UNIT D

Light and Geometric Optics

Light travels through colourful stained glass windows.

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Unit Task

In this unit, you will learn about light, mirrors, and lenses and many devices that use or produce light. For your unit task, you will examine the design of streetlights. The function of streetlights is to illuminate the ground, but they waste light by also illuminating the sky. You will design a shade to reduce the light pollution streetlights cause.

Essential Question

How can we effectively use the properties of light in technological devices and procedures to enhance society?

Exploring

These doctors are examining a woman's stomach using a camera on the end of a cable that has been fed down her throat. The screen on the upper left shows the inside of her stomach.

Camera on a Pill

"Say ahhhhhhhhh..." This is an instruction your doctor might give as she peers into your throat. But no matter how wide you open your mouth, your doctor cannot see very far. To look for problems farther down the digestive tract, doctors use a camera and a tiny light on the end of a flexible cable to take pictures of the inside of your stomach and slightly beyond, as shown in the photograph above. However, the next 8 m of your digestive tract, called the small intestine, can be more difficult to reach. The small intestine is fragile and narrow, with many twists and turns. No camera on a cable can safely reach that far. This is where the "pill camera" comes in.

The wireless capsule endoscope is a device carrying a miniature digital camera that can be swallowed like a pill and will pass through your entire digestive system. The pill camera can take over 800 000 photographs during an 8-hour trip through the digestive system. The photographs are taken with flash photography, using tiny LED lights on the pill. A computer puts the photographs together like pieces of a jigsaw puzzle into a single image. These images can provide much more information than an X-ray.

The pill camera can take over 800 000 photographs during an 8-hour trip through the digestive system.

Miniature Technology

The most recent capsule endoscopes have the tiny digital camera facing out from the side of the capsule. This gives a good view of the wall of the small intestine. However, the camera can view only one part of the intestine wall at a time. For this reason, the inside of the capsule is designed so that it can spin in a complete circle. A tiny motor drives the camera and lights through a 360-degree rotation. Since the camera and lights are mounted on the inside part of the capsule, the outside part does not have to spin at all.

The capsule is just the right size so that it will pass through the small intestine without changing direction and without getting stuck. The capsule is pushed along by the same muscle contractions that move food along. It is specially designed so that it will not be attacked by stomach acids and does not irritate the sensitive lining of the intestine. The pill camera is also disposable. There is no need to recover it after it is excreted to return it to the doctor.

As amazing as this technology is, there are still more astounding optical technologies being developed for medical treatment. Optical tweezers use a laser beam to hold and move microscopic objects. Laser micro-scalpels are being refined to target individual cancer cells. Optical textiles can record and transmit a patient's heart rate and respiration to a technician in another room. Dentists may someday soon be using laser light to detect hidden cracks and early demineralization in a tooth by measuring the light and heat emitted by the tooth. Innovative technologies like these allow us to use the properties of light in new ways.

A capsule endoscope, commonly called a pill camera

D1 STSE *Science, Technology, Society, and the Environment*

Using Optical Devices

In 1610, Italian physicist Galileo pointed one of the first telescopes ever made into the night sky and discovered that Jupiter had several moons. Prior to this time, no one knew of any moons orbiting the planet. Today, using more advanced telescopes we have found 63 moons orbiting Jupiter. There may be even more moons to discover as we refine our technology.

Telescopes have given us the ability to see deeper into the universe and with more clarity than ever before. However, telescopes are not the only devices that make use of the properties of light and vision to enrich our lives. Optics is the study of the behaviour and properties of light, and many devices that we use each day involve the technology of optics.

1. In class, brainstorm and record as many optical devices as you can that have an impact on our lives. Think of medical, scientific, and personally practical items.
2. Identify and discuss how each device affects science, society, and the environment.

10 Light is part of the electromagnetic spectrum and travels in waves.

Water waves ripple outward from their source.

Skills You Will Use

In this chapter, you will:

- use appropriate terminology related to light and optics
- gather data from laboratory and other sources and record the data using appropriate formats, including tables, flowcharts, and diagrams
- communicate ideas, procedures, results, and conclusions in writing

Concepts You Will Learn

In this chapter, you will:

- describe and explain various types of light emissions
- identify and label the visible and invisible regions of the electromagnetic spectrum
- describe the properties of light and use them to explain naturally occurring optical phenomena

Why It Is Important

Investigating the properties of light can help you understand the countless ways you use light and interact with light every day.

Before Reading

Thinking Literacy

The Importance of Graphics

Graphics have several purposes in a text:

- to support our understanding of the words we read
- to add information that is not in the words
- to help us see the importance and even beauty of an object or idea

Preview this chapter, and match one graphic to each of these purposes.

Key Terms

- amplitude • bioluminescence • chemiluminescence
- electrical discharge • electroluminescence • fluorescent
- frequency • incandescent • opaque • phosphorescence
- translucent • transparent • triboluminescence
- wavelength

10.1 Light and the Electromagnetic Spectrum

Here is a summary of what you will learn in this section:

- Light is a form of energy that travels in waves.
- Properties of light, such as wavelength, amplitude, and frequency, can be explained using the wave model.
- The electromagnetic spectrum includes radio waves, microwaves, and infrared waves, which have wavelengths longer than visible light, and ultraviolet, X-rays, and gamma rays, which have wavelengths shorter than visible light.
- Different colours of the visible spectrum have different wavelengths.

Figure 10.1 Nighttime soccer

Light and Colour

It's a shot to the net! The goalkeeper leaps, the kicker holds his breath, and the crowd roars (Figure 10.1). High above, mostly unnoticed, rows of bright white lights shine down on the game. Nighttime soccer is possible because we can illuminate a stadium using lights that mimic daylight. By positioning spot lights on all sides of the playing field, it is even possible to reduce the shadows that would occur using only one or two bright lights. Multiple stadium lights reduce the shadows, and this makes both watching and playing the game much easier.

And then there are the colours. The powerful stadium lights often make colours on the field much more vivid than in regular daylight. The green of the grass appears greener, the red shirts are redder, and the ball — frozen forever in this photograph just above the goal line — is a brighter white.

How can white light allow us to see objects of so many different colours? It is because there is more to light than meets the eye. White light is actually composed of a combination of many colours — all the colours of the rainbow, in fact. From the red light of a traffic light to the amber of anti-glare glasses to the violet light used in dentistry, our world is brighter and more colourful thanks to our many sources of light (Figures 10.2 and 10.3 on the next page).

Figure 10.2 Specially coloured anti-glare glasses help people who have difficulty reading or driving at night.

Figure 10.3 A dentist uses ultraviolet light to set a filling.

D2 *Quick Lab*

What Is White Light Made Of?

Purpose

To observe the components of white light

Materials & Equipment

- ray box with one slit
- equilateral glass prism
- white paper

CAUTION: Do not shine bright light into anyone's eyes.

Procedure

1. Set the prism upright on the desk so that the rectangular sides are vertical.
2. Place the ray box about 20 cm away from the prism so that the ray shines on the prism.
3. Slowly rotate the prism. Observe the direction of light that emerges from the prism.
4. Hold a piece of white paper in the path of the light emerging from the prism about 50 cm away from the prism. Observe.
5. If you do not see anything interesting, try rotating the prism again.

Figure 10.4 An equilateral prism

Questions

6. (a) What colours did you see when light from the ray box shone through the prism?
   (b) What is the order of the colours?
   (c) How easily could you determine where one colour ended and another colour began?
7. Where do you think the colours came from in step 4?
8. Where have you seen prisms or objects that remind you of prisms in your day-to-day life?

During Reading Thinking Literacy

Graphics Support Text

Examine the graphics on this page and the next page carefully. How do the graphics support your understanding of the text explanations? Share your thoughts with a partner.

Energy in a Wave

A **wave** is a disturbance that transfers energy from one point to another without transferring matter. In a water wave, energy passes through water from one point to another as the wave rises and falls. This movement of energy allows the wave to do work. Imagine that a duck sits on the surface of a lake. The duck moves up and down with the wave, which means that the wave transfers energy to the duck (Figure 10.5). The wave moves the water up and down, but the water does not move forward with the wave. Only energy moves forward.

Figure 10.5 The duck moves up and down with the wave, but does not move forward or back as the wave passes beneath it.

Properties of Waves

Several terms will help you discuss how waves transfer energy. The highest point in a wave is called a **crest**, and the lowest point is called a **trough** (Figure 10.6 on the next page). The level of the water when there are no waves is called the **rest position**. Three important properties of all waves are wavelength, amplitude, and frequency.

- **Wavelength** is the distance from one place in a wave to the next similar place on the wave; for example, the distance from crest to crest. The standard symbol for wavelength is λ, the Greek letter lambda. Wavelength is measured in metres.
- **Amplitude** is the wave height from the rest position of the wave to the crest or the wave depth from the rest position to the trough. The energy transferred by a wave depends, in part, on its amplitude. The larger the amplitude, the more energy that is carried. The smaller the amplitude, the less energy that is carried.
- **Frequency** is the rate of repetition of a wave. Figure 10.6 shows waves passing a dock. If wave crests pass the dock 10 times in a minute, the frequency of the wave is 10 cycles/minute. The energy transferred by a wave often depends on the frequency of the wave as well as its amplitude. The higher the frequency, the more energy the wave passes along. The standard symbol for frequency is f. Frequency is usually measured in hertz (Hz), which is cycles per second.

Figure 10.6 All waves have a wavelength and amplitude.

Relationship between Frequency and Wavelength

Imagine you had a pan of water and you began gently tapping the surface of the water (Figure 10.7). You would create a series of wave crests. Suppose you made one new wave crest every second. Would it take more energy or less energy to create three wave crests every second? It would take more energy because you would need to tap much faster.

When you create more wave crests per second, the frequency of the wave increases. As the frequency increases, the crests are closer together. So, as more energy is put into making a wave, the frequency of the wave increases and the wavelength shortens. Frequency and wavelength have an inverse relationship, which means that when one value increases, the other decreases. As frequency increases, wavelength decreases. As frequency decreases, wavelength increases.

There is a mathematical relationship among the speed, v, the frequency f, and the wavelength λ of the wave: $v = f \times \lambda$. For example, if the wavelength of a wave is 10 cm and the frequency is 5 cycles/s, then the speed is 50 cm/s.

Figure 10.7 As the frequency of the wave increases, wavelength decreases.

Learning Checkpoint

1. Draw a wave and label:

(a) crest

(b) trough

(c) rest position

(d) wavelength

(e) amplitude

The Electromagnetic Spectrum

Light is a form of energy. Visible light is only a tiny fraction of the energy that surrounds us every day. We are also surrounded by invisible light-like waves, which together with visible light are called electromagnetic radiation.

Uses of the Electromagnetic Spectrum

1 **Radio waves** are the longest wavelength and lowest frequency waves. Radio waves are used to carry information around the world. Different combinations of amplitude, frequency, and wavelength are used for communications in mines, on submarines, and on aircraft.

Besides being used for radio signals, radio waves are also used for television signals, cellphones, and satellite communications for broadband Internet. Radio waves are used in magnetic resonance imaging machines (MRI) to make soft tissues appear visible and to produce an image of the part of the body being studied (Figure 10.9).

Figure 10.9 A false colour image of a brain made using MRI technology. Different colours are assigned by a computer to different types of tissue.

2 **Microwaves** have shorter wavelengths than radio waves, so they also have a higher frequency and carry more energy. When microwaves are used to heat food, they make the water particles in food vibrate, which causes the food to heat up.

Microwaves are used in radar to measure the speed of automobiles and to monitor aircraft in flight. Since microwaves can travel through clouds and can be used both day and night, they are used to map Earth and other objects from space (Figure 10.10). Microwave communications signals can be sent through Earth's atmosphere to a satellite where they are amplified and then sent back to Earth.

Figure 10.10 RADARSAT maps Earth's surface by radar, which is a type of microwave. Microwaves are also used to measure the average height of oceans and to detect changes in sea level.

3 **Infrared waves** have shorter wavelengths than microwaves but longer wavelengths than light waves. We experience infrared waves as heat. When you feel heat holding your hand close to a hot cup of tea, you are feeling infrared radiation. Images of infrared radiation are called thermograms because they produce an image based on heat (Figure 10.11).

Special equipment that can sense infrared radiation is used in burglar alarms, motion sensors, and night vision goggles. Other infrared devices provide heat to keep food warm in fast-food restaurants.

Figure 10.11 The white and yellow areas in this thermogram show the greatest heat loss from the house.

Figure 10.8 The electromagnetic spectrum

Electromagnetic radiation is a wave pattern made of electric and magnetic fields that can travel through empty space. The entire range of electromagnetic radiation extends from the shortest gamma rays to the longest radio waves and includes light. This range is called the **electromagnetic spectrum** (Figure 10.8).

Suggested Activity
D4 Quick Lab on page 390

4 **Ultraviolet rays** carry more energy than visible light and therefore have a shorter wavelength and higher frequency than visible light. The main sources of ultraviolet radiation are the Sun and other stars. A small amount of ultraviolet radiation is beneficial to human health. However, extended exposure to ultraviolet radiation can burn the skin and increase the risk of skin cancer.

Ultraviolet radiation is used to disinfect drinking water and waste water and in DNA analysis (Figure 10.12). It is also used in detective work to reveal the presence of substances that cannot be seen under visible light.

Figure 10.12 Scientists analyzing DNA over an ultraviolet light box need to wear a shield to protect their eyes from the UV light.

5 **X-rays** are very high energy radiation that can penetrate human tissues. X-rays have difficulty passing through bone, making them useful for medical imaging. X-rays are also used as a security measure to scan luggage at airports. The rays pass through the clothes in the luggage but are absorbed by metal or hard plastic objects. Another use for X-rays is photographing the inside of engines, pipelines, and other machines to check for fractures or damage (Figure 10.13).

Figure 10.13 A photograph of the inside of binoculars taken with X-rays

6 **Gamma rays** are extremely high energy radiation that can penetrate human tissues. Gamma rays are used to sterilize medical equipment. Doctors use short bursts of gamma rays from different angles in order to kill a maximum number of cancerous cells and a minimum number of healthy cells. Technicians who work with high energy waves such as X-rays and gamma rays must wear a shield, such as a lead apron, to protect themselves from radiation. Gamma rays are produced within our galaxy and in other galaxies by phenomena such as neutron stars and black holes (Figure 10.14).

Figure 10.14 A map of the universe made using gamma rays

The Wave Model of Light

An important part of science is developing models. A **model** is a representation of an object, event, or a process based on our observations of its characteristics and properties. A **property** is an attribute common to all substances or objects of the same group. We use models to help us understand complex concepts.

Light can be modelled and compared with water waves. Both light and water waves can transfer energy, and they both travel outward in all directions from their source. In the **wave model of light**, we use similarities between light and the movement of waves on the surface of water to explain several properties of light that we can see. For example, Figure 10.15 shows what happens when sunlight or white light is shone through a prism. A **prism** is a transparent glass or plastic object with flat, polished sides (Figure 10.16). The light separates into the colours of the rainbow, including red, orange, yellow, green, blue, and violet. The range of different colours of light is called the **visible spectrum**.

Figure 10.15 A prism separates light into the colours of the rainbow.

Figure 10.16 The visible spectrum

The colours of the visible spectrum can be explained using the wave model. The difference between colours of light is that each colour has a different wavelength and frequency. Red light has the longest wavelength and lowest frequency in visible light. Violet light has the shortest wavelength and highest frequency in visible light (Table 10.1 and Figure 10.17 on the next page).

Table 10.1 Approximate Frequency and Wavelength of Colours

Colour	Frequency (Hz)	Wavelength (nm)
red	4.3×10^{14}	700
orange	5.0×10^{14}	600
yellow	5.2×10^{14}	580
green	5.7×10^{14}	550
blue	6.4×10^{14}	450
violet	7.5×10^{14}	400

Figure 10.17 The visible spectrum has red light at one end, violet light at the other end, and all the other colours in between. Red light has a relatively long wavelength of 700 nm (nanometres) while violet light has a shorter wavelength of about 400 nm. A nanometre is one-billionth of a metre, so 700 nm is 0.000 000 7 m.

Additive Colour Theory of Light

The **additive colour theory** of light states that white light is composed of different colours (wavelengths) of light. It is possible to produce white light by combining only three colours. One such combination is red, green, and blue. These three colours of light are known as primary colours. If you mix correct amounts of all three primary colours of light, you will make white light (Figure 10.18(a)). If you mix only two of the primary colours together, you will make a secondary colour. The secondary colours of light for red, green, and blue are magenta, yellow, and cyan as shown in Figure 10.18(b).

Figure 10.18 (a) All three primary colours together produce white light. (b)The three primary colours of light are red, green, and blue. When paired, they can create three secondary colours: magenta, yellow, and cyan.

Figure 10.19 The subtractive theory applies to pigments and dyes. It is the opposite of the additive theory of light.

Subtractive Colour Theory of Light

When a light wave strikes an object, some wavelengths of light **reflect**, which means that they bounce off the object. Other wavelengths are absorbed by the object. The colour you see when you look at an object depends on the wavelengths that are reflected. For example, a red rose reflects red wavelengths of light and absorbs other colours.

According to the **subtractive colour theory** of light, coloured matter selectively absorbs different colours or wavelengths of light. The colours that are absorbed are "subtracted" from the reflected light that is seen by the eye. A black object absorbs all colours, whereas a white object reflects all colours. A blue object reflects blue and absorbs all other colours.

The primary and secondary colours of light for the subtractive theory are opposite to the colours of the additive theory (Figure 10.19). Cyan, magenta, and yellow are the primary subtractive colours, while red, green, and blue are the secondary subtractive colours.

Suggested Activity
D3 Quick Lab on page 389

It is important to remember that the subtractive theory of light applies to pigments and the colours that they absorb. A pigment is a powder used to colour substances. If a colour is absorbed, it will not make it to your eye. You only see the reflected colours (Figure 10.20). Paint and pigment manufacturers mix all three of the primary subtractive colours in varying degrees to make any range of colours reflect from a surface. The printing press that produced this book used the three primary subtractive colours to create all the pictures you see.

Figure 10.20 How subtractive colours reflect light

Take It Further

Inkjet printers employ subtractive colour technology. Refill ink cartridges come in cyan, magenta, and yellow. Find out more about how inkjet printers apply the three inks to a page to create all possible colours. Begin your research at *ScienceSource*.

Learning Checkpoint

1. What property of a light wave determines the colour of the light?
2. List the six general categories of colour from the longest wavelength to the shortest wavelength.
3. What is the visible spectrum?
4. What does the additive colour theory of light state?
5. What does the subtractive colour theory of light state?

D3 Quick Lab

Component Colours of Light

Purpose

To experiment with the component colours of light using subtractive colour theory

Materials & Equipment

- red, green, blue colour filters
- computer screen or LCD projector

Procedure

1. Make an observation table like the following for recording your observations. Give your table a title.

	Colour of Circle on Screen		
Filter Colour	**Yellow Circle Appears**	**Cyan Circle Appears**	**Magenta Circle Appears**
Red			
Green			
Blue			

2. Your teacher will display three coloured circles on the computer screen of the primary subtractive colours of yellow, cyan, and magenta.
3. Hold up the red filter in front of your eyes as you look at the three circles on the screen. Record the colour that each circle appears to be. Be as accurate with your description of the colour as possible. Fill in the row for the red filter in your observation table.
4. Repeat step 3 with the green filter.
5. Repeat step 3 with the blue filter.
6. Optional: At a computer terminal, launch the picture editing application indicated to you by your teacher. On a new document, create a circle and fill it with any colour, then open the colour editing dialogue box and adjust the settings to the values indicated in Table 10.2. Record the colour you see.

Table 10.2 Picture Editing Colour Levels

Colour Level			
Red	**Green**	**Blue**	**Colour Produced**
255	0	0	
0	255	0	
0	0	255	
0	255	255	
255	0	255	
255	255	0	

Questions

7. The transparent colour filters act like pigments to block certain colours and allow only one colour to reach your eyes. State what colours are blocked by the:
   (a) red filter
   (b) green filter
   (c) blue filter
8. If a colour becomes black while viewing it through a coloured filter, what does that tell you about the colour(s) of light reaching your eyes?
9. If a colour appears washed out while viewing it through a coloured filter, what does that tell you about the colour(s) of light reaching your eyes?
10. Explain your observations for step 3.
11. Explain your observations for step 4.
12. Explain your observations for step 5.
13. Optional: Compare the colours created in step 6 to Figure 10.19 on the previous page. Were the colours you created on the monitor the same as the colours shown in the illustration? Explain.

D4 Quick Lab

Seeing the Invisible (Teacher Demonstration)

Purpose

To observe evidence of ultraviolet and infrared radiation and to examine protection from ultraviolet radiation

Materials & Equipment

- infrared-based remote controller
- digital camera
- black light
- Canadian currency note
- yellow felt pen
- paper
- yellow highlighter
- SPF 25 or greater sunblock
- vegetable oil

CAUTION: Do not look at the black light for long periods of time.

Procedure

Part 1 — Infrared Controller

1. Locate the part of the infrared remote controller that produces the infrared signal. Verify that the signal it transmits is invisible to the unaided eye.
2. Point the controller at a digital camera and view the controller in operation through the camera display. What do you see? Record your observations in your notebook.

Part 2 — Black Lights

3. Black lights release as much radiation as a regular light, but most of the radiation is in the form of ultraviolet radiation, which is invisible to humans. Hold a Canadian currency note up to the black light. What do you see? Record your observations in your notebook.

Part 3 — Sunblock

4. Using the yellow felt pen, draw three circles about 3 cm in diameter on a sheet of paper and colour them in. Label the series of circles "felt pen."
5. Using a yellow highlighter, make three more circles the same size and colour them in. Label them "highlighter."
6. Cover one "highlighter" and one "felt pen" circle with SPF 25 or greater sunblock.
7. Cover another "highlighter" and "felt pen" circle with vegetable oil.
8. Leave the remaining two circles untreated.
9. Use the black light to shine radiation on all of the yellow circles. Record your observations in your notebook.

Questions

10. In Part 1, the digital camera detected radiation in the infrared region of the spectrum and then displayed it in the visible spectrum. Did the visible radiation have a longer or a shorter wavelength than the radiation that was produced by the controller? Explain.
11. (a) Explain how the markings on the currency note that were invisible in ordinary light became visible under a black light in Part 2.
    (b) How might a black light be used to determine whether a currency note is a forgery?
12. (a) Briefly describe each of the circles in Part 3 as they appeared under black light.
    (b) What was the reason for leaving two circles untreated?
    (c) What was the reason for covering two circles with oil?
    (d) Explain why both a felt pen and a highlighter pen were used in this activity.
13. You may have observed that the camera and the remote control allowed you to "see" ultraviolet and infrared rays, light that is usually invisible to the human eye. How was this possible?

10.1 CHECK and REFLECT

Key Concept Review

1. (a) Draw a wave that has a wavelength of 3 cm and an amplitude of 1 cm.
   (b) Label the amplitude and the wavelength of the wave in (a).
   (c) Draw and label the rest position of the wave in (a).
   (d) Label the crest and the trough of the wave in (a).
2. Explain the term "frequency" as it applies to a wave.
3. What is electromagnetic radiation?
4. (a) List three types of radiation of the invisible spectrum that have wavelengths longer than visible light.
   (b) Name one application for each of these three types of radiation.
5. (a) List three types of radiation of the invisible spectrum that have wavelengths shorter than visible light.
   (b) Name one application for each of these three types of radiation.
6. What properties of light does the wave model of light explain?
7. Identify six general categories of colour of the visible spectrum, from highest frequency to lowest frequency.
8. Compare red light with blue light.
   (a) Which has the longer wavelength?
   (b) Which has the higher frequency?

Connect Your Understanding

9. During a theatrical play, red and green spotlights overlap. Explain the colour audience members will see where the spotlights overlap.
10. (a) What are two ways in which radio waves and X-rays are similar?
    (b) What are two ways in which radio waves and X-rays are different?
11. (a) Which poses more of a danger to human health, very long wavelength radiation or very short wavelength radiation?
    (b) Explain why.
12. A balloon appears yellow when seen in white light. Explain the colour it will appear in:
    (a) green light
    (b) magenta light
13. Many houses in warm climates have white walls and roofs, like the one in this photo. Explain why this is a wise choice.

Question 13

14. A huge problem facing aid workers in tropical disaster areas is providing safe drinking water. Scientists are testing a simple idea: fill a clear plastic water bottle with water, put on the cap, and let it sit in direct sunlight for a day.
    (a) Explain why this idea might work.
    (b) Discuss the advantages and disadvantages of this method over boiling water or adding chemicals.

Reflection

15. Describe three ideas from this section that you are interested in learning more about.

For more questions, go to *ScienceSource*.

10.2 Producing Visible Light

Here is a summary of what you will learn in this section:

- Fluorescent light bulbs use much less energy than incandescent light bulbs to produce the same amount of light.
- In both fluorescent and phosphorescent light, a phosphor glows after being exposed to energized particles.
- Chemiluminescence, including bioluminescence, produces cool light from a chemical reaction.
- An electric current passing through a gas or a solid can produce light.

Figure 10.21 In the deep, dark ocean water, this jellyfish uses its light to attract fish, which become trapped in the jellyfish's tentacles.

WORDS MATTER

"Bioluminescence" comes from the Greek word *bios*, meaning living, and the Latin word *lumen*, meaning light.

Lighting Up the Deep

The most important natural source of light on Earth is the Sun. There are, however, other natural sources of light, such as light from other stars, fire, and lightning. Light is also produced by some plants and animals.

The ability of a plant or animal to produce light is called **bioluminescence**. Some algae, jellyfish, insects, crustaceans, bacteria, earthworms, and fungi produce light by bioluminescence (Figure 10.21).

Bioluminescence is very common among sea creatures. In fact, 90 percent of all sea creatures are bioluminescent. Fish that live deep in the ocean have to create their own light because no sunlight can reach that far down. They use their light to find prey, scare off predators, attract mates, or to camouflage themselves. Some fish produce their own light, while others have bacteria that carry out the light-producing chemical reaction for them.

The black sea dragon and the angler fish have a special long spine with a bulb as a lure, attracting smaller fish into their waiting jaws (Figure 10.22). Flashlight fish use their light to help keep their school together as they swim. They can quickly turn off their light if a predator approaches.

Figure 10.22 Angler fish

If you have ever walked through a meadow on a warm summer evening, you may have seen flickering light produced by fireflies. Fireflies attract mates by flashing light in a specific pattern. Fireflies produce their light by a chemical reaction (Figure 10.23).

Figure 10.23 Fireflies emit light from a light-producing organ in their abdomen.

D5 *Quick Lab*

Sources of Light Emission (Teacher Demonstration)

Purpose

To observe several methods of producing light

Materials & Equipment

Some or all of:

- light bulb connected to a dimmer switch
- beaker
- tonic water
- overhead projector
- black light
- pliers
- wintergreen candy
- glow-in-the-dark paints
- plasma ball

CAUTION: Do not shine bright light into anyone's eyes. Incandescent light sources can become very hot. Do not touch the bulbs or block air flow around the light bulbs. Keep all electrical devices and metals away from the plasma ball.

Figure 10.24 A plasma ball

Procedure

1. Work with a partner or in your group to predict all the possible sources that can produce light. Record your predictions in your notebook.
2. Observe as your teacher demonstrates various sources of light. After each demonstration, record your answer for questions 3 and 4.

   Sample Demonstrations

   A. A clear light bulb containing a filament is connected to a dimmer switch. Observe as the switch is turned up and down.

   B. Fill the beaker with tonic water, and place it on an overhead projector. Hold a black light near the beaker. Then, apply clear sunscreen to the outside of the beaker and hold the black light near the beaker again.

   C. Use a pair of pliers to crush wintergreen-flavoured candy in a darkened room.

   D. Use glow-in-the-dark paints to write a message on a piece of paper. Hold the paper near a light source. Remove the light source, darken the room, and observe the message.

   E. Turn on a plasma ball, and touch it.

Questions

3. For each demonstration, was the light produced by high temperature, electricity, chemical reaction, or some combination of these?
4. For each demonstration, explain in a sentence or two why or how light is produced.
5. Return to your predictions from step 1. How do the sources of light demonstrated apply to your predictions in step 1?

Sources of Light

Light produced by the Sun or other stars is called natural light. Light produced through human technology is called artificial light. Think about how many times you flip on a switch and the light immediately comes on. In most cases, the light bulb that lights up is either a fluorescent bulb or an incandescent bulb.

Incandescent Light

WORDS MATTER

"Incandescent" has its roots in the Latin word *incandescere*, which means to become white with heat.

Incandescent light is light that is produced by an object, such as a metal, that is at a very high temperature. Inside an incandescent light bulb is a filament, which is a thin piece of wire (Figure 10.25(a)). When you turn on an incandescent bulb, electric current flows through the filament, heating it to an extremely high temperature. The filament emits light as a way to release some of its energy. The light you see from an incandescent bulb is the filament glowing.

Incandescent bulbs are extremely inefficient. Only 5 percent of the electrical energy used in an incandescent light bulb is converted to light. The rest of the energy is released as heat. Because they waste more energy than fluorescent lights, incandescent bulbs are being eliminated from widespread use.

Figure 10.25 (a) An incandescent bulb and (b) a compact fluorescent bulb. The fluorescent bulb uses a quarter the energy of the incandescent bulb but contains more toxic materials than an incandescent bulb.

Fluorescent Light

Fluorescent light is light emitted by some substances when they are exposed to electromagnetic radiation. A fluorescent light bulb is a glass tube filled with a small amount of a gas such as mercury vapour. The inside of the bulb is coated with a white powder called a phosphor. A **phosphor** is a substance that glows after being exposed to energized particles. As electric current passes through a fluorescent bulb, it energizes the atoms in the gas, which then emit ultraviolet radiation. The ultraviolet radiation strikes the phosphor on the inside of the bulb, which then glows and emits light (Figure 10.25(b)). Compact fluorescent light bulbs are much more efficient than incandescent light bulbs, but they still release up to 80 percent of their energy as heat (Figure 10.26).

Figure 10.26 A researcher testing the endurance of fluorescent light tubes

Phosphorescent Light

In fluorescent lights, the phosphor emits light only while it is exposed to ultraviolet radiation. However, some substances have the ability to store energy from radiation. **Phosphorescence** is the ability to store the energy from a source of light and then emit it slowly over a long period. Phosphorescent materials glow in the dark for some time after being energized by light (Figure 10.27). The light from glow-in-the-dark objects eventually fades, but it can be re-energized if the object is held close to a light source for a few minutes.

Figure 10.27 This glow-in-the-dark toy emits light by phosphorescence.

Chemiluminescence

Chemiluminescence is light produced from a chemical reaction without a rise in temperature. Because the chemical reaction gives off very little heat, the light produced is sometimes referred to as cool light. All forms of bioluminescence are special kinds of chemiluminescence.

An example of chemiluminescence is the light produced in glow sticks (Figure 10.28). Chemiluminescence is also used in analyzing crime scenes. Investigators use a chemical called luminol to detect traces of blood because the chemical glows when it reacts with the iron found in blood (Figure 10.29).

Figure 10.29 Luminol makes a blood stain glow in the dark.

Figure 10.28 A glow stick is activated when the stick is bent. This action breaks a glass vial inside the stick and allows two chemicals to mix and react.

Learning Checkpoint

1. What do all incandescent materials have in common to cause them to emit light?
2. What percentage of electrical energy used in an incandescent light bulb is converted to light?
3. How is the ultraviolet radiation produced in a fluorescent light transformed into visible light?
4. What is phosphorescence?
5. Why is chemiluminescence sometimes referred to as cool light?

During Reading Thinking Literacy

Get the Picture

Even without an accompanying photograph, good readers use words to make pictures in their minds. Read the passage describing triboluminescence. Try to see the examples vividly in your mind.

Triboluminescence

Producing light from friction is called **triboluminescence**. Some crystals can be made to glow simply by rubbing them together or crushing them. The Ute Aboriginal people of Utah and Colorado traditionally made ceremonial rattles containing 30 pieces of quartz. The rattle was made of thin buffalo hide to permit flashes of light to pass through. Triboluminescence can also be produced by breaking apart sugar crystals or rubbing a diamond (Figure 10.30).

WORDS MATTER

"Triboluminescence" comes from the Greek word *tribein*, meaning to rub, and the Latin word *lumen*, meaning light.

Figure 10.30 This faint light was produced by crushing a wintergreen candy with a hammer.

Electric Discharge

An **electric discharge** is a method for producing light in which an electric current passes through the air or another gas, such as neon (Figure 10.31). Lightning is one example of an electric discharge. Just as a bolt of lightning can light up the sky, carbon-arc light sources can be used to produce searchlights with beams so powerful that their light can reflect off of the bottoms of high clouds. A carbon-arc light involves passing an electric current through the air, or another gas, between two carbon rods (Figure 10.32).

Figure 10.31 When electricity is discharged through the element neon, which is a gas, the neon glows intensely.

Figure 10.32 Carbon arc lighting was once used in lighthouses.

Light-Emitting Diode (LED)

The process of transforming electrical energy directly into light energy is called **electroluminescence**. Electroluminescent devices consume much less energy than sources such as fluorescent devices. A **light-emitting diode** (LED) is an electroluminescent light source made out of a material called a semiconductor. A semiconductor is a material that can be made to change how well it conducts electricity. Some semiconductors can be made to emit light when a small electric current is passed through them.

LEDs do not have a filament. Instead, they are solid materials. This makes them very rugged, because they do not contain any delicate parts (Figure 10.33). In fact, some LED devices from the 1960s are still operating today. Because they can operate using small amounts of electricity, LEDs are very efficient producers of light and radiate very little heat. LEDs are used in many places, such as in electronic billboards, traffic lights, decorative lights, and handheld displays (Figure 10.34). LEDs can also replace incandescent and fluorescent light bulbs, conserving energy and lasting a longer time. For example, LEDs can light up much faster than incandescent bulbs, so LEDs are often used for rear brake lights in automobiles. Their faster lighting time means that the driver following the automobile has more time to react and avoid an accident.

Figure 10.33 An LED is a device that produces large amounts of light from very little energy input.

Figure 10.34 LEDs provide the backlight for many handheld devices.

OLEDs

An **organic light-emitting display** (OLED) is a light source made of several extremely thin layers of organic molecules that use an electric current to produce light. An OLED is made of thousands of individual organic light-emitting diodes that use different organic molecules to emit different colours of light. OLEDs use less energy than some other displays because they do not require a backlight to function. They are thinner, lighter, brighter, and more flexible (Figure 10.35). In fact, they are so flexible that OLEDs can be rolled up or embedded in fabrics or clothing. OLED technology has potential application in small screens such as cellphones, medical equipment, and head-mounted displays, and in large screens, such as television and computer screens. OLEDs are more expensive to produce than some other displays and are easily damaged by water, but these disadvantages are diminishing as their design continues to be refined.

Figure 10.35 A researcher holds a panel of organic light-emitting diodes.

Figure 10.36 Plasma screens use fluorescence to emit light.

Plasma Displays

Many large-screen televisions use a technology called a plasma display, which can produce brighter images than an LCD display but requires much more electrical power to operate (Figure 10.36). In a **plasma display**, each colour is a tiny fluorescent light in which an electrical signal causes a gas, such as neon, to release ultraviolet radiation. The ultraviolet radiation is absorbed by phosphors that then radiate light in the visible spectrum. Different phosphors are used to produce red, green, and blue light. By varying the brightness of each primary colour, millions of colours can be produced.

Figure 10.37 A light micrograph of a colour LCD screen, magnification 20× at 6 × 7 cm

Liquid Crystal Displays

Laptop computers, digital watches, cellphones, iPods, and many flat-panel television sets use a different technology than plasma displays and LEDs. In a **liquid crystal display** (LCD), a white light, such as a fluorescent light or light-emitting diode, shines behind a liquid crystal. A **liquid crystal** is a solid that can change the orientation of its molecules like a liquid, but only when electricity is applied. The crystal can block light or transmit light depending on how much electricity is applied to it. Red, green, and blue filters are placed in front of the crystal to produce these colours. A special filter called a polarizing filter blocks the red, blue, or green colours in any combination to produce any colour of light. In Figure 10.37, each tiny square of colour is called a pixel.

Since liquid crystal displays work by blocking light, the white light that shines behind the crystals is always on, and just like blinds that cover a window, the crystal does not block all the light coming through. For this reason, the black in LCDs does not appear completely black, but only dark grey.

Suggested STSE Activity
D6 Decision-Making Analysis on page 399

Suggested Activity
D7 Quick Lab on page 400

Learning Checkpoint

1. What term is used to describe light produced by friction?
2. How does an electric discharge produce light?
3. One of the main components of a light-emitting diode is a semiconductor. What is a semiconductor?
4. What happens in each tiny fluorescent light in a plasma display?
5. What is a liquid crystal?

D6 STSE *Decision-Making Analysis* Skills Reference 4

SKILLS YOU WILL USE
- Organizing information from research
- Drawing conclusions

Is a Plasma Television or an LCD Television Better for the Environment?

Figure 10.38 (a) Plasma screen and (b) LCD screen. Each type of screen has advantages and disadvantages.

Issue

What is on tonight? In Canada, the answer is sure to be a lot of televisions. Most Canadian homes have one or more televisions, and unlike many small or portable electronic devices, televisions can use a considerable amount of electrical energy. This means that by consuming electricity, televisions are significant producers of greenhouse gases. Televisions may also contain toxic and difficult to recycle materials,

The environmental impact of a particular type of television can vary depending on how large its screen is and how often it is used. Which kind of television is best for the environment?

Background Information

There are different types of televisions depending on what technology is used to make the display screen. Two very common recent technologies are plasma and liquid crystal display (LCD). Each type has its advantages and disadvantages, and there may not be just one correct answer when it comes to which is more eco-friendly.

The biggest advantage of LCD televisions may be that they last up to twice as long as other types. LCD televisions are lighter weight and thinner, and they consume less energy than a plasma type. However, the largest LCD screens use significantly more energy than smaller ones. The biggest disadvantage of LCD televisions may be in their components. LCD components use both mercury and nitrogen trifluoride (NF_3), a gas that is over 10 000 times more potent a greenhouse gas than carbon dioxide. Currently, the amount of NF_3 being added to the atmosphere is about equal to the amount of other greenhouse gases being added from operating two million cars.

Plasma televisions are often used in very large displays and are known for a sharp and detailed picture. They have a wide viewing angle so they can be seen more easily from the side. Also, black appears darker on plasma screens. Some plasma televisions use up to 30% less power than other plasma brands of the same screen size. Power consumption increases greatly with screen size, more than other style displays. For example, a very large living room plasma display may consume more than four times more energy than that of a traditional picture tube television. The electricity bill is correspondingly higher as well. Some types of plasma screen include lead in their components.

Analyze and Evaluate

Your task is to compare plasma versus LCD televisions in terms of which is better for the environment. The most eco-friendly choice might be to not have a television at all, especially one with a very large screen. Complete the following steps in your analysis.

1. ***ScienceSource*** Update the background information given above. Look for new technologies that might be better than plasma or LCD displays. If so, then you will need to explain why they are better. Manufacturing processes change. For example, LCD manufacture that does not involve mercury is currently being developed.
2. Make a list in point form of advantages and disadvantages of each technology.

Skill Practice

3. Make a list of ways you or your family make use of television and what features in a television you think are important for the way you use one.
4. Make a conclusion about whether your family wishes to use a television and, if so, what kind is best for you.

D7 Quick Lab

Analyzing Light Sources

Figure 10.39 Diffraction grating glasses

Diffraction grating glasses (Figure 10.39) are useful for analyzing and comparing the light produced by various sources. The glasses function much like a prism, splitting light into its spectrum of component colours.

Purpose

To analyze the light from various sources using diffraction grating glasses

Materials & Equipment

- diffraction grating glasses
- paper
- overhead projector
- pencil crayons
- various light sources including bright white light; red, green, and blue LEDs; fluorescent light; coloured and clear, low power incandescent bulbs

CAUTION: Do not shine bright light into anyone's eyes. Incandescent light sources can become very hot. Do not touch the bulbs or block air flow around them.

Procedure

1. Put on the diffraction grating glasses. To become familiar with the images produced by diffraction grating glasses, look at the light from one of the regular lighting fixtures in the room. Record your observations. If there are multiple images, describe how they are arranged. Record how many different colours are visible and whether the spectrum is distinct or fuzzy.
2. Using four sheets of opaque paper, cover most of the top of an overhead projector, leaving a 2 cm × 2 cm region uncovered. Project this onto a screen. Darken the room. The projected image should look like a bright, tiny white dot. Observe the dot through your diffraction grating glasses.
   (a) Compare what you see here with what you observed in step 1. How are your observations similar? How do they differ?
   (b) Observe the colours that are present in the spectrum. What colours are most intense?
   (c) Using pencil crayons, draw one spectrum showing the relative amounts of each colour.
3. Examine a fluorescent light using diffraction grating glasses.
   (a) How does the fluorescent light spectrum differ from the lights in step 1 and step 2?
   (b) Draw the spectrum.
4. Examine each of the red, green, and blue LEDs. Observe their spectra.
   (a) Are any of the LEDs purely one colour with no other colours in their spectrums?
   (b) Was there one colour that seemed to be present in all of the LEDs more than any other? If so, what colour was it?
   (c) Draw each spectrum.

Questions

5. (a) Decide which of the white lights you observed were the most and least pleasant to light a room with. Explain what aspect of the light source made it pleasant or unpleasant for you.
   (b) Compare the spectra of each light source, and suggest which parts of the spectra seem most responsible for producing a pleasant or unpleasant lighting effect.

10.2 CHECK and REFLECT

Key Concept Review

1. (a) What are two examples of natural light?
   (b) What are two examples of artificial light?
2. Why could light bulbs be called heat bulbs?
3. How is the light in an incandescent light bulb produced?
4. How is the light in a compact fluorescent light bulb produced?
5. Why are incandescent light bulbs being eliminated from widespread use?
6. State what percentage of electrical energy is converted to light energy in:
   (a) an incandescent bulb
   (b) a compact fluorescent bulb
7. What type of light is produced by a glow-in-the-dark object?
8. What are three examples of chemiluminescence?
9. What is the term used to describe the process in which light is produced by rubbing materials together?
10. (a) How does an electric discharge produce light?
    (b) What is one example in nature of light produced by electric discharge?
    (c) What is one example of artificial light produced by electric discharge?
11. What is a light-emitting diode?
12. What is electroluminescence?
13. (a) What does LED stand for?
    (b) What are three advantages of LEDs?
14. (a) What does LCD stand for?
    (b) What is a drawback of plasma displays compared to LCD displays?

Connect Your Understanding

15. Why is it important to consider how energy efficient a light bulb is when making a decision about which light bulb to purchase?
16. The model in the photograph below is wearing makeup that contains phosphors. The phosphors release ultraviolet radiation under special lights called black lights. Is this an example of fluorescence or phosphorescence? Explain your answer.

Question 16

17. Suggest several ways to provide emergency lighting where you need it if the power goes out. Consider factors such as brightness, duration, and cost.

Reflection

18. (a) Describe one concept from this section that you found easy to understand.
    (b) Why you think it was easy for you to understand?
    (c) Describe one concept from this section that you found challenging to understand.

For more questions, go to *ScienceSource*.

10.3 The Ray Model of Light

Here is a summary of what you will learn in this section:

- The ray model illustrates many properties of light including how light interacts with matter.
- Opaque objects block light, forming a shadow.
- Transparent materials transmit light freely.
- Translucent materials transmit light but obscure the image.
- Regular reflection transmits an image and occurs when light hits a smooth surface. Reflection from a rough surface produces diffuse reflection.

Figure 10.40 A glass window transmits light and reflects light.

Interacting with Light

Have you ever been window-shopping on a bright day? The glare from the glass can make it difficult to see the display behind the window. Window glare is light that is reflected toward you from the outside surface of the glass. You may have had to cup your hands around your eyes in order to see into the store. When you do this, you block out the reflecting sunlight with your hands. Reduce the glare, and suddenly you can see inside the store.

You may have noticed a similar problem with glare when reading a glossy magazine. If you hold the magazine at a certain angle, light reflects off the page and makes it difficult to read. Change the angle of the magazine a little, and the words and pictures are visible once again.

Most people deal with glare by adjusting how they are viewing the object. You make adjustments automatically because you are used to light behaving in regular, predictable ways. In fact, most of us know many of the properties of light without ever having studied light formally. For example, we can usually tell something about a surface just by observing the way light interacts with it. In Figure 10.40, the sharp, clear image in the reflection tells us that the glass is flat and highly polished. A line of glare running down a magazine page tells us the paper is gently curved.

Predicting the Behaviour of Light

The behaviour of light is so familiar to most of us that we can make good predictions about situations we may never have been in. For example, Figure 10.41 is an underwater photograph looking up toward the surface of the water. Even if you have never swum before, your general experience with light would help you to figure out where the Sun is located in the photograph and to predict that the surface of the water is uneven.

To find the Sun, we use our understanding that light tends to travel in straight lines, so we can follow the light rays back to the source. At the bright spots on the surface, more light is passing into the water. At the darker spots, more light is being reflected away. From this, we conclude that the surface of the water is uneven.

Figure 10.41 Light travels in straight lines in the water.

D8 *Quick Lab*

Does a Plane Mirror Reverse Left and Right?

Purpose

To examine images in a plane mirror

Materials & Equipment

- paper
- plane mirror
- masking tape
- (optional) video camera and display

Procedure

1. Write your name on a piece of paper. Observe what that looks like when you view its reflection in the plane mirror.
2. Print a short, clear message. Have your partner attempt to read the message only by looking at its reflection.
3. Look into the mirror and, while looking only at the mirror, try to write the letters "ABCDE" so that the image in the mirror does not appear reversed. Are some letters more difficult to write than others? If so, why?

Questions

4. Use the masking tape to label the left side of the mirror "L" for left. Then, hold your right hand up to the mirror so that the palm of your hand reflects in the mirror. The thumb of your right hand should be closest to the masking tape marked "L". Look at the image in the mirror. Is the thumb in the reflection closer to the masking tape marked "L" or to the other side of the mirror? Do objects that are actually on your left side appear in the reflection on your left side or on your right side?
5. (Optional) If your class has access to a video camera and display, try viewing yourself in the display and performing various actions. Begin by touching your nose with a finger, and then, looking at the display, touching your left eyebrow. Try combing your hair. Which is easier, working with a mirror image or with your unreflected image as displayed by a camera? Explain why.

Light and Matter

In the **ray model of light**, light is represented as straight lines called rays, which show the direction that light travels. Ray diagrams are drawings that show the path that light takes after it leaves its source (Figure 10.42). Each ray ends with an arrow to indicate the direction of travel. Ray diagrams can help explain why the brightness of a light changes with distance. The more rays that reach your eyes, the brighter the object appears (Figure 10.43).

Figure 10.42 Light rays travel away from a light source in every direction. To show all the light rays, you would have to show an infinite number of arrows, not just a few rays as in this figure.

Figure 10.43 Fewer light rays reach your eyes when you are farther from a light source.

You can use ray diagrams to help you describe what happens when light strikes an object. Light travels in straight lines until it strikes something. Some materials let the light pass through — they transmit light. Some materials absorb light, and other materials reflect light. The properties of the matter in an object determine what happens to the light. Materials may be classified according to how they transmit, absorb, and reflect light (Figure 10.44 and Figure 10.45 on the next page).

- **Transparent** materials, such as clear glass or clear plastic, transmit light freely as shown in Figure 10.44(a). Transparent materials absorb and reflect very little light. That is why you can see clearly through a window pane.
- **Translucent** materials transmit some light, but not enough to see through the material clearly, as shown in Figure 10.44(b). A frosted window pane is a good example of a translucent material. Some light can pass through, but you cannot see what is on the other side of the frosted glass in any detail.
- **Opaque** objects absorb and reflect light, but they do not transmit it, as shown in Figure 10.44(c).

Figure 10.44 (a) The transparent glass allows light to pass through freely. (b) The translucent glass allows only some light to pass through. (c) The opaque glass prevents light from passing through.

Figure 10.45 Ray diagrams show how light is affected by transparent, opaque, and translucent materials.

Shadows

You can use ray diagrams to help explain the size and location of shadows and why some shadows are sharp and well defined while other shadows have less distinct edges. A shadow occurs when an opaque object blocks the direct light from a light source. A ray diagram illustrates how the size of a shadow depends on the size of the object blocking the light and its distance from the light source (Figure 10.46).

Figure 10.46 The shadow is larger if the object is closer to the light source.

A small light source casts shadows that are sharp and well defined. If the light source is large compared to the object blocking the light, then the shadows will not have a sharp edge, because the object only partly blocks the light. The wider the light source is, the more blurred the shadows will be. The **umbra** is the part of the shadow in which all light rays from the light source are blocked. The area of partial shadow from a non-point light source is called the **penumbra**. A ray diagram can show why some shadows form with a penumbra (Figure 10.47).

Figure 10.47 A ray diagram illustrates how the umbra and penumbra form in a shadow when the light source is not a point.

Light Reflection

Suggested Activities
- D10 Quick Lab on page 407
- D11 inquiry Activity on page 408

You can see this book and other objects around you because light reflects off surfaces. Incoming rays travel parallel to one another. In **regular reflection**, the light rays strike a smooth surface and reflect in the same direction, staying parallel to one another. All the rays are reflected at the same angle, so when these reflected rays reach your eyes, they are almost the same as before they were reflected, as shown in Figure 10.48(a). When regular reflection occurs, it is possible to see an image in the reflection.

(a) (b)

Figure 10.48 (a) Regular reflection and (b) diffuse reflection

However, even objects that do not reflect an image can still reflect light. For example, although the pages of this book appear smooth, they are rough enough to cause light to be scattered in many directions. When light rays reflect off a rough or uneven surface, they do not remain parallel but are scattered in different directions, resulting in a **diffuse reflection** as shown in Figure 10.48(b). Because the light is scattered, you can see the page from almost any angle.

Take It Further

During a full lunar eclipse, Earth casts a shadow over the Moon. However, the Moon does not disappear from view. Instead, it appears orange or red. Find out why. Begin your research at *ScienceSource*.

Learning Checkpoint

1. How does a transparent object interact with light?
2. How does a translucent object interact with light?
3. How does an opaque object interact with light?
4. What is diffuse reflection?

D9 STSE Science, Technology, Society, and the Environment

How Do You Choose a Sun Protection Product?

The Sun protection factor (SPF) of a skin product is a measure of how well the product absorbs UV-B rays, which are the Sun's rays that can burn your skin. SPF of 10 means that you could stay out in the Sun before getting a sunburn 10 times longer than you could if you had no protection.

1. What does SPF of 25 on a skin product indicate?
2. As a consumer, why is it important to pay attention to more than just the SPF printed on the label?
3. If you could make a sunscreen that only reflected UV rays or only absorbed UV rays, explain which type you would make and why.

D10 Quick Lab

Some Properties of Light

Purpose

To use the behaviour of light to classify materials

Materials & Equipment

- ray box
- wax paper
- block of wax
- block of wood
- clear triangular glass prism
- plane mirror
- frosted glass
- bubbles from bubble-blowing liquid
- DVD
- paper

CAUTION: Do not shine bright light into anyone's eyes. Incandescent light sources can become very hot. Do not touch the bulbs or block air flow around the light bulb.

Procedure

1. Make a table of observations using the headings below. Give your table a title.

Material	Reflection (regular, diffuse or none)	Other Properties (transparent, translucent, opaque, etc.)

2. Hold the wax paper upright on your desk while your partner next to you shines a light on it. Observe whether it reflects the light and, if so, whether the reflection is regular or diffuse. Record your observations in the second column of the table.
3. While the light is still shining on the wax paper, look at the other side of it to determine if it is translucent, transparent, or opaque. Record your observations in the third column of the table.
4. If the wax paper exhibits any unexpected properties, indicate "other" in the third column and briefly describe the properties.
5. Repeat steps 2 through 4 for all the other materials in the table.

Questions

6. Which materials exhibited the following properties?
   (a) opaque
   (b) transparent
   (c) translucent
   (d) reflective
   (e) regular reflection
   (f) diffuse reflection
7. (a) Which materials exhibited other properties?
   (b) Describe each property.
8. Compare how the prism interacted with light to how the DVD interacted with light.
   (a) How were they similar?
   (b) How were they different?
9. How can you use the behaviour of light to classify materials?
10. Figure 10.45 is a micrograph showing a paper towel at a magnification of 150× at 10 cm. What does the micrograph show about the way that a paper towel reflects light?

Figure 10.49 Photomicrograph of the surface of a paper towel (magnification 150X)

D11 *Inquiry Activity*

Skill Reference 2

SKILLS YOU WILL USE
- Observing and recording observations
- Interpreting data/information to identify patterns or relationships

Shadows and Rays

Question

How can you use ray diagrams to predict the size and shape of shadows created by opaque objects?

Materials & Equipment

- a bright light source, such as a ray box, flashlight, or overhead projector
- triangle, rectangle, or similar shape cut from cardboard
- retort stand and clamp
- chart paper to trace on
- adhesive tape
- pencil/marker
- material to simulate light rays, such as drinking straws attached end to end, metre sticks, or wooden dowels

CAUTION: Do not shine bright light into anyone's eyes. Incandescent light sources can become very hot. Do not touch the bulbs or block air flow around the light bulbs.

Procedure

1. Work with a partner. Tape a sheet of chart paper to the wall. Set up the light source about 2 m from the wall, shining toward the paper.
2. Cut a triangle or other shape from cardboard, and calculate its area. Mount the triangle on the retort stand, and place it between the light and the wall, 1 m from the wall. Call this position the reference position (Figure 10.50).

Figure 10.50 Step 2

3. Trace the shadow of the triangle on the chart paper. Calculate the area of the shadow you have traced.
4. Create several straight simulated light rays. Attach one end of the simulated rays to the light source and the other end to the edges of the shadow. The "light rays" should just touch the edge of your triangle as they pass.
5. Sketch the arrangement of the light source, simulated light rays, triangle, and shadow. Record the distances separating the light source, triangle, and shadow.
6. Move the triangle closer or farther away from the wall. Adjust your "light rays" so that they still touch the triangle as they pass. Predict whether the shadow size will increase or decrease based on the new locations of the rays.
7. Test your prediction by turning on the light source. Record the new distances and areas.
8. Repeat steps 6 and 7 to create two sets of data: one with your triangle placed closer to the light source than the reference position, and one with your triangle placed farther from the light source than the reference position.

Analyzing and Interpreting

9. What can you generally (qualitatively) say about the distance between a light source and an object and the shadow it casts?
10. What can you say about the edge of the shadow on your paper when the object is farthest from the source compared with when it is closest to the source? Is it as well defined in both positions?

Skill Practice

11. Would the same results be achieved if the object's position stayed the same but the position of the light source changed? Explain.

Forming Conclusions

12. Describe how you can use ray diagrams to predict the size and shape of shadows created by opaque objects.

10.3 CHECK and REFLECT

Key Concept Review

1. What is the ray model of light?
2. Draw a simple ray diagram of light rays travelling out from a light bulb.
3. What are two properties of light that you can show using a ray diagram?
4. What three things can happen when light strikes an object?
5. Use a labelled ray diagram to show the difference between transparent, translucent, and opaque objects.
6. What determines how light rays behave when they strike an object?
7. Describe how a penumbra differs from an umbra, using the ray model of light.
8. (a) What is the difference between regular reflection and diffuse reflection?
   (b) Give an example of each type of reflection.
9. Look at the photograph of the water below. What is the best description of the property of this water: opaque, transparent, or translucent? Explain your answer.

Question 9

10. Use the ray model of light to show light as it approaches, passes through, and is reflected off a glass surface.

Connect Your Understanding

11. A basketball does not give off light. Explain with the aid of a ray diagram how you are able to see a basketball.
12. Explain why a piece of metal would make a better reflector than a piece of wood.
13. Explain, with the help of ray diagrams, why the shadow created by your hand on a wall grows larger when you move your hand toward the light source.
14. Under what conditions can a transparent material become translucent or even opaque?
15. A spotlight shines on an actor on a stage. Describe the type of shadow the actor is likely to cast.
16. Explain why you agree or disagree with the following statement: No object is perfectly transparent or perfectly opaque.
17. In terms of subtractive light theory, explain why some objects are considered opaque.
18. One style of solar collector panel for domestic hot water consists of a sheet of glass on top, a sheet of black painted metal on the bottom, and water flowing between. Describe the steps of what happens to sunlight striking such a panel.

Reflection

19. Why do you think it is important in your life to understand how light interacts with matter?

For more questions, go to *ScienceSource*.

Investigating CAREERS in Science

Great CANADIANS in Science — Willard S. Boyle

Figure 10.51 Willard S. Boyle

Figure 10.52 A charge-coupled device, part of the Keck telescope in Hawaii

Digital cameras and camcorders are very common in our modern world but if it had not been for the invention of the charge-coupled device (CCD), they might not exist today.

You can find a CCD in a wide range of imaging products, such as camcorders, cellphone cameras, telescopes, and imaging satellites. If you compare a camera to a human eye, then the CCD is like the retina at the back of the eye that turns the image focussed onto its surface into a digital picture. CCDs work by converting light, X-rays, ultraviolet rays, or infrared waves into a pattern of electric charges on a silicon chip. The charges are then converted into an image file, doing away with a need for film.

Today, a less expensive technology replaces the CCD in most consumer electronics, but in devices where the very best picture is needed, like astronomical telescopes, CCDs are used (Figure 10.52).

The CCD was invented in 1969 at Bell Labs, a world-famous research facility, by a brilliant Canadian scientist — Willard S. Boyle (Figure 10.51).

Boyle earned a PhD in physics from McGill University in 1950. Three years later, he began working at Bell Labs in New Jersey.

Bell Labs recruited the best and brightest research scientists from all over the world. Boyle quickly distinguished himself by finding a way to make lasers produce a continuous beam of light instead of operating in bursts, which until then was the only way they worked.

In 1969, along with a colleague, George E. Smith, Boyle was given the task of exploring new areas of solid state physics. They invented the CCD, and very quickly the scientific community and electronic companies showed interest. The age of digital image processing was born.

Questions

1. Why is the CCD such an important invention?
2. ***ScienceSource*** Find out how CCDs are used in the Keck telescope and other optical telescopes.

Science in My FUTURE Optician

Figure 10.53 An optician assists customers in selecting eyeglasses.

The job of an optician is a dual one. It is to help people to see better and at the same time to look good. Prescription eyewear spans the worlds of both fashion and health care. An optician is trained in both and more.

As an optician, you would have a career as a certified health care professional with two to three years of post-secondary training. Your job is primarily to provide eyewear for persons who have completed an eye exam with a physician or optometrist (Figure 10.53). While the prescribing physician is concerned exclusively with medical aspects of vision care, your task is to help meet both the vision requirements given in the prescription and the individual needs and preferences of the customer. You may also find yourself supervising or managing the activities of other opticians or student opticians.

The most common form of corrective eyewear is eyeglasses. Contact lenses run a close second. Other forms include special prosthetic devices to help people with special vision needs. As a highly qualified technician, you would be trained in all forms of vision care technologies.

Opticians apply their knowledge on a daily basis to order, inspect, and custom fit prescription eyewear.

There are many aspects to an optician's job. While you help to ensure vision requirements are met, your customer may be much more interested in finding the right pair of frames. You will often be called upon to help judge a customer's new look.

Opticians can work in a variety of environments. Many opticians operate their own small businesses. Some opticians work in more specialized care centres such as hospitals. Other opticians specialize in grinding lenses and cutting them into frames.

A successful optician definitely needs to enjoy working one-on-one with people of all ages and from all walks of life. Part of your training will include being able to explain technical information in clear, straightforward ways to non-technical people. Customers will depend on you to be able to instruct them in the care and handling of equipment such as contact lenses. You will need to enjoy listening to the needs and concerns of customers. As the population of Ontario ages, the need for corrective eyewear and opticians is expected to grow.

To become an optician, you will need to complete a two- or three-year college program in ophthalmic dispensing including an apprenticeship, which is often a co-op placement. The practical experience is needed to meet the requirements of being able to register as a member the College of Opticians as well as prepare you for licensing exams. The licence is a requirement for working as an optician in most provinces of Canada.

Questions

1. List three highly technical aspects of the role of an optician and also three non-technical aspects.
2. ***ScienceSource*** Find out the difference between these related professions: optician, optometrist, and ophthalmologist.

10 CHAPTER REVIEW

ACHIEVEMENT CHART CATEGORIES

- (k) Knowledge and understanding
- (t) Thinking and investigation
- (c) Communication
- (a) Application

Key Concept Review

1. What two models are used to describe how light behaves? (k)
2. What is the difference between a crest and a trough in a wave? (k)
3. What is the resting position of a wave? (k)
4. What is the difference between amplitude and wavelength? (k)
5. (a) Sketch the electromagnetic spectrum, labelling seven general types of radiation. (k)
   (b) List two technological applications of each form of radiation. (k)
6. Why does a dental technician put a lead apron over you when you are getting dental X-rays? (k)
7. List the main categories of colour of the visible spectrum in order from the longest wavelength to the shortest wavelength. (k)
8. What is produced when all colours of visible light are combined? (k)
9. Use labelled diagrams to explain how each secondary colour of light is formed. (c)
10. (a) What is the minimum number of colours needed to produce white light? (k)
    (b) Give one example of a combination of colours that will combine to produce white light. (k)
11. Describe how light is produced in a fluorescent bulb. (k)
12. (a) Which colours are absorbed in a green object? (k)
    (b) Which colours are reflected from a green object? (k)
13. Classify each of the following types of light according to its source. (k)
    (a) firefly
    (b) lightning
    (c) glow stick
14. (a) State seven ways that light can be produced. (k)
    (b) Give an example of an application of each type of light production. (k)
15. How is the size of a shadow related to the distance of the object from the light source? (k)
16. (a) What three terms are used to describe how light behaves when it strikes matter? (k)
    (b) Draw and label a ray diagram explaining each term. (k)
17. Is a glow-in-the-dark dial on a watch or clock an example of phosphorescence or fluorescence? Explain your answer. (k)

Question 17

Connect Your Understanding

18. Use the wave model of light to explain the difference between infrared light and ultraviolet radiation. (t)

19. Explain why it is not possible to increase both the frequency and the wavelength of a wave at the same time. (t)

20. Black light (shown below) refers to any light source that produces primarily ultraviolet radiation.

(a) Provide a possible reason why it is called black light. (a)

(b) Describe a use for black light. (a)

Question 20

21. (a) Write a sentence that describes the relationship between the energy of electromagnetic radiation and its frequency. (c)

(b) Write a sentence that describes the relationship between the energy of electromagnetic radiation and its wavelength. (c)

22. What is a possible disadvantage of using fluorescent bulbs? (t)

23. Provide two reasons why an LED would be a preferable light source to an incandescent or fluorescent light bulb. (a)

24. Describe the conditions necessary to create a penumbra. (t)

25. Draw a flowchart that shows the steps of how a plasma screen creates a display of colours. (c)

26. Give two reasons why a plasma display might be preferable to an LCD display. (a)

27. If white light produced from the primary colours red, green, and blue reflects off a yellow surface and then passes through a prism, what colours will be present? (a)

28. Explain why a colour inkjet printer can still print black characters even when its black ink cartridge has run out. (a)

29. Describe why a photographer or film producer would want the lighting director to use two or more lights in most of the scenes being photographed. (a)

Reflection

30. What can you explain about light and its properties that you were not able to explain before reading this chapter? (c)

After Reading

Thinking Literacy

Reflect and Evaluate

How do graphics help you to understand text? Write a one-paragraph explanation for struggling readers to summarize how graphics can help them to understand new ideas and information. Exchange paragraphs with a partner, and revise your suggestions based on new ideas from your partner's paragraph.

Unit Task Link

Look at streetlights in your neighborhood to see what kind of light pollution they create. Think about ways that this light pollution could be reduced by using a shade over the light. Will the material you use be transparent, translucent, or opaque? Research streetlights that reduce light pollution. Start your research at ***ScienceSource***.

11 Ray diagrams model the behaviour of light in mirrors and lenses.

Buildings reflected in an Amsterdam canal

Skills You Will Use

In this chapter, you will:

- investigate the laws of reflection using plane and curved mirrors
- predict characteristics of images formed by mirrors and test those predictions
- investigate the refraction of light
- use ray diagrams and equations to predict position and characteristics of images formed by lenses
- calculate the velocity of light as it refracts through different media

Concepts You Will Learn

In this chapter, you will:

- describe images formed by mirrors and lenses
- explain partial and total reflection and refraction
- identify the factors that affect refraction as light passes from one medium to another

Why It Is Important

Our understanding of light as a ray that travels in a straight line has led to the invention of mirrors and lenses that perform a variety of functions. Learning about light will help you understand, select, and use optical devices and vision aids.

Before Reading

Thinking Literacy

Reading Diagrams

Diagrams provide a lot of information, often in a small format. You may have to read diagrams differently from word text. Skim this chapter, and preview the diagrams. How are they similar to and different from each other? What are some important features that may help you to understand diagrams?

Key Terms

• angle of incidence • angle of reflection • angle of refraction • concave • convex • focal length • focal point • magnification • mirage • normal refraction • virtual image

11.1 Mirrors

Here is a summary of what you will learn in this section:

- The angle of incidence equals the angle of reflection.
- Plane mirrors produce a virtual image that is upright and located as far behind the mirror as the reflected object is in front of it.
- Concave mirrors produce an enlarged, upright, virtual image if the object is closer to the mirror than the focal point.
- Concave mirrors produce an inverted, real image if the object is farther away from the mirror than the focal point.
- Convex mirrors produce an upright, virtual image that is smaller than the object.

Figure 11.1 The stainless steel mirror above Viganella is controlled by computer to follow the path of the Sun.

Figure 11.2 The construction of the mirror

Brightening a Winter's Day

Summer in the Italian village of Viganella high in the Italian Alps is peaceful, warm, and above all — sunny. But winter is another story. As the hours of daylight shrink each autumn and the Sun spends less and less time above the horizon each passing day, Viganella loses its direct view of the Sun. Viganella is located at the bottom of a steep valley, and every winter the mountains block out the Sun's rays from November 11 to February 2. During this time, the village is completely in the mountain's shadow.

But thanks to the science of optics, that situation has now changed. In 2006, a large flat mirror was placed at the top of one of the nearby mountains and directed at the village square (Figure 11.1). Airlifted into position with a helicopter at a total cost of about $170 000, the 5 m × 8 m rectangular sheet of stainless steel is perched high above Viganella (Figure 11.2).

The mirror is controlled by computer so that as the Sun moves across the sky each winter day, the mirror always reflects into the village. Residents and tourists need not fear that the mirror will set them aflame or fry them into crisps, even on a hot summer's day. There is no magnifying-glass effect in which sunlight is focussed to a point. The mirror is flat, so that the Sun's rays are reflected without being concentrated.

Our understanding of how to control light for applications such as the mirror in Viganella is based on the orderly way that light reflects. The science of how light reflects and bends is called **geometric optics**.

D12 *Quick Lab*

Mirror Images

Purpose

To observe and count the number of reflections you can see in two plane mirrors

Materials & Equipment

- 2 plane mirrors
- tape
- felt pen
- protractor
- paper clip

Figure 11.3 Handle glass mirrors carefully.

Procedure

1. Place two mirrors together so that their reflective surfaces face each other. Attach the tape so that the mirrors can open into a "V" shape (Figure 11.3).
2. Use the felt pen to label the mirrors as R for right and L for left.
3. Using a protractor, set the mirrors on a sheet of white paper open to an angle of 72°.
4. Bend a paper clip so that it will stand up, and place it in front of the right mirror.
5. Look into the mirrors, and count the number of images of the paper clip that you can see in each of the mirrors. Record your results.
6. Increase the angle between the mirrors to 90°. Observe and record the number of images of the paper clip you see in each mirror.
7. Open the mirrors even wider, to 120°. Observe and record the number of images of the paper clip you see in each mirror.

Question

8. What is the relationship between the angle of separation of the two mirrors and the number of reflections that you see?

During Reading Thinking Literacy

Diagrams Require Special Reading Techniques

You cannot always read diagrams the way you read words, left to right and top to bottom. Look at the whole diagram first. Then, read the caption, and look again at the diagram. Let your eye follow the flow of the diagram. Are there arrows? Are there labels? What do they tell you? After examining the diagram, make notes about what you learned from it.

The Law of Reflection

Smooth, shiny surfaces like calm water, mirrors, glass, and even polished metal allow you to see an image. The smoother the surface is, the better the image will be. An **image** is a reproduction of an object produced by an optical device like a mirror. An **optical device** is any technology that uses light.

Light rays bounce off a mirror in a similar way to how a hockey puck bounces off the boards of an ice rink. To understand how light behaves when it reflects off a mirror, it helps to look at the reflection of a single ray of light in a ray diagram (Figure 11.4).

Figure 11.4 If the angle of incidence equals 45°, then the angle of reflection is also 45°.

WORDS MATTER

The word normal comes from the Latin word *norma*, meaning a carpenter's square.

The dashed line drawn perpendicular to the mirror at the point of reflection represents an imaginary line called the **normal**. The incoming ray is called the **incident ray**. The angle between the incident ray and the normal is called the **angle of incidence**, labelled i. The angle between the reflected ray and the normal is called the **angle of reflection**, labelled r. The relationship of these two angles is one of the most important properties of light, called the **law of reflection**:

> When light reflects off a surface, the angle of incidence is always equal to the angle of reflection.

Figure 11.5 The mirrors in a bicycle tail light reflect headlight beams back to the driver of the car that sent them.

Although the law of reflection may appear very simple, it is also very useful. For example, the law of reflection is used to design reflective tail lights for bicycles. A tail light is designed to reflect light from the headlights of the car behind it. This helps to make the bicycle more visible to the driver of the car. The ray diagram in Figure 11.5 shows how two mirrors arranged at an angle of 90° can use two reflections to send reflected rays back in the same direction as the incident rays, no matter where the incident rays come from. In each reflection, the angle of incidence equals the angle of reflection.

Using the Law of Reflection

The law of reflection can be written using mathematical symbols. The Greek letter theta, θ, is commonly used as the symbol for an angle. Subscripts are used to identify the angle. If the angle of incidence is θ_i and the angle of reflection is written as θ_r, then the law of reflection is:

$$\theta_i = \theta_r$$

The angle of incidence and the angle of reflection are always measured from the normal and not from the surface of the object. This is because some surfaces are curved, making it difficult to measure an angle from the surface.

Suggested Activity
D13 Quick Lab on page 428

Plane Mirrors

The law of reflection applies to light rays reflected from both flat mirrors and curved mirrors. Any mirror that has a flat reflective surface is called a **plane mirror**. When you look into a plane mirror, your image appears to be as far behind the mirror as you are in front of it. In fact, the mirror may appear to be a kind of glass window. However, it is not possible to catch this image on a piece of paper placed behind the mirror, since no light from the object reaches this point. Because the light rays are not coming from where your image appears to be, we say that your image in a plane mirror is a virtual image. A **virtual image** is any image formed by rays that do not actually pass through the location of the image (Figure 11.7 below).

Figure 11.6 Reverse printing will be read normally when viewed in a mirror.

Image Orientation in a Plane Mirror

When you look in a mirror, your left hand appears to be a right hand. If you hold a textbook up to a mirror, you will notice that the text appears to be reversed. Sometimes, emergency vehicles are labelled in reverse printing so their signs can be read in a car's rear-view mirror, as in Figure 11.6.

The ray diagram in Figure 11.7 shows why this happens. To understand how the image forms, we draw a few rays from various points on the girl's face, and reflect them into her eyes. There is only one rule — the rays must follow the law of reflection. Once we have done this, we have shown the actual path of the light rays.

What does the girl see? To find out, we can extend the reflected rays back in a straight line behind the mirror to form the virtual image. So when the girl looks in the mirror, the image of her right eye is directly in front of her right eye in the virtual image. If she lifted her left arm, the arm in the virtual image would lift directly in front of it. The virtual image is an exact reflection of the real object.

Figure 11.7 A ray diagram shows how a virtual image forms in a plane mirror.

Suggested Activity
D16 Problem-Solving Activity on page 432

Learning Checkpoint

1. What is the difference between a reflected ray and an incident ray?
2. (a) What does the law of reflection state in words?
   (b) Write the law of reflection using mathematical symbols.
3. What is a plane mirror?
4. What is a virtual image?

Curved Mirrors

Figure 11.8 A reflection produced by a mirror with several curves

The strange image you see in a funhouse mirror is produced by a mirror that has flat, outward-curved, and inward-curved sections in it as shown in Figure 11.8. While they may be fun to look at, mirrors with multiple curves have no real practical uses. However, mirrors with a single curvature find many uses in our homes and optical devices. Two types of curved mirrors are concave (converging) and convex (diverging).

Curved Mirror Terminology

Like plane mirrors, curved mirrors obey the law of reflection. However, when parallel light rays strike a curved surface, each ray of light will reflect at a slightly different position. All of these rays eventually meet at a common point. The point where light rays meet, or appear to meet, is called the **focal point**, F (Figure 11.9).

The middle point of a curved mirror is called the **vertex**. The principal axis is an imaginary line drawn through the vertex, perpendicular to the surface of the curved mirror. The distance between the vertex and the object is represented by d_o. The distance between the vertex and the image is d_i. The height of the object is h_o, and the height of the image is h_i.

The **focal length**, f, is the distance from the vertex to the focal point of a curved mirror. If the object is farther away from the mirror than the focal point, the reflected rays form a real image. A **real image** is an image formed by light rays that converge at the location of the image. If you place a piece of paper at the spot where a real image forms, a focussed image would appear on the paper or screen. If the screen were moved slightly, the image would appear blurred because the reflected rays would not be converging at the screen's new location.

Figure 11.9 A ray diagram for a converging mirror

Concave Mirrors

A **concave mirror**, also called a **converging mirror**, has a surface that curves inward like a bowl (Figure 11.10). The image formed by a concave mirror depends on how far the object is from the focal point of the mirror. If the object is far away from the focal point, the reflected rays form an inverted image as shown in Table 11.1. The closer the object gets to the focal point, the larger the image becomes. If the object is between the focal point and the mirror, like the bird in Figure 11.11, the image becomes upright and enlarged. When the object is exactly at the focal point, all rays that leave the object reverse direction at the mirror and are reflected away from the mirror parallel to each other. In this case, no image is formed.

Figure 11.10 Parallel light rays approaching a concave mirror.

Figure 11.11 A virtual image produced by a converging mirror. The bird is between the focal point and the mirror so the virtual image is larger than the real bird.

Table 11.1 Ray Diagrams for Concave Mirrors

Distance of Object from Mirror, d_o	Type of Image Formed	How the Image Is Viewed	Ray Diagram
Object is more than two focal lengths.	Smaller than object, inverted, real	The mirror can project an image on a screen placed in front of the mirror.	
Object is between one and two focal lengths.	Larger than object, inverted, real	The mirror can project an image on a screen placed in front of the mirror.	
Object is at focal point.	No image is formed.	No image is formed.	
Object is between mirror and focal point.	Larger than object, upright, virtual	Viewer looks into the mirror to see the image.	

Drawing a Concave Mirror Ray Diagram

When you draw ray diagrams, you can sketch in the object or use an upright arrow to represent the object, as shown in Figure 11.12. Show real rays as solid lines. Use dashed lines to present virtual rays, which are rays that only appear to exist behind the mirror. Follow the steps in Figure 11.12 to draw a ray diagram of a concave mirror.

Figure 11.12 Concave mirror ray diagram

1. The first ray of a concave mirror ray diagram travels from a point on the object parallel to the principal axis (ray 1). Any ray that is parallel to the principal axis will reflect through the focal point on a converging mirror.
2. The second ray travels from a point on the object toward the focal point (ray 2). Any ray that passes through the focal point on a converging mirror will be reflected back parallel to the principal axis.
3. Draw the real image where the rays intersect.

Some Uses for Concave Mirrors

Concave mirrors are specially designed to collect light and bring it to a single point. This is why concave mirrors are used in telescopes to collect light rays from a great distance and bring them together.

Can concave mirrors be used to send out beams of light rays as well? Imagine that a bright light were placed at the focal point of a concave mirror and allowed to shine into the mirror in Figure 11.10 on the previous page. By reversing the direction of the arrows in the ray diagram, you can see that the light rays would leave the mirror as parallel rays. That is why you will find concave mirrors in flashlights, car headlights, dental examination lights, and other applications (Table 11.2).

Figure 11.13 The concave mirror for the Hubble telescope is being prepared for launch into space.

Table 11.2 Some Uses of Concave Mirrors

Device	Use of Concave Mirror
Flashlight	To produce a parallel beam
Telescope	To collect light from a distant source and focus it for viewing
Cosmetic mirror	To produce an enlarged image
Headlights of a car	To produce a parallel beam of light that can be directed down (low beam) or straight ahead (high beam)

Solar Ovens

A **solar oven**, also called a solar cooker, is a device that uses light from the Sun as its energy source. A solar oven transforms sunlight directly into heat that can be used for cooking or boiling water (Figures 11.14 and 11.15). By making use of solar energy, precious resources can be saved. For example, trees are scarce in the Himalayas and using solar energy instead of wood for heat helps preserve forests.

A solar oven uses several strategies for producing heat, such as using a concave mirror to concentrate the Sun's rays, converting light to heat through absorption if the interior of the oven is a dark colour, and using a clear cover so that the Sun's rays can enter but very little heat can leave. The most efficient ovens create an insulated space where the food is cooked.

Figure 11.14 A man examines a solar oven that is heating water in Ladakh, high in the Himalayan Mountains.

Figure 11.15 This solar oven is located on a city rooftop.

Calculating Magnification

Concave mirrors have a number of uses including magnification. **Magnification** is the measure of how much larger or smaller an image is compared with the object itself. The magnification of an image, as compared with the object, may be the same size, enlarged, or diminished (smaller). Magnification is expressed as a ratio of the height of the image to the height of the object.

$$\text{magnification} = \frac{\text{image height}}{\text{object height}} \quad \text{or} \quad M = \frac{h_i}{h_o}$$

Magnification can also be determined by taking the ratio of the distance from the image to the mirror and the distance from the object to the mirror.

Suggested Activity
D15 Inquiry Activity on page 430

$$\text{magnification} = \frac{\text{image distance}}{\text{object distance}} \quad \text{or} \quad M = \frac{d_i}{d_o}$$

These are very general definitions of magnification. You can use either formula to determine magnification. Be sure to use the same units for both heights or both distances in the calculation. However, no units are required in the answer since the units cancel out during the calculation. If the image is bigger than the object, then the magnification will be greater than 1. If the image is smaller than the object, the magnification will be less than 1.

Practice Problems

1. A microscope produces an image that is 1.00×10^{-4} m high from an object that is 4.00×10^{-7} m high. What is the magnification of the microscope?
2. A concave mirror produces an image on a wall that is 30.0 cm high from an object that is 6.5 cm high. What is the magnification of the mirror?
3. A pinhole camera produces a 2.34×10^{-2} m image of a building that is actually 50.0 m high. What is the magnification of the camera?

Example Problem 11.1

A microscope produces an image that is 5.50×10^{-4} m high from an object that is 2.00×10^{-6} m high. What is the magnification of this microscope?

Given

Object height $h_o = 2.00 \times 10^{-6}$ m

Image height $h_i = 5.50 \times 10^{-4}$ m

Required

Magnification $M = ?$

Analysis and Solution

The correct equation is $M = \dfrac{h_i}{h_o}$

Substitute the values and their units, and solve the problem.

$$M = \frac{h_i}{h_o}$$

$$M = \frac{5.5 \times 10^{-4}\ \text{m}}{2.00 \times 10^{-6}\ \text{m}}$$

$$= 275$$

Paraphrase

The magnification of the microscope is 275 times.

Practice Problems

1. An object is placed 75 cm from a concave mirror. A real image is produced 50 cm away. What is the magnification?
2. A person standing 3.00 m from a glass window sees her virtual image 3.00 m on the other side. What is the magnification of the window?
3. A camera creates a real image of a tree 40 m away. The image is formed 3.0 cm behind the lens. Find the magnification.

Example Problem 11.2

A candle is placed 22 cm from a concave mirror. A virtual image is produced 53 cm from the mirror. What is the magnification?

Given

Object distance $d_o = 22$ cm

Image distance $d_i = 53$ cm

Required

Magnification $M = ?$

Analysis and Solution

The correct equation is $M = \dfrac{d_i}{d_o}$

Substitute the values and their units, and solve the problem.

$$M = \frac{d_i}{d_o}$$

$$M = \frac{53\ \text{cm}}{22\ \text{cm}}$$

$$= 2.4$$

Paraphrase

The magnification of the mirror is 2.4 times.

Example Problem 11.3

An electron microscope magnifies a virus that is 3.50×10^{-7} m. If the magnification is 3.70×10^{5}, how big will the image be?

Given
Object height $h_o = 3.50 \times 10^{-7}$ m
Magnification $M = 3.70 \times 10^{5}$

Required
Image height $h_i = ?$

Analysis and Solution
The correct equation is $M = \frac{h_i}{h_o}$

Rearrange it to solve for the variable needed: $h_i = Mh_o$

Substitute the values and their units, and solve the problem.

$$h_i = Mh_o$$
$$h_i = (3.70 \times 10^{5})(3.50 \times 10^{-7}\ \text{m})$$
$$= 0.130\ \text{m}$$

Paraphrase
The size of the image is 0.130 m or 13.0 cm.

Practice Problems

1. A slide projector has a magnification of 50. How wide will the projected image be if the slide is 2.8 cm wide?
2. A concave mirror creates a virtual image of a candle flame that is 10 cm high. If the magnification of the mirror is 12.5, what is the height of the candle flame?
3. A magnifying glass will magnify 6 times. If the magnifying glass is held over a page and magnifies a letter that is 2 mm tall, how big is the image?

Example Problem 11.4

A concave mirror creates a real, inverted image 16.0 cm from its surface. If the image is 4.00 times larger, how far away is the object?

Given
Image distance $d_i = 16.0$ cm
Magnification $M = 4.00$

Required
Object distance $d_o = ?$

Analysis and Solution
The correct equation is $M = \frac{d_i}{d_o}$

Rearrange it to solve for the variable needed: $d_o = \frac{d_i}{M}$

Substitute the values and their units, and solve the problem.

$$d_o = \frac{d_i}{M}$$
$$d_o = \frac{16.0\ \text{cm}}{4.00}$$
$$= 4.00\ \text{cm}$$

Paraphrase
The object is 4.00 cm from the mirror.

Practice Problems

1. An insect is magnified 12 times by a concave mirror. If the image is real, inverted, and 6 cm from the mirror, how far away is the insect?
2. A lens produces a real image that is 23 times bigger than the object. If the object is 14 cm away, how far away is the image?
3. A human hair is placed 3 mm from a powerful microscope lens that has a magnification of 40 times. How far from the lens will the image be formed?

Convex Mirrors

Figure 11.16 Parallel light rays approaching a convex mirror

A mirror with a surface curved outward is a **convex mirror**, also called a **diverging mirror** (Figure 11.16). Instead of collecting light rays, a convex mirror spreads out the rays. A convex mirror produces a virtual image that is upright and smaller than the object (Figure 11.17). The image is a virtual image because although the reflected rays appear to be originating from behind the mirror, if a screen were placed there, the incident light rays would not reach it. The rays would be blocked by the mirror.

Figure 11.17 A virtual image produced by a diverging mirror is smaller than the object.

Table 11.3 Ray Diagram for Convex Mirror

Distance of Object from Mirror, d_o	Type of Image Formed	How the Image Is Viewed	Ray Diagram
All distances in front of the mirror	Smaller than object, upright, virtual	Behind the mirror between the vertex and the focal point	

Drawing a Convex Mirror Ray Diagram

You can follow the steps in Figure 11.18 to draw a ray diagram of a convex mirror.

Figure 11.18 Convex mirror ray diagram

1. The first ray of a convex mirror ray diagram travels from a point on the object parallel to the principal axis (ray 1). Any ray that is parallel to the principal axis will appear to have originated from the focal point on a diverging mirror.
2. The second ray travels from a point on the object toward the focal point (ray 2). Any ray that is directed at the focal point on a diverging mirror will be reflected back parallel to the principal axis.
3. Draw the virtual image where the rays appear to intersect.

Uses for Convex Mirrors

If you were to compare a convex mirror with a plane mirror of the same size, you would discover that more objects can be seen in the convex mirror. For this reason, convex mirrors are often used as security mirrors in stores (Figure 11.19). A convex mirror allows you to view a large region of the store from one location. For the same reason, convex mirrors are used in vehicles as side-view mirrors and rear-view mirrors. However, if you look in a convex mirror, it appears as if the image is originating from a smaller point behind the mirror. Because of these smaller images, convex mirrors on cars often have a warning such as the one shown in Figure 11.20 that objects in the mirror are closer than they appear.

You may have noticed convex mirrors used in some automatic teller machines and computers (Figure 11.21). A convex mirror allows the machine users to see what is happening behind them while they are facing the machine screen. Many camera phones include a convex mirror so that you can accurately aim the camera to take a self-portrait.

Figure 11.19 A store security mirror

Figure 11.20 A side-view mirror

Figure 11.21 A security mirror on an automatic teller machine

Learning Checkpoint

1. What is a real image?
2. What is a virtual image?
3. Name the features of the ray diagram identified as A, B, C, and D.

4. Draw a ray diagram where the object is between one and two focal lengths from a concave mirror with a focal length of 5 cm.
5. Draw a ray diagram where the object is more than two focal lengths from a concave mirror with a focal length of 5 cm.

Take It Further

The first astronaut to walk on the Moon, Neil Armstrong, put a special mirror on the Moon's surface that was able to reflect light directly back in the direction from which it came. Scientists from Earth shine laser light at this mirror. Find out how this mirror works and what has been learned from pointing a laser from Earth at the mirror. Begin your research at ***ScienceSource***.

D13 Quick Lab

Plane Mirror Reflection

The reflective surface of the mirror may be at the back of the mirror or at the front of the mirror depending where the reflective coating was applied to the glass or plastic you are using.

Purpose

To investigate the law of reflection using a plane mirror

Materials & Equipment

- ruler
- paper
- protractor
- plane mirror
- ray box or light source that can be made into a single 1-mm wide slit source

CAUTION: Do not shine bright light into anyone's eyes. Incandescent light sources can become very hot. Do not touch the bulbs or block air flow around the light bulbs.

Procedure

1. Use the ruler to draw a straight vertical line in the middle of a piece of paper. Use the protractor to create a perpendicular normal at the approximate centre of the first line.
2. Place the mirror upright along the vertical line. Hold the mirror in place. The normal should be perpendicular to the surface of the mirror.
3. Shine a ray of light at an acute angle to the normal so that it reflects where the normal meets the reflecting surface. Use the ruler to trace the incident ray between the light source and the mirror. Then, trace the reflected ray that reflects from the mirror.
4. Label the incident ray as i_1. Label the reflected ray as r_1 (Figure 11.22).
5. Repeat step 2 two more times with different angles. Be sure to label the successive incident and reflected rays as i_2, r_2 and i_3, r_3.
6. Measure and record the angle between each light ray and normal.

Questions

7. Compare the results of the angles of incidence and reflection. Describe how they are related.
8. (a) Are your results exactly the same as the law of reflection? Explain.

   (b) What aspects of your experimental method could make your results different from the law of reflection?

Figure 11.22 A sample drawing

D14 Skill Builder Activity

Drawing Ray Diagrams for Concave and Convex Mirrors

Concave Mirrors

1. Copy Figure 11.23(a) into your notebook.

Figure 11.23(a) Draw the object and the mirror.

2. To determine where the image of the tip of the arrow will be, draw two rays. Draw the first ray parallel to the principal axis until it strikes the mirror and reflects through the focal point (Figure 11.23(b)).

Figure 11.23(b) Draw the first ray.

3. Draw the second ray through the focal point until it strikes the mirror and reflects parallel to the principal axis (Figure 11.23(c)).

Figure 11.23(c) Draw the second ray.

4. These two rays intersect at only one location. This is where the image of the tip of the arrow is. Draw the inverted image (Figure 11.23(d)).

Figure 11.23(d) Draw the inverted real image.

5. Repeat the process for other parts of the object.

Convex Mirrors

1. Copy Figure 11.24(a) into your notebook.

Figure 11.24(a) Draw the object and mirror.

2. Draw the first ray parallel to the principal axis until it strikes the mirror, where it reflects away in a line that appears to come from the focal point. Draw a dashed line from the point on the mirror where the ray strikes through the focal point (Figure 11.24(b)).

Figure 11.24(b) Draw the first ray.

3. Draw the second ray toward the mirror heading for the focal point until it strikes the mirror and reflects back parallel to the principal axis. Draw a dashed line through the mirror parallel to the principal axis until it intersects the first dashed line (Figure 11.24(c)).

Figure 11.24(c) Draw the second ray.

4. The intersection of both dashed lines represents the virtual image of the tip of the arrow. The image for a convex mirror is always virtual, upright, and smaller.

Figure 11.24(d) Draw the upright, virtual image.

D15 *Inquiry Activity*

Skills References 2, 8

SKILLS YOU WILL USE

- Gathering, organizing, and recording relevant data from inquiries
- Processing and synthesizing data

Concave Mirrors

Question

How does the distance of the object from a concave mirror affect the size and orientation of the image?

Materials & Equipment

- 2 optical benches
- good quality concave mirror with a predetermined focal length
- light source, such as candle or light bulb
- metre stick with millimetres marked
- screen

CAUTION Light Bulb: Do not shine bright light into anyone's eyes. Incandescent light sources can become very hot. Do not touch the bulbs or block air flow around the light bulbs.
Candle: Tie back long hair, secure loose clothing, and avoid sudden movement when using candles. Make sure the candle is in a secure holder. Be careful not to get the screen too close to the flame. Be careful when moving the candle so you are not burned by a drop of melted wax. Dispose of all matches in an appropriate location.

Procedure

1. Copy Table 11.4 into your notes. Record the focal length of your concave mirror as supplied by your teacher in the table title.
2. Set up the first optical bench with the concave mirror at one end and the light source at the other end. The concave mirror should be angled slightly away from the light.
3. Light the candle, or turn on the light bulb. Darken the room. Align a second optical bench with a screen so that the reflected image of the light strikes the screen, as shown in the diagram. It does not need to be in focus yet. The optical benches are now aligned and should not be moved (Figure 11.25 on the next page).

Table 11.4 Concave Mirror Focal Length: _____

Distance of Candle from Mirror	Object Distance d_o (cm)	Image Distance d_i (cm)	Orientation (upright or inverted)	Object Height h_o (cm)	Image Height h_i (cm)	Magnification
3 times the focal length						
2 times the focal length						
1.5 times the focal length						
Focal length						
0.5 of the focal length						

D15 *Inquiry Activity (continued)*

Figure 11.25 Step 3

4. Move the candle to the distance indicated in the first row of the table in the "Distance of Candle from Mirror" column. Write this actual distance into the table in the "Object Distance d_o" column that is beside it.
5. Slowly move the screen along the length of the bench until the image of the candle flame comes into focus. Measure the distance from the mirror to the screen. Record this distance as the image distance, d_i in the table. Record the orientation of the flame in the table.
6. Very carefully measure the size of the actual flame or bulb and the height of the image of the light. Record these values in your chart.
7. Repeat steps 4 to 6 for the next distance indicated in the table, until all rows of the table are complete.

Analyzing and Interpreting

8. How do you explain the results obtained when the object was placed at 0.5 of the focal length from the mirror?

Skill Practice

9. Complete the magnification column of the table. Show one of your calculations.

Forming Conclusions

10. Using the completed table, form a conclusion about:
    (a) the magnification of the image based on the object's distance from the mirror
    (b) the orientation of the image based on the object's distance from the mirror

D16 Problem-Solving Activity

Skills References 3, 6

SKILLS YOU WILL USE

- Identifying sources of error
- Expressing results accurately and precisely

Laser Light Security System

Recognize a Need

The local museum is displaying a number of priceless artifacts in two adjoining rooms that are connected by an open door (Figure 11.26). Security is provided by a laser light and light sensor combination.

Figure 11.26 A floor plan of the museum

Problem

How can you set up a security system using the laser and the light sensor?

Materials & Equipment

- 2 empty shoe boxes
- tape
- piece of paper 60 cm × 60 cm and 2 cm × 2 cm
- protractor
- ruler
- selection of small plane mirrors
- modelling clay
- Class 1 or 2 laser

CAUTION: Do not shine the laser light in anyone's eyes.

Criteria for Success

- The laser light must enter one of the rooms from whichever direction you choose, through a small opening in the side of the room. It must bounce off all the windows and the outside doors. Finally, it must hit a 2 cm × 2 cm piece of paper attached to the wall of the last room that represents the alarm sensor.

Brainstorm Ideas

1. Brainstorm how to arrange plane mirrors within the rooms (shoe boxes) so that the light ray from the laser will bounce off every window and the two outside doors and hit the paper alarm sensor.

Make a Drawing/Build a Model

2. Firmly tape the two shoe boxes together in the orientation shown in Figure 11.26. Place the shoe boxes on a large piece of white paper and trace their outlines. Remove the boxes and draw the location of the windows and doors on the paper.
3. Plan the location of the mirrors based on the position of the doors and windows. Use a protractor and ruler to draw in the mirrors at the proper location and angle so the light ray will bounce off all the windows, the two outside doors, and finally the white paper sensor in the last room.
4. Use the ruler to draw a line on the paper that shows the path of the light ray as it moves through the rooms.
5. Build a 3D model of the rooms using the shoe boxes. Attach plane mirrors to the walls in the proper positions to represent the windows and the two outside doors.
6. Position the alarm sensor in your model.

Test and Evaluate

7. Have your teacher use a laser to test the effectiveness of your alarm system. Make adjustments to the mirrors as needed.

Skill Practice

8. How accurate did you have to be in placing your mirrors so the beam reflected properly?
9. What strategies did you use to ensure accurate placement?
10. How could you improve your solution?

Communicate

11. How well did the drawing of the mirrors and their angles correspond to what actually happened?

11.1 CHECK and REFLECT

Key Concept Review

1. Describe the law of reflection as a relationship between the angle of incidence, the angle of reflection, and the normal.
2. Describe the kinds of images that can be formed by plane mirrors.
3. (a) What type of mirror produces only diverging rays?
   (b) What type of mirror can produce both converging and diverging rays?
4. Describe what kind of mirror you would use if you needed to view a large, spread-out area in a small mirror.
5. Compare the shapes of convex and concave mirrors. How are they similar, and how do they differ?
6. What kind of images do convex mirrors form?
7. What are three uses for convex mirrors?
8. A lighted object is placed at the focal point of a concave mirror. Describe the light rays reflecting off the mirror.
9. Describe how the positions of a mirror, incident ray, reflected ray, and normal are related.
10. How does your image in a mirror compare with looking directly at yourself?
11. A bacterium has a length of 5.5×10^{-6} m but seen through a powerful microscope appears to be 1.2×10^{-3} m. What is the magnification of the microscope?
12. A virtual image is produced by a convex mirror that is 1.60 cm from the mirror. If the magnification is 0.20, how far from the mirror is the object?

Connect Your Understanding

13. Use a ray diagram with five rays to show how a car headlight uses a concave mirror to direct light.
14. Draw the following ray diagram: three rays, travelling generally left to right, converge 10 cm away from a concave mirror and are reflected away from the mirror as parallel rays.
15. Draw a ray diagram to determine the position of an image formed by a concave mirror that has a focal length of 3.0 cm and a 2.0 cm object positioned 6.0 cm from the mirror.
16. If you can see someone in a mirror, can that person see you? Explain why or why not. Use a ray diagram if necessary.
17. Draw a view from above of an arrangement of mirrors that would allow you to see the back of your head. Mark the angles of incidence and reflection on your diagram.
18. Does diffuse reflection, shown below, follow the law of reflection? Explain why it does or does not.

Question 18

Reflection

19. (a) Describe one idea you found easy to learn in this section.
    (b) Why do you think it was easy to learn?
    (c) Describe one idea you found difficult to understand in this section.
    (d) What did you do to help yourself understand it?

For more questions, go to *ScienceSource*.

11.2 The Refraction of Light

Here is a summary of what you will learn in this section:

- Refraction is the bending of light as it passes between media that have different refractive indices.
- Refraction occurs due to the change in the speed of light in different media.
- The index of refraction of a medium is the ratio of the speed of light in a vacuum compared to the speed of light in the medium.
- As light passes at an angle from a less dense medium into a more dense medium, the light ray bends toward the normal.
- Snell's law relates the indices of refraction of a medium to the angle of incidence and reflection.

Figure 11.27 Laser light is transmitted along optical fibres for use in surgery.

Fibre Optics

One of the most important properties of light is that it tends to travel in straight lines. If you need light to bend around a corner or to shine into a difficult-to-reach place, you might want to use optical fibres. An **optical fibre** is a thin, transparent glass tube that can transmit light even around corners (Figure 11.27). This is because the light in a fibre optics tube cannot escape until it reaches the end of the tube.

How does an optical fibre conduct a light ray around a corner? Imagine a long, curved tunnel whose walls, floor, and ceiling are lined with mirrors. If you were to shine a laser beam into the tunnel, the beam of light would change direction each time it reflected from a mirror and would make it all the way to the end of the tunnel. This is exactly what happens on the inside of the optical fibre. The light ray reflects off the inside of the walls of the glass fibre. When the thin glass fibre bends around a corner, the light ray goes around the corner through a series of reflections.

We use fibre optics systems to transmit telephone and Internet communications. A single optical fibre can be as thin as a human hair, yet transmit thousands of different signals at the same time (Figure 11.28). This is because each signal is sent at a different wavelength through the same cable. Just as two flashlight beams can cross each other and then continue on their way unaffected, thousands of light beams can pass through the same cable. A typical optical fibre cable can be made from thousands of optical fibres tightly packed together.

Figure 11.28 A single optical fibre can fit through the eye of a needle.

D17 *Quick Lab*

Observing Refraction

Purpose

To observe whether the bending of light affects the way we see certain objects

Materials & Equipment

- glass of water
- pencil
- jar lid with opaque rim
- coin

Procedure

1. Insert a pencil into the glass of water. Observe the glass from the side at various angles. Record your observations using labelled diagrams.
2. Place a jar lid with an opaque rim on a desk and put a coin in the middle.
3. Keep watching the coin while you lower the height of your head until the coin just disappears from view behind the rim of the lid (Figure 11.29).
4. Keeping your head at the same level, pour water into the lid, on top of the coin. Observe. Record your observations using labelled diagrams.

Figure 11.29 Step 3

Questions

5. Describe the path of light from the water to the air.
6. Draw a ray diagram of the light rays from the coin to your eye:
   (a) in step 3
   (b) in step 4
7. Compare your drawings in question 6 with those done by classmates.
   (a) How are your drawings similar?
   (b) How are your drawings different?

Figure 11.30 The spoon appears to be broken because light rays change direction as they move from air into water and from water into air.

Refraction

Although light travels in straight lines, it bends when it passes from one medium into another, such as from air into water. A **medium** (plural: media) is a material that is being used or is undergoing a process. The bending of light rays as they pass between two different media is called **refraction**. Refraction causes some very interesting visual effects. For example, the handle of the spoon in Figure 11.30 appears to be broken at the level of the top of the water. When light from the spoon passes from the water into the air, the light rays are bent. Refraction is more than just an optical curiosity. It is used in designing and building camera lenses, eyeglasses, and telescopes.

Refraction is due to changes in the speed of light. For example, as light moves from air into water, its speed decreases. Different media slow down light by different amounts. The more that light slows down, the more the light is refracted.

You may have stood beside a pool or lake and seen something on the bottom that you wanted to pick up. Yet, when you dove in, the object was not where it appeared to be. This is because the light rays changed direction at the surface of water as they passed between the water and the air. Figure 11.31 shows light rays moving from water into air and refracting as they leave the water. When we view the refracted light rays, we assume they have travelled in a straight line. If you trace the light rays that reach the eyes back in a straight line, you will find that they do not lead to the chest. Instead, the light from the chest in deep water appears to be coming from shallower water.

During Reading Thinking Literacy

Purpose of an Illustration

State the topic and purpose for the illustrations on these and the following pages in this section. Find words in the caption that also occur in the text. Write a statement about how the illustration helps you to understand a concept or idea.

Figure 11.31 The underwater chest appears to be higher than it really is.

The Speed of Light

In the vacuum of space, where there are very few particles, light travels at almost 300 million m/s or 3.0×10^8 m/s. Moving at this speed, light could travel seven times around the Earth in one second. However, just like a student trying to move from class to class when the hallways are full, it is impossible for light to move at top speed when particles get in the way.

A ray of light is electromagnetic radiation, which is transmitted in waves. The particles in a medium slow down the passage of the waves, which results in light travelling more slowly through a block of glass, for example, than it travels through a vacuum.

The effects of changes in the speed of light can be seen in Figure 11.32. The light ray strikes the Plexiglas at an angle. As the light enters the Plexiglas, it slows down and refracts (a). When the light leaves the Plexiglas and enters the air, it speeds up and refracts again (b). Notice that light does not refract inside the block. Light refracts only at the boundary when it is entering or leaving a medium. This photograph also shows that refraction is a reversible process, in that the angle of refraction entering the block is exactly reversed as the light leaves the block. The light ray immediately speeds up again as it leaves the block.

Figure 11.32 Light refracts as it enters and then leaves this block of Plexiglas.

The Index of Refraction

The amount by which a transparent medium decreases the speed of light is indicated by a number called the **index of refraction**, also called the refractive index. The larger the refractive index, the more the medium decreases the speed of light.

Light travels fastest in a vacuum. The refractive index of the speed of light in a vacuum is assigned a value of 1.00. A value of 1.00 can also be used for air, since the fourth decimal place does not affect calculations based on Table 11.5. Since water, glass, diamond, and other media all slow down light, they have higher values than air.

The refractive index of a medium, n, is determined by comparing the speed of light in the medium, v, with the speed of light in a vacuum, c. This leads to the following definition:

$$\text{index of refraction of material} = \frac{\text{speed of light in vacuum}}{\text{speed of light in medium}}$$

$$\text{or} \quad n = \frac{c}{v}$$

Since units cancel, a refractive index value does not have any units.

Table 11.5 Index of Refraction for Selected Media

Media	Index of Refraction
vacuum	1.00 (exactly)
air	1.0003
carbon dioxide gas	1.0005
water	1.33
alcohol	1.36
Pyrex glass	1.47
Plexiglas	1.49
table salt	1.51
flint glass	1.61
sapphire	1.77
cubic zirconia	2.16
diamond	2.42
gallium phosphide	3.50

Practice Problems

1. The speed of light in leaded glass is 1.66×10^8. What is the index of refraction of this type of glass?
2. The speed of light in quartz is 2.10×10^8 m/s. What is the index of refraction of quartz?
3. The speed of light through a material is 1.24×10^8 m/s. What material is it? (Hint: Refer to Table 11.5 on page 437.)

Example Problem 11.5

The speed of light in a sample of glass is 1.91×10^8 m/s. The speed of light in a vacuum is 3.00×10^8 m/s. What is the refractive index of this glass?

Given

Speed of light in glass $= 1.91 \times 10^8$ m/s
Speed of light in vacuum $= 3.00 \times 10^8$ m/s

Required

Refractive index $n = ?$

Analysis and Solution

The correct equation is $n = \frac{c}{v}$

Substitute the values and their units, and solve the problem.

$$n = \frac{c}{v}$$
$$= \frac{3.00 \times 10^8 \text{ m/s}}{1.91 \times 10^8 \text{ m/s}}$$
$$= 1.57$$

Paraphrase

The refractive index is 1.57.

Practice Problems

Use Table 11.5 on page 437 to answer the following questions.

1. What is the speed of light through alcohol?
2. What is the speed of light through gallium phosphide?
3. What is the speed of light through sapphire?

Example Problem 11.6

What is the speed of light in water given that water has a refractive index of 1.33?

Given

Refractive index of water $n = 1.33$
Speed of light in vacuum $c = 3.00 \times 10^8$ m/s

Required

Speed of light in water $v = ?$

Analysis and Solution

The correct equation is $n = \frac{c}{v}$

Rearrange it to solve for the variable needed: $v = \frac{c}{n}$

Substitute the values and their units, and solve the problem.

$$v = \frac{c}{n}$$
$$= \frac{3.00 \times 10^8 \text{ m/s}}{1.33}$$
$$= 2.26 \times 10^8 \text{ m/s}$$

Paraphrase

The speed of light in water is 2.26×10^8 m/s.

How Light Refracts

You can picture the beam of light as the leading edge of a wave, as shown in Figure 11.33. At first, all the waves are parallel. Then, the light waves are compressed as they enter the water and slow down. If the light strikes the surface of the water at an angle, that part of the light beam that enters first will slow down first. Notice in the diagram that this changes the direction of the waves and also the direction of the ray of light. It is like a line of skaters changing direction because the skaters at one end slow down on rough ice (Figure 11.34).

Figure 11.33 Light can be represented as a series of waves that compress and change direction as they enter water on an angle.

Figure 11.34 Skater E slows down, making the entire row of skaters turn.

Suggested Activity
D18 Inquiry Activity on page 444

The angles of the refracted light rays are usually measured from the normal, drawn at 90° to the surface where the light ray crosses between the two media. When light travels from air, with a low refractive index, into water, with a higher refractive index, it bends toward the normal. When light travels from a denser (higher refractive index) medium into a less optically dense (lower refractive index) medium, it bends away from the normal.

The angle of incidence, θ_i, and the angle of refraction, θ_R, are measured from the normal. Figure 11.35 shows the angle of incidence, θ_i, and the angle of refraction, θ_R, as light refracts moving from (a) air to glass, and from (b) glass to air.

Figure 11.35 Light moves (a) from air to glass and (b) from glass to air.

Figure 11.36 This diamond is colourless but, due to dispersion, it acts as a prism to split white light up into its individual colours.

Dispersion

A special kind of refraction occurs in both a diamond and raindrops. A diamond can appear completely colourless and yet glitter in all colours of the rainbow because the amount of refraction is different for each colour. Since white light contains many colours, a single beam of white light can enter a diamond and be split into a whole rainbow of colours, as shown in Figure 11.36. This kind of refraction is called dispersion. **Dispersion** is the refraction of white light into separate wavelengths, or colours.

The most common type of dispersion is in the formation of a rainbow. When sunlight passes through a raindrop, some light is reflected. Some light is refracted twice, once on entering the raindrop and once on leaving. Both refractions cause the separation of the white sunlight into the colours of the rainbow (Figure 11.37).

Figure 11.37 (a) White sunlight is split into the colours of the rainbow by refraction in a raindrop. (b) An observer sees different colours from different raindrops.

Learning Checkpoint

1. What is refraction?
2. Define "index of refraction."
3. What refracts light more, a sapphire or a diamond?
4. What direction does light bend when it travels from a denser medium to a less dense medium?
5. How is refraction related to dispersion?

Snell's Law

The phenomenon of refraction had been observed for centuries, but it was not until 1621 that its cause was stated mathematically. Willebrord Snell (1591–1626) was a Dutch astronomer and mathematician who is credited with identifying the exact relationship between the angle of incidence and the angle of refraction.

Snell's law is a formula that uses values for the index of refraction to calculate the new angle that a ray will take as a beam of light strikes the interface between two media (Figure 11.38). If you call the indices of refraction of the two media n_1 and n_2 and call the angles of incidence and the angle of refraction θ_1 and θ_2, then the formula for Snell's law is:

$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$

Figure 11.38 Snell's law relates the indices of refraction with the angle of incidence and the angle of refraction.

Example Problem 11.7

When light passes from air into water at an angle of 60° from the normal, what is the angle of refraction?

Given
Index of refraction of air $n_1 = 1.00$
Index of refraction of water $n_2 = 1.33$
Angle of incidence $\theta_1 = 60°$

Required
Angle of refraction $= \theta_2$

Analysis and Solution
The correct equation is $n_1 \sin\theta_1 = n_2 \sin\theta_2$

Manipulate it to solve for the variable needed $\sin\theta_2 = \dfrac{n_1 \sin\theta_1}{n_2}$

Identify air as medium 1 and water as medium 2.

Substitute the values and their units, and solve the problem.

$$\sin\theta_2 = \frac{n_1 \sin\theta_1}{n_2}$$

$$= \frac{1.00 \times \sin(60°)}{1.33}$$

$$= \frac{1.00 \times 0.8660}{1.33}$$

$$= 0.6511$$

Therefore, $\theta_2 = 40.62°$

Paraphrase
The angle of refraction is 41°.

Practice Problems

1. When light passes from air into water at an angle of 30° from the normal, what is the angle of refraction?
2. When light passes from water into diamond at an angle of 45° from the normal, what is the angle of refraction?
3. The refractive index of the lens in a human eye is 1.41. If a ray of light goes from the air into the lens at an angle of 55.0°, what is the angle of refraction?

Suggested Activity
D19 Inquiry Activity on page 445

Practice Problems

1. A ray of light approaches a jar of honey at an angle of 30.0°. If the angle of refraction is 19.5°, what is the refractive index of honey?
2. A block of amber is placed in water, and a laser beam travels from the water through the amber. The angle of incidence is 35° while the angle of refraction is 24°. What is the index of refraction of amber?
3. A red laser beam travels from flint glass into lemon oil. The angle of incidence is 40.0° and the angle of refraction is 44.4°. What is the refractive index of lemon oil?

Example Problem 11.8

In an experiment, a block of cubic zirconia is placed in water. A laser beam is passed from the water through the cubic zirconia. The angle of incidence is 50°, and the angle of refraction is 27°. What is the index of refraction of cubic zirconia?

Given
From Table 11.5, the index of refraction of water is 1.33.
Angle of incidence $\theta_1 = 50°$
Angle of refraction $\theta_2 = 27°$

Required
Index of refraction $= n_2$

Analysis and Solution
The correct equation is $n_1 \sin\theta_1 = n_2 \sin\theta_2$

Rearrange it to solve for the variable needed $n_2 = \dfrac{n_1 \sin\theta_1}{\sin\theta_2}$

Substitute the values and their units, and solve the problem.

$$n_2 = \frac{n_1 \sin\theta_1}{\sin\theta_2}$$
$$= \frac{1.33 \times \sin(50°)}{\sin(27°)}$$
$$= \frac{1.33 \times 0.7660}{0.4540}$$
$$= 2.244$$

Paraphrase
The index of refraction of cubic zirconia is 2.2.

Total Internal Reflection

Sometimes, such as in the case of fibre optics, light does not pass from one medium to another but stays within the medium as shown in Figure 11.39. In **total internal reflection**, light reflects completely off the inside wall of a denser medium (higher index of refraction) rather than passing through the wall into a less dense medium (lower index of refraction).

This same effect can happen in water as a ray of light reaches the surface between the water and the air. Recall that when light passes from a denser material, such as water, into a less dense medium, such as air, the light refracts away from the normal. As the angle of incidence increases, the angle of refraction increases.

Figure 11.39 Light rays reflect from the inside of a fibre optics tube.

At a certain angle, called the critical angle, the refracted ray of light follows a path exactly along the surface of the water. Even though the light refracts, it does not leave the water. In a way, the light is "trapped" inside the water (Figure 11.40).

Figure 11.40 When the angle of incidence is greater than the critical angle, total internal reflection occurs.

Take It Further

Refractive index has many uses, including identifying gemstones. It can also be used to find the concentration of solutions. Find out about these and other uses of the refractive index. Begin your research at ***ScienceSource***.

What if the angle of the incident ray is increased even farther? The light ray is no longer refracted. Instead, it is completely reflected back inside the water. In an optical fibre, light is passed into the end of the fibre at an angle greater than the critical angle. Because the fibre is made of glass, which has a higher index of refraction than the surrounding medium, the light ray is completely reflected inside the fibre.

Suggested Activity

D20 Design a Lab on page 446

Mirages

Both total internal reflection and refraction play a role in forming a mirage (Figure 11.41). A **mirage** is an image of a distant object produced as light refracts through air of different densities (Figure 11.42). Since the light rays pass through layers of air with progressively lower indices of refraction, eventually the light is totally internally reflected.

Figure 11.41 What looks like a puddle of water from the distance is actually an image of the sky that is produced as light from the sky is bent near the surface of the road up into the eyes of the observer.

Figure 11.42 Light from an object in the sky is refracted due to the difference in density of the air above the pavement compared with the air higher up.

D18 *Inquiry Activity*

Skills References 2, 8

SKILLS YOU WILL USE

- Interpreting data/information to identify patterns or relationships
- Identifying sources of error

Refraction Measurement and Patterns

Question

What is the refractive index of tap water?

Materials & Equipment

- adhesive tape
- 360° protractor
- an aquarium or transparent container with flat vertical sides
- water
- ray box with single slit
- scientific calculator

CAUTION: Do not shine bright light into anyone's eyes. Incandescent light sources can become very hot. Do not touch the bulbs or block air flow around the light bulbs.

Figure 11.43 Step 3

Procedure

1. Make a table with the following headings. Give your table a title.

θ_1	θ_2	$\sin\theta_1$	$\sin\theta_2$

2. Tape the protractor to the container near the bottom so that the line from 0° to 180° is aligned vertically with the container's edge. Half the protractor should be flush with the side of the container, and the other half should be in air.
3. Fill the container with water so that the protractor is completely below the water line (Figure 11.43). The 90° angle is the normal for the incoming ray. The 270° angle is the normal for the water.
4. Hold the ray box so that the beam of light traces a path across the face of the protractor and enters the water. Begin with the angle 5° above the normal. This should be the 95° angle on the protractor. Record the refracted angle of the beam in water. Remember to measure magnitude of this angle from the 270° mark on the protractor.
5. Repeat step 4 for increments of 5° up to 50°.
6. Calculate $\sin\theta_1$ and $\sin\theta_2$ for each measured value of θ_1.
7. Draw a scatter plot of $\sin\theta_2$ against $\sin\theta_1$.

Analyzing and Interpreting

8. Is there a pattern in the data? Explain.
9. (a) Find the slope of the line.

   (b) Using Snell's law as a guide, determine what the slope represents.

   (Hint: what does $\frac{\sin\theta_1}{\sin\theta_2}$ equal?)
10. Assume the index of refraction of air is 1. Use the slope of the line to determine the index of refraction of water.

Skill Practice

11. The closer the points are to a straight line, the better your measurement skills. What does your graph suggest about the quality of your data collection skills?
12. Why should a scatter plot of θ_2 against θ_1 not be completely straight?

Forming Conclusions

13. Look up the index of refraction of water in Table 11.5 on page 437. How close was your value to this value? Explain any difference.

D19 *Inquiry Activity*

Skills References 2, 8

SKILLS YOU WILL USE

- Observing and recording observations
- Identifying sources of error

Index of Refraction

Question

What is the index of refraction of various transparent solid media?

Materials & Equipment

- paper
- glass, Perspex, or similar acrylic, various other transparent media
- ray box with single slit
- ruler
- protractor
- scientific calculator

CAUTION: Do not shine bright light into anyone's eyes. Incandescent light sources can become very hot. Do not touch the bulbs or block air flow around the light bulbs.

Procedure

1. Copy the following table into your notebook. Give your table a title.

Medium	Angle of Incidence	Angle of Refraction	Index of Refraction	Speed of Light

2. Place a sheet of paper flat on a table. Draw a vertical line through the middle of the sheet, from the top to the bottom. You will place the edge of the transparent object on this line.
3. Choose three transparent media. Place one of the transparent objects flat on the paper on the right side of the line you drew, so that one edge of it is aligned with the line.
4. Place the ray box on the left side of the paper. Shine the single ray so that it strikes the transparent object at an angle to the surface. Draw a dot on the paper where the light ray leaves the ray box. Draw a second dot where the light ray strikes the transparent object. Draw a third dot where the ray exits the transparent object.
5. Remove the transparent object and draw a line that connects the first and second dots. This is the incident ray. Then draw another line that connects the second and third dots. This is the incident ray. Draw a horizontal normal line at the second dot. This line should be perpendicular to the vertical line you drew in step 2.
6. Use the protractor to measure the angle of incidence (between the normal and the incident ray) and the angle of refraction (between the normal and the refracted ray).
7. Use Snell's law to calculate the index of refraction of the medium. (See page 442 for an example calculation. Note that the index of refraction of air is 1.0003.)
8. Calculate and record the speed of light in each medium.
9. Repeat steps 2 through 8 for the remaining two materials.

Analyzing and Interpreting

10. How does the index of refraction relate to the amount of refraction the ray experiences?

Skill Practice

11. Show the calculations you did to determine the index of refraction in each transparent medium you used.
12. Compare the values you calculated for the refractive index of the media with the known values provided by your teacher. Explain any discrepancy in the two sets of values.

Forming Conclusions

13. (a) In which of the media is the speed of light the slowest? Why do you think so?

    (b) Is there a way to tell which medium has the slowest speed of light by just looking at the material? Explain.
14. What conclusions can you draw about the speed of light in the three different media and about transparent media in general?

D20 Design a Lab

Skills References 2, 8

SKILLS YOU WILL USE

- Formulating questions
- Controlling variables

Transmitting Light Rays through Liquids

Question

What happens to a ray of light as it is transmitted through different liquids?

Design and Conduct Your Investigation

1. This activity involves investigating what happens to light when it travels through different liquids. You will need to develop a clear inquiry question, propose a hypothesis, identify variables or related factors, create a process for gathering data, and recognize where your results may end up. First, brainstorm all the questions you have about the behaviour of light in liquids. Choose one question that you would like to investigate further.
2. Narrow your question so it is something you can actually investigate. Ask yourself "What do I want to know? How could I find out? What do I think the answer might be?" Phrase your question as a cause-and-effect question, such as "How does (your choice of an independent variable) affect (your choice of a dependent variable)?"
3. Once you have phrased your question, write a hypothesis. Your hypothesis makes a prediction that your experiment will test. Your hypothesis should indicate the relationship between the independent and dependent variables.
4. Plan your experiment to test your hypothesis.
   - Make sure your experiment is a fair test by determining which variables you will need to control and which variable you will change.
   - Identify what tools, equipment, and material you need (Figure 11.44).
   - Carefully consider any safety issues involved in performing your experiment. Record any safety precautions you will take.
5. Write up the step-by-step procedure you will follow to perform your experiment. Record your procedure clearly so that others could follow it to perform the same experiment.
6. Decide how you will record your results clearly. Prepare any charts, tables, graphs, or sketches you will need.
7. Obtain your teacher's approval of your plan, and then perform your experiment. Use your scientific and technical skills to follow your procedure. Be sure to gather and record both qualitative and quantitative observations in your lab notes.
8. After you have completed your experiment, clean up and put away your equipment and materials.
9. Analyze your data. You may find it helpful to create a visual representation, such as a graph, or to make calculations in order to identify patterns or trends in the data. Ask yourself "What is the meaning of the data I collected? How else can I interpret the data?"
10. Use your completed analysis of your data to draw conclusions that support or refute your hypothesis. Address any errors you noted as you performed your experiment, and indicate their effect on the observed results.
11. Write a summary statement that answers the question you posed. Remember to use your data and observations to support your answer.
12. Communicate your results clearly using the correct terminology, symbols, conventions, SI units, and number of significant figures.

Figure 11.44 These are some materials and equipment you might consider using.

11.2 CHECK and REFLECT

Key Concept Review

1. When is light travelling at its fastest?
2. What is dispersion?
3. Under what conditions can you slow down light and then speed it up again?
4. Describe how light changes its direction when moving from one medium to another.
5. Copy the following diagram into your notebook. Label all the lines and angles.

Question 5

6. What property of a medium is given by its index of refraction?
7. Through which medium does light pass more quickly, one with a refractive index of 2.0 or one with a refractive index of 3.0?
8. (a) What is total internal reflection?
   (b) When does it occur?
9. (a) What is the formula for Snell's law?
   (b) Explain how you would calculate the changing speed of light using Snell's law.
10. Describe how Snell's law can be used to describe the bending of light toward and away from the normal.

Connect Your Understanding

11. Determine the refractive index of a medium if the speed of light slows to 1.2×10^8 m/s.
12. Jade has a refractive index of 1.61. If light approaches the gem at an angle of 80.0°, what is the angle of refraction?
13. A student is given a clear material to identify. She shines a laser at the surface of the material at an angle of 25.0°. The angle of the refracted ray is 16.7°. What material is it?
14. Calculate the index of refraction of a material if the angle of incidence is 60° and the angle of refraction is 50°.
15. A light ray passes from a vacuum into a substance where its speed is 2.26×10^8 m/s. What is the substance?
16. A super-dense material called a "Bose-Einstein condensate" has a refractive index of 1.76×10^7. What is the speed of light in this material?
17. How do reflection and refraction affect light similarly?
18. How do reflection and refraction affect light differently?
19. Why is it not possible to have an index of refraction less than 1.0?

Reflection

20. (a) What do you think is the most interesting information you learned in this section?
    (b) How does this information connect with what you already knew about the subject?
21. What scientific terms do you understand better now than you did before you read this section?

For more questions, go to *ScienceSource*.

11.3 Lenses

Here is a summary of what you will learn in this section:

- Lenses refract light in useful ways to form images.
- Concave lenses, which cause light to diverge, are used in multi-lens systems to help produce images.
- Convex lenses cause light to converge and can be used in magnifying glasses or to project images on a screen.
- When the object is farther away from a convex lens than the focal point, the image is real and inverted.
- When the object is closer to the lens than the focal point, the image is virtual and upright.

Figure 11.45 Police officers using night vision goggles while patrolling along the St. Lawrence River

Seeing in the Dark

Imagine taking to the skies in a helicopter over the forests of northern Ontario. It is the middle of the night, and all you see out the window is total blackness. Your task is to fly to a remote forest location and rescue a team of firefighters needing emergency evacuation. Or picture yourself on night patrol watching along the shores of the St. Lawrence River (Figure 11.45). Would you be ready for such a mission?

In addition to excellent training, it helps to have good equipment, including radar, radio, lights, and night vision goggles (Figure 11.46). Modern night vision goggles are so sensitive that the tiny amounts of starlight reflecting off forests can be amplified to levels visible to pilots and rescue staff to give a clear view of the countryside. With these ultra-sensitive devices, you can literally fly and search by starlight.

Figure 11.46 Night vision goggles

Night vision goggles use lenses to focus light onto a device called an image intensifier. Inside the intensifier, the light energy releases a stream of particles. These particles then hit a phosphor-coated screen. The phosphors glow when the particles strike them. The person wearing the goggles sees a glowing green image (Figure 11.47).

Figure 11.47 The image intensifier of night goggles amplifies the particles before they hit the screen. The image appears as shades of green.

D21 *Quick Lab*

Observing Lenses

Purpose

To observe how concave and convex lenses affect light

Materials & Equipment

- convex lens (bulges out)
- concave lens (middle is thinner than the edges)
- light source, such as a candle
- screen, such as a piece of paper
- candle holder, such as sand and a metal tray

CAUTION: If an open flame is used, it must be secured so that it cannot fall over. Keep all combustible materials away from open flames. Tie back long hair before using an open flame.

Procedure

1. Look though each lens at the printed text in this student book. Record your observations.
2. Look through both lenses at some printed text. Record your observations.
3. Try to use each of the lenses to project a candle flame or light onto a screen or piece of paper. Record your observations.

Questions

4. Which single lens would be most useful as a magnifying glass?
5. How should the convex and concave lenses be arranged to make a distant object appear closer?
6. What arrangement of lenses is most effective in projecting the image of a light source onto a piece of paper?

WORDS MATTER

The word "lens" is derived from the Latin word *lenticula*, which means lentil. A lens is in the shape of a lentil like those shown here.

Types of Lenses

If you have ever used a microscope, telescope, binoculars, or a camera, you have worked with one or more lenses (Figure 11.48). A **lens** is a curved transparent material that is smooth and regularly shaped so that when light strikes it, the light refracts in a predictable and useful way.

Most lenses are made of transparent glass or very hard plastic. These materials have several useful properties. For example, they are strong and hard. They can also be shaped and polished. By shaping both sides of the lens, it is possible to make light rays diverge or converge as they pass through the lens. The most important aspect of lenses is that the light rays that refract through them can be used to magnify images or to project images onto a screen. Relative to the object, the image produced by a thin lens can be real or virtual, inverted or upright, larger or smaller.

Figure 11.49 Lenses can be grouped into two types, converging and diverging, depending on how they refract the light that enters them.

Lens Terminology

Figure 11.50 illustrates some of the terms associated with both converging and diverging lenses:

Figure 11.50 (a) Converging lens and (b) diverging lens

- The principal axis is an imaginary line drawn through the optical centre perpendicular to both surfaces.
- The **axis of symmetry** is an imaginary vertical line drawn through the optical centre of a lens.
- Both kinds of lenses have two principal focuses. The focal point where the light either comes to a focus or appears to diverge from a focus is given the symbol F, while that on the opposite side of the lens is represented by F′.
- The focal length, f, is the distance from the axis of symmetry to the principal focus measured along the principal axis. Since light behaves the same way travelling in either direction through a lens, both types of thin lenses have two equal focal lengths.

Concave Lenses

A **diverging lens** is sometimes called a **concave lens** because it is thinner in the centre than at the edges. As parallel light rays pass through a concave lens, they are refracted away from the principal axis. This means the light rays diverge and they will never meet on the other side of the lens (Figure 11.51). The image formed is always upright and smaller than the object (Figure 11.52 and Table 11.6).

Figure 11.51 A concave lens causes light rays to diverge.

Figure 11.52 A diverging lens forms an upright, smaller image.

Table 11.6 Images Formed by Concave Lenses

Distance of Object from Lens	Type of Image Formed	How the Image Is Used	Ray Diagram
All distances	Smaller, upright	Some types of eyeglasses and telescopes make use of the diverging properties of concave lenses. These lenses are often used in combination with converging lenses.	

Drawing a Ray Diagram for a Lens

A ray diagram is a useful tool for predicting and understanding how images form as a result of light rays emerging from a lens. The index of refraction of a lens is greater than the index of refraction of air. This means that when a light ray passes from air into the lens, the light ray bends, or refracts, away from the lens surface and toward the normal. When the light passes out of the lens at an angle, the light rays refract again, this time bending away from the normal. In other words, light rays undergo two refractions, the first on entering the lens and the second on leaving the lens (Figure 11.53).

Figure 11.53 (a) Concave lens (b) and convex lens

In your ray diagrams in this unit, assume you are working with a thin lens. A **thin lens** is a lens that has a thickness that is slight compared to its focal length. An example of a thin lens is an eyeglass lens. You can simplify drawing a ray diagram of a thin lens without affecting its accuracy by assuming that all the refraction takes place at the axis of symmetry.

Drawing a Concave Lens Ray Diagram

Ray diagrams for lenses are similar to ray diagrams for curved mirrors. You need to use two rays to predict image location. You can follow the steps in Figure 11.54 to draw a ray diagram of a concave lens.

Figure 11.54 Concave lens ray diagram

1. The first ray of a concave lens ray diagram travels from the tip of the object parallel to the principal axis (ray 1). When it emerges from the lens, it appears to come from the principal focus.
2. The second ray travels from the tip of the object through the optical centre of the lens and is not refracted (ray 2).
3. Draw the virtual image where the rays appear to intersect.

Convex Lenses

A **converging lens** is also called a **convex lens** because it is thicker at the centre than at the edges. As parallel light rays travel through a convex lens, they are refracted toward the principal axis. This causes the rays to move toward each other. The light rays cross at the focal point of the lens. Converging lenses are often used as magnifying glasses (Figure 11.56).

Figure 11.55 A convex lens causes light rays to converge.

Figure 11.56 A converging lens can be used as a magnifying glass.

Forming a Real Image

Convex lenses are useful because they can form a real image on a screen. For example, the light rays coming from one point on the flame in Figure 11.57 diverge and strike the lens at different places. However, the lens redirects all those rays so that they converge at a single point. The screen must be placed so that the light rays strike it exactly as they converge. This way, when the light rays reflect off the screen, they are coming from a single point, just like when they originally left a single point on the candle.

At the same time, the lens must also redirect all light rays that come from a point at the base of the candle and send them to a single point on the screen. The rays then reflect off the screen in all directions, just like when the light rays from the base of the candle left the candle. When the rays from every point on the candle are sent to the screen, a complete image is formed. You can compare the type of image formed at different distances as well as some of the uses of convex lenses in Table 11.7.

During Reading

Comparing Graphics and Text

Read the paragraph on forming a real image, and then look at the graphics beneath the explanation. Which was easier to understand — the word text or the graphics? Would you be able to understand one feature without the support of the other, i.e., words without graphics or graphics without words? How did each graphic help you to understand the idea more fully?

Figure 11.57 As you can see in this illustration, there is one drawback to convex lenses. The image is upside down!

Suggested Activity
D24 Quick Lab on page 459

Table 11.7 Images Formed by Convex Lenses

Distance of Object from Lens	Type of Image Formed	How Image Is Used	Ray Diagram
More than two focal lengths	Smaller, inverted, real	A camera uses this distance to make smaller images of an object.	
Between one and two focal lengths	Larger, inverted, real	Photographic enlargers, slide projectors, and movie projectors use this distance.	
Less than one focal length away	Larger, upright, virtual	Magnifying glasses and reading glasses make use of this distance.	

Drawing a Convex Lens Ray Diagram

You can follow the steps in Figure 11.58 to draw a ray diagram of a convex lens.

1. The first ray of a convex lens ray diagram travels from the tip of the object parallel to the principal axis (ray 1). When it emerges from the lens, it passes through the principal focus.
2. The second ray travels from the tip of the object through the optical centre of the lens and is not refracted (ray 2).
3. Draw the real image where the rays appear to intersect.

Suggested Activity
D25 Inquiry Activity on page 460

Figure 11.58 Convex lens ray diagram

Learning Checkpoint

1. Describe the difference in shape between a convex lens and a concave lens.

2. Which lens, convex or concave, can also be called a *diverging* lens?

3. Why do light rays bend twice when lenses are used?

4. Draw a ray diagram for a convex lens when the object is situated:

(a) more than two focal lengths away from the lens

(b) exactly two focal lengths from the lens

Thin Lens Equation

The distance of the object from the lens, d_o, the distance of the image from the lens, d_i, and the focal length of a lens, f, can all be related using the **thin lens equation**. Given any two of these quantities, you can use the thin lens equation to solve for the third:

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

Keep in mind the following points when working with the thin lens equation (see also Table 11.8).

- A concave lens has a negative focal length and a negative distance to the image.
- A convex lens has a positive focal length and either a positive or negative distance to the image, depending where the object is placed.
- The image distance d_i is positive if the image is real and negative if the image is virtual.

Table 11.8 Images Formed by Convex Lenses

Lens Type	Focal Length	Distance to Object	Distance to Image
Convex	positive	positive	positive or negative depending on object location

Take It Further

Large glass lenses can be extremely heavy. However, because refraction only occurs at the surface of a lens, the middle material can be removed, as long as the lens surface remains correctly curved. These lenses are called Fresnel lenses, and they are used in lighthouses and overhead projectors. Find out more about how Fresnel lenses are constructed and used. Begin your research at ***ScienceSource***.

Suggested Activity

D26 Inquiry Activity on page 461

Example Problem 11.9

A convex lens of a magnifying glass is held 2.00 cm above a page to magnify the print. If the image produced by the lens is 3.60 cm away and virtual, what is the focal length of the magnifying glass?

Given

Distance of the object from the lens, $d_o = 2.00$ cm

Distance of the virtual image from the lens, $d_i = -3.60$ cm

Required

Focal length of the lens, f

Analysis and Solution

The correct equation is $\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$

Substitute the values and their units, and solve the problem.

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

$$\frac{1}{f} = \left(\frac{1}{2.00} + \frac{1}{-3.60}\right)\frac{1}{\text{cm}}$$

$$\frac{1}{f} = \frac{0.222}{\text{cm}}$$

Take the reciprocal of both sides.

$$f = 4.50 \text{ cm}$$

Paraphrase

The focal length is about 4.50 cm.

Practice Problems

1. A powerful magnifying glass produces a real image 4 mm from the convex lens. If the object was placed 28 mm away, what is the focal length of the lens?
2. Determine the focal length of a convex lens that produces a virtual image at a distance of 30 mm when the object is placed 15 mm away.
3. The objective lens of a microscope is convex. The light from a specimen 4.0 mm from the lens forms a real image 10.0 mm from the lens. What is the focal length of this lens?

Example Problem 11.10

A convex lens has a focal length of 60.0 cm. A candle is placed 50 cm from the lens. What type of image is formed, and how far is the image from the lens?

Given

Focal length of the convex lens, $f = 60$ cm

Distance of the object from the lens, $d_o = 50$ cm

Required

Distance of the image from the lens, d_i

Analysis and Solution

A convex lens has a positive focal length, so $f = 60.0$ cm

Use the thin lens formula: $\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$

Rearrange the formula for $\frac{1}{d_i}$: $\frac{1}{d_i} = \frac{1}{f} - \frac{1}{d_o}$

Substitute the values and their units, and solve the problem.

$$\frac{1}{d_i} = \frac{1}{f} - \frac{1}{d_o}$$

$$\frac{1}{d_i} = \left(\frac{1}{60} - \frac{1}{50}\right)\frac{1}{\text{cm}}$$

$$\frac{1}{d_i} = \frac{-0.003333}{\text{cm}}$$

Take the reciprocal of both sides of the equation to eliminate the fractions.

$d_i = -300$ cm

Paraphrase

Since d_i is negative, the image is virtual and is located 300 cm from the lens.

Practice Problems

1. A convex lens has a focal length of 15 cm. An object is placed 20 cm from the lens. What type of image is formed? How far from the lens is the image?
2. A convex lens focusses the light from the image of a bacterium that is 0.02 cm from the lens. If the focal length of the lens is 0.03 cm, how far from the lens is the image?
3. A convex lens has a focal length of 5.0 cm. If a penny is placed at the focus, where is the image of the penny formed?

Example Problem 11.11

A camera with a 200-mm lens makes a real image of a bird on film. The film is located 201 mm behind the lens. Determine the distance from the lens to the bird.

Given

Focal length of lens, $f = 200$ mm

Image distance, $d_i = 201$ mm

Required

Object distance of the bird from the lens, d_o

Analysis and Solution

Use the thin lens formula: $\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f}$

Rearrange the formula for $\frac{1}{d_o}$: $\frac{1}{d_o} = \frac{1}{f} - \frac{1}{d_i}$

Substitute the values and their units, and solve the problem.

$$\frac{1}{d_o} = \frac{1}{f} - \frac{1}{d_i}$$

$$\frac{1}{d_o} = \left(\frac{1}{200} - \frac{1}{201}\right)\frac{1}{\text{mm}}$$

$$\frac{1}{d_o} = \frac{2.4876 \times 10^{-5}}{\text{mm}}$$

Take the reciprocal of both sides of the equation to eliminate the fractions.

$d_o = 4.02 \times 10^4$ mm

Paraphrase

The bird is about 40.2 m away from the camera lens.

Practice Problems

1. A convex lens with a focal length of 18 mm produces an image 25 mm from the lens. How far from the lens is the object?
2. Where is the object placed if a convex lens with a focal length of 7.00 cm produces a virtual image 3.00 cm from the lens?
3. An image of a candle is produced by a convex lens 14 cm away. If the focal length of the lens is 7.0 cm, how far from the lens is the candle placed?

D22 STSE Science, Technology, Society, and the Environment

Two-Way Mirrors

A two-way mirror is partly reflective and partly transparent. The reflective coating of a two-way mirror is not nearly as thick on a regular mirror so that some light gets reflected and some passes through. For the mirror to work properly, there must be a significant difference in the brightness of light on the two sides. The side where the observers are positioned must be dark so that no light goes through the mirror to the other room. The other side, where the person being observed is located, must be bright so that enough of the light is reflected and the person does not see through to the other side.

1. How might you be able to tell if you were looking at a two-way mirror, without looking at it from the other side?
2. Two-way mirrors are sometimes used in training hospitals so interns can watch operations being performed. Brainstorm other situations in which two-way mirrors would be useful.
3. What issues do you think arise from the use of two-way mirrors?

D23 Skill Builder Activity

Drawing Ray Diagrams for Convex Lenses

Convex (Converging) Lenses

1. Copy Figure 11.59(a) into your notebook To determine where the image of the top of the arrow will be, draw the first ray parallel to the principal axis until it strikes the lens and refracts through the focal point.

Figure 11.59(a) Draw the first ray.

2. Draw the second ray from the tip of the arrow through the optical centre of the lens (Figure 11.59(b)).

Figure 11.59(b) Draw the second ray.

3. Draw the real image where the rays appear to intersect. A real image is shown as a solid arrow (Figure 11.59(c)).

Figure 11.59(c) Draw the real image.

4. Optional: You can add a third ray to check your work. Draw the third ray travelling from the top of the arrow toward the secondary focus on the far side of the lens. When this ray emerges from the lens, it travels parallel to the principal axis (Figure 11.59(d)).

Figure 11.59(d) Optional: Draw a third ray to check your work.

D24 Quick Lab

Focal Length

Purpose

To find a good approximation of the focal length of any convex lens and see the relationship between the curvature of the lens and the focal length

Materials & Equipment

- ruler
- 279 × 432 mm blank paper
- several flat convex lenses of different focal lengths
- ray box with several parallel rays of light
- 216 × 279 mm blank paper

CAUTION: Do not shine bright light into anyone's eyes. Incandescent light sources can become very hot. Do not touch the bulbs or block air flow around the light bulbs.

Procedure

1. Copy the data table below into your notes. Give your table a title.

Lens	Focal Length (cm)	Radius (cm)
1.		
2.		
3.		
4.		

2. Use your ruler to draw a straight line lengthwise across the middle of the 279 × 432 mm paper. This line will act as the principal axis for each lens.
3. Near one end of the paper, draw a vertical line that intersects the first line at 90°. This line will act as the axis of symmetry for each lens.
4. Place the first convex lens on the principal axis aligned with the axis of symmetry as shown in Figure 11.60.

Figure 11.60 Step 4

5. Place the ray box off the paper so that the rays will shine parallel to the principal axis through the lens. An equal number of rays should be above and below the principal axis.
6. Look to see where the rays converge on the principal axis. If they converge above or below the axis, adjust the ray box a little to make them converge on the principal axis.
7. Place a dot at the location where the rays converge. This is the focus. Remove the lens, then measure the distance from the vertex, which is the intersection of the principal axis and the axis of symmetry, to the dot. Record this as the focal length.
8. Determine the radius of the lens by placing the lens on a sheet of 216 × 279 mm paper and tracing one side of the lens to create an arc. Reposition the lens so that the arc is extended until you have traced a full circle. Measure the radius of this circle, and record it in your table.
9. Repeat steps 4 to 8 for the remaining lenses.

Questions

10. Explain how you determined the radius of the lens once you drew the circle.
11. What is the relationship between curvature (radius) of the lens and focal length of the lens?
12. Explain how you would modify this lab to make it work for:

    (a) concave lenses

    (b) concave mirrors

D25 *Inquiry Activity*

Skills Reference 2

SKILLS YOU WILL USE
- Conducting inquiries safely
- Using appropriate formats to communicate results

Convex Lens Images

Question

How does the distance between an object and a convex lens affect image formation?

Materials & Equipment

- cardboard stand
- sheet of unlined white paper
- adhesive tape
- light bulb and socket
- battery and wires
- 2 convex lenses with different focal lengths
- modelling clay
- metre stick

CAUTION: Do not shine bright light into anyone's eyes. Incandescent light sources can become very hot. Do not touch the bulbs or block air flow around the light bulbs.

Procedure

1. Prepare a data table that will allow you to record the following values. Give your table a title.

   Distance (cm) from bulb to lens (d_o)
   Distance (cm) from the lens to the screen (d_i)
   Size of the glass part of the light bulb (h_o)
   Size of the image on the screen (h_i)
   Orientation of the image (inverted or upright)
2. Tape the paper onto the cardboard stand. This is your "screen."
3. Measure the height of the glass part of the bulb. Record this in your notebook as the object height.
4. Determine the focal length (f) of your lens as shown in Figure 11.61:
   - Using the modelling clay for support, place the lens in between the stand and the bulb.
   - Move the screen and bulb slowly inward, then outward, keeping the lens in the middle. At a certain distance, an inverted image of the same size as the actual bulb will come into focus on the screen.
   - Measure the distance between the bulb and lens. This measurement is equal to $2f$. Divide the value by 2 to determine the focal length of your lens. Record this value for f in your notebook.

Figure 11.61 Finding the focal length of the lens

5. Record values in your data table for the following placements of the light bulb: $2.5f$, $2f$, $1.5f$, and $0.5f$. In each case, you will need to move the screen until the image comes into focus before recording your data. If at any time you cannot get an image on the screen, look at the bulb through the lens. If you see an image through the lens, estimate h_i, but do not record a value for d_i.
6. Repeat steps 3 to 5 with another convex lens of different focal length.

Analyzing and Interpreting

7. (a) Is the image formed by a convex lens always inverted?

   (b) If not, under what conditions is it upright?
8. (a) What happens to h_i as the bulb is moved toward the lens?

   (b) What happens to d_i?
9. What type of image is formed when the bulb is placed closer than one focal length?
10. How does focal length affect convex lens image formation?

Skill Practice

11. Draw ray diagrams to represent the images formed at the different bulb placements for both lenses.

Forming Conclusions

12. (a) Convex lenses are often used in computer projectors. Explain why an image changes size and must be refocussed when a projector is moved closer to or farther from the screen. Use the data you have collected in this activity.

    (b) Explain why different projectors might have convex lenses of different focal lengths.

D26 *Inquiry Activity*

Skills References 2, 8

SKILLS YOU WILL USE

- Interpreting data/information to identify patterns or relationships
- Identifying sources of error

Identifying the Properties of Images

Question

How can you use ray diagrams to determine the properties of images formed by convex lenses?

Materials & Equipment

- 3 sheets of legal paper
- sharp pencil
- ruler
- calculator

Procedure

1. Make an observation table with the rows and columns shown at the bottom of this page. Name the table "Convex Lens Focal Length 4.0 cm."
2. Turn a piece of legal paper sideways. Use the ruler to draw a horizontal line across the middle of the paper. This is the principal axis of the lens.
3. At the midpoint of the principal axis, draw a perpendicular vertical line that is 5.0 cm above and below. This is the axis of symmetry of the lens. Label the axis "Convex Lens."
4. Measure 4.0 cm to the left of the vertex along the principal axis, and place a dot. This is the secondary focus, *F'*, of the lens. Do the same thing on the other side of the lens for the primary focus, *F*. Label both focuses.
5. Place two more dots at twice the focal length, and label them 2*f'* and 2*f* accordingly.
6. Repeat steps 2 to 5 twice to create a total of three convex lens diagrams.
7. Using one of the convex lens diagrams, draw a vertical arrow at d_o as indicated in the "Convex Lens" table to the height h_o.
8. Complete the ray diagram to produce the image of the arrow at the appropriate place on the diagram. Label the object and the image.
9. Measure and record d_i and h_i. Then, finish the next two ray diagrams for convex lenses using the values in the next two rows of the table.

Analyzing and Interpreting

10. Write a general statement that relates the size, orientation, and type of image to the object for a convex lens when:
    (a) d_o is greater than 2*f*
    (b) d_o is between 2*f* and *f*
    (c) d_o is less than *f*

Skill Practice

11. Use the data you collected to interpolate where the object would have to be placed so that the magnification of a convex lens would be exactly 1.
12. Calculate d_i and h_i using the thin lens and magnification equations for each set of data in the table. Compare these values to the ones you obtained using ray diagrams. Do they agree? If not, suggest reasons why the values are different.

Forming Conclusions

13. Describe how you can use ray diagrams to determine the properties of images formed by convex lenses.

Object Data		Image Characteristics				Image Data		Calculate	
d_o (cm)	h_o (cm)	Side of Lens	Real or Virtual	Size	Upright or Inverted	d_i (cm)	h_i (cm)	d_i	h_i
10.0	2.0								
6.0	2.0								
2.0	2.0								

11.3 CHECK and REFLECT

Key Concept Review

1. (a) What type of lens produces a real image?
   (b) What type of lens produces a virtual image?

2. A converging lens produces a real image 10 cm from the lens when the object is placed 30 cm from the lens.
   (a) What is the focal length of the lens?
   (b) What is the magnification of the lens?

3. An object is placed at each of the following distances from a converging lens. For each location, draw a ray diagram and state the properties and location of the image. (Hint: Choose a convenient value for f.)
   (a) $2.5\,f$
   (b) $1.5\,f$
   (c) $0.75\,f$

4. Suggest one use for each lens set-up in question 3.

5. What is one use for a diverging lens?

6. An object 1.2 cm high is placed 4.0 cm from a converging lens that has a focal length of 3.0 cm.
   (a) What is the location of the image?
   (b) What is the size of the image?

7. A converging lens is placed 12 cm from a wall chart. The focal length of the lens is 15 cm.
   (a) What is the location of the image?
   (b) What is the magnification?

8. A photographer uses his camera to view some deer in a field. If the image of the deer is produced 120.14 mm from a convex lens that has a focal length of 120 mm, how far away are the deer?

Question 8

Connect Your Understanding

9. At what distance from a convex lens must an object be placed so that the image is the same distance from the lens?

10. A student examines a ladybug using a magnifying glass with focal length of 5.0 cm. He holds the magnifying glass 3.5 cm above the ladybug. What is the magnification?

11. A photographer uses a telephoto lens to take a photograph of a 50-m high building that is 1000 m away. The image on the negative is 2.0 cm high. What is the focal length of the lens?

12. How can you find a good approximation of the focal length of an unknown concave lens by using an unknown convex lens as a starting point?

Reflection

13. Why do you think it is important to understand how light travels through lenses?

14. What analogy or model could you use to remember the differences between virtual and real images?

For more questions, go to *ScienceSource*.

SCIENCE everywhere

Self-Adjusting Glasses

The man in this photograph is wearing glasses that correct his blurry vision. The unusual thing is that he adjusted his own lenses without the help of an optometrist in determining his lens prescription. In fact, over one billion people in the world do not have access to an optometrist. Low-cost glasses that can be adjusted by the wearer may be part of the solution for making good quality, low-cost vision correction a reality for the whole world.

This pair of self-adjusting glasses is constructed by sandwiching a fluid-filled sac inside a flexible plastic lens. More fluid means a thicker lens and a stronger correction in the glasses. To make an adjustment, the wearer uses a small syringe to add or remove the fluid, and a small screw to lock the amount of fluid in the lens. One design hurdle is finding a way to produce the glasses in bulk cheaply. Another difficulty is the bulky frame that is currently needed. Dr. Silver and others are working to overcome these difficulties.

The inventor of self-adjusting glasses is Joshua Silver, a professor at Oxford University in England. Dr. Silver wondered whether people could correct their own vision if they could manually adjust the focussing power of the lenses. This would be just like anyone focussing a camera or a pair of binoculars. By 2008, Dr. Silver had already seen 30 000 pairs of his self-adjusting glasses delivered to people in 15 developing countries. By 2020, he would like to see 100 000 pairs distributed annually at a cost of less than $2 per wearer.

11 CHAPTER REVIEW

ACHIEVEMENT CHART CATEGORIES

- (k) Knowledge and understanding
- (t) Thinking and investigation
- (c) Communication
- (a) Application

Key Concept Review

1. Describe how the law of reflection applies similarly to regular and diffuse reflection. (k)

2. Use a ray diagram to show why images produced by plane mirrors are considered to be virtual images. (k)

3. (a) Name three places where concave mirrors are useful. (k)

(b) Name three places where convex mirrors are useful. (k)

4. (a) What are the properties of images that a convex mirror can produce? (k)

(b) What are the properties of images that a concave mirror can produce? (k)

5. (a) What are the properties of images that a concave lens can produce? (k)

(b) What are the properties of images that a convex lens can produce? (k)

6. Explain why the speed of light can vary when it travels through transparent or translucent materials. (t)

7. Explain what happens to the direction of a light ray if it enters a medium with a lower refractive index. (k)

8. Explain why the incident and refracted angles are measured from the normal instead of the surface. (k)

9. What properties of light does Snell's law explain? (k)

10. Draw ray diagrams for a converging mirror and state the properties of the image formed for the following object positions: (k)

(a) $3.0\,f$ (b) $1.4\,f$ (c) $0.70\,f$

11. Draw ray diagrams for a diverging mirror and state the characteristics of the image at the following object positions: (k)

(a) $1.0\,f$ (b) $0.50\,f$

Connect Your Understanding

12. A convex lens is placed near an object. The height of the image is 3.8 mm, giving a magnification of 0.26.

(a) What is the height of the object? (a)

(b) Does the answer depend on whether the image is real or virtual? Explain. (t)

13. Describe the properties of a lens that determine its focal length. (t)

14. The image of a 30-cm-tall rose is captured by a camera with a 28-mm lens. The image forms 29 mm behind the lens.

(a) How far is the lens from the rose? (a)

(b) How high is the image? (a)

15. Light passes from a diamond into air. The angle of refraction as the light emerges from the diamond is 25°. What was the angle of incidence? (a)

16. A ray of light passes from the air into a sapphire at an incident angle of 15°. Calculate the angle of refraction. (a)

17. An eyelash mite measures 0.28 mm long. What is the magnification if a microscope produces a 56-mm image? (a)

Question 17

18. A student looks at the letters on a page through a convex lens. The student holds the lens so the image of the letters appears to be 12 cm from the lens. The focal length of the lens is 24 cm.

(a) How far away from the page is the student holding the lens? a

(b) What is the magnification of the lens? a

19. An object placed near a convex lens is magnified 14 times. The image formed is 6.0 cm high. What is the height of the object? a

20. A layer of oil floats on top of water. A ray of light in the oil approaches the surface of the water at an angle of 40°. It is refracted at an angle of 35.6°. What is the refractive index of the oil? a

21. A ray of light approaches the flat surface of a diamond at normal incidence 0.0°. What is the angle of refraction? a

22. A camper viewing the reflection of the full Moon in a smooth lake notices that the image is almost perfectly circular. What would happen to the image of the Moon if the water became rough? t

23. You look at an image in a reflecting surface. How can you tell if the image is real or virtual? a

24. Explain the conditions required for total internal reflection. a

25. A compound microscope uses a convex objective lens that magnifies the object 40.0 times. If the object is 0.20 mm high, how high is the image? a

26. Lenses and mirrors both create images by redirecting light. Make a chart to compare the differences and similarities in how lenses and mirrors create images. t

27. You have been given several pieces of clear, hard, rock-like material from a fraud investigation. The subject of the investigation is accused of trying to substitute cubic zirconia for diamond. Explain the steps you would follow to identify the material. t

28. (a) Suppose you were camping and forgot to bring matches for your campfire. Explain how you could start a fire with a converging piece of glass. a

(b) Would a diverging piece of glass work equally well for this job? Explain why it would or would not. t

Reflection

29. What can you explain about light and the way it interacts with matter that you were not able to before this chapter? c

30. What are three concepts from this chapter that you are interested in learning more about in this class or in the future? c

After Reading

Reflect and Evaluate

Interview a partner about the challenges of reading graphics. Why can graphics be difficult to read and understand? How can graphics support you in understanding concepts and ideas? Together, create a poster on the computer using a diagram or flowchart to alert readers to strategies for reading graphics.

Unit Task Link

Your Unit Task is to design and build a shade for a streetlight that reduces light pollution in the night sky. What kind of mirror or lens will you use to make most of the light shine downward? How will the design of your shade prevent light from shining upward? Sketch some possible designs you could use for your shade.

12 Optical devices help us see farther and more clearly than we can with unaided eyes.

Astronomers use a copper vapour laser and a reflecting telescope to stabilize the twinkling images of stars.

Skills You Will Use

In this chapter, you will:

- identify and locate print and electronic sources that are relevant to research questions
- gather data from laboratory and other sources, and organize and record the data using appropriate formats, including tables, flowcharts, graphs, and/or diagrams
- select, organize, and record relevant information on research topics from various sources, including electronic, print, and/or human sources

Concepts You Will Learn

In this chapter, you will:

- analyze technological devices that use properties of light
- explain how optical devices have enhanced society
- analyze technological devices and procedures related to human perception of light
- evaluate the effectiveness of technological devices and procedures related to human perception of light

Why It Is Important

Our knowledge of human vision helps us to correct and extend our ability to see, which helps us to understand and appreciate our universe. Optical devices such as microscopes and telescopes use mirrors and lenses to help us see objects that are very small or very far away.

Before Writing

Thinking Literacy

Write for Your Reader

Good writers put themselves in the place of their readers, and so they make their writing easy to understand and interesting to read. Skim section 12.1, and choose two subtopics. Read at least one paragraph under each subtopic. What made the information easy to understand and interesting?

Key Terms

• astigmatism • compound microscope • cornea
• far-sighted • laser • near-sighted • photonics • photons
• reflecting telescope • refracting telescope

12.1 Human Perception of Light

Here is a summary of what you will learn in this section:

- Focussing of light in your eye is accomplished by the cornea, the lens, and the fluids contained in your eye.
- Light is detected by the retina, which contains rod cells, used for low light vision, and cone cells, used for bright light colour vision.
- Far- and near-sightedness and astigmatism are conditions in which the eye is not able to converge light rays correctly in order to form a clear image on the retina.
- Many types of vision problems can be corrected.

Figure 12.1 Human vision can detect many aspects of an object including shape, colour, and movement.

Perceiving Light

How is your vision? If you have good vision, you can be reading this page, look away to see a distant object, and then continue reading, always in perfect focus. You can recognize shapes in Figure 12.1 and in the classroom. You can quickly detect when something moves, even at the edge of your visual field. If the light is bright enough, you can make out a vast range of colours. If the room becomes dark, you can no longer see colour, but you can still detect shapes among the shadows.

Perception of light is an amazing ability, but it is not an ability that everyone shares equally. Many people benefit at some point in their lives from technologies or procedures that improve perception of light. For example, on a bright day, polarized sunglasses can both reduce glare and block harmful ultraviolet rays. Anti-glare night vision glasses can help drivers filter out light rays that can be a problem at night when trying to see past the headlights of oncoming cars. Even the reflection of light bouncing off of the white page of a textbook can make it very difficult for some people to read the black letters of the text. In this case, eyeglasses with a blue or yellow tint can be helpful. Visual perception is a very complex process that involves both eyesight and using your brain to make sense of the images received by your eyes.

Vision testing is normally done by a trained professional called an **optometrist.** In some situations, the optometrist will refer you to a physician who specializes in eye care, called an **ophthalmologist** (Figure 12.2).

Eye exams normally take about half an hour. Your eye care provider will have you identify letters or shapes on an eye chart and may place different lenses in front of your eyes to find out whether this can help you see more clearly. Other tests include checking for double vision, depth perception problems, and colour vision deficiencies. There is even a test to measure the pressure inside your eye. By catching problems early, it is often possible to correct problems or to prevent problems from getting worse.

Figure 12.2 An ophthalmologist uses a device called an ophthalmoscope to determine whether contact lenses are a good choice for correcting a patient's vision.

D27 *Quick Lab*

What Do You See?

Purpose

To use different aspects of vision to make sense of images

Figure 12.3 Step 1

Figure 12.4 Step 2

Figure 12.5 Step 3

Procedure

1. Are the horizontal lines in Figure 12.3 straight or curved? Make a prediction. Then use a ruler to check the result.
2. There are two different images in Figure 12.4. What do you see? Ask classmates what they see.
3. The Canadian flag in Figure 12.5 is coloured black and blue-green. Stare at the flag for about 20 s, and then immediately look at a white page. What do you see? You may need to try this several times.

Questions

4. For Figure 12.3, suggest whether the ability to detect edges and straightness occurs in the eye, the brain, or both.
5. For Figure 12.4, suggest whether the ability to give meaning to an image occurs in the eye, the brain, or both.
6. For Figure 12.5, suggest whether the ability to adapt to changes in colours occurs in the eye, the brain, or both.

Human Vision

In order to evaluate optical technologies related to the human perception of light, it can be helpful to understand how your own eyes work to focus light and detect images (Figure 12.6).

The outer surface of your eye where light enters is made of a transparent layer of tissue called the **cornea**. Light can pass right through the cornea because even though it is made of living cells, it is completely clear. Your cornea is made of strong tissue that is tough enough to protect your eye and hold it together, while remaining extremely sensitive to touch. The cornea is about as thick as a credit card and is sensitive enough to send you a strong pain signal if anything touches it. If it suffers from a small scratch, the cornea can heal itself. The light rays that arrive at your eye are refracted by the cornea. This helps direct the light correctly into your eye. Without the refractive properties of your cornea, you would not be able to focus.

WORDS MATTER

"Pupil" is derived from the Latin word *pupa*, meaning little doll, indicating the tiny reflections of people visible in pupils. The word "iris," the name of the structure that determines eye colour, is derived from the Greek word for rainbow.

Figure 12.6 A cross-section of the human eye

After passing through the cornea, the light rays reach the pupil. The **pupil** is the dark circle that you see when you look at someone's eye. It is actually just a hole that allows light to pass into the eye. The pupil is black for exactly the same reason the entrance to a cave appears dark — light rays enter the cave but do not leave. The pupil is created by a circular band of muscle called the **iris**. When people refer to their eye colour, they are referring to the colour of the iris. The iris controls the size of the pupil, and so it controls the amount of light that enters the eye. In dim light, the iris opens and the pupil dilates (becomes wider) to let in more light. In bright light, the iris closes and the pupil contracts (becomes smaller) so that less light enters (Figure 12.7). Changes in pupil size happen automatically; you do not have to think about it.

(a)

(b)

Figure 12.7 (a) Dilated pupil and (b) contracted pupil

Focussing the Light

Good eyesight requires precise focussing of light rays onto the retina. The **retina** is the inner lining at the back of the eye that acts as a projection screen for the light rays entering your eye (Figure 12.8). Most of the focussing of light in your eye is done by the cornea. However, the entire eye is a focussing system that involves the cornea, the lens, and even the spaces in front of and behind the lens that are filled with a watery fluid.

Figure 12.8 The image formed on the retina is inverted, but your brain interprets the image as being right side up.

Changing the Shape of the Lens

You may recall that a convex lens collects light and directs it to a focal point. Your eye includes a convex lens. Your lens allows you to change your focus so that you can see an object clearly regardless of whether it is right in front you or all the way out at the horizon. The lens is able to adjust its focal length because, unlike the cornea, it is attached to a tiny circle of muscles that can change its shape (Figure 12.9). When the muscles supporting your lens contract, the circle they form shrinks. This releases tension on your lens, allowing it to expand on its own into a more spherical or thicker shape. Your lens can now strongly refract light, which helps you focus on very near objects. Try focussing on this page when it is very close. You may be able to feel the muscles in your eye working.

When the circular muscle is relaxed, the circle they form expands, pulling your lens flatter and thinner. This is excellent for seeing distant objects. You may have noticed that if you allow your eyes to relax, nearby objects, such as this textbook, go out of focus, but distant objects are clear.

Figure 12.9 The muscles change the shape of the lens so you can focus on objects at various distances. (a) Position of muscles and shape of lens when focussing on nearby objects and (b) distant objects

Detecting Light

Suggested Activity •
D28 Inquiry Activity on page 478

Getting light into the eye and focussing it on the retina are only part of the task of seeing an image. In order for you to see, light rays must be absorbed by **photoreceptors**, which are cells in the retina that are sensitive to light. Photoreceptors include rod cells and cone cells (Figure 12.10). **Rod cells** help us detect shapes and movement in low light situations. Our brain does not recognize differences in colour from signals gathered by rod cells. Instead, we detect only shades of grey. Most of us are so used to our low light vision abilities that we do not even notice that we are not seeing in colour. **Cone cells** are photoreceptor cells used to detect colour. In humans, cone cells come in three types, each of which detects a different primary colour of red, green, or blue particularly well.

Figure 12.10 This is a false-colour electron micrograph image showing rod and cone photoreceptor cells in the retina at a magnification of 1800× at 10 cm. Cones are found in the central region of the retina. The more numerous rods are located outside the central region of the retina.

There is one place on the retina of every healthy eye called the blind spot, which has no photoreceptors and which cannot detect light. The **blind spot** is the place where the optic nerve attaches to the retina. The **optic nerve** connects your eye to your brain. You do not notice your blind spot because your brain "fills in" that spot with whatever colours are nearby in what you are looking at. You can use Figure 12.11 to help you detect your blind spot.

Figure 12.11 To find the blind spot in your right eye, close your left eye, and stare at the plus sign. Slowly move the book toward you and away from you. When the black spot disappears, you have found your blind spot.

Learning Checkpoint

1. What is the function of the cornea?
2. What structures control the amount of light that enters the eye?
3. What is the function of the retina?
4. What are two types of photoreceptors?
5. Where is the blind spot located?

Correcting Vision Problems Using Lenses

The most important and widespread technological device related to human perception of light is the lens, whether it is a lens made of tempered glass or hardened plastic used in eyeglasses or a tiny plastic contact lens that floats on your cornea. Almost any focussing problem can be improved by placing a lens in front of your eyes.

Many people have trouble focussing clearly at some point during their life. Focussing problems sometimes occur in young children and teenagers, as their eyes grow along with the rest of their body. With aging, many adults become less able to see nearby objects clearly as the lenses in their eyes gradually harden and become less able to change shape. Most eye problems fall into one or more categories: far-sightedness, near-sightedness, and astigmatism.

Far-Sightedness

People who are **far-sighted** can see distant objects clearly, but they cannot see nearby objects clearly. The light rays from nearby objects diverge more strongly than rays from distant objects, which enter the eye nearly parallel. In far-sightedness, the eye cannot make the lens thick enough to refract diverging light rays from nearby objects correctly on the retina. Instead, the image falls into focus behind the eye, resulting in a blurry image on the retina. Adding a converging lens in front of the eye helps the light rays form the image correctly on the retina as shown in Figure 12.12.

(a) far-sightedness (b) far-sightedness corrected by convex lens

Figure 12.12 (a) Far-sightedness and (b) far-sightedness corrected by a converging lens

Near-Sightedness

(a) near-sightedness

(b) near-sightedness corrected by concave lens

Figure 12.13 (a) Near-sightedness and (b) near-sightedness corrected by a diverging lens

People who are **near-sighted** can see nearby objects clearly but cannot see distant objects clearly. In near-sightedness, the nearly parallel rays that arrive at the eye from distant objects are refracted so much that the image forms in front of the retina instead of on it. This happens because the eye cannot make the lens thin enough, resulting in a blurry image. To correct near-sightedness, a diverging lens is placed in front of the eye, causing light rays from distant objects to diverge as they approach the eye. The eye then causes the light rays to converge properly, just as with light rays coming from nearby objects, and the light rays fall correctly onto the retina in focus (Figure 12.13).

Astigmatism

A common condition is called **astigmatism**, in which the eye is unable to form a clear image because of an irregular shape of the cornea or lens. For example, the cornea may be shaped more like a football than the typical baseball shape. This irregular shape causes an image to be formed on more than one place on the retina, which results in blurry vision (Figure 12.14).

There are two general types of astigmatism. In one type, the eye refracts light better along the vertical axis. In this type, a person has difficulty seeing horizontal lines clearly, such as in the letters E or F. In the second type of astigmatism, the eye refracts light better along the horizontal axis and the person has difficulty focussing on vertical lines like I and J. Common symptoms of astigmatism include headaches and fatigue.

Almost all eyes have some irregularities in the shape of the cornea or lens. However, astigmatism needs to be corrected only if it interferes with normal vision. Like both far-sightedness and near-sightedness, astigmatism can be corrected with eyeglasses, contact lenses, or laser surgery (Figure 12.15).

Figure 12.14 Astigmatism is a vision problem that results from a cornea that has an irregular shape.

Figure 12.15 Contact lenses sit directly on the cornea and can be used to correct far- and near-sightedness as well as astigmatism.

Reshaping the Cornea

Laser eye surgery is a general term for several different kinds of procedures that involve correcting vision by reshaping the cornea using energy from a laser (Figure 12.16). The procedures can be used to correct far- and near-sightedness as well as astigmatism. Millions of people worldwide have had successful laser surgery, eliminating their need for corrective lenses. However, as with any surgical procedure, it is not without risk. In some cases, laser surgery leads to poor night vision or problems caused by dry eyes.

Figure 12.16 Laser surgery, also called refractive eye surgery, reshapes the cornea in order to allow the eye to focus correctly.

Laser surgery is not suitable for everyone who might want it. This is due to differences in eyes from one person to another. The first task of every laser surgeon is to assess whether the procedure is appropriate for an individual patient and, if so, to give the patient enough information to make an informed decision. Some people delay having laser surgery because the procedure is only several decades old, and the long-term effects of laser surgery are not yet known.

During Writing

Thinking Literacy

Writing to Analyze

Scientists begin their writing with an important idea, question, or problem. They ask "What is important and why?" Then, they provide background information to help them draw a conclusion. When you analyze issues, start with a question, and then find the information you need to understand the answer.

Suggested STSE Activity

D29 Decision-Making Analysis Case Study on page 480

Learning Checkpoint

1. Where does the image form in persons who are far-sighted?
2. What type of lens is used to correct far-sightedness?
3. Where does the image form in persons who are near-sighted?
4. What type of lens is used to correct near-sightedness?
5. What causes astigmatism?

Optical Technologies for Persons with Blindness

You may have heard the term "blindness" applied to any type of vision impairment that prevents someone from being able to do important activities such as reading, driving a car, or seeing their friends clearly. Total blindness means that the person does not perceive any light at all. The term "legally blind" is often used to describe people with very low vision who, even with corrective lenses, would need to stand about 6 m from an object to see it as clearly as a normally sighted person could from about 60 m away. The term "legally blind" is also applied to people whose visual field is less than 20° instead of the 180° seen by those with normal vision.

Almost all people who are legally blind are able to detect some degree of light and form an image of some kind (Figure 12.17). For example, a legally blind person might be able to see using peripheral vision but not be able to form an image in the centre of the visual field. In another case, a legally blind person might see only a tiny spot at the centre of the visual field and not have any peripheral vision.

Figure 12.17 (a) Loss of the centre of vision field and (b) loss of peripheral vision

Many people who have very low vision can have most of their sight restored by wearing glasses or contact lenses or through surgery. For example, laser surgery can be used to help re-attach a retina that has become detached from the back of the eye. Laser surgery can also be used to remove cataracts, which are cloudy areas of the lens. Some treatments, such as retinal implants, are still very experimental. A retinal implant is an experimental procedure in which an electronic device is surgically implanted into the retina in order to replace natural photoreceptors that no longer function. The device can digitally detect light and transform it into electrical signals that can stimulate functioning parts of the retina to send signals to the brain.

Colour and Vision

True **colour blindness**, which is the ability to only see shades of grey, is very rare, occurring in about 1 person in 40 000. Colour-blind persons are able to see which traffic light in a stop light is on, but they cannot tell whether it is red or green. They must be careful to remember the position of the red and green relative to each other. Colour blindness is not always a disadvantage. In some cases, it allows a person to be able to more easily recognize an object set in a highly complicated colour background.

Colour vision deficiency is a more common condition, occurring in about 1 percent of females and 8 percent of males. **Colour vision deficiency** is the ability to distinguish some colours but not others (Figure 12.18). In one form of colour vision deficiency, often referred to as red-green colour deficiency, red and green appear to be the same colour. This is due to a lack of cone photoreceptors that detect red. Many people are not even aware that they have a colour vision deficiency until they are in their teens or later.

Some persons with a perceptual condition called dyslexia find it difficult to read text if it is written on a white background. In many cases, eyeglasses with coloured filters make reading much easier as they make the page appear to be coloured.

Take It **Further**

One of the roles of vision is to judge how far away objects are. Distance cues such as the size of familiar objects are called monocular cues, because only one eye is needed. The use of two eyes allows the brain to construct a 3D image and is called binocular vision. Find out more about depth perception using monocular and binocular vision. Begin your research at ***ScienceSource***.

Figure 12.18 Persons who have full colour vision will see the number 5 in (a) and 74 in (b).

Learning Checkpoint

1. (a) How many degrees of visual field does a legally blind person have?
   (b) How many degrees of visual field does a person with normal vision have?
2. What are two technologies involving the use of a laser that can help people who are losing their sight?
3. Identify one advantage and one disadvantage of being colour blind.
4. What optical technology can help people with dyslexia?

D28 *Inquiry Activity*

Skills Reference 2

SKILLS YOU WILL USE

- Using equipment, materials, and technology accurately and safely
- Communicating ideas, procedures, and results in a variety of forms

Sheep Eye Dissection

Question

How do the various parts of the eye function together to make an image appear on the retina?

Materials & Equipment

- preserved sheep eye
- dissection tray
- dissecting probe
- scissors
- tweezers
- hand lens
- prepared slides of retinal cells
- optional: microscope
- optional: ray box

CAUTION: The scissors and probe need to be handled with care.
If you cut yourself, seek first aid from your teacher.
Keep your hands away from your eyes and mouth.
Wash your hands thoroughly with soap after you finish the activity.
Dispose of all biological material according to your teacher's instructions.

Procedure

Part 1 — External Structures

1. Place a sheep eye in your dissection tray. Rotate the eye until the cornea is facing you.
2. Locate the following on the outside of the eye:
   - fat: yellow tissue that surrounds the eye and cushions it from shock
   - optic nerve: a white cord on the back of the eye about 3 mm in diameter that carries messages between the eye and the brain
   - muscles: reddish or grey flat muscles around the eye used to raise, lower, and turn the eye
3. Examine these structures on the front surface of the eye:
   - eyelids: two moveable covers that protect the eye from dust, bright light, and impact
   - sclera: tough, white outer coat of the eye that extends completely around the back and sides of the eye to protect and enclose it
   - cornea: a clear covering (preservative often makes this appear cloudy) over the front of the eye that allows light to come into the eye
   - iris: round black tissue through the cornea that controls the amount of light that enters the inner part of the eye (may be coloured in humans)
   - pupil: the round opening in the centre of the eye that allows light to enter and whose size is controlled by the iris

Part 2 — Internal Structures

4. Place the eye in the dissecting pan so it is again facing you. Using the tip of your probe, gently pierce the white part of the eye about 1 cm away from the edge of the cornea. Make a hole large enough for your scissors.
5. Using your scissors, carefully cut around the cornea. Try not to disturb the inside of the eye as you cut. Use the edge of the cornea as a guide. Pick up the eye, and turn it as needed to make the cut. Fluid called aqueous humour will come out of the eye as you cut.
   - aqueous humour: fluid found in the space between the cornea and lens that nourishes the cornea and the lens and gives the front of the eye its form and shape
6. Carefully remove the cornea from the front of the eye. Try looking through it. Cut the cornea in half to note its thickness. Observe and record your observations in your notebook.

D28 *Inquiry Activity (continued)*

7. Observe the lens, the iris, and the ciliary muscle at the front of the eye with the cornea removed. Observe and record the shape of the lens. Optional: use a bright ray box to shine light through the cornea and the lens to see the optical effects of their shapes.
   - iris: dark tissue of the eye that contains curved muscle fibres
   - lens: hard, solid structure that can be seen through the pupil
   - ciliary body: black muscle fibres located on the back of the iris that change the shape of the lens
8. Carefully remove the lens and vitreous humour from the eye. Use your tweezers and probe to carefully work around the edges of the lens.
   - vitreous humour: clear jelly-like substance found behind the lens that helps to maintain the shape of the eye and supports the inner structures, such as the retina and the lens.
9. Cut the back of the eye partly away from the iris and ciliary body to expose the retina and the blind spot.
   - retina: tissue in the back of the eye where light is focussed.The surface of the retina is covered with blood vessels that bring oxygen and nutrients to the retina and remove waste. The retina in a living eye is smooth.
   - blind spot: nerve cell fibres carrying impulses from the retinal receptors leave the eye in this region and enter the optic nerve
10. Sketch a labelled diagram of the eye.
11. Dispose of the eye parts and your gloves as directed by your teacher. Follow your teacher's instructions for cleaning your work area.
12. Optional: Use a microscope to observe a prepared slide of retinal cells and look for rods and cones.

Analyzing and Interpreting

13. (a) What differences did you notice between a sheep eye and a human eye?

    (b) What do the differences suggest about a sheep's vision?
14. Draw a labelled diagram showing the structure of the eye.

Skill Practice

15. Show, through a diagram or model, how the flexible part of the eye works to change the ability of the eye to focus.

Forming Conclusions

16. Describe how the various parts of the eye function together to make an image appear on the retina.
17. The eye is a fairly simple structure as compared to a camera, yet it has remarkable abilities. What are some things a human eye (Figure 12.19) can do that a camera cannot do?

Figure 12.19 Human eye, side view

CASE STUDY

D29 STSE *Decision-Making Analysis* Skills Reference 4

DI Key Activity

SKILLS YOU WILL USE

- Formulating questions
- Evaluating reliability of data and information

Evaluating Laser Vision Correction

Issue

For most people with vision problems, the opportunity to decrease or eliminate dependency on glasses or contact lenses is very appealing. Millions of people have had partial or full sight restored through refractive eye surgery. Are the benefits of the surgery worth the risks?

Background Information

Laser vision correction uses an excimer laser to adjust the focal length of the eye by changing the curvature of the cornea. Excimer lasers apply ultraviolet light of wavelength 193 nm to vaporize tiny amounts of tissue from the cornea.

There are two ways that the laser can be used to correct the curvature (Figure 12.20). One technique is called surface surgery. The surface layer is removed using chemicals, and then the laser is used to remove some tissue just below the surface layer.

Another technique is called flap surgery. Here, the surface layer is left intact. An instrument called a microkeratome is used to cut a thin flap of tissue that includes the surface layer from the front surface of the cornea. This flap is folded back, exposing an inner layer of the cornea. Once tissue is removed with the laser, the flap is returned to its original position.

Refractive eye surgery may not be suitable for patients who:

- are in their early 20s or younger
- have needed a change in their lens prescription during the past year
- actively participate in contact sports, such as boxing, wrestling, and martial arts
- have a history of eye injuries or disease
- have large pupils, thin corneas, inflammation of the eyelids, or previous refractive surgery
- are pregnant or have diabetes

Most patients enjoy problem-free vision as a result of refractive eye surgery. However, some patients do experience problems as a result of the procedure.

A small percentage of patients lose of some of the vision that they already have. Some patients develop visual symptoms, such as severe dry eyes and night vision difficulties due to glare and halos around lights. Other patients experience vision that is undertreated or overtreated so they still need glasses. Some of the results may diminish as people age and their focal length changes. Long-term data are not yet available because the procedures are so new.

Figure 12.20 Refractive eye surgery

Analyze and Evaluate

1. Describe the types of disorders that laser eye surgery is intended to correct.
2. Identify the risks and benefits associated with these surgical procedures.
3. Laser vision correction surgery is advertised in the media (i.e., television, radio, etc.). Describe the effects that media promotion of the surgery may have.
4. Discuss the question "Is laser vision correction surgery safe?" Consider the social, technological, and economic factors that may affect your position.

Skill Practice

5. Suppose you had vision problems that could be corrected by laser surgery. How would you decide whether to have the surgery? What would be your main concerns and questions?

12.1 CHECK and REFLECT

Key Concept Review

1. Draw and label an illustration of the human eye from a side view.
2. Your cornea allows light to enter your eye. What are two other functions of the cornea?
3. (a) Compare the pupil to a doughnut hole. In this analogy, what structure in the eye represents the doughnut?
   (b) How does this structure work?
4. (a) What is the shape of your lens when viewing distant objects?
   (b) What is the shape of your lens when viewing nearby objects?
5. What is the function of the retina?
6. What do photoreceptors detect?
7. What does the optic nerve connect?
8. Describe how improper focussing by the eye causes:
   (a) far-sightedness
   (b) near-sightedness
9. (a) What type of lens should a person who is far-sighted use?
   (b) What type of lens should a person who is near-sighted use?
10. What condition is shown below?

Question 10

11. (a) Describe a potential benefit of laser eye surgery.
    (b) Describe a potential risk of laser eye surgery.
12. (a) Can a legally blind person see? Explain.
    (b) Use your own words to write a definition of blindness.
13. How is colour blindness different from colour vision deficiency?
14. What is the most common form of colour vision deficiency?

Connect Your Understanding

15. If you wanted to use a friend's eyeglasses as a magnifying glass, would you ask someone who is far-sighted or someone who is near-sighted?
16. (a) How are rod cells and cone cells similar?
    (b) How are rod cells and cone cells different?
17. What does a laser surgery method of vision correction have in common with wearing glasses to correct vision?
18. Write an explanation for each of the following audiences on how the human eye works. You may wish to include a labelled diagram.
    (a) your teacher
    (b) a kindergarten student

Reflection

19. What can you explain about the eye and its capabilities that you were not able to before reading this section?

For more questions, go to *ScienceSource*.

12.2 Technologies That Use Light

Here is a summary of what you will learn in this section:

- Cameras collect and focus light in order to form an image.
- Microscopes are made of two convex lenses that are arranged to make magnified images of objects.
- Refracting telescopes use lenses to collect and focus light, whereas reflecting telescopes use mirrors for the same process.
- A telephoto lens magnifies a distant object. A wide-angle lens provides a large field of view.

Figure 12.21 An amateur astronomer uses a telescope to view the Milky Way galaxy.

The Invention of the Telescope

Some of the most fascinating discoveries of the last few hundred years have come about thanks to astronomers observing the sky with telescopes (Figure 12.21). Telescopes are fairly common now as shown in Figure 12.22, but when the telescope was first invented its existence was kept secret.

The first documented invention of a telescope was by the Dutch spectacle-maker Hans Lippershey. When one of his apprentices held up two lenses in front of his eyes, he was surprised to find that distant objects appeared even closer than when looking through only one lens. Lippershey placed the lenses at either end of a tube and in 1608 took his invention to the Dutch government. The Dutch government realized that telescopes could give a great advantage in warfare, so they decided to keep the invention a secret. The secret was not well kept, however, and within a year, lens crafters all over Europe were building and selling small telescopes.

Figure 12.22 Coin-operated telescopes are available in some scenic locations for the public to use.

Hans Lippershey himself helped spread the news of the telescope to the most famous and productive scientist of his time — the Italian astronomer and physicist Galileo Galilei. Galileo obtained one of Lippershey's telescopes and within a few months improved the design and built what was then the most powerful telescope in the world, able to magnify objects up to 30 times. He turned his telescope to the sky and became the first person in history to see mountains on the Moon.

Technology Development Continues

Galileo also discovered that four moons orbited the planet Jupiter. His discovery provided evidence that the Sun was the centre of the solar system rather than Earth. This started a race to build the best telescope possible. Larger lenses were used to capture more light and increase magnification. Thin lenses have better optical properties than thick ones but need to be spaced farther apart, so telescopes became both wider and longer. The largest early telescopes were much too large to hold, and in some designs one lens would be mounted on the roof of a building while the other lens was placed on the ground. Many sizes, shapes, and arrangements of lenses were tried, but eventually every design came upon the same insurmountable problem. Lenses refract different colours of light differently. Just as a prism can split sunlight into a rainbow, even the best lenses refract different colours of light in different ways. For example, this resulted in the image of a planet being surrounded by circles of different colours.

A new design was needed. By the late 1700s, another great scientist, Isaac Newton, had designed a telescope in which the large convex lens normally placed at the front of the telescope was replaced with a large concave mirror placed at the back of the telescope (Figure 12.23). This type of telescope was difficult to build because the technology needed to grind a mirror to the correct shape was not well developed. However, the advantages were great because mirrors were much lighter than lenses and they did not absorb some of the light, as big lenses had a tendency to do. This same design is used by all the largest and most powerful telescopes today.

Figure 12.23 Sir Isaac Newton's reflecting telescope

D30 *Quick Lab*

Extending Human Vision

Purpose

To appreciate the value of extended vision

Procedure

1. Choose a photograph in this student book that was taken using a telescope and that you think reveals important information about its subject.
2. Choose a photograph in this book that was taken using a microscope and that you think reveals important information about its subject.
3. Choose your favourite photograph in this student book.
4. Share your choices with members of your group Discuss your reasons for each of your choices.

Question

5. Consider all the choices your group has presented. Which image gives information that has had the most important effect on society? Explain why.

Cameras

Figure 12.24 This portable imaging device is equipped with a head-mount display for inspecting the sanitation of food-processing equipment.

Our view of ourselves, our planet, and our universe has grown enormously by learning how to extend our vision. Laser light and fibre optics have allowed us to transmit light within the human body. Microscopes have allowed us to see a world of structures and organisms that was completely unknown just a few hundred years ago. Using telescopes, we have observed stars exploding in deep space, temporarily outshining nearby galaxies containing billions of stars. We can record images of all these very large and very small subjects using cameras.

The recent increased availability of small, inexpensive, and low-power cameras has had important social effects. Because they are incorporated into cellphones and mobile digital devices, cameras can be taken almost anywhere and images can be transmitted almost instantly around the world. This widespread use of cameras has raised concerns about privacy, but it has allowed easier communication between communities of people in different locations.

Cameras are also used in industrial applications, such as automated vision systems to ensure quality control (Figure 12.24). For example, the Canadian Food Inspection Agency uses colour digital photography to monitor food colour and compare it with the colours of good quality food. If the colour of the food product does not match an acceptable stored value, an alarm goes off and the food product is manually inspected.

Figure 12.25 The parts of a simple camera that uses film

Parts of a Camera

A **camera** is basically a lightproof box with a lens at one end to form a real, inverted image on a light detector or light-sensitive plate or film (Figure 12.25). For a distant object, the image distance d_i is equal to the focal length of the lens. For nearer objects, the lens must be moved farther from the light detector so that the image is still focussed. A **shutter** controls the length of time light is allowed in. The **diaphragm** is the part of the camera that controls the aperture. The **aperture** is the opening that the light passes through, much like how the iris controls the pupil in the human eye. A large aperture is helpful in low light situations or when the subject of a photograph is far away. The larger the aperture, the greater the amount of light that can be collected by the camera.

Suggested Activity
D32 Inquiry Activity on page 493

Suggested STSE Activity
D33 Decision-Making Analysis on page 494

Almost all cameras use a convex lens to refract light rays onto a light detector, such as a charge-coupled device (CCD), that records the image. The image is usually recorded digitally and can be produced as a paper photograph, as an image for display on a monitor, or as a moving image or video. The image is stored on a memory chip and can be transferred to a computer, printer, or other electronic device.

Types of Lenses

The farther away an object is, the dimmer it is and the fewer the light rays that can reach the camera. A **telephoto lens** increases the amount of light that is collected and magnifies a distant object. A telephoto lens has a long focal length, which is why it protrudes so far in front of the camera (Figure 12.26).

The opposite of a telephoto lens is a **wide-angle lens**, which captures a wider angle of view (Figure 12.27). The shape of a wide angle lens is more spherical and has a shorter focal length than a telephoto lens. Cellphone cameras usually have a wide-angle lens.

Figure 12.26 A telephoto lens magnifies distant objects.

Figure 12.27 A photograph of the aurora borealis taken using a wide-angle lens

Digital Images

When the light detector in a digital camera records an image, it does so by registering different parts of the image on many thousands or millions of different detectors. Each tiny area of the image is assigned a single colour and brightness (Figure 12.28). These tiny picture elements are known as **pixels**. When the pixels are combined, an apparently continuous image is produced. The greater the number of pixels, the more closely the image resembles the original object.

WORDS MATTER

"Pixel" is formed from pix, which is a slang expression meaning pictures, and el, which is short for elements.

Figure 12.28 A digital image is made by combining thousands of individual pixels.

Digital Image Manipulation

Digital cameras can produce a range of optical effects, from highly detailed and realistic to manipulated and abstract. Because every image is composed of pixels, each of which is stored as a series of numbers, it is possible to manipulate the images by using software to change the values of the numbers stored for every pixel. For example, sometimes people's eyes appear bright red in photographs (Figure 12.29). This is because light from the camera flash passes into the eye, reflects off the red blood vessels inside of the eye, and then passes out again through the pupil. The red in the photograph can be removed using image editing software.

Image editing software allows many changes and improvements to the images captured by a camera. You can brighten the colours, remove unwanted objects in the photograph, sharpen or soften images, change colours, or even take objects from one photograph and add them to another. For example, you can take a photograph of yourself and insert it into a photograph of a scene from a foreign land that you have never visited. All of these changes allow increased creativity in making images more realistic or less realistic. However, manipulating images also raises concerns when the changes are applied to images in mass media such as magazines and newspapers.

Suggested STSE Activity
D34 Decision-Making Analysis on page 495

Figure 12.29 A digital image can be modified using software.

Learning Checkpoint

1. What is the difference between a shutter and an aperture?
2. (a) What is an advantage of widespread camera use?

   (b) What concerns have been raised over widespread camera use?
3. How does the focal length of a wide-angle lens compare to the focal length of a telephoto lens?
4. How is a digital image produced from pixels?

Microscopes

Some of the most important advances in health care during the last few hundred years have been the result of our ability to view the microscopic world, both directly through microscopes and indirectly through images. One of the first discoveries made using a microscope was that there were living things so tiny that they could not be seen with the unaided eye. The discovery was made by Antonie van Leeuwenhoek, a Dutch amateur scientist in the 1600s. Although his microscopes were very simple in design and had only one lens, van Leeuwenhoek used them to look at things like pond water, blood, and the plaque from his own teeth. What he saw astounded him. He wrote about his discoveries of "little animalcules" which were really the first descriptions of microscopic items such as bacteria, algae, and red blood cells. Van Leeuwenhoek's discoveries surprised the scientific world. Up until then, people had no idea there were organisms so small that you could not see them.

These discoveries confirmed one of the single most important health improvements in human history: the importance of washing hands. Prior to these discoveries, people did not realize that doctors moving from patient to patient in hospitals were spreading micro-organisms. The progress of entire plagues could be checked simply by having good sanitation.

WORDS MATTER

The suffix "-scope" is derived from the Greek verb meaning to view. In modern usage, a scope means an instrument for viewing. The prefix "micro-" means tiny, "tele-" means distant, and "peri-" means around or above. A microscope is for viewing tiny objects; a telescope is for viewing distant objects; and a periscope is for viewing objects above the scope.

Parts of a Microscope

In a **compound microscope**, a pair of convex lenses causes a small object to appear magnified when viewed through the eyepiece. The specimen is placed on a glass slide and then illuminated with a light source. Light travels through the objective lens, which is a convex lens at the bottom of the tube close to the specimen. Like a simple magnifying glass, the lens forms an upright enlarged image of the object when the object being viewed is less than one focal length from the lens. By using a second convex lens in the eyepiece, a magnification of hundreds or thousands of times can be achieved. Notice in Figure 12.30 that the light rays from the object converge inside the microscope and then diverge again. This crossing over of the light rays causes the image to become inverted. As a result, when you look through a microscope, the image is upside down.

Another type of microscope that uses light is the confocal microscope, which uses a laser beam to light the specimen. The image of the specimen is then digitally enhanced so it can be viewed on a computer monitor.

Figure 12.30 A compound microscope allows you to see great detail by combining the power of at least two lenses.

During Writing Thinking Literacy

Evaluating Information

Background information is never the whole story when you are analyzing an issue or situation. You need to make a final judgement or evaluation of the situation by telling your readers what is most important and why they should care about the topic. Make recommendations about what should be done.

Telescopes

A **telescope** is an optical device that provides enlarged images of distant objects. The lenses and mirrors in a telescope collect light from distant objects and focus it so the objects can be viewed directly or recorded using a charge-coupled device. There are two main reasons why it is difficult to see an object that is far away. One reason is that any distant object appears very small. But there is another equally important reason, which is that the farther away an object is, the dimmer it becomes. Recall that we see an object because light rays radiate off it and pass into our eyes. The more light rays that reach our eyes, the brighter the object appears. At greater distances, fewer light rays reach our eyes.

A telescope uses either a concave mirror or a convex lens that is much larger than human eyes so that it can gather more light. This is why some telescopes are so large — not to magnify better, but to collect more light. There are two main types of telescopes: refracting telescopes and reflecting telescopes.

Figure 12.31 A microscope and refracting telescope have a similar design.

Refracting Telescopes

A **refracting telescope** is similar in design to a microscope, in that they both have two lenses, one on each end of a long tube. However, unlike a microscope, the objective lens in a telescope is the larger lens. Because the object viewed with a telescope is far away, the objective lens has a very long focal length. This is more suitable for focussing light rays that are almost parallel when they strike the lens, which is how light rays arrive at the telescope when coming from an object a great distance away. This also explains why refracting telescopes can be very long. The rays refracted by the objective lens need a long distance before they converge, as in the diagram in Figure 12.31.

Refracting telescopes are often used by amateur astronomers because of their portability. However, refracting telescopes are rarely used for astronomical research because very large lenses are heavy and can sag under their own weight. Another disadvantage is that lenses absorb some of the light that passes through them.

Binoculars

Using a combination of several mirrors and lenses, it is possible to make a refracting telescope more compact. For example, **binoculars** are two short refracting telescopes attached together as shown in Figure 12.32. The two telescopes are made shorter by using prisms inside that act as mirrors to redirect the path of light rays.

Figure 12.32 Binoculars have two reflective prisms on either side to make the arrangement more compact.

Reflecting Telescopes

The largest telescopes are built using mirrors because mirrors do not absorb light. In a **reflecting telescope**, light enters from one end of a tube and then reflects off of a concave mirror toward a small plane mirror. This small mirror directs the light into an eyepiece, camera, or other instrument (Figure 12.33).

One of the largest telescopes, the Gemini North telescope is located in Hawaii and is operated by Canada and six other countries The Gemini North telescope has a flexible mirror 8 m in diameter that can be adjusted in microseconds to correct for disturbances in the atmosphere that would cause blurry images (Figure 12.34). Together with a second telescope, called Gemini South, located in Chile, the entire sky can be viewed.

Figure 12.34 The Gemini North telescope in Hawaii is one of the largest telescopes in the world.

Figure 12.33 In a reflecting telescope, a large concave mirror collects light and causes it to converge.

Learning Checkpoint

1. What lenses are used in a compound microscope?
2. Why is the image you view through a microscope upside down?
3. Why are some telescopes very large?
4. What are two main types of telescopes?
5. How are binoculars made more compact than telescopes?

Lasers

WORDS MATTER

The word "laser" is an acronym that stands for "**l**ight **a**mplification by **s**timulated **e**mission of **r**adiation."

A **laser** is an optical device that produces a form of light in which all the light rays are almost perfectly parallel, all have the same wavelength, and all of the wave crests and troughs are exactly lined up. Laser light is very different from incandescent light, which is usually a jumble of different wavelengths with the wave crests and troughs arranged randomly (Figure 12.35).

Figure 12.35 (a) In laser light, the light waves are parallel, have the same wavelength, and have wave crests and troughs aligned. (b) In ordinary light, different wavelengths (colours) of light are combined randomly.

Laser light is used in communications, consumer electronics, bar code readers, and DVD players, where information on the DVD is encoded in a manner similar to bar codes but in a microscopic size. You may also be familiar with lasers used in entertainment (Figure 12.36).

Lasers used in different applications vary tremendously in brightness. However, all lasers are bright enough to do permanent damage to the retina of your eye, which is why you should never look directly into a laser beam, even briefly. The brightness of a laser depends on the power used to generate the light, the colour of the light, and how well it remains in a tight beam. Very little energy is needed to operate lasers compared to other forms of light production. For example, an outdoor laser show can shoot bright laser beams using less energy than is needed in a standard household light bulb. The difference between the two is that all the energy in a laser is concentrated into a single beam. Stadium lasers are safe to view because they are kept at a distance and not directed straight into an audience.

Figure 12.36 Lasers are often used in light shows.

Lasers in Medicine

Lasers are used as a diagnostic tool in medicine to detect cancer. Many forms of cancer produce chemicals that leave the cancer cells and enter the bloodstream. By taking a sample of blood and shining laser light through the blood, it is now possible to detect certain kinds of cancers before they cause symptoms or grow large enough to be detected by an X-ray.

Colours of Laser Light

Because our eyes are more sensitive to green light than red or blue, a green laser beam appears brighter to us than a laser beam of a different colour (Figure 12.37). Although laser beams are more tightly concentrated than ordinary light beams, they still spread out. In fact, a laser beam may be several kilometres in diameter by the time it reaches the Moon. Astronauts from the Apollo missions left mirrors on the Moon. The mirrors are used with lasers to measure the distance between Earth and the Moon.

670 nm	diode
650 nm	diode
635 nm	diode
633 nm	helium-neon
568 nm	krypton
532 nm	diode
514 nm	argon
488 nm	argon
473 nm	diode
458 nm	argon
416 nm	krypton
410 nm	diode

Figure 12.37 Some common colours of laser light. The column on the left shows the wavelengths of light produced by the various types of lasers listed on the right.

Photonics

In the wave model of light, different colours of light have different wavelengths. Another way of modelling how light travels is by thinking of light as a series of many tiny packets of energy called **photons**. In this model, the colour of light is related to the amount of energy carried by each photon. It has been found, for example, that a photon of blue light carries more energy than a photon of yellow or red light. A photon of ultraviolet light carries even more energy than a photon of blue light, which is why ultraviolet light can damage skin, whereas blue, yellow, or red light cannot. Both the wave and the photon models of light each account for some properties of light. However, both models are needed to account for all of the properties.

Technologies that make use of the way in which light travels as photons are called **photonics**. Photonic technologies are used in many applications including laser technologies, digital cameras, solar energy generation, and computers with components that use light instead of electricity.

Take It Further

Canadian scientists are guiding the building of the world's largest optical telescope, the Thirty Meter Telescope (TMT). The 30-m mirror in the telescope will actually be made of many smaller mirrors. and the telescope will be nearly 100 times more sensitive than existing telescopes. Find out more about Canada's role in building the TMT. Begin your research at ***ScienceSource***.

Digital Cameras

The widespread availability of tiny, inexpensive still and video cameras has occurred partly due to photonics technologies in image capture. Just as a solar cell absorbs photons of light to produce electricity, millions of tiny, individually wired cells can be grouped together on a grid to detect many different photons at one time. Combining all of these detectors at once creates an image. The most common form of detector is a charge-coupled device (Figure 12.38).

Figure 12.38 A charge-coupled device (CCD)

Figure 12.39 Long rows of solar cells

Solar Cells

Solar cells convert sunlight directly into electrical energy (Figure 12.39). When a photon of sunlight is absorbed by an atom of a metal, such as lithium, an electron within the atom receives the energy of the light. This permits the electron to move away from the atom along a circuit. The flow of electrons in the circuit is electric current.

Solar cells have existed for many decades. Recent emphasis on renewable and clean energy production has inspired intensive research into new and widespread applications for high-efficiency solar cells.

Optical Computers

Traditional computers use electronic components to perform their functions through the movement of electrons in electric circuits. In an optical computer, photons take the place of electrons and optical switches and components do the calculating and other functions within the central processing unit of the computer. Optical computing is currently in an intensive research and development phase. Optical computers are expected to be much smaller but also to operate much faster than electronic devices.

D31 STSE *Science, Technology, Society, and the Environment*

Digitally Edited Photographs

Before photographs appear in a newspaper or magazine, a photo editor removes any "noise" including dust or distracting elements. Removing a distracting element might mean taking out a tree branch that is obscuring part of a statue, or it might mean removing a building or cars from the background. Photographs of people are often airbrushed to smooth out skin features. Sometimes, an editor also adds elements to a photograph, such as increasing the size of a crowd gathered to watch an event or adding fireworks to a night sky. These changes mean that the photographs you view in a magazine or newspaper may no longer be accurate portrayals of the events they capture.

1. Take the approach that digital editing is acceptable. Develop an argument that supports your position from the point of view of:
   (a) the editor of a news magazine
   (b) the editor of a fashion magazine
2. Take the approach that digital editing is only sometimes acceptable. Explain when it should be allowed.

D32 Quick Lab

Disassembling a Disposable Camera

Purpose

To disassemble a disposable camera to identify its optical systems

Materials & Equipment

- non-flash disposable camera
- small tool set
- parts tray

CAUTION: Do NOT use a camera equipped with any type of flash or power source.

Figure 12.40 The interior of a disposable camera

Procedure

1. Perform a safety check before starting your disassembly. Make sure you are wearing eye protection. Inspect the camera carefully for a flash. If it has a flash, DO NOT proceed. Return the camera to your teacher. If your camera has an outer paper and/or plastic covering, remove it. Inspect the camera carefully, looking for power sources such as batteries. If you see a battery, DO NOT proceed. Return the camera to your teacher.
2. Find the screws or clips that hold the case together, and open the case (Figure 12.40).
3. Identify optically important parts such as the shutter and lens. Observe and record the kind of lens. Notice how it is positioned with respect to the film so that it will produce an inverted image. See Figure 12.25 on page 484.
4. Carefully take the camera apart. Organize your camera parts to show how the optically important components collect and convert light to produce a focussed image.
5. Organize all other components to show how they encase the optical parts while permitting access to the interior of the camera.

Questions

6. (a) What parts of the camera are optically important?
   (b) What parts are not optically important?
7. (a) Which parts of the camera are similar in function to the eye?
   (b) Which parts of the camera are different in function from the eye?
8. (a) Describe how the camera could be used to make a good model for the eye.
   (b) Describe the limitations of the camera as a model for the eye.
9. What other uses can you think of for the film?

D33 STSE Decision-Making Analysis

Skills Reference 4

SKILLS YOU WILL USE

- Gathering, organizing, and recording relevant information from research
- Drawing conclusions

Single-Use Cameras: Useful Convenience or Wasteful Extravagance?

Figure 12.41 Single-use cameras are also called disposable cameras. This single-use camera is specially made for taking photographs underwater.

The Issue

Camera manufacturers have found specialty markets for devices called single-use cameras. In a single-use camera, a small number of photos are taken and then the camera is recycled (Figure 12.41). For example, some people store a single-use camera in their car. If there is a collision, they will be able to make a visual record as evidence in a legal proceeding. Are single-use cameras useful to society? Or are they a wasteful extravagance because of the amount of energy involved in producing and then immediately recycling them after one use?

Background

Inexpensive, good quality digital cameras designed for long-term use are widely available. These cameras are very versatile. They can display the images saved in their memory. Uploading images to a computer or the Internet for display or printing is relatively easy. Yet, despite the many conveniences of the standard digital camera, manufacturers have found that there is also a market for single-use cameras. Single-use cameras are designed for people who might be without a regular camera. These cameras are useful while on vacation or participating in some form of recreation where an expensive camera might be at risk of damage, such as whitewater rafting.

Some single-use cameras are designed for specific applications such as underwater use while snorkelling or swimming. Not only are they waterproof, they are specially adapted for light conditions under water. Other kinds of specialized single-use cameras are available for indoor/low light conditions, night photography, and wide-angle scenery shots. Another application is at celebrations, where the hosts pass a number of cameras out among the guests. At the end of the event, the cameras are collected and the photos are assembled as a record of the event.

Single-use cameras are convenient for someone who already owns a good quality digital camera and does not wish to buy a second one. There is even an application available in a single-use camera that is not available with traditional ones. Some single-use cameras can produce a hard copy of a photograph right on the spot — at the beach, the party, or wherever.

Critics of single-use cameras point out that recycling is only one part of an overall strategy of reduce, reuse, and recycle. Even recycling costs energy and other resources. Another criticism is that the research into disposable cameras might be better spent on research into making cameras more rugged and less prone to damage.

Analyze and Evaluate

1. Read the above background information. Create a chart comparing the advantages and disadvantages of single-use cameras compared to standard multi-use digital cameras.
2. ***ScienceSource*** Research recent developments in the use and recycling of single-use cameras.

Skill Practice

3. What is your conclusion about whether single-use cameras are a useful convenience or an extravagant waste of money, energy, and resources?

DI Key Activity

D34 STSE *Decision-Making Analysis* Skills Reference 4

SKILLS YOU WILL USE
- Thinking critically and logically
- Communicating ideas, procedures, and results in a variety of forms

Visual Recording Devices and Privacy

Issue

Does the widespread use of visual recording devices infringe on people's privacy?

Background Information

You are going out with friends for the afternoon. First, you stop at an automated teller machine. While you make your transaction, your actions are recorded on a security camera in the machine. Then, you catch a bus to go to the city park to meet your friends. A camera installed above the driver captures your image as you step into the bus. When you arrive at the city park to meet your friends, you wait next to a statue in the centre of the park. A group of tourists comes by and they all take photos of the statue — and you. A mother is playing with her children close by and recording them on her video camera. Sometimes, the children play close by you and you are included in the recording. When your friends finally arrive, they take out their cellphones and everyone squeezes together to get into one photograph. The next day, your friend posts the image on her website.

Cameras have evolved to become smaller, easier to transport, and able to produce higher quality images. We can take them almost anywhere and use them almost anytime (Figure 12.42). Security cameras record transactions in stores and are used by police and security personnel to identify people who enter and exit buildings (Figure 12.43). Video cameras are installed in some schools to record activities in the classrooms and halls. Cameras installed on satellites, airplanes, trees, and road signs can be used to track vehicles on highways. Your friend with a video camera or cellphone might record events at a party and then later post the recording on the Internet.

Photographic images are used for a wide range of purposes that benefit society. But what are the rights of the person being photographed? When is camera use an invasion of privacy? Should there be limits to when and how cameras can be used?

Figure 12.42 You can transmit an image around the world almost instantly.

Analyze and Evaluate

1. ***ScienceSource*** Your task is to choose one side of the argument and research the issue. You will present your findings as a class presentation. Your teacher will provide more details about how to present your information.
2. You may wish to interview friends and family members to gain their perspectives.
3. Sort the information according to usage of images: culture, education, security, policing, entertainment, and the environment.

Skills Practice

4. **Web 2.0** Develop your research as a Wiki, a presentation, a video, or a podcast summarizing your opinion. For support, go to ***ScienceSource***.

Figure 12.43 A video surveillance camera

12.2 CHECK and REFLECT

Key Concept Review

1. How are cameras used in food inspection?
2. What is the relationship between the size of the aperture and the amount of light that can be collected by a camera?
3. How is a telephoto lens different from a wide-angle lens?
4. How are digital images manipulated?
5. What are two reasons why it is difficult to see something that is far away?
6. Why was the discovery of microbial life forms important for advancement in public health?
7. Describe the arrangement of lenses in a microscope.
8. Use a ray diagram to help you explain the path of light through a microscope.
9. Which type of telescope is closest in design to a microscope?
10. What is the difference between a reflecting telescope and a refracting telescope?
11. Why is a reflecting telescope better for astronomical observations than a refracting telescope?
12. What other optical device do binoculars closely resemble? Explain.

Question 12

13. List three ways that laser light is different from ordinary light.
14. What are three uses of laser light?
15. Why should you never look directly at a laser beam?
16. Why does a green laser beam seem brighter to us than a laser beam of another colour?
17. What is the name given to individual packets of light energy?
18. What is photonics?
19. What are four applications of photonics?
20. What is a photon?

Connect Your Understanding

21. How has accessibility to optical technologies such as telescopes and microscopes affected our perception of the natural world?
22. What are some ways that the increased use of cameras has affected society?
23. What areas of photonics will likely become even more useful in addressing environmental needs related to energy and people's health?
24. What areas of photonics will likely become even more useful in addressing societal needs in the area of information and community building?
25. What are five careers based on the optics discussed in this section?

Reflection

26. (a) Describe your opinion about widespread camera use as a result of reading this section.
    (b) If your opinion changed while reading this section, explain how and why it changed.

For more questions, go to *ScienceSource*.

COOL IDEAS

from JAY INGRAM

Jay Ingram is an experienced science journalist, author of *The Daily Planet Book of Cool Ideas*, and host of *Daily Planet* on Discovery Channel Canada.

A Wall of Water?

Figure 12.44 A layer of warmer air above a layer of cooler air can cause light to refract and create a mirage.

Things are not always what they seem. As you drive along the highway on a hot summer day, the distant pavement looks wet. But when you get there, it is perfectly dry. Why? Light travels through layers of air of different temperatures; when a highway is heated by the Sun in summer, the highway warms the air just above it. Light travelling down toward the pavement then curves up as it travels through the warm air. The result is that we see a mirage — an image of the sky, superimposed on the road.

Sometimes, the air close to the surface of Earth is cooler than the air above it. In this case, the light that is reflected from an object located on the surface gets refracted and appears to come from a location above the horizon, as shown in Figure 12.44. This type of mirage is called a superior mirage.

A superior mirage could be spectacular over the ocean. A scientist named Waldemar Lehn at the University of Manitoba thinks that Viking sailors crossing the Atlantic Ocean a thousand years ago might have been tricked by a superior mirage into thinking they had entered an oceanic whirlpool. Viking writings describe sea fences that were "higher than lofty mountains."

Imagine you are on a Viking ship crossing the dangerous ocean south of Greenland. The air around you is cold, but above it lies a layer of warmer air. Light always bends towards the colder air. That means that light streaming in your direction from the horizon would curve down, and you would actually be able to peek over the horizon.

Not only would you be able to see much farther, but in extreme cases the actual horizon would seem to rise up — all around you. You might think you had just blundered into the middle of a gigantic whirlpool and you were surrounded by a terrifying wall of water on all sides.

Question

1. How would an understanding of optics have helped early explorers such as the Vikings?

12 CHAPTER REVIEW

ACHIEVEMENT CHART CATEGORIES

- (k) Knowledge and understanding
- (t) Thinking and investigation
- (c) Communication
- (a) Application

Key Concept Review

1. Draw and label the human eye:

(a) from a side view (k)

(b) from the front view (k)

2. Describe how the human eye accomplishes its task of collecting the right amount of light. (k)

3. State the two structures that refract light as it enters the eye. (k)

4. Describe what occurs in each of these conditions and how the condition is treated using lenses.

(a) near-sightedness (k)

(b) far-sightedness (k)

(c) astigmatism (k)

5. Explain the term "legally blind." (k)

6. What are two technologies that use laser light to help restore vision? (k)

7. What happens during a retinal implant? (k)

8. What is colour vision deficiency? (k)

9. What lack in the eye causes the inability to see the number 5 in the circle below? (k)

Question 9

10. How do eyeglasses with colour filters help people with dyslexia to read? (k)

11. (a) What type of lens is usually found in a camera, concave or convex? (k)

(b) Where is the image formed in a camera? (k)

12. How are images taken through a telephoto lens different from images taken through a wide-angle lens? (k)

13. (a) What is a pixel? (k)

(b) How are pixels used to make a photographic image? (k)

14. How is a digital image manipulated? (k)

15. (a) Who discovered the first microscopic creatures? (k)

(b) How did this discovery benefit society? (k)

16. Describe the arrangement of lenses in a compound microscope. (k)

17. Describe an advantage and a disadvantage of the design of a refracting telescope over a reflecting telescope. (k)

18. Describe the arrangement of mirrors and lenses in a reflecting telescope. (k)

19. (a) Why do lasers require comparatively little energy to operate? (k)

(b) Why is it dangerous to look directly at a laser beam? (k)

20. (a) How do solar cells make use of photonics? (k)

(b) How do optical computers make use of photonics? (k)

Connect Your Understanding

21. State a benefit and a limitation of each of the following devices. a

(a) microscope

(b) refracting telescope

(c) reflecting telescope

(d) binoculars

(e) camera

22. What could happen to your sight if the muscles surrounding the pupil did not work properly? t

23. Why might the Canadian Ophthalmological Society suggest different colour vision standards for drivers of personal vehicles, taxi or bus drivers, and emergency vehicle drivers? a

24. (a) Make a chart that lists the parts of the eye and the parts of a camera and their function. k

(b) What do the camera and the eye have in common? t

(c) How are the camera and the eye different? t

25. "All cats are grey in the dark." Using your knowledge of how the eye works in low light, explain why this expression is true. t

26. It is possible for the retina to detach from the back of the eye. What would the effect of retinal detachment be on someone's vision? t

Question 26

27. How can we perceive hundreds of different colours when the cones in the retina are sensitive mostly to the three primary colours? t

28. Describe how a person with blindness would need different techniques or technologies to carry out daily living as compared to a person who is colour blind. t

Reflection

29. Describe what you found most challenging in learning about how optical devices and the human eye work together. c

30. Describe an optical device that you would like to see invented in your lifetime. Include a labelled sketch of a possible design as part of your answer. c

After Writing

Thinking Literacy

Reflect and Evaluate

This chapter offers several opportunities for you to analyze issues or situations. Using one of your written pieces, explain to a partner what you have learned about the importance of asking an initial question, providing background information, and making an evaluation of the issue or situation.

Unit Task Link

In your unit task, you will design and build a shade for streetlights that will reduce or eliminate light pollution in the night sky. Will your design reduce light pollution but still illuminate a wide area of ground? Make a list of tools and materials that you will need to build your streetlight.

UNIT D Summary

KEY CONCEPTS	CHAPTER SUMMARY

10 Light is part of the electromagnetic spectrum and travels in waves.

- Electromagnetic spectrum
- Wave model of light
- Sources of light
- Ray model of light
- Interactions of light with matter

- Several properties of light can be explained using the wave model.
- White light can be separated into all the colours of the rainbow, with each colour having a different wavelength.
- The electromagnetic spectrum is split into various parts, some with longer wavelengths than visible light and some shorter than visible light.
- Light can be produced in many ways.
- White light may be treated as a combination of three different primary colours that can be combined or separated.
- The ray model describes how light interacts with matter.
- Light can be absorbed, reflected, or refracted as it goes from one medium to another.

11 Ray diagrams model the behaviour of light in mirrors and lenses.

- Law of reflection
- $M = \frac{h_i}{h_o}$ and $M = \frac{d_i}{d_o}$
- $n = \frac{c}{v}$
- $n_1 \sin\theta_1 = n_2 \sin\theta_2$
- $\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$

- The law of reflection states that the angle of incidence equals the angle of reflection as measured from the normal.
- Concave mirrors can be used for magnification. Magnification is the measure of how much larger or smaller an image is compared with the object itself.
- The speed of light is highest in a vacuum and lower in different media.
- Refraction is the bending of light as it crosses the boundary between two media.
- Snell's law relates the angles of incidence and refraction of a light ray to the indices of refraction of the two media.
- Total internal reflection occurs when light reflects completely off the wall within a denser medium rather than passing through into a less dense medium.
- Images can be virtual or real depending on how they were reflected or refracted by mirrors or lenses.
- The thin lens equation relates the distance of the object from the lens, the distance of the image from the lens, and the focal length of the lens.

12 Optical devices help us see farther and more clearly than we can with unaided eyes.

- Human vision
- Correcting human vision problems
- Use of cameras
- Microscopes and telescopes
- Laser light
- Photonics

- Human vision can be corrected using lenses.
- Laser vision correction involves reshaping the cornea and has both advantages and disadvantages.
- Widespread use of cameras has raised concerns over privacy.
- Microscopes and telescopes make use of lenses and mirrors.
- Photonics, the technology of using photons of light, has many applications that benefit society.

VOCABULARY

- additive colour theory (p. 387)
- amplitude (p. 382)
- bioluminescence (p. 392)
- chemiluminescence (p. 395)
- crest (p. 382)
- diffuse reflection (p. 406)
- electric discharge (p. 396)
- electroluminescence (p. 397)
- electromagnetic radiation (p. 385)
- electromagnetic spectrum (p. 385)
- fluorescent (p. 394)
- frequency (p. 382)
- gamma rays (p. 385)
- incandescent (p. 394)
- infrared waves (p. 384)
- light-emitting diode (p. 397)
- liquid crystal (p. 398)
- liquid crystal display (p. 398)
- microwaves (p. 384)
- model (p. 386)
- opaque (p. 404)
- organic light-emitting display (p. 397)
- penumbra (p. 405)
- phosphor (p. 394)
- phosphorescence (p. 395)
- plasma display (p. 398)
- prism (p. 386)
- property (p. 386)
- radio waves (p. 384)
- ray model of light (p. 404)
- reflect (p. 388)
- regular reflection (p. 406)
- rest position (p. 382)
- subtractive colour theory (p. 388)
- translucent (p. 404)
- transparent (p. 404)
- triboluminescence (p. 396)
- trough (p. 382)
- ultraviolet rays (p. 385)
- umbra (p. 405)
- visible spectrum (p. 386)
- wave (p. 382)
- wave model of light (p. 386)
- wavelength (p. 382)
- X-rays (p. 385)

KEY VISUALS

The visible spectrum of white light

- angle of incidence (p. 417)
- angle of reflection (p. 417)
- axis of symmetry (p. 450)
- concave lens (p. 451)
- concave mirror (p. 421)
- converging lens (p. 452)
- converging mirror (p. 421)
- convex lens (p. 452)
- convex mirror (p. 421)
- dispersion (p. 440)
- diverging lens (p. 451)
- diverging mirror (p. 426)
- focal length (p. 420)
- focal point (p. 420)
- geometric optics (p. 417)
- image (p. 418)
- incident ray (p. 418)
- index of refraction (p. 437)
- law of reflection (p. 418)
- lens (p. 450)
- magnification (p. 423)
- medium (p. 436)
- mirage (p. 443)
- normal (p. 418)
- optical device (p. 418)
- optical fibre (p. 418)
- plane mirror (p. 419)
- real image (p. 420)
- refraction (p. 436)
- Snell's law (p. 441)
- solar oven (p. 423)
- thin lens (p. 452)
- thin lens equation (p. 454)
- total internal reflection (p. 442)
- vertex (p. 420)
- virtual image (p. 419)

Light refracts as it moves from one medium into another.

- aperture (p. 484)
- astigmatism (p. 474)
- binoculars (p. 489)
- blind spot (p. 472)
- camera (p. 484)
- colour blindness (p. 477)
- colour vision deficiency (p. 477)
- compound microscope (p. 487)
- cone cells (p. 472)
- cornea (p. 470)
- diaphragm (p. 484)
- far-sighted (p. 473)
- iris (p. 470)
- laser (p. 490)
- near-sighted (p. 474)
- optic nerve (p. 472)
- optometrist (p. 469)
- ophthalmologist (p. 469)
- photons (p. 491)
- photonics (p. 491)
- photoreceptors (p. 472)
- pixels (p. 485)
- pupil (p. 470)
- reflecting telescope (p. 489)
- refracting telescope (p. 488)
- retina (p. 471)
- rod cells (p. 472)
- shutter (p. 484)
- telephoto lens (p. 485)
- telescope (p. 488)
- wide-angle lens (p. 485)

Visual recording devices are used around the world.

UNIT D Task

How Much Light Is Too Much Light?

Figure 12.45 The night sky from an Ontario town (a) during a blackout and (b) with light pollution

Getting Started

When the power went out in Ontario in August 2003, many people looked at the night sky in amazement. They had not realized how many stars were visible from their communities and cities because the beauty of the night sky was usually hidden behind a haze of light.

The yellowish dome of light that you may see over a distant city at night is caused by light pollution. Light pollution is a term given to unwanted, unnecessary, and wasteful light.

Your Goal

An astronomical observatory is to be built near your city. In order for the observatory to be effective, the light pollution in the city must be drastically reduced. Your goal is to design a shade for streetlights. The streetlights must continue to illuminate the streets and walkways, but there should be as little wasted light energy as possible distributed to the sides or above the streetlights.

Criteria for Success

- Your shade must illuminate surfaces below the light but allow little or no light to show on the sides and above the shade.
- Your shade will be evaluated by the amount of light that illuminates the ground and the amount of light that pollutes the sky. Your teacher will use a light meter to measure the light intensity produced at different heights above and below the streetlight.
- You will need to be prepared to discuss with the class the design of your shade and how it accomplishes its goals.

What You Need to Know

Many cities and communities have a problem with light pollution caused by parking lot lights, lights in commercial buildings and sports facilities, and streetlights.

The function of streetlights is to illuminate the streets, but many designs of lights also distribute light up and to the side. Some streetlights waste as much as 25 percent of their energy by lighting up the sky as well as illuminating the ground. The glare from inefficient lighting can be hazardous to vehicle drivers on the road and to airplane pilots flying overhead. The cost of all that wasted energy is passed on to the taxpayers and ultimately to the environment.

What You Need

- heat-resistant materials
- light bulb and socket as set up by your teacher
- light meter

CAUTION: Do not shine bright light into anyone's eyes. Incandescent light sources can become very hot. Do not touch the bulbs or block air flow around the bulbs. Heat resistant materials should be used around the bulb. No material should actually touch the bulb or the connections on the socket.

Procedure

1. Meet with your group members to discuss the role each team member will play in researching, designing, and building the shade. As well as preventing upward illumination, consider how wide a patch of ground is illuminated. A broad illumination is better than a spotlight since it means streetlights may be placed farther apart so fewer are needed and more energy is saved.
2. ***ScienceSource*** Research how streetlights are designed and how they contribute to light pollution for astronomers. Also research new streetlight designs that reduce or eliminate the upward illumination of streetlights. List a bibliography of all websites and books consulted to research the project.
3. Work together to decide what materials are needed. Create a drawing or detailed plan of how it will be constructed, and include a materials list. Before proceeding with the construction of the shade, show these plans to your teacher for feedback and approval.
4. Your teacher will set up one light fixture and bulb for the class. This will enable all projects to be tested in the same conditions. Your teacher must approve your design before you can test it.
5. Place your shade on the light. Use the light meter to test the shade. Measure the intensity of the light in three places:
   (a) on the ground directly underneath the light. Also measure how wide a path of ground is illuminated.
   (b) at a height of 1.0 m, 30 cm to the left or right of the light. This value should be much less than at the ground.
   (c) at a height of 1.5 m, 30 cm to the left or right of the light. This value should be as close to zero as possible.

   Your teacher will use the same method to check for the intensity of the light provided by your shade.
6. If necessary, make whatever modifications necessary to improve your shade based on the results of step 5. Be sure to test the shade in exactly the same conditions as the first test.
7. When you are satisfied with the performance of the shade, submit it to your teacher for testing. Prepare a summary of the features the shade has to make it effective. Be ready to discuss your design with the teacher/class.

Assessing Your Work

8. What do you think were the design features that best enabled the shade to reduce light pollution?
9. Did the features that helped to reduce light pollution also reduce the light available at ground level? If so, what modifications could you incorporate into your shade that would increase the light available at ground level without producing light pollution?
10. What design features did you see in shades produced by other groups that your shade did not have? Assess the effectiveness of these other designs.
11. Identify the issues that might arise if a city were to implement a shade similar to the one that you designed to eliminate light pollution.

UNIT D Review

ACHIEVEMENT CHART CATEGORIES

- (k) Knowledge and understanding
- (t) Thinking and investigation
- (c) Communication
- (a) Application

Key Terms Review

1. Create a mind map using the following terms. You may add more terms if you wish. (c)
   - angle of incidence
   - angle of reflection
   - angle of refraction
   - camera
   - concave mirror
   - converging lens
   - convex mirror
   - diverging lens
   - focal point
   - luminescence
   - magnification
   - microscope
   - mirage
   - telescope
   - virtual image

2. In a short paragraph, describe properties of light. You may wish to use some of the terms from question 1. (c)

10 Light is part of the electromagnetic spectrum and travels in waves.

3. (a) Draw a sketch of the electromagnetic spectrum. (k)
   (b) Label the different types of electromagnetic radiation. (k)

4. What is the difference between electromagnetic radiation and the electromagnetic spectrum? (k)

5. (a) What is the amplitude of the wave below? (k)
   (b) What is the wavelength of the wave below? (k)
   (c) Copy the wave into your notebook and label amplitude, wavelength, crest, trough, and resting position. (k)

Question 5

6. What is the relationship between wavelength and frequency? (k)

7. List the colours of the visible spectrum, from lowest to highest energy. (k)

8. (a) What are the three primary colours of light? (k)
   (b) What are the three secondary colours of light? (k)
   (c) Describe how each secondary colour of light is produced. (k)

9. In terms of subtractive colour theory, explain why a darker coloured object will heat up faster than a lighter coloured object. (k)

10. What colour of light would you observe if you combined equally bright lights of the three primary colours? (k)

11. (a) Name seven different sources of light. (k)
    (b) Give an example of each source. (k)

12. State how fluorescence and phosphorescence are:
    (a) similar (k)
    (b) different (k)

13. What assumption does the ray model of light make about how light travels? (k)

14. (a) List three terms that describe how light interacts with various materials. (k)
    (b) Give an example of each interaction. (k)

15. Is light transmitted through the frosted glass shown below? Explain. (k)

Question 15

16. How many primary colours does an LCD or plasma display need to produce all the colours of the rainbow? (k)

17. Use the ray model of light to describe the difference between penumbra and umbra. (k)

11 Ray diagrams model the behaviour of light in mirrors and lenses.

18. (a) State the law of reflection. (k)
    (b) Does the reflected ray in the illustration below obey the law of reflection? Explain why it does or does not. (k)

Question 18

19. How is a virtual image different from a real image? (k)

20. Draw a ray diagram to show why your image is reversed in a plane mirror. (k)

21. How is the focal point of a mirror different from the vertex? (k)

22. (a) Draw a ray diagram of an object 0.75*f* from a concave mirror. (k)
    (b) Draw a ray diagram of an object 0.75*f* from a convex mirror. (k)

23. What are two versions of the magnification formula? (k)

24. State two uses for:
    (a) a concave mirror (k)
    (b) a convex mirror (k)

25. What is the definition of refraction? (k)

26. Which substance refracts light more, water or glass? Explain why. (k)

27. What is the speed of light? (k)

28. (a) What is the definition of index of refraction? (k)
    (b) What is the formula for calculating the index of refraction of a material? (k)

29. What is a common example of dispersion? (k)

30. State the quantities that are related by Snell's law. (k)

31. (a) Define critical angle. (k)
    (b) How can the value of the critical angle be measured? (k)

32. How can you tell the difference between regular and diffuse reflection? (k)

33. Which will be larger: the critical angle at an air-glass interface or the critical angle at a water-glass interface? Explain. (k)

34. How does a mirage form? (k)

UNIT D Review (continued)

35. (a) Draw a ray diagram for an object 0.75*f* from a converging lens. (k)
(b) Draw a ray diagram for an object 1.25*f* from a converging lens. (k)

36. State the thin lens equation. (k)

37. In the thin lens formula for a convex lens, state when the image distance is:
(a) positive (k)
(b) negative (k)

38. Explain the appearance of the reflection of the building in the photograph below. (k)

Question 38

12 Optical devices help us see farther and more clearly than we can with unaided eyes.

39. List two parts of the eye that can refract light. (k)

40. What structure controls the amount of light that enters the eye? (k)

41. What features of an image are primarily collected by:
(a) rods (k)
(b) cones (k)

42. State the cause of:
(a) far-sightedness (k)
(b) near-sightedness (k)

43. (a) What type of vision problem does the eye below have? (k)
(b) Copy the diagram into your notebook. Add a correcting lens to your diagram, and show how the lens bends the light rays to focus the image on the retina. (k)

Question 43

44. Laser eye surgery can be used in some cases to correct far-sightedness and near-sightedness. What are three other conditions of the eye that can be treated with laser surgery? (k)

45. Compare the features of an image from a telephoto lens and an image from a wide-angle lens. (k)

46. Use a labelled ray diagram to show how an image is produced in a microscope. (c)

47. (a) What type of telescope is the preferred type for large astronomical observatories? (k)
(b) Why is it preferable? (k)

48. How is laser light different from ordinary light? (k)

49. How does photonics model properties of light? (k)

Connect Your Understanding

50. Draw a ray diagram and write a short explanation to show why it is sometimes difficult to reach a coin that is underwater in a pond. (c)

51. A flashlight does not lose power as you walk away from it, but as you get farther and farther, it appears to be less and less bright. Explain why. (a)

52. Describe three situations where sunlight is seen as the visible spectrum. (a)

53. You are standing outside in the dark, waiting for a fireworks display, and an extremely bright flash goes off right above you. Describe the behaviour of your pupils before, during, and after the flash. (t)

54. When part of the Moon passes through Earth's umbra, the result is a partial lunar eclipse, as shown below. What happens when the entire Moon passes through Earth's umbra? Draw a labelled diagram as part of your answer. (t)

Question 54

55. If you wish to take a picture of faint stars in the night sky, how should you adjust your camera? (t)

56. Describe how night vision goggles enhance human vision. (c)

57. Many grocery stores carry "reading glasses" that you can buy to help you read small print. What kind of lenses do you think these glasses use? Explain. (a)

58. Explain why you agree or disagree with the following statements. For any you disagree with, provide the correct statement. (t)

(a) The normal is drawn at a 90° angle to the mirror or lens.

(b) When light is reflected from a curved mirror, the angle of incidence is twice the angle of reflection.

(c) If you want to see farther into space, build a telescope with a bigger convex mirror.

(d) The two main lenses of the microscope are the eyepiece and the objective lens.

59. Why is it important that a optical fibre not have any scratches on its surface? (c)

60. When purchasing a diamond, people often use a microscope to look for tiny imperfections within the diamond. In which case would the imperfections be more visible, with the diamond immersed in water or in air? Why? (t)

61. A hiker sees a mirage of trees in the sky. Draw a diagram to show how this is possible. Label the different air temperature regions. (c)

UNIT D Review (continued)

62. Describe what is happening in the following photograph. (a)

Question 62

Skill Practice

63. A movie projector magnifies an image on 70.0-mm film to fill a screen 2.40×10^4 mm wide. What is the magnification provided by the projector? (k)

64. A concave lens produces a virtual image of a flower petal 2.00 cm from the lens. Determine the magnification of the lens if the petal is 8.30 cm from the lens. (k)

65. When light passes through sodium gas at –272°C, it slows to 16.7 m/s. What is the index of refraction of sodium gas at this temperature? (k)

66. Light travels through a salt crystal that has a refractive index of 1.52. What is the speed of light in the crystal? (k)

67. Titan is a moon of Saturn that has liquid methane in the atmosphere. Liquid methane has an index of refraction of 1.29. If a beam of light from the Sun approaches the atmosphere of Titan at an angle of 36.0°, what is its angle of refraction? (k)

68. A human hair follicle like the one in the photo below appears to be 5.5×10^{-3} m in width when viewed by a lens that magnifies 50 times. What is the actual width of the hair follicle? (k)

Question 68

69. A lens produces a larger, upright, virtual image that is 12.25 cm from the lens. The object is located 5.10 cm away. What is the focal length of the lens? (k)

70. A convex lens has a focal length of 1.80 cm. If it is held 3.0 cm from an object, how far from the lens is the image formed? (k)

71. A far-sighted person wearing a pair of glasses looks at the soup display in the grocery store. If the convex lenses in the glasses have a focal length of 2.40 m and form a virtual image 2.60 m from the lenses, how far away is the display? (k)

72. Follow these steps to find the relationship between the focal length of a spherical concave mirror and its radius of curvature:

- Draw a concave mirror with a radius of at least 20 cm.
- Mark the centre of the mirror on the principal axis.
- Draw a ray parallel to the principal axis, no more than 3 cm away from the axis.
- Draw a dotted line from the point of incidence to the centre of the mirror. This is the normal.
- Use the law of reflection to draw the reflected ray.
- Locate where the ray crosses the principal axis. This is the focal point.

(a) How do you know the dotted line is the normal?

(b) How can you be sure that you have found the focal point?

(c) Compare the radius and the focal length. Hypothesize their relationship.

(d) Describe how you might verify this relationship. t

Revisit the Big Ideas and Fundamental Concepts

73. (a) Describe the differences between refraction and reflection as a way to change the direction of a light ray. c

(b) Describe how our understanding of these principles benefits society. c

74. How have various optical technologies changed human perceptions of the natural world? a

75. How have optical technologies such as cellphone cameras and security cameras changed human behaviour? t

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76. Describe some ways that optical devices have extended human capabilities and reduced the impact of disease, wear and tear, and trauma on the human eye. c

77. What are three different ways that human health has been affected by optical instruments? c

78. How have optical fibres enhanced our ability to communicate information? t

79. (a) Describe an example of when you think digital manipulation of an image is a good idea. c

(b) Describe an example of when you think digital manipulation should not be allowed. c

Reflection

80. What can you explain about light and the way it interacts with matter that you were not able to before reading this unit? c

81. Explain why it is important for you to understand properties of light and optics in your daily life. c

82. (a) Choose an optical device that you think has affected your life the most. c

(b) Explain how it has contributed to your life. c

83. What ideas in this unit are you are interested in learning more about? c