You Find Out? ✷ Analyzing and Interpreting

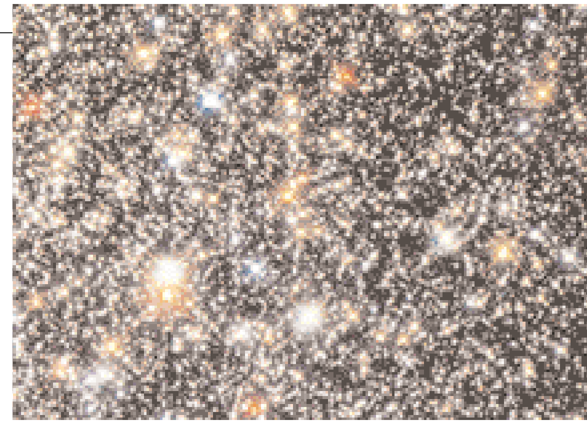
1. What colour did you see when you spun the disk? The result should have been a fairly clear white. Perhaps your mixture looked too red. If so, make up a second paper disk. Adjust the size of the colour strips so that the red ones are smaller than the others. Repeat the activity.
2. Sometimes the white will appear as dark grey. How could you brighten the mixture?

Pause & Reflect

In your Science Log, list some reasons why people use colour in their clothing and homes. What are some ways in which animals use colour?

Off the Wall

What colour is starlight? To our eyes, the stars in the night sky look like small points of white light. In fact, stars range widely in colour. If you studied them with a powerful telescope, you would see that some are bluish white or pale green. Others are yellow or orangey-red. Astronomers use the colour of a star to infer its surface temperature. (Think of a glowing light bulb or a hot toaster element.) A yellow star, such as the Sun, is relatively hot. Its surface temperature is about 6000°C. A red star is relatively cool — only about 3000°C! A blue star is extremely hot, between 20 000°C and 35 000°C.



TOPIC 6 Review

1. (a) What is a spectrum?
   (b) Make a labelled drawing, in colour, of the solar spectrum, beginning with violet.
2. What common assumption about white light did Sir Isaac Newton show to be wrong?
3. (a) Why does grass look green or a rose look red?
   (b) What determines the colour of an object?
4. Describe some uses of the three additive primary colours.
5. (a) If green and blue light are combined, what colour is produced?
   (b) If red and green light are combined, what colour is produced?
   (c) If blue and red light are combined, what colour is produced?
6. If the walls of this experiment box were lit by red light instead of white light, what colours would the walls appear to be? Explain your answer.

7. **Apply** On a traffic light, the colours red, amber, and green represent stop, caution, and go. Describe several other objects or devices that use colours for practical purposes.
8. (a) Explain how the two types of cells in the retina of the human eye respond to light.
   (b) Which of these two types of cells detect colour?

TOPIC 7 # The Wave Model of Light

You have seen many situations in which light travels in straight lines. For example, light that shines through a rectangular window will produce a sharp, bright rectangle of light inside the room. Sir Isaac Newton tried to explain why this happens. He proposed that light beams are made of streams of extremely tiny, fast-moving particles. These tiny particles of light, he suggested, could only travel in straight lines. Newton believed that the particles could not travel around objects. Explore Newton's idea further in the activity below.

Find Out ACTIVITY

An Unexpected Behaviour of Light

You already know what happens to light when it passes through a regular-sized window. However, would the same result occur if the window is very small?

Safety Precautions

Materials

showcase lamp

microscope slide

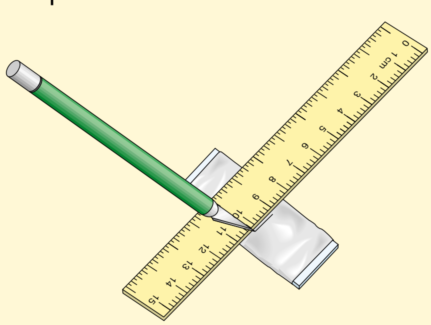
piece of aluminum foil slightly larger than the microscope slide

sharp knife such as a hobby knife

red filter or cellophane; blue filter or cellophane

ruler

coloured pencils or labels



Procedure Performing and Recording

1. Place the aluminum foil on one side of the microscope slide. Smooth the foil out and wrap it slightly around the edges of the slide.
2. Cut a slit in the foil partway across the width of the slide. Use a ruler to guide the knife. CAUTION Be careful when using the knife. If you cut yourself, tell your teacher immediately.
3. Make the room as dark as possible. Then turn on the showcase lamp.
4. Look through the slit at the filament of the showcase lamp. Be sure that the filament and the slit are both vertical. Draw a diagram showing how the filament appears. If you see colours, show them on your diagram. You may use coloured pencils or labels.
5. Hold a red filter over the slit and look at the glowing filament again. Now use a blue filter in place of the red. Draw the two patterns that you see.

What Did You Find Out? Analyzing and Interpreting

1. Describe what you saw when you looked through the single slit without a filter.
2. What difference did it make when you replaced the red filter with a blue filter?
3. In what ways is the light doing something that you would not have expected?

Looking at Wavelength

Think about what you observed in the previous Find Out Activity. Light does not seem to consist of speedy little particles that travel in straight lines, does it? When light passes through a small opening, it spreads out around each side of the opening. To explain this behaviour, Dutch scientist Christiaan Huygens (1629–1695) proposed that light travels as a wave, not as a stream of particles.

To visualize the features of a wave, examine Figure 3.55. The high parts of a water wave are called **crests**. The low parts between the crests are called **troughs**. As the wave moves to the right, the duck rises up as the crest passes. Then the duck drops down as the trough passes.

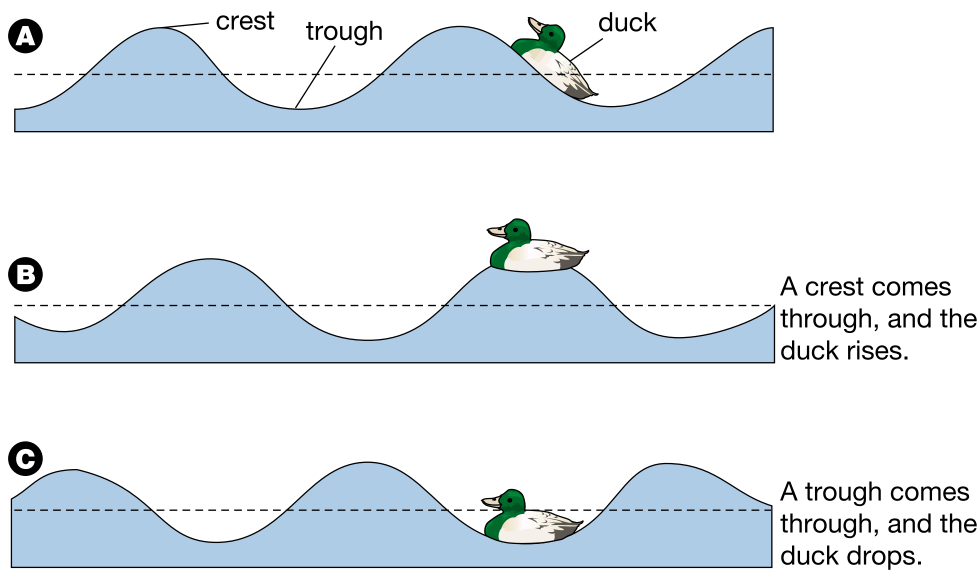


Figure 3.55 Water waves

The duck and the water around it do not move forward. They just move up and down as the wave passes. The distance from crest to crest, or from trough to trough, is called the **wavelength**. You can also think of a wavelength as the distance covered by one complete crest plus one complete trough (see Figure 3.56).

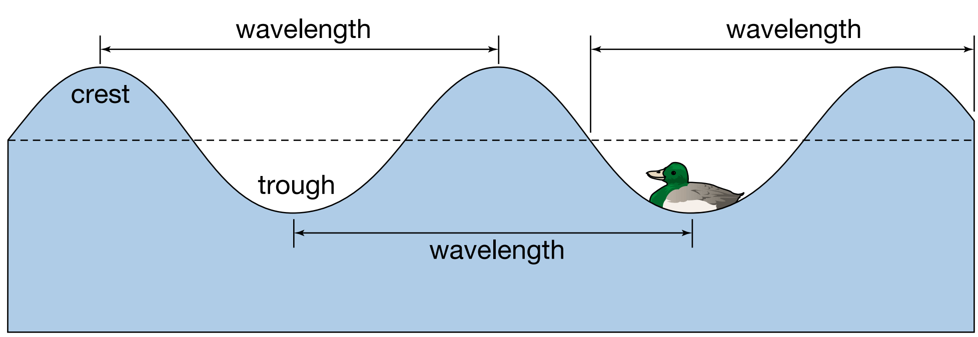


Figure 3.56 A wavelength can be measured in three different ways: the distance from crest to crest; the distance from trough to trough; or the distance covered by one complete crest plus one complete trough.

If the wind starts to blow, the water will become rougher. Soon, higher crests and deeper troughs will form. The height of the crest or the depth of the trough from the rest position is called the **amplitude** (see Figure 3.57). The amplitude is a good indication of the amount of energy transmitted by the wave.

The rate at which the duck and the water move up and down is called the frequency, *f*. **Frequency** is the number of cycles completed by a vibrating object in a unit of time. Frequency is usually measured in **hertz,** or cycles per second. If something vibrates 20 times in a second, its frequency is said to be 20 hertz (20 Hz).

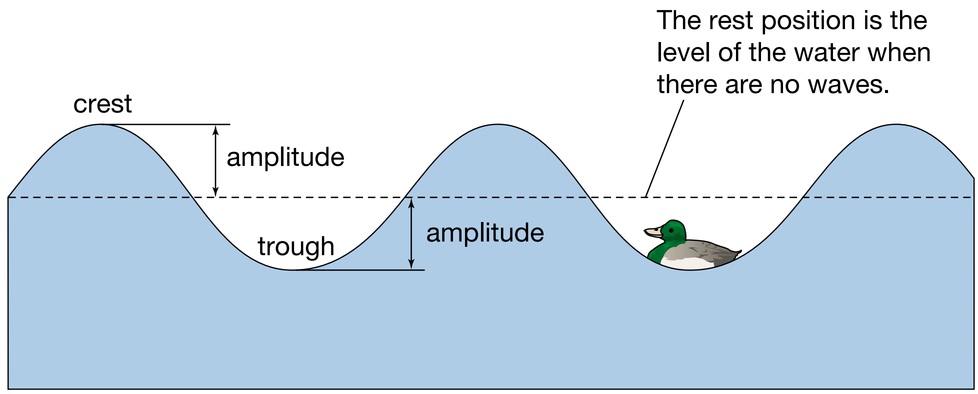


Figure 3.57 The amplitude of a wave indicates the height of the crests from the rest position. A wave's amplitude also indicates the depth of the troughs from the rest position.

The Wave Model of Light

Scientists have developed a model of light by looking at how light behaves, and then trying to explain what they see. As you learned in earlier science studies, a model is a way of representing something in order to try to understand it better and to make predictions. One explanation of light behaviour is the **wave model of light**, which pictures light travelling as a wave. This model does not explain everything about how light behaves. However, it helps explain a great deal. Thinking about light in terms of waves helps explain otherwise unpredictable behaviour, such as why light curves around an opening. Just as for water waves, the distance between the crests or the troughs of a wave of light as it travels through space is called a wavelength.

When light passes through a small opening, the waves spread out. How far the waves spread out depends on the wavelength of the wave. Waves with short wavelengths spread out very little. Waves with long wavelengths spread out more. Explore the relationship between frequency and wavelength in the next investigation. Then discover the relationship between wavelength and colour in Inquiry Investigation 3-I on page 240.

INQUIRY

INVESTIGATION 3-I

SKILLCHECK
- Initiating and Planning
- ✹ Performing and Recording
- ✹ Analyzing and Interpreting
- Communication and Teamwork

Exploring Frequency and Wavelength

Suppose you are observing a duck floating on the water. You might notice that when the crests of the waves are far apart, it takes longer for the duck to bob up and down. However, when the crests are close together, the duck bobs up and down much more frequently. This suggests that there might be a relationship between frequency and wavelength. You will state this relationship as a hypothesis to test in this investigation.

Question

What is the relationship between the frequency and the wavelength of a wave?

Hypothesis

Make a hypothesis about the effect on a wavelength when the frequency of the wave changes.

Apparatus

slinky-like coil
overhead projector and screen
pencil
transparent container with a flat bottom, such as a casserole dish

Materials

piece of tape or string
water

Procedure

Part 1
Waves on a Coil

1. Work with a partner. Attach a piece of tape or string at about the halfway mark of the coil.

2. Hold each end of the coil and stretch it out along the floor. Be careful not to stretch it too much. These coils can be damaged easily. CAUTION Handle the coil carefully to prevent it from "knotting up."

3. Hold one end of the coil 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.

4. Repeat step 3 but have your partner move the end of the coil quickly from side to side to provide a higher frequency. **Observe** and **draw a diagram** of the resulting wave. Indicate the wavelength. Label this diagram.

Part 2
Waves in Water

1. Carefully place the container on the stage of the overhead projector. Fill the container with water to a depth of about 1 cm.

2. Dip the eraser end of the pencil into the water to create ripples. Focus the projector until the ripples are sharp.

3. Move the pencil slowly up and down in the water. The ripples should appear as light and dark rings on the screen. The bright rings are crests and the dark rings are troughs. You have probably noticed that the troughs are easier to detect than the crests. **Draw a diagram** of the pattern you **observe**. Label your diagram "low-frequency waves."

4. Now move the pencil up and down at a faster rate. **Draw a diagram** of the dark rings you **observe**. Label this diagram.

Pause& Reflect

A female soprano sings a higher frequency (higher pitch) note than a male baritone. Which singer is producing waves of longer wavelength? Write your answer in your Science Log.

Analyze

1. What happened to the wavelength of the coil when you moved the coil more quickly from side to side?
2. As the coil wave travelled from one student to the other, in which direction did the marked coil move?
3. What do you call the distance between the dark rings that you saw on the overhead projector?
4. What happened to the wavelength of the water waves when you moved the pencil up and down at a faster rate?

Conclude and Apply

5. What happens to the size of the wavelength when the frequency increases?
6. What happens to the size of the wavelength when the frequency decreases?
7. **(a)** In this investigation, which was the manipulated variable?
   (b) Which was the responding variable?
8. **(a)** In general, how is frequency related to wavelength?
   (b) Did your observations support your hypothesis?

INQUIRY

INVESTIGATION 3-J

SKILLCHECK

Initiating and Planning

Performing and Recording

Analyzing and Interpreting

Communication and Teamwork

Why Are Colours Different?

The wave model of light provides an answer to one of the original questions that began this unit. What makes blue light different from red light? You will discover the answer in this investigation.

A diffraction grating consists of a piece of glass or plastic made up of many parallel slits. Diffraction gratings commonly have as many as 12 000 slits per centimetre. If light travels as a wave, this grating will intensify the effects you saw when you observed light through a single slit in aluminum foil.

Question

If light behaves like a wave, how is the wave for one colour different from the wave for another colour?

Hypothesis

Make a hypothesis about what property of a wave determines its colour.

Apparatus

diffraction grating (or rainbow glass)
showcase lamp

Safety Precautions

Never look directly at the Sun. Damage to your eyes could result. Do not touch the bulb on the showcase lamp. You could burn yourself.

STRETCH Your Mind

You read in Topic 6 that the colour with which a heated object glows can indicate its temperature. You also learned that astronomers use this knowledge to study stars. Some stars glow red or yellow, while others glow white. Conduct research at your library or search the Internet to discover how astronomers use colour to determine not only the temperature of stars, but also their age.

Procedure

1. Set up a showcase bulb so that its filament is vertical.
2. Darken the room and turn on the lamp.
3. Position yourself a few metres away from the showcase lamp.
4. Hold the diffraction grating so that the slits are vertical. Look at the lamp through the diffraction grating. You may notice a pattern that repeats itself. Just concentrate on the patterns immediately to the left and right of the bright filament. **Record your observations** as a diagram. Label any colours you see.

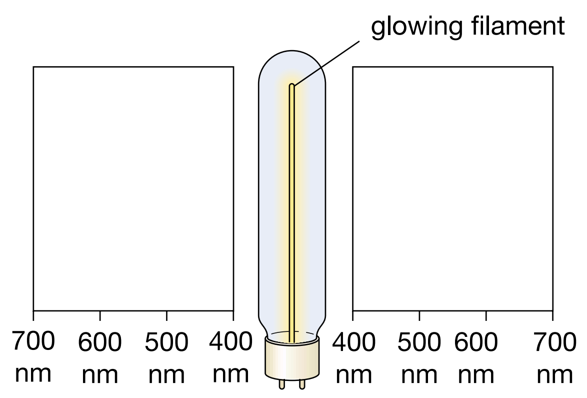
Analyze

1. In what way is light behaving like a wave in this investigation?

2. You learned that waves with longer wavelengths spread out more than waves with shorter wavelengths. Based on that information and your observations in this investigation, which colour of light has the longest wavelength? Which colour has the shortest wavelength?

Conclude and Apply

3. Copy the following diagram into your notebook. Try to place the colours that you saw onto the diagram in the same way they appeared to you.



Note: The unit of length used here is the *nanometre* (nm). 1 nm = 0.000 000 001 m.

4. Based on your observations, state the wavelengths for
   (a) red light
   (b) orange light
   (c) yellow light
   (d) green light
   (e) blue light

Extend Your Knowledge

5. Did your observations in this investigation support your hypothesis?

6. Use a sharp pencil to punch a hole in the middle of a large piece of cardboard. **CAUTION** Be careful when punching the hole. Allow sunlight to pass through the hole and fall on a piece of white paper. Look at the bright spot through the diffraction grating. **CAUTION** Do not look directly at the Sun.
   (a) List the range of colours that you observe in the solar spectrum.
   (b) Which colour is closest to the bright spot?
   (c) Which colour is farthest from the bright spot?
   (d) Which colour or colours seem to be the brightest?
   (e) Are there any major differences between the spectrum produced from the showcase bulb and the solar spectrum?

7. Look through the diffraction grating at a glowing fluorescent tube.
   (a) List the range of colours that you observe in the fluorescent spectrum.
   (b) Which colour is closest to the glowing tube?
   (c) Which colour is farthest from the glowing tube?
   (d) Which colour or colours seem to be the brightest?
   (e) Are there any major differences between this spectrum and the others that you have observed?

INTERNET CONNECT

www.school.mcgrawhill.ca/resources/

Astronomers use an instrument called a spectroscope to analyze a star's spectrum. In your notebook, make some notes about what a star's spectral pattern reveals about the star. Go to the above web site. Go to **Science Resources**, then to **SCIENCEFOCUS 8** to find out more about spectra and star analysis.

Light Waves in Action

We can explain sunsets such as the one in Figure 3.58 using the wave model of light. As light waves from the Sun travel through Earth's atmosphere, they strike particles of different sizes, including dust and grit. The longer wavelengths of the reds and oranges tend to pass around these particles. The shorter wavelengths, especially blue and violet, strike the particles and reflect and scatter off them, as shown in Figure 3.59.

At sunset, the sunlight we see passes through about 700 km of Earth's atmosphere. At this time of the day, the sunlight passes through many more particles than earlier in the day. This allows plenty of opportunity for many of the blue and violet waves to be reflected away. Red and orange waves remain to colour the clouds of the sunset.

Some of the waves with shorter wavelengths are reflected into space. However, if you look straight overhead at sunset, you will see the blue light that has been reflected toward you.

Figure 3.58 A sunset near Sooke, British Columbia. As the golden disk of the Sun sinks below the horizon, low-lying clouds light up with shades of orange, red, and purple. Where do these colours come from?

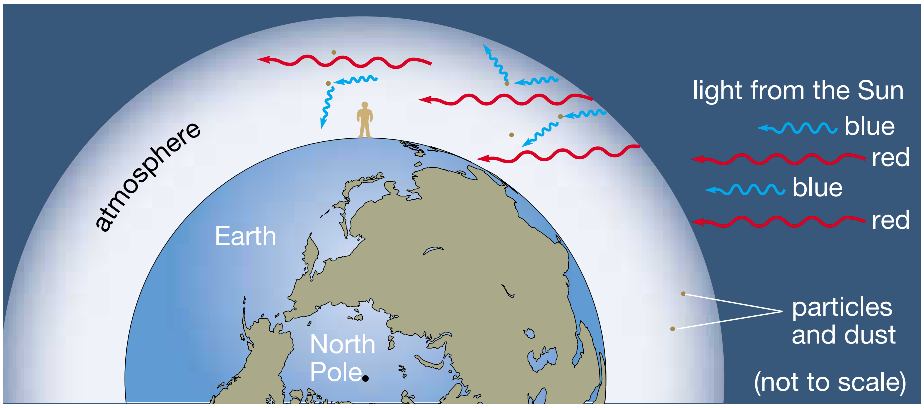


Figure 3.59 Some wavelengths of light can pass around particles in Earth's atmosphere. Other wavelengths are reflected and scattered by them.

DidYouKnow?

Volcanic eruptions throw tonnes of dust and grit into the atmosphere. This often results in spectacular sunsets for months after an eruption.

Find Out ACTIVITY

Making Sunsets in the Classroom

If you can put an appropriate number of particles in the path of light, you can mimic the wave effects of blue skies and sunsets. In this activity, you will pass light through water that contains a small amount of powdered coffee whitener.

Safety Precautions

Materials

powdered coffee whitener

spoon

large beaker or tall glass

overhead projector

screen

cardboard large enough to cover the stage of the overhead projector

scissors

water

Procedure — Performing and Recording

1. Cut a hole in the cardboard just slightly smaller than the base of the beaker or glass. **CAUTION** Be careful when using sharp objects such as scissors.

2. Place the cardboard on the stage of the overhead projector.

3. Almost completely fill the beaker with water. Place the beaker over the hole in the cardboard.

4. Turn on the projector and focus the light onto a screen. **Observe** the appearance of the water as light passes up through it. Also observe the colour of the light on the screen.

5. Add a tiny amount of the whitener to the water and stir. Describe any changes in the appearance of the water and in the light on the screen. **Record** your observations.

6. Try adding different amounts of whitener until you obtain the best effect.

What Did You Find Out? — Analyzing and Interpreting

1. Were you successful in separating the reds and the blues?

2. How does this demonstration relate to blue skies and red sunsets?

3. **Apply** Sunrises do not generally show as much colour as sunsets. What does that tell you about the air quality at night compared to daytime? (Keep in mind that the light at sunrise has passed through early morning air. The light at sunset has passed through daytime air.)

Cool Tools

Scientists are using laser light to trap and cool tiny particles of matter. Why? Many properties of matter change at temperatures near the coldest temperature possible, which is absolute zero (–273.15°C).

Physicists are trying to bring small samples of matter to the coldest possible temperature, in order to better understand magnetism and the behaviour of particles in matter. They can bring matter to extremely low temperatures by using special lasers to decrease the vibrations of the particles that make up the material.

Laser Light

In 1966, Theodore H. Maiman a physicist at Hughes Aircraft Company in California became the first person to use a process called **l**ight **a**mplification by the **s**timulated **e**mission of **r**adiation, or **laser** light. Laser light is quite different from the other types of light you have studied. However, an understanding of the wave model of light helped scientists develop laser light and its many applications.

As you have already seen, an incandescent light bulb gives off many different colours. In terms of the wave model, this means that many different frequencies and wavelengths are produced, as shown in Figure 3.60A. Moreover, the waves are all jumbled. Crests from one wave might overlap a trough from another. This makes the waves work against each other. Such light is called **incoherent**.

A laser, on the other hand, emits waves with only one frequency or wavelength, as shown in Figure 3.60B. In addition, all the waves line up to work together. Such light is called **coherent**.

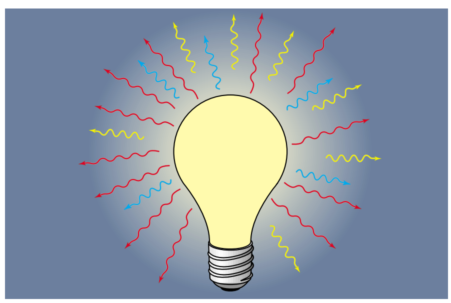


Figure 3.60A An incandescent bulb gives off many frequencies of incoherent light.

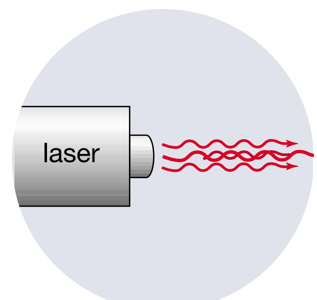


Figure 3.60B A laser gives off a single wavelength (frequency) of coherent light.

Lasers are used for many purposes. Supermarkets and other retail outlets use laser scanners to read bar codes on products. Over fractions of a centimetre, lasers read digitized data on compact discs (CDs). A tiny laser beam focusses on the revolving disc's shiny surface. The resulting pattern of reflections carries the information. You may have seen police officers using lasers to measure the speed of cars. Figures 3.61A and B show how lasers are used in fibre optics.

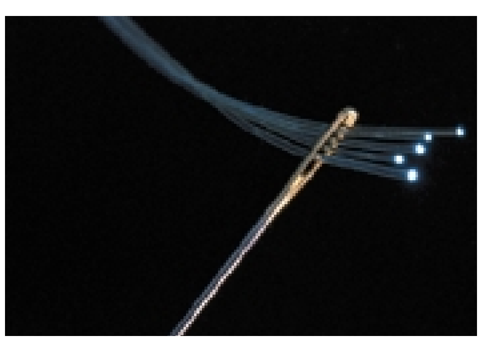


Figure 3.61A Because of its strength and coherence, laser light can be used to carry information over long distances through fibre optic cables. Such cables use the laws of reflection to carry light signals.

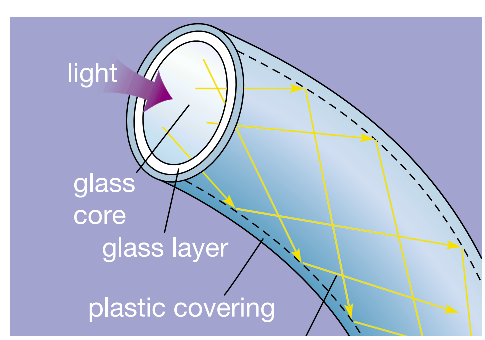


Figure 3.61B An optical fibre is designed to reflect light so that it is piped through the length of the fibre without escaping, except at the ends.

Laser light can be released in pulses or in a continuous beam. In either form, it can be powerful enough to make precise cuts through metal. Laser beams often serve as scalpels in modern surgery. Their heat can be so intense that they can instantly seal broken blood vessels as neatly as they cut through them. Eye surgeons use lasers. For example, lasers can shave off areas of the cornea in order to correct problems caused by irregularities in eyeball shape. Surgeons can also focus narrow, intense laser beams onto the back of the eye to "spot weld" a detached retina. One day, dentists will use silent laser "drills" to work on teeth. They will use laser light to vaporize cavities instead of drilling into them.

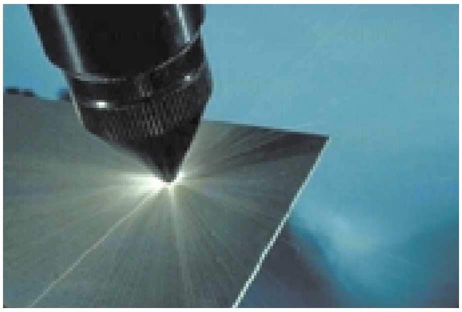


Figure 3.61C Laser light can cut steel for circular saw blades.

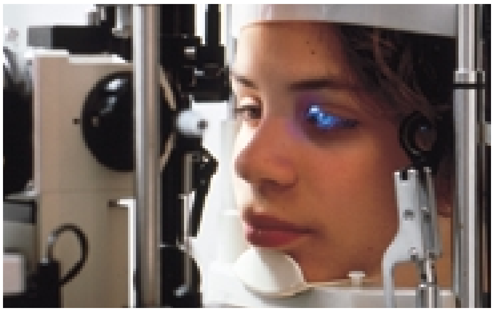


Figure 3.61D Laser beams are used to "spot weld" a detached retina back into place.

Career CONNECT

Does This Job Appeal to You?

When Ron Kumabe splices two pieces of glass fibre optic cable together, he does it very carefully. First, he has to join the two plastic-coated cylinders precisely. Otherwise, not enough light will bounce through the cable to carry the telephone company's communication signal. Second, if he accidentally bends the cable, it will break and be useless. Besides these difficulties, Ron must do this tricky work outdoors, at the location where the newly joined cables will be buried underground.

As a fibre optics splicer, Ron does the following:

- works with his hands
- is outdoors much of the time
- uses specialized tools
- works as part of a team
- provides a service to a customer
- must be careful and precise in his work
- is not required to dress in business clothes
- works in a new location with each new customer

Based on the statements above, does this sound like the job for you? Do some of the aspects of this job match your own career expectations? For each job feature listed, decide if you consider that aspect of Ron's job desirable or not. If it is not desirable, decide what you would prefer. Write your own career wish list based on your responses. Begin by: "I would enjoy a job in which I…"

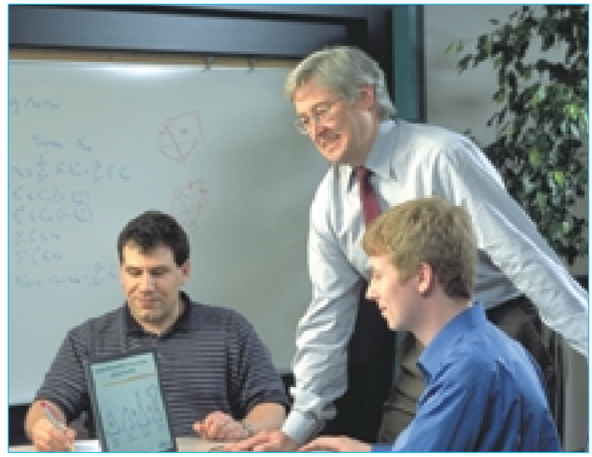
DidYouKnow?

Just one optical fibre can carry thousands of phone conversations at the same time.

Across Canada

Whether you realize it or not, Dr. Wayne Grover may have helped you place the last telephone call you made. With the arrival of the Internet, people all over the world have come to depend heavily on the sophisticated, interlinked network of fibre optic cables that deliver phone conversations, computer data, and video information. What would happen if just one cable in that system failed? Network traffic using that pathway could grind to a halt. This stoppage would interfere with business communication and essential services such as 911 and air traffic control.

This is the sort of crisis that Dr. Wayne Grover has worked very hard to eliminate. He is a professor of engineering at the University of Alberta. He is also Chief Scientist at a company called TR*Labs*, and a founding inventor in the field of "self-healing" telecommunications networks. Through his research, he has developed technology that enables networks to adapt when there is a faulty cable. The networks can now reroute their traffic through a different working pathway. What is remarkable is that this rerouting happens in a split second and it occurs automatically. No one has to flip a switch or monitor traffic. The network fixes the problem all by itself! This explains the term "self-healing."



Dr. Wayne Grover

Today, given billions of telephones and millions of Internet users, Dr. Grover's innovations are considered essential. They are in use all over the world.

TOPIC 7 Review

1. Draw a wave with a wavelength of 4 cm and an amplitude of 1 cm. Label a crest, a 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)** Describe one way in which light behaves like a wave instead of a particle.
   (b) Why do scientists prefer to talk about a wave model of light instead of saying that light *is* a wave?

4. **(a)** Give some examples of light-based technologies you have learned about in this Topic.
   (b) Explain the purpose of each technology.

5. **Apply** A woman went into a store to buy purple shoes to match her purple purse. Inside the store she found shoes that matched perfectly. However, once she got outside, she found that they no longer matched well. Why might this have happened?

TOPIC 8 Beyond Light

Earlier in this unit, you learned that the Sun is the most abundant source of light on Earth. However, there is far more to sunshine than meets the eye! Besides the visible energy that we call light, the Sun also radiates invisible energy. The light we can see is just a tiny band of a much broader spectrum of visible and invisible energy.

You have seen how water waves can be used to represent how light moves through space. However, light is a very different kind of wave from those that travel through water. In a water wave, water particles vibrate up and down as the wave passes through the water. In a light wave, electrical and magnetic fields vibrate. As a result, light is classified as electromagnetic radiation. Visible light energy and all the invisible forms of radiant energy exist on the **electromagnetic spectrum**, as shown in Figure 3.62.

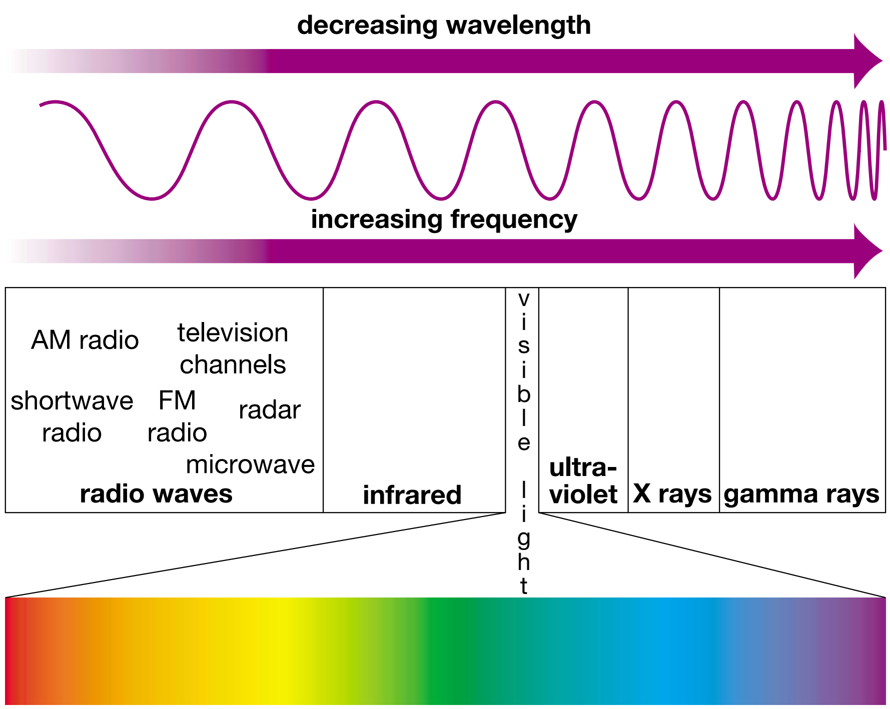


Figure 3.62 The electromagnetic spectrum

Different colours of light represent different frequencies and wavelengths of light. The table shows the wavelength and frequency of the colours in the visible spectrum. In the rest of this Topic, you will examine more closely the bands of invisible energy beyond the red and violet ends of the visible light spectrum.

Wavelength and Frequency of Colours in the Visible Spectrum

Colour	Wavelength in vacuum (nm)	Frequency (Hz)
red	700	4.3×10^{14}
orange	600	5.0×10^{14}
yellow	580	5.2×10^{14}
green-blue	500	6.0×10^{14}
violet	400	7.5×10^{14}

Math CONNECT

The frequency of red light is given as 4.3×10^{14} Hz. This method of expressing a large number is called *scientific notation*. The number 10^{14} means $10 \times 10 \times 10 \times 10 \times 10 \times 10 \times 10 \times 10 \times 10 \times 10 \times 10 \times 10 \times 10 \times 10$. How would you express the number 5 000 000 000 in scientific notation?

Skill POWER

To learn more about scientific notation, turn to Skill Focus 4.

DidYouKnow?

A nanometre (nm) is equal to 0.000 000 001 m. Expressed in scientific notation, this is 1.0×10^{-9} m. Red light has a wavelength of 700 nm or 0.000 000 7 m (7.0×10^{-7} m). The nanometre is so tiny that about 500 000 of them would fit across the thickness of a sheet of paper.

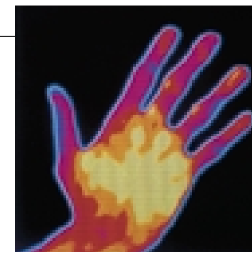
Infrared Radiation

Figure 3.63 Infrared lamps called "brood lights" are used to keep baby chicks warm.

Red light has a wavelength of about 700 nm. If you could stretch it out to 1000 nm, it would become heat radiation or **infrared radiation**. Your eyes would no longer see it, but your skin would sense it. Because infrared radiation is heat radiation, anything that is warmer than its surroundings emits more infrared rays. Infrared radiation has many uses. Motion sensors, burglar alarms and heat lamps use this technology. Figure 3.63 shows an infrared lamp being used to warm a baby chick.

Cool Tools

A thermogram of a hand, like the one shown here, can help diagnose circulation problems by detecting infrared radiation. A thermogram is an example of "infrared imaging." Warmer areas show up as yellow, orange, and red. Cooler areas are green, blue, and black. Would the problem area show up as warmer or cooler than the other parts of the hand?



Find Out ACTIVITY

Infrared Reflections

You have just learned that infrared radiation is like light. As a result, you would expect that infrared rays should behave like light. Modern remote control units use infrared radiation to send a signal to the receiver in a television or VCR. In this activity, you will test the reflection of infrared rays off various surfaces.

Materials

television set or VCR with a remote control unit

several different types of surfaces (for example, a smooth surface, a rough surface, a metallic surface, and a non-metallic surface)

Procedure

1. Use each surface to try to reflect radiation from the control unit toward the television or VCR.
2. Aim the control unit away from the television or VCR and hold one of the surfaces in front of it. Be sure to stand slightly to one side so that you do not block the reflected radiation.
3. Repeat step 2 for each type of surface.
4. Observe which kind of surface provides the strongest reflection.

What Did You Find Out?

1. Does infrared radiation reflect from all the surfaces?
2. List the surfaces in order, from the strongest reflector to the weakest reflector.
3. **Thinking Critically** Do the results of this activity support the prediction that infrared radiation should behave like light?
4. **Design Your Own** You have seen that light spreads out slightly when it passes through a small opening. Will infrared radiation behave in a similar way? Make a hypothesis and design an experiment to test it. What will your manipulated variable and your responding variable be? Decide on a control. Show your design to your teacher before you begin.

Radio Waves

Suppose you could stretch the infrared wave out again even farther so that the wavelength becomes a few millimetres long. You would begin to obtain **radio waves**. Radio waves have a longer wavelength and a lower frequency than visible light. Different types of radio waves have different uses.

Microwaves have the shortest wavelength and the highest frequency of all the radio waves. Microwave ovens use a specific wavelength or frequency of microwave that is strongly absorbed by water particles. When the water particles in the food absorb microwaves, they begin to vibrate quickly and become hot. Only foods that contain water particles can be heated using microwaves.

Microwave frequencies are also used in telecommunications (see Figure 3.64). Microwaves can be transmitted to telecommunications satellites that orbit Earth. The satellites receive microwave signals, amplify them, and retransmit them to a new location.

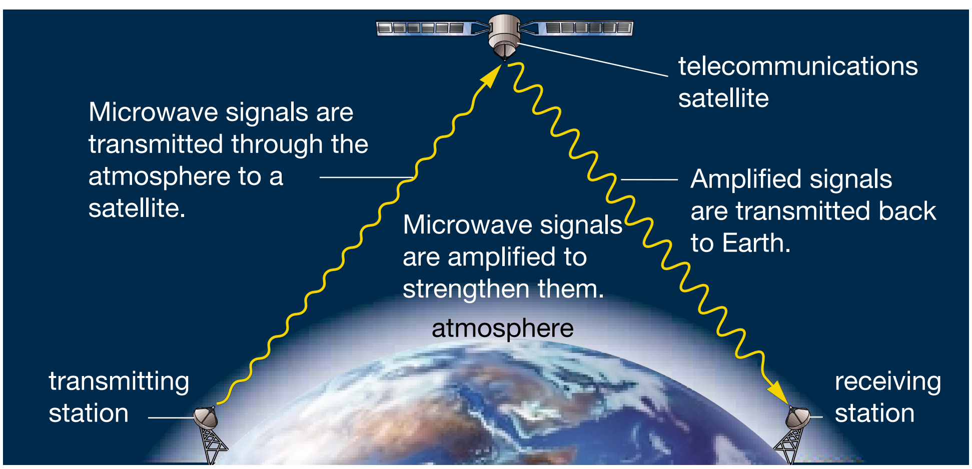


Figure 3.64 Signals sent by satellites can travel vast distances. One satellite can replace many ground-based relay stations. (This illustration is not drawn to scale.)

Microwaves are also used in radar. In this case, microwaves are beamed out through the air. The waves that reflect from an object tell the radar operator the location and speed of the object. As Figure 3.65 shows, air traffic controllers depend on radar to guide aircraft.

Radio waves with longer wavelengths than microwaves are used to broadcast radio and television programs. Most radio waves are harmless. In fact, radio waves are streaming through you right now. However, it is not known for certain whether long-term exposure to sources of radio waves could be harmful to people (see Figure 3.66).

Figure 3.65 Air traffic controllers use radar to guide airplanes safely during take-offs and landings.

Figure 3.66 Scientists are studying whether there is any danger from long-term exposure to radio waves, especially those emitted by electronic equipment such as computers, microwave ovens, and televisions. So far, there is no clear evidence of harm.

Remote Imaging Technologies

Did you know that radio waves are passing through you at this very moment? The signals from radio stations, television stations, cell phones, and even the distant stars all pass through your body every instant of every day. From time to time, radio waves also come from a Canadian satellite known as RADARSAT(see Figure 3.67).

As this satellite passes overhead, it sweeps the ground below it with radio waves. These radio waves can penetrate haze, fog, clouds, and rain. The manner in which these waves reflect back to the satellite gives scientists many kinds of information. When RADARSAT is over the ocean, for example, it watches for ice floes that can imperil shipping. It also monitors oil spills so that workers can identify where environmental damage might occur. When over the land, RADARSAT locates possible sites for oil, natural gas, and minerals. The satellite does this by gathering data about the geographical features of Earth's surface. RADARSAT images of floods (such as the one in Figure 3.68) show engineers where to put sandbags to protect lives and property.

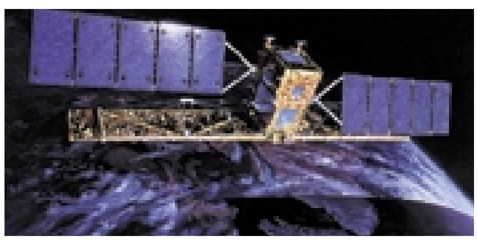


Figure 3.67 RADARSAT-1 takes pictures of Earth's surface using radar, not light.

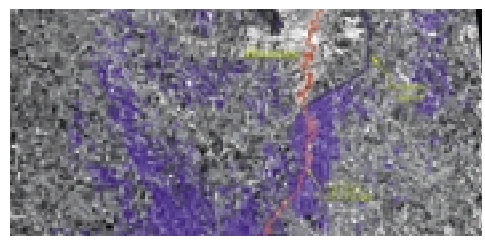


Figure 3.68 A RADARSAT image of the Red River flood in Manitoba, 1997

Other Canadian observation satellites known as LANDSAT record how different parts of the light from the Sun reflect back to the satellite. Probably LANDSAT's most important use is related to agriculture. The satellite can observe the extent of various crops or forests and monitor damage caused by insects and disease. When such information is determined worldwide, scientists can predict potential regions of famine. This can allow governments to take early steps to ease an approaching disaster. LANDSAT can also observe weather patterns and flooding.

For both types of satellites, the information is stored digitally on tape and then broadcast down to receiving stations for scientific analysis.

DidYouKnow?

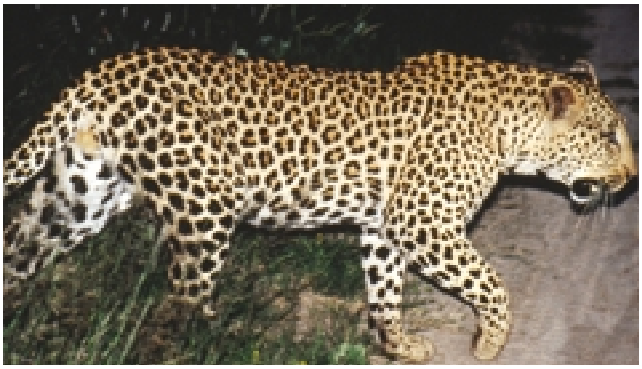
The Canadian Centre for Remote Sensing in Ottawa maintains two receiving stations for LANDSAT and RADARSAT. One station is in Prince Albert, Saskatchewan. The other is in Gatineau, Québec. The satellite image shown here demonstrates how LANDSAT can be used for land use and planning. The image shows a view of the southern part of Alberta. Most of the frame is covered by a "patchwork" pattern of fields, typical of this part of Canada.

INVESTIGATION 3-K

Extending Night Vision

Think About It

Through the nighttime forest, a spotted leopard stalks its prey. The eyes of this hunter see well in the dark. The pupils are wide open to let in the faint light from the moon and the stars. A red glow seems to burn in the leopard's eyes. Unfortunately for the leopard's prey, a resting deer, this glow is too faint to be seen.



The leopard and its prey are being secretly observed. A biologist is flooding the scene with infrared radiation from a set of devices known as "light-emitting diodes" (LEDs). Neither animal can see this radiation. However, the night-vision scope on the biologist's rifle can convert the reflected infrared radiation into a visible image.

The biologist aims a tranquillizing dart toward the leopard. The deer flees safely through the darkness. Once the leopard is asleep, a radio collar is attached. This collar emits radio waves that will be detected by satellites. In this way, the biologist can study the leopard's nightly activities.

Procedure

Initiating and Planning | Communication and Teamwork

1. Work in teams of three or four. Using the Internet and/or library resources, research the latest model of night scopes. How much does this equipment cost? How is it maintained? What are some privacy or safety issues associated with the use of this technology?

2. Find out about other optical equipment that can help humans see in the dark. One example is night-vision windshields in cars. What other devices are available? What are their uses? How do they work? In which occupations are night-vision technologies used?

Analyze

Analyzing and Interpreting

Based on your findings, brainstorm ways in which we might improve upon these devices in the future, or use them in different ways.

Extend Your Skills

Expand upon the most interesting facts your team discovered and share them with your classmates. Write a short article on the future of night-vision technologies. Alternatively, write a scene from a short story in which one of these futuristic devices is used.

INTERNET CONNECT

www.school.mcgrawhill.ca/resources/
What is a "nocturnal animal"? To find out, visit the above web site. Go to **Science Resources**. Then go to **SCIENCEFOCUS 8** to find out where to go next. Search for information on night vision in nocturnal animals. In your notebook, draw and label a diagram, showing how an animal's eyes enable it to see in the dark.

DidYouKnow?

Bumblebees can see ultraviolet radiation, which helps them detect patterns on flowers.

Ultraviolet Radiation

Just beyond the violet end of the visible part of the electromagnetic spectrum, wavelengths of 200 nm are known as **ultraviolet (UV) radiation**. This radiation is very energetic. It causes tanning, which is the skin's way of trying to protect itself from the ultraviolet waves. Ultraviolet radiation can damage the cornea, the front surface of the eye. This can lead to a fogging of the cornea, causing a slow loss of vision. As Figure 3.69 shows, sunglasses that block ultraviolet radiation will protect the cornea from damage.

In recent years, more and more ultraviolet radiation from the Sun has been reaching the surface of Earth. This is due to a decrease in Earth's **ozone layer**. Ozone, a form of oxygen, is located in Earth's atmosphere about 20–25 km above the ground (see Figure 3.70). When UV radiation from the Sun reaches the atmosphere, ozone absorbs much of the UV radiation. This absorption prevents the UV light from reaching Earth's surface.

Figure 3.69 You can prevent damage to your skin from ultraviolet radiation by wearing light clothing that covers your arms and legs. You can also use sunscreens. Sunglasses that block ultraviolet radiation can help protect your eyes.

However, Earth's ozone layer appears to be thinning. Some chemicals used in aerosol spray cans are able to rise through the atmosphere and break down the ozone particles. Freon, a gas once frequently used in refrigerators and air conditioners, can also destroy ozone particles. Fortunately, many spray products such as deodorants and hair sprays are now manufactured without ozone-destroying chemicals. Also, the use of Freon has been banned in many countries.

Looking Ahead

Will a decrease in the ozone layer change the effectiveness of sunscreens? You may wish to consider this as you think about your end-of-unit investigation. Research the Internet or other sources to see if sunscreen manufacturers are taking any steps to develop sunscreens with higher levels of SPFs to combat the increasing amounts of ultraviolet light that is reaching Earth.

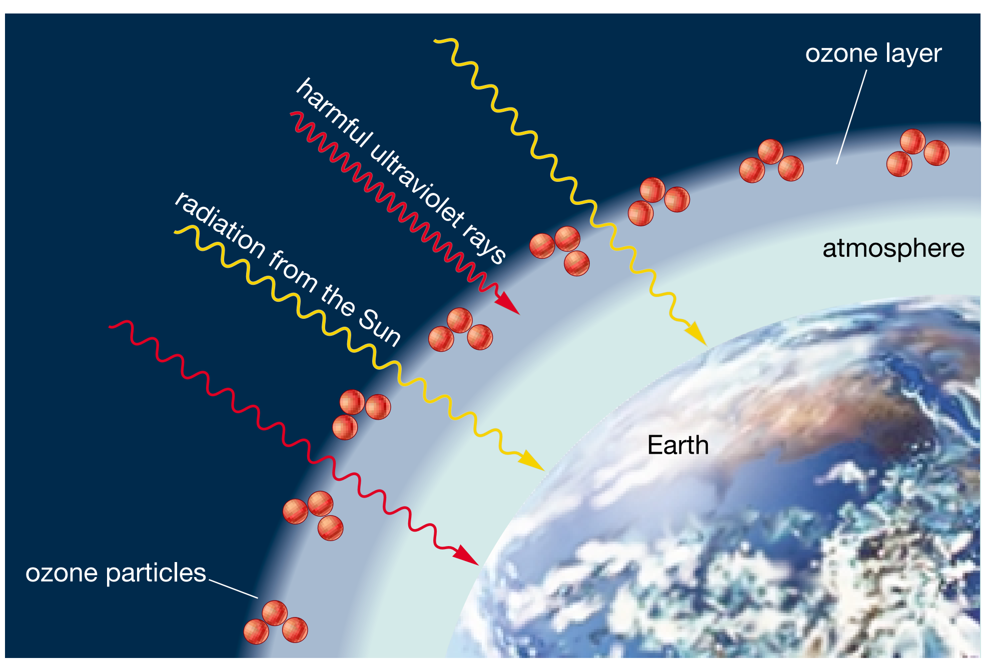


Figure 3.70 Earth's ozone layer (not to scale)

X rays

At even shorter wavelengths and higher frequencies on the radiant energy spectrum are **X rays**. These waves are very penetrating and extremely energetic. X rays pass easily through tissue such as skin and muscle. However, X rays are absorbed by bone (see Figure 3.71).

People who work with X rays protect themselves from harmful radiation by leaving the room while the equipment is being used. When a dentist takes an X ray of your teeth, he or she places a shielding pad on your body to protect you. The dentist then leaves the room before operating the X-ray machine.

INTERNET CONNECT

www.school.mcgrawhill.ca/resources/

Search the Internet to explore how infrared waves, ultraviolet waves, and X rays help investigators solve crimes. Visit the above web site. Go to **Science Resources**. Then go to **SCIENCEFOCUS 8** to find out where to go next. In your notebook, write a scene from a detective story, in which one of these waves is being used to help solve a crime.

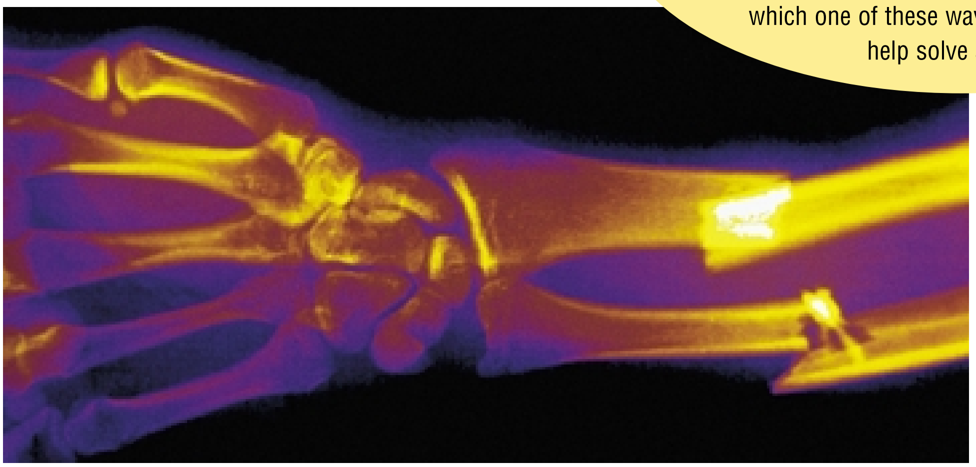


Figure 3.71 X rays are commonly used to locate a break in a bone, such as this forearm fracture.

Across Canada

Dr. Li-Hong Xu

When astronomers spot a new comet with their telescopes, University of New Brunswick physicist Dr. Li-Hong Xu knows her telephone may start ringing. Colleagues around the world will be asking her if the comet's infrared light shows the tell-tale signature of her favourite substance, methanol. In outer space, methanol can be found in clouds between stars, in the birthplaces of new stars, and in comets. The vibrations of the particles in methanol produce infrared light patterns. Dr. Xu studies these patterns with spectroscopes (instruments used to observe a spectrum of light). The results of her studies help astronomers determine how cold and thin the outer space material is.

Methanol is important not only in space, but also on Earth. For example, it is used as a race car fuel and as a raw material for making plastics. Thus, Dr. Xu also receives calls from various industries seeking her advice about applications for methanol.

Li-Hong Xu was born in Suzhou, China, a city famous for its gardens and scholars. She grew up in the turmoil of the Cultural Revolution of the late 1960s. Because of the social and political upheaval, there were often no regular classes in schools. However, Li-Hong studied on her own by borrowing textbooks from her friends' older sisters and brothers. Her advice to Canadian students is, "Take advantage of the stable environment in Canada to learn all you can. You never know whether you will get a second chance. Knowledge is a valuable possession that will accompany you throughout life."

Gamma Rays

Gamma rays, as shown in Figure 3.62 on page 249, have the shortest wavelength and the highest energy of all the waves in the electromagnetic spectrum. Gamma rays result from nuclear reactions and can kill cells. However, sometimes the ability to destroy cells is useful. When doctors discover a cancerous tumour in a patient's body, they may decide to destroy the tumour with gamma rays. This is known as **radiation therapy**.

As you have learned, visible light represents only a small part of the electromagnetic spectrum. We are surrounded by energy waves. However, many of these waves are invisible. They exist in frequencies we cannot see. Nonetheless, these invisible waves serve important roles, from transmitting music to our homes to saving lives in hospitals.

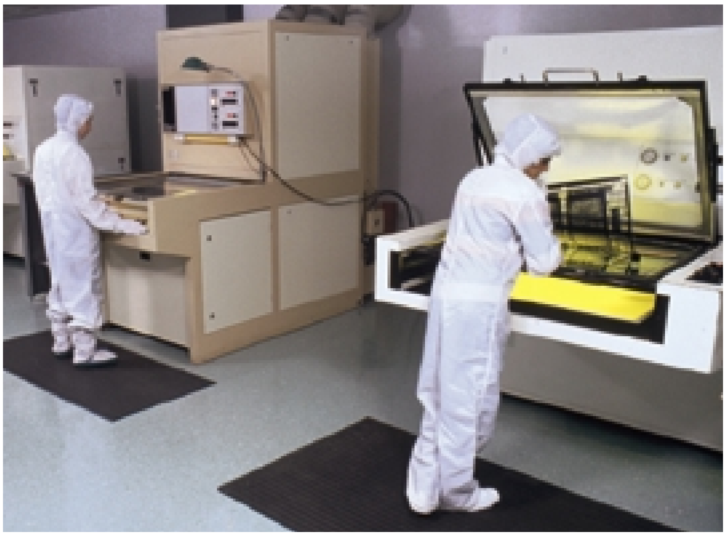


Figure 3.72 People who work with materials that give off gamma rays must wear special clothing. The clothing cannot block the gamma rays. It does, however, keep the radioactive materials off skin and clothing.

TOPIC 8 Review

1. List five types of radiation other than visible light and give a use for each type.
2. (a) Which part of the electromagnetic spectrum has the highest frequency?
   (b) Which part of the electromagnetic spectrum has the lowest frequency?
3. (a) Which type of radiation from the Sun causes tanning?
   (b) Explain why the thinning of the ozone layer is a problem.
4. **Apply** What can you do to reduce the damage to the ozone layer?
5. Convert the following to metres.
   (a) 100 nm
   (b) 900 nm
6. **Apply** Think of some potential uses for
   (a) a technology that extends night vision
   (b) a remote-imaging technology
7. **Thinking Critically** Express the numbers in question 5 above in scientific notation.

Pause& Reflect

In your Science Log, make a list of all the forms of invisible radiant energy that you have learned about, in order of increasing frequency. List one application for each form of radiant energy.

Wrap-up TOPICS 6-8

If you need to check an item, Topic numbers are provided in brackets below.

Key Terms

spectrum
solar spectrum
additive primary colours
secondary colours
rods
cones
colour blindness
complementary colours
crests
troughs
wavelength
amplitude
frequency
hertz
wave model of light
laser
incoherent
coherent
electromagnetic spectrum
infrared radiation
radio waves
microwaves
radar
ultraviolet (UV) radiation
ozone layer
X rays
gamma rays
radiation therapy

Reviewing Key Terms

1. In your notebook, match the description in column A with the correct term in column B.

A

- unit of frequency
- causes tanning
- red plus blue
- longest wavelength of the electromagnetic spectrum
- produces coherent light
- a pattern of colours in light
- longest wavelength of visible light
- produces spectra by refraction
- absorbs ultraviolet radiation
- distance from crest to crest

B

- spectrum (6, 7)
- prism (6)
- radio waves (8)
- ultraviolet radiation (8)
- ozone layer (8)
- laser (7)
- hertz (7)
- magenta (6)
- wavelength (7)
- red (6)
- gamma ray (8)
- cones (6)

Understanding Key Concepts

2. Make a drawing to show what colour you will see if you shine green light and blue light onto the same spot on a white screen. (6)

3. Describe two technological applications of the three additive primary colours. (6)

4. Explain how the human eye perceives colours. (6)

5. Describe evidence that shows that light behaves as a wave. (7)

6. Explain the difference between colours in terms of frequencies and wavelengths. (7)

7. Explain applications of light waves, such as blue skies, red sunsets, and laser light. (7)

8. Describe some technological applications associated with the different regions of the electromagnetic spectrum. (8)

9. Describe some dangers associated with the different regions of the electromagnetic spectrum. (8)

UNIT 3

Ask an Expert

Solar cells convert light from the Sun and other sources into electrical energy. Have you ever seen a solar cell? Judy Kitto has seen thousands of them. Her company, Solar Power Systems, designs and sells a wide range of solar systems. Her own house is an example of a solar home system.

Q What exactly is a solar power system?

A It's a system of solar cells built into panels connected to a battery and then to some other equipment. The solar cells provide the energy to charge the battery with electrical power, and the battery provides the electrical power to run the other equipment.

Q What kinds of systems do you design and sell?

A I've designed all kinds of systems. Farmers often want a system to power an electric fence or to pump water from a pond or river to their fields. People with cottages or homes in remote areas that have no hydro-electric service sometimes ask me to design whole-home power systems. They may be using propane or kerosene lamps for light and they may have no electric appliances, such as toasters or hair dryers. Solar power can be more convenient for them, and cheaper in the long run.

Q Can you run everything in a house on solar power?

A Well, solar power generates electricity, so technically you can do anything with it that you could do with electricity. Solar power is not always practical, though. It would take a very large, very expensive system to heat my home in the winter, for example. Our daylight hours are shortest when the weather is coldest. In other words, the time when you need the most power is the time when the least power is available. I use wood to heat my home, but solar power runs my lights and many other appliances.

Q Are your clients mostly farmers and home-owners then?

A No, I also sell systems to boat-owners to power their lights and their fishfinders. Recreational vehicle owners buy solar systems, too, because these systems allow them to park anywhere and still have electricity to cook or to turn on the lights. Recently, I devised a small solar system to churn up and aerate the water in a fish pond to keep the fish healthy.

Q Does everything stop working at night when there is no Sun?

A That's where the batteries come in. During the day, the solar panels send a lot of electrical energy to the batteries all the time. Then, when I turn on a light or make toast, I use some of the electricity stored in the battery. When I design a system, I am careful to find out how much electricity the client needs and to recommend a battery large enough to store more power than the client will probably need. Many home systems also have a backup generator that runs on gasoline. If the batteries get low, the generator comes on automatically to charge them up again.

These 18 solar panels produce 900 W of power. The panels power Judy's indoor lights, outside sensor lights, water softener, water pressure pump, washing machine, iron, microwave oven, toaster, electric garage door, satellite dish, two TVs, two VCRs, two offices, two computers, a photocopier, and a fax machine.

Q If it rains for six days straight, wouldn't the generator have to run the whole time?

A Grey, rainy days still provide some solar energy. You'd be surprised by how little light it takes to power the panels. Once, on a very clear, still night, our panels generated one amp of electricity just from the light of the full Moon!

Q How did you learn everything you need to know to design and sell a wide range of solar systems?

A Mostly, I learned about solar power from reading the product manuals. My husband and I started this business together, and at first he was the one with the electronics know-how. Then he got sick and I had to take over. I read everything I could, including all of the material written by the manufacturers of the solar products. I also had the knowledge I'd gained from living in our solar house for seven years or so. I learned more with each new system I developed. Some of my clients were sceptical at first, but they seem to be convinced, now, that I know what I'm talking about!

EXPLORING Further

Battery Bonus

Compare two solar-powered calculators, one that has a backup battery and one that does not. (Most calculators that have a backup battery will say so on the calculator itself or on its packaging. It may be called a "dual-powered" calculator.)

Try some simple equations on each of the calculators, in a brightly lit room, in a dimly lit room, and while moving from a bright area to a dim area. How much light is necessary to power the calculators? What is the advantage of having a backup battery in a calculator?

DESIGN YOUR OWN

INVESTIGATION

SKILLCHECK
- Initiating and Planning
- Performing and Recording
- Analyzing and Interpreting
- Communication and Teamwork

Testing SPF

Think About It

In recent years, you've probably heard many news reports about Earth's thinning ozone layer. These reports have highlighted how important it is to shield your skin from harmful ultraviolet rays. Shopping for sunscreen, however, can be a confusing experience. Many different brands of sunblock products are available in drugstores. These products feature a wide array of SPFs (Sun Protection Factors), ranging from 0 to 45. When buying sunscreen, you have to sort through many competing advertising claims. Is a sunscreen with a Sun Protection Factor of 45 actually three times more effective than one with a Sun Protection Factor of 15, for example?

In this investigation, your team will ask and then try to answer a question related to sunscreen products and their claims. You can use either blueprint paper (sodium azide paper) or "dia-light paper" as an indicator of ultraviolet light exposure. Both these types of paper fade quickly from yellow to white when exposed to sunlight.

Apparatus (per student or group)

several petri dishes

scissors

watch with a second hand (or other timing device)

Materials (per student or group)

approximately one-half sheet of photosensitive paper

(Note: Do not put sunscreen directly on the paper!)

at least 5 sunscreen products (ranging from SPF 0 to 45)

any other materials of your choice, depending on your experimental design

Safety Precautions

- Do not get sunscreen in your eyes.
- Be careful when using sharp objects such as scissors.
- Clean up your work area after the investigation. Dispose of waste materials as instructed by your teacher.
- Wash your hands after completing this investigation.

Initiate and Plan

1. Your team will decide on an experimental question to investigate.

2. Formulate a hypothesis or a prediction that will answer your question. Base your hypothesis on previous knowledge and on inferences arising from past observations.

3. **Design an experiment** to test your hypothesis or prediction. Use words and a sketch to explain your experimental design. Think about the order in which you should carry out the steps in your procedure. Also, decide which will be the manipulated variable(s), and which will be the responding variable(s) in your experiment. Decide on a control as well. (You might find it helpful to refer to the Experimental Design Checklist on the next page.)

4 Share your question and your experimental design in a feedback session with your teacher and with other students in your class. Be prepared to offer constructive criticism and suggestions to other teams.

Perform and Record (Test Your Hypothesis)

5 Set up and perform your experiment. If necessary, carry out second or third trials. Make any modifications to your experiment, if necessary.

6 **Gather and record** data and observations as you conduct your experiment. Decide how to record and present your data in a clear format (table, graph, diagram, etc.).

Analyze and Interpret (Draw Conclusions)

7 Draw conclusions based on the results of your experiment. Discuss your conclusions with your team.

8 Was your hypothesis supported? If so, what evidence supported it?

9 Write up a laboratory report. Be sure to include the following:

- Introduction
- Hypothesis or Prediction
- Procedure (listed step by step), including a sketch
- Data/Observations in suitable form (table, graph, etc.)
- Conclusion(s)

Experimental Design Checklist

1. Have you clearly stated the purpose of your experiment, the question you want to answer?
2. Have you written your best guess (hypothesis) about what you expect the answer will be?
3. Have you written a step-by-step procedure?
4. Have you obtained all the information you need from a variety of sources?
5. Did you make a complete list of all the materials necessary?
6. Have you identified all the variables in your experiment?
7. Identify all sources of error that you can think of in your design.
8. Did you repeat your experiment several times? How many?

Skill POWER

For tips on designing your own experiment, turn to Skill Focus 6.

UNIT 3 Review

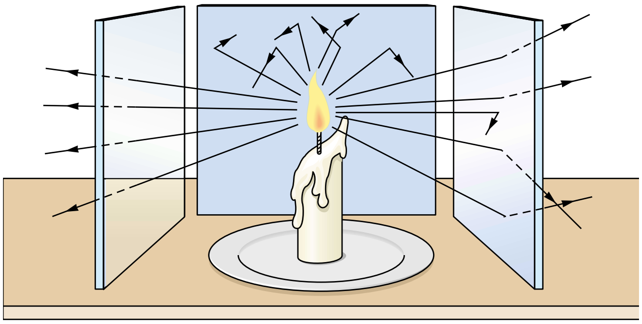
If you need to check an item, Topic numbers are provided in brackets below.

Unit at a Glance

- Light is a form of energy that is visible to the human eye.
- Light travels in straight lines.
- When light strikes a surface, it can be absorbed, transmitted, or reflected.
- Light is produced through different energy paths in incandescence, fluorescence, phosphorescence, and chemiluminescence (bioluminescence).
- Plane and curved mirrors reflect light to produce images.
- An image can be either real or virtual.
- Refraction is the bending of light as it passes from one medium into another.
- Convex and concave lenses produce images through refraction.
- Lenses form images in the human eye and in optical devices such as eyeglasses, contact lenses, cameras, telescopes, and microscopes.
- The function and structure of the human eye are similar to the structure and function of a camera.
- Mammalian eyes differ in structure and function from the eyes of many other species.
- According to the wave model of light, different colours have different frequencies and wavelengths. These wave properties produce effects such as vivid sunsets and rainbows.
- Light is a small portion of the electromagnetic spectrum, which includes radio waves, infrared radiation, ultraviolet radiation, X rays, and gamma radiation.
- New technologies such as laser surgery and remote imaging technologies can enhance human vision.
- Light-based technologies have furthered scientific knowledge, including knowledge of the nature of light itself.

Understanding Key Concepts

1. In your notebook, rewrite the following sentences correctly by unscrambling the key terms.
   - **(a)** An DESCNETINCAN bulb gives off more THEA than a FORSCEENTUL bulb. (1)
   - **(b)** The ANGEL of DENICENIC equals the ANGEL of TRECILFONE. (2)
   - **(c)** TRACIFONER is the BINGEND of THLIG. (3)
   - **(d)** The SNEL in a RACAME forms a LEAR image on the MILF.
   - **(e)** The LOW has large SILUPP to see in the dark.
   - **(f)** The three DATIVIED RAMIPRY colours are ERD, ERENG and LUBE.
   - **(g)** The distance from the middle of one STERC to the middle of the next STERC is one WEAVLTHENG.
   - **(h)** DORIA VEWAS have the longest WEAVLTHENGS.
   - **(i)** RAVIOLUTTLE radiation causes NANTING.
2. Describe what happens to light when it strikes different surfaces. (1)



3. Name two natural and some artificial sources of light. (1)

4. State which part of the human eye corresponds to each of the following parts of the camera, and explain why. (4)
   (a) the film
   (b) the diaphragm
   (c) the aperture
   (d) the lens

5. Why does your eye have a blind spot? (4)

6. You are looking at a friend. If the friend starts to move away, what must the lens in your eye do to keep the friend in sharp focus? (4)

7. If you step out of a lighted house into a dark backyard, what sudden change occurs in your eye? What is this process called? (4)

8. What happens to the size and location of the image formed by a convex lens as the object comes closer to the lens? (4)

9. List the colours in the visible spectrum in order, beginning with red. (6)

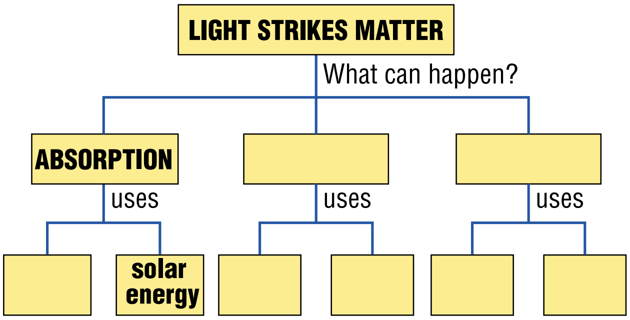
10. Which cells in the retina are responsible for detecting colour? (6)

11. How does the wavelength of a wave change if its frequency decreases? (7)

12. Identify a use for
   (a) X rays (8)
   (b) microwaves (8)

Developing Skills

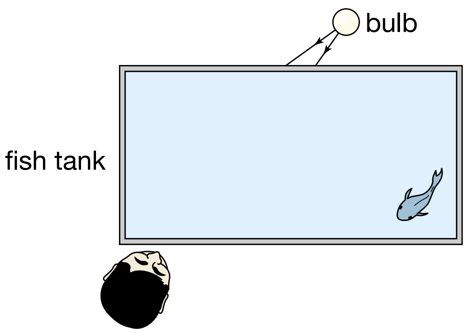
13. Copy and complete the following concept map.



14. A student who is 140 cm tall stands in front of a vertical plane mirror that is 200 cm away. The mirror is 180 cm high and stands on the floor.
   (a) Make a scale drawing of this situation, reduced to one twentieth the actual size.
   (b) Use the laws of reflection to locate the image of the head and feet of the student.

Problem Solving/Applying

15. The diagram below shows the top view of a fish tank full of water. In your notebook, draw a larger diagram similar to this one. A student looks through the tank at a small light bulb on the other side of the tank. Show the refraction of the two incident rays as they travel into the water, then back into the air. Will the student see the bulb to the left or the right of its actual position? Will the bulb seem closer or farther away? (3)



16. Give evidence to support
   (a) a wave model for light
   (b) the idea that red light has a longer wavelength than blue light

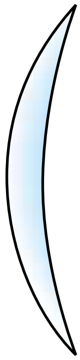
17. Using diagrams, compare and contrast
   (a) rod cells and cone cells
   (b) infrared radiation and ultraviolet radiation

18. What is the cost of burning a 100 W light bulb for a day if electrical energy costs 8¢/kW•h?

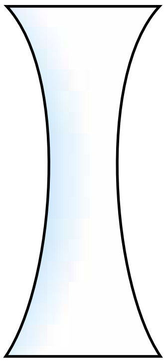
19. If electricity costs 8.0 ¢/kW•h, how much does it cost to run a 7.0 W nightlight for 10 h?

20. (a) Diagram A below shows a side view of a convex lens used as a contact lens to help someone read. Why is it designed this way?
   (b) Diagram B shows the side view of a concave lens. How could you change its shape so that one side is convex but the lens is still concave? Remember, it must remain a concave lens. What kind of vision problem do you think lens B is meant to correct?

A



B



21. Radio waves have a lower frequency than light waves. Which of the two has the shorter wavelength?

22. (a) A singer's vocal chords vibrate back and forth 1320 times in 4 s. What is the frequency of the singer's note in hertz?
   (b) A yo-yo goes up and down 10 times in 20 s. What is its frequency in hertz?

23. Find a mathematical relationship between the values for frequency and wavelength in the table on page 249. (Hint: Multiply the wavelength times the frequency for each colour.)

24. Draw an accurate diagram of a wave that has a wavelength of 6.0 cm and an amplitude of 5.0 cm.

25. What is the frequency of each of the following motions?
   (a) A bird flaps its wings 30 times in 10 s.
   (b) A dog jumps up and down 4 times in 6.0 s.

26. A magnifying lens is a convex lens used to examine tiny objects. Explain how a magnifying glass creates an enlarged image. Use a diagram in your explanation.

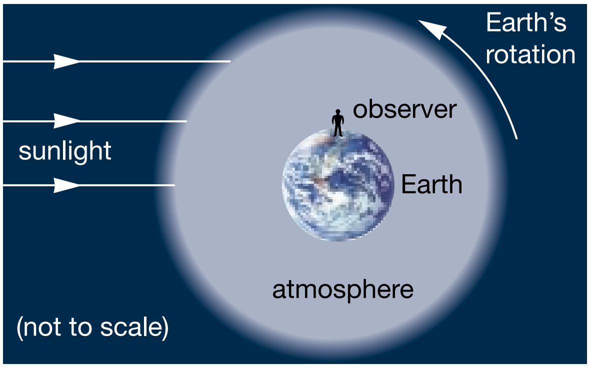
27. You are designing a telescope to study distant galaxies. What would be the main feature of your design if you wanted your telescope to gather as much light as possible? What might be some limitations on your design?

28. Imagine aliens have landed on Earth. You find out that their visual organs have only two types of colour-sensing cells. One type responds mainly to green. The other responds to blue and violet. Which colours would they see as well as we do? How could you write a secret message on paper in such a way that the aliens would not notice the message?

Critical Thinking

29. When sunlight travels from the vacuum of space into Earth's atmosphere, it slows down slightly. Why?

30. Copy the following diagram and show the bending that occurs when light enters our atmosphere. Because of this, does the Sun appear higher or lower in the sky at sunset and sunrise?



31. State three ways in which the compound microscope is similar to the refracting microscope.

32. How could you make a large image of your face seem to hover above ground in a dark foggy street?

33. The word SCIENCE has been painted on a black wall. The "S" is red, the "E"s are blue, and the rest of the letters are green. What will you see if you shine magenta light on the word? Explain your answer.

34. Your vision involves more than your sight. Explain.

35. Many optical devices are designed to create an image. To create a sharp, clear image, every ray of light that leaves a point on an object should arrive at one point on the image. Draw a simple pinhole camera with a small source of light in front of it. Draw all the rays that can leave the object and strike the back of the camera. Now draw the same pinhole camera but give it a much larger hole, like one punched by a pencil. Again, draw all the rays that can leave the object and strike the back of the camera. What is one critical requirement for a pinhole camera that makes a sharp image?

Pause& Reflect

Go back to the beginning of the unit on page 174 and check your original answers to the Focussing questions. How has your thinking changed? How would you answer these questions now that you have investigated the topics in this unit?