UNIT D

Light and Geometric Optics

Light travels through colourful stained glass windows.

Contents

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.

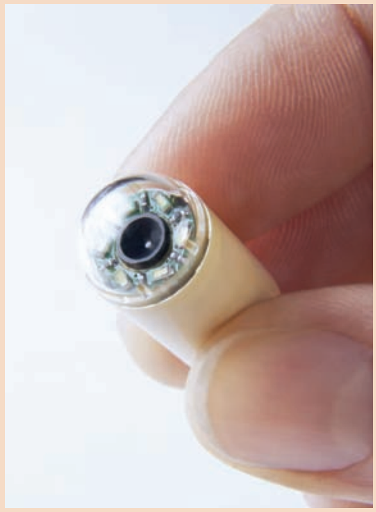
The pill camera can take over 800 000 photographs during an 8-hour trip through the digestive system.

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.

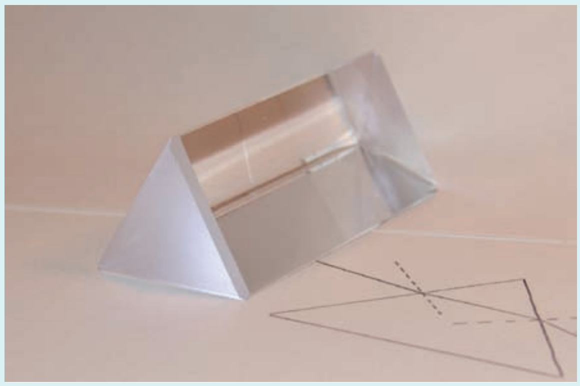


Figure 10.4 An equilateral prism

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.

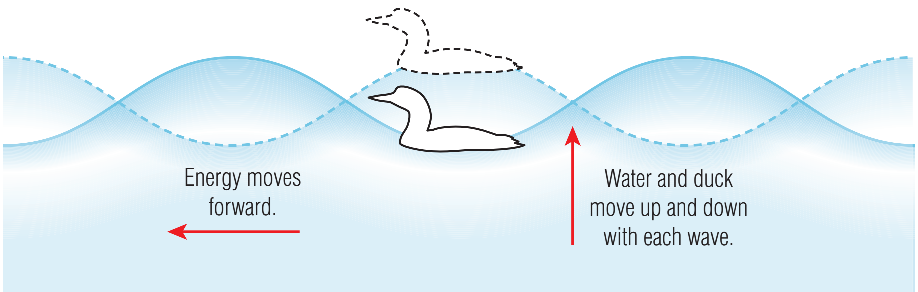


Figure 10.5 The duck moves up and down with the wave, but does not move forward or back as the wave passes beneath it.

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.

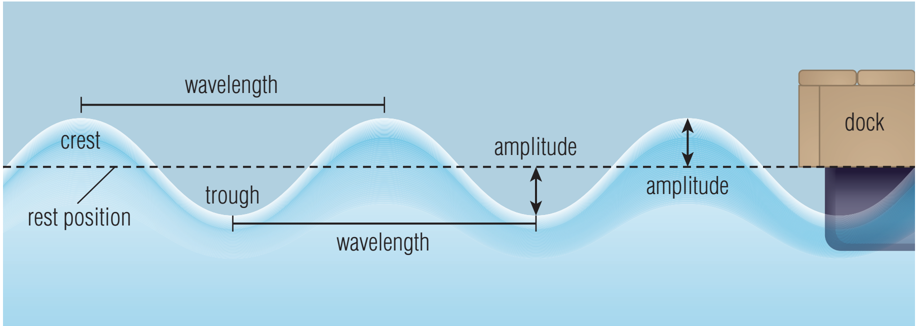


Figure 10.6 All waves have a wavelength and amplitude.

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.

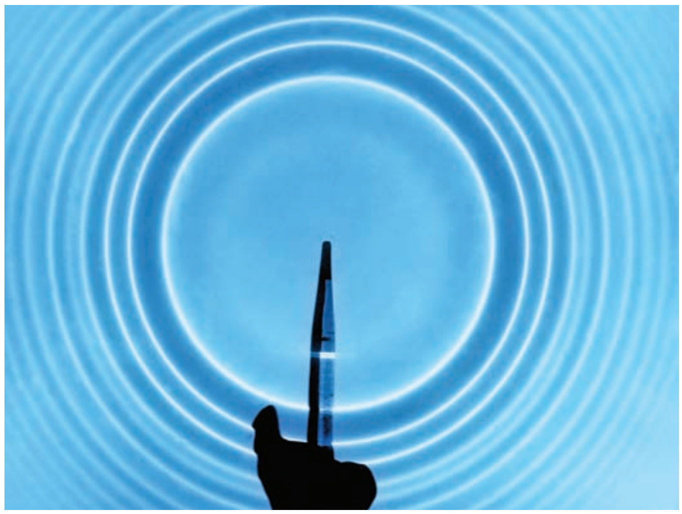


Figure 10.7 As the frequency of the wave increases, wavelength decreases.

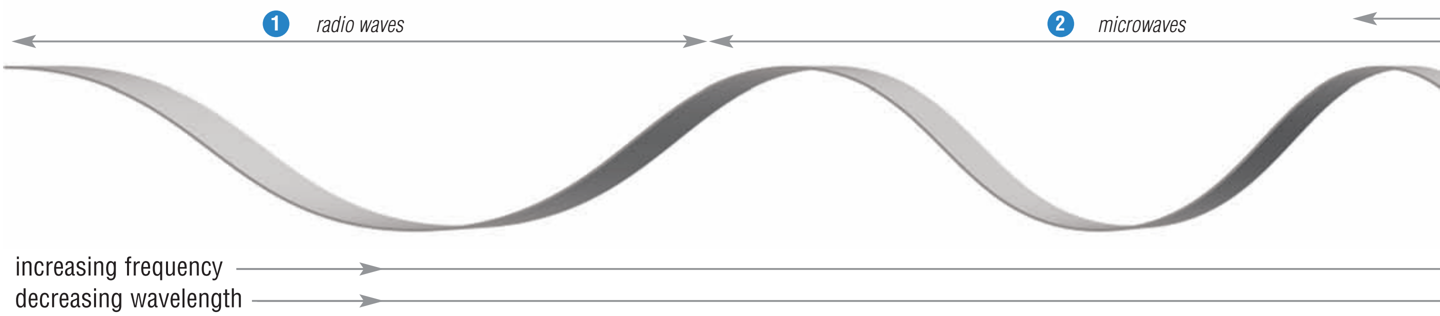
Learning Checkpoint

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).

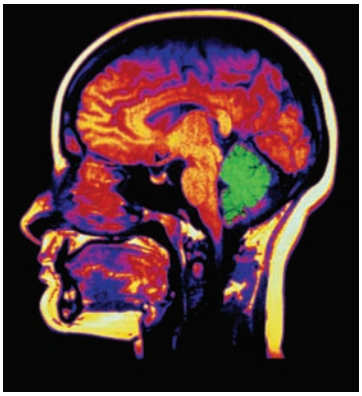


Figure 10.9 A false colour image of a brain made using MRI technology. Different colours are assigned by a computer to different types of tissue.

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 •
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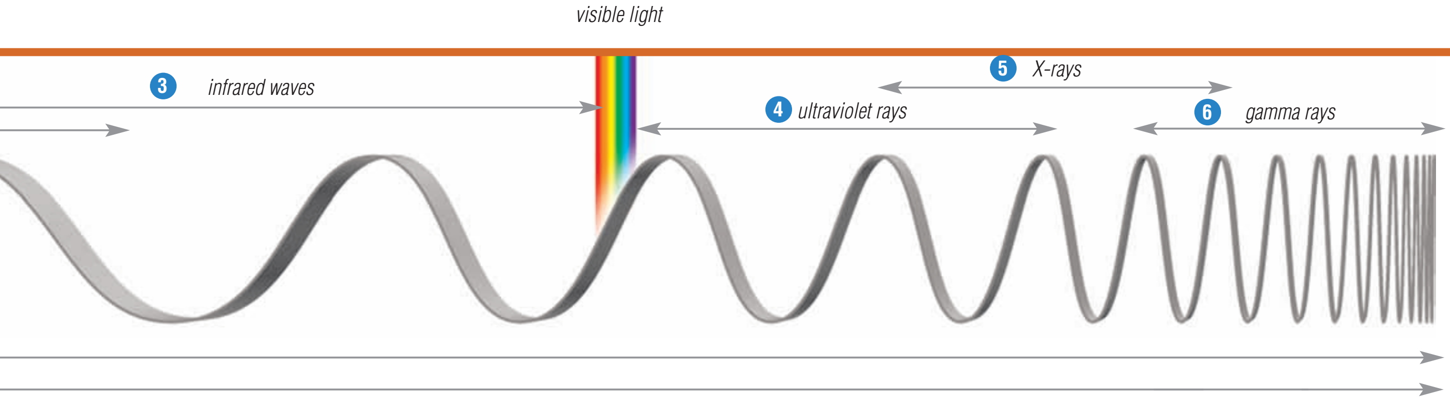


4 **Ultraviolet rays** carry more energy than visible light and therefore have a shorter wavelength and higher frequency than visible light. The main sources of ultraviolet radiation are the Sun and other stars. A small amount of ultraviolet radiation is beneficial to human health. However, extended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

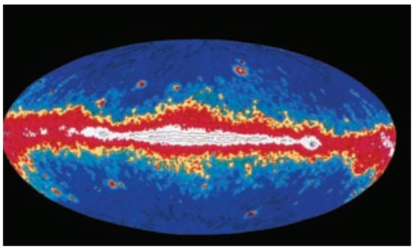


Figure 10.14 A map of the universe made using gamma rays

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**.

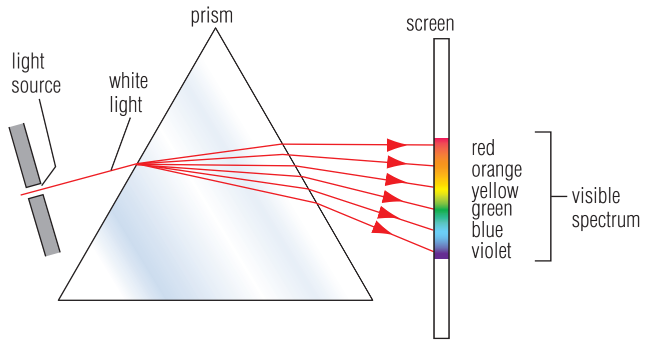


Figure 10.15 A prism separates light into the colours of the rainbow.

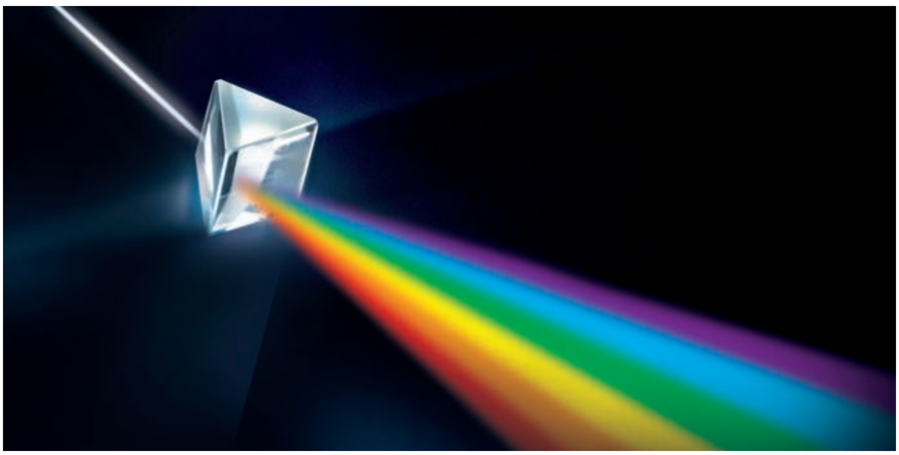


Figure 10.16 The visible spectrum

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

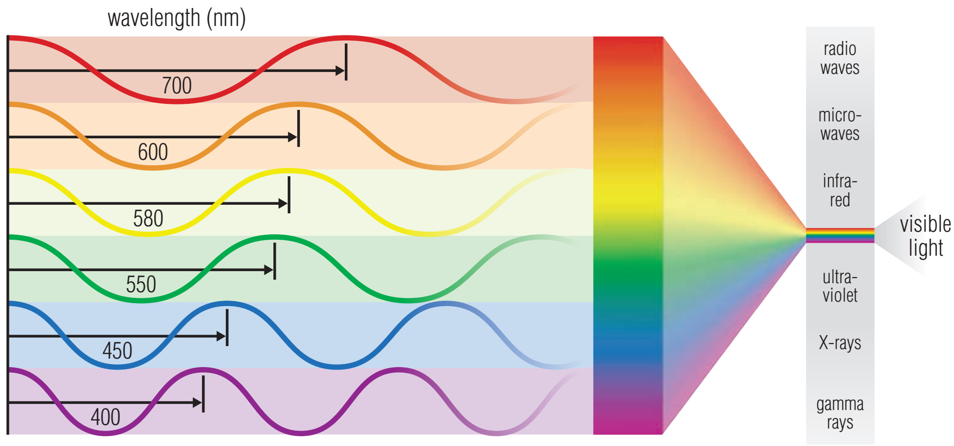


Figure 10.17 The visible spectrum has red light at one end, violet light at the other end, and all the other colours in between. Red light has a relatively long wavelength of 700 nm (nanometres) while violet light has a shorter wavelength of about 400 nm. A nanometre is one-billionth of a metre, so 700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

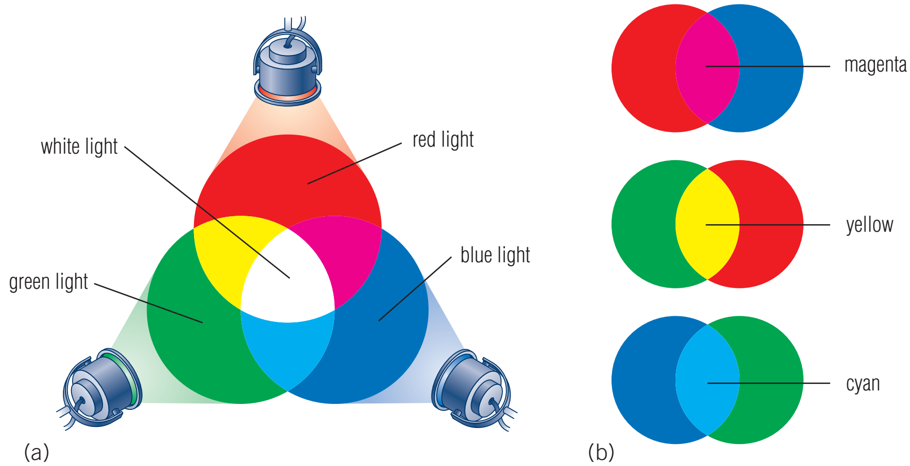


Figure 10.18 (a) All three primary colours together produce white light. (b)The three primary colours of light are red, green, and blue. When paired, they can create three secondary colours: magenta, yellow, and cyan.

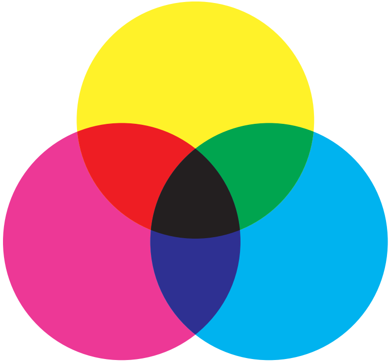


Figure 10.19 The subtractive theory applies to pigments and dyes. It is the opposite of the additive theory of light.

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.

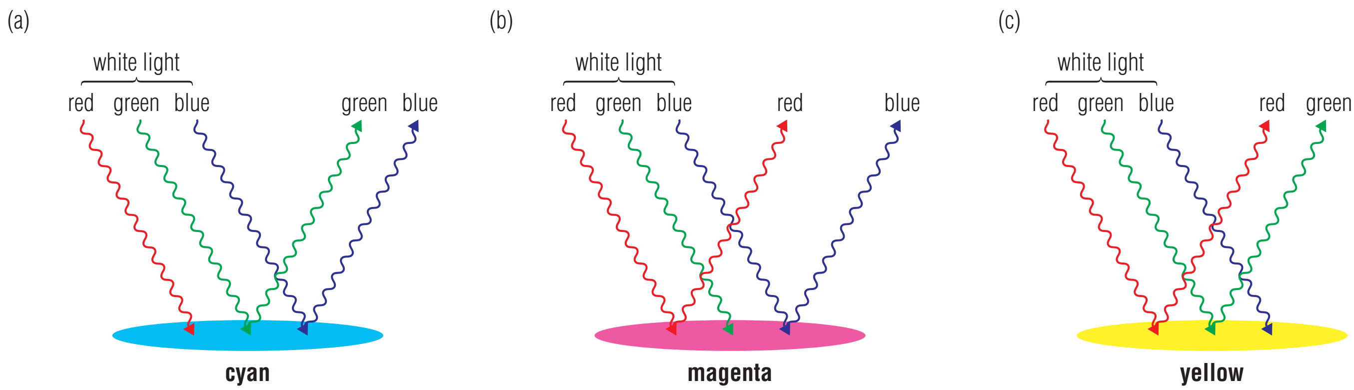


Figure 10.20 How subtractive colours reflect light

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.

DI Key Activity

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.

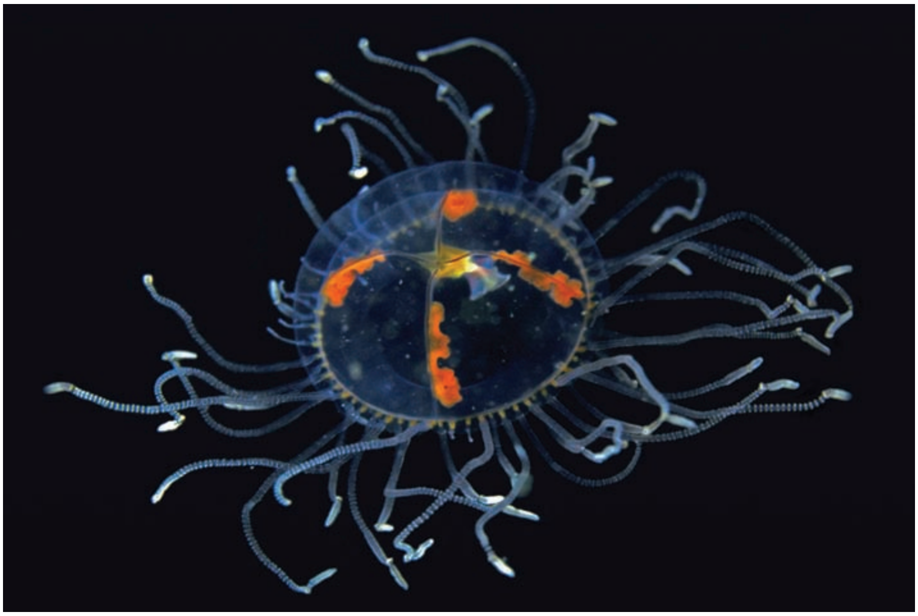


Figure 10.21 In the deep, dark ocean water, this jellyfish uses its light to attract fish, which become trapped in the jellyfish's tentacles.

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.

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.

Figure 10.24 A plasma ball

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.

WORDS MATTER

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

Incandescent Light

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.

(a)

(b)

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.

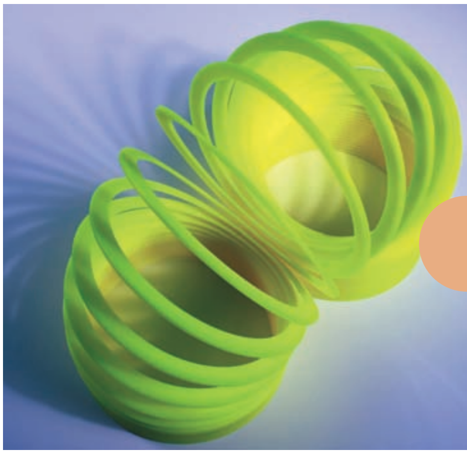


Figure 10.27 This glow-in-the-dark toy emits light by phosphorescence.

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).

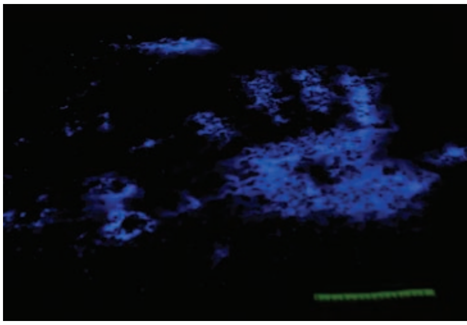


Figure 10.29 Luminol makes a blood stain glow in the dark.

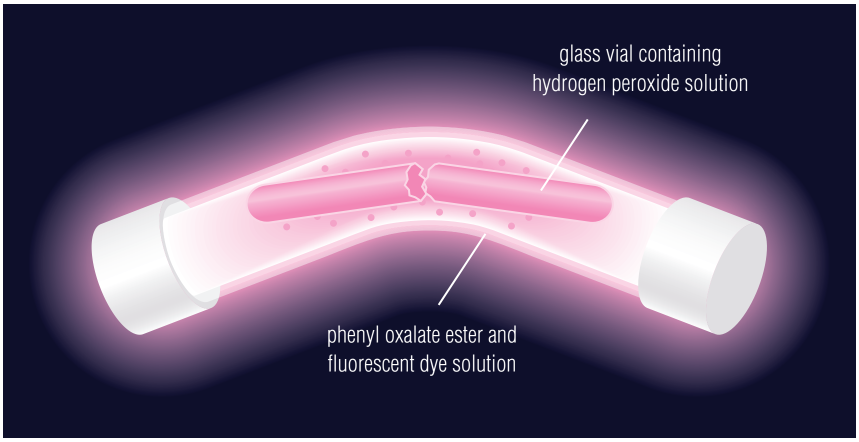


Figure 10.28 A glow stick is activated when the stick is bent. This action breaks a glass vial inside the stick and allows two chemicals to mix and react.

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.

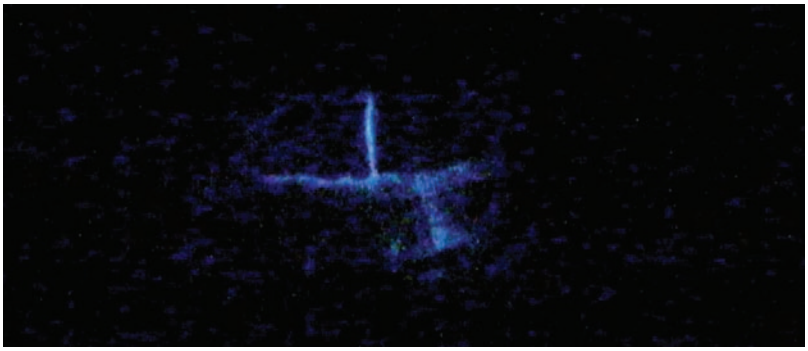


Figure 10.30 This faint light was produced by crushing a wintergreen candy with a hammer.

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.

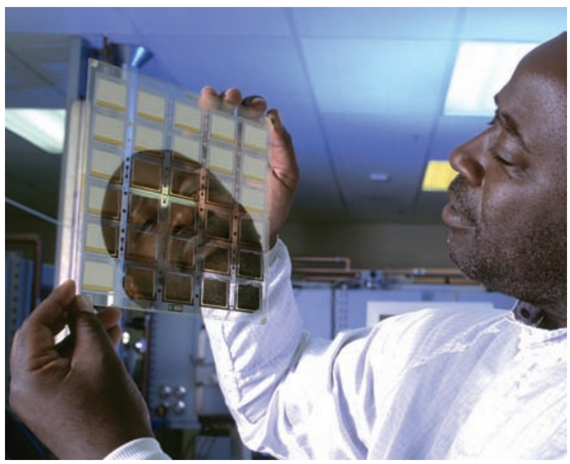


Figure 10.35 A researcher holds a panel of organic light-emitting diodes.

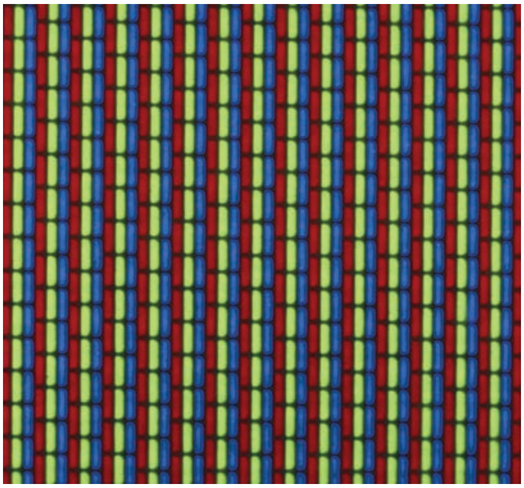


Figure 10.36 Plasma screens use fluorescence to emit light.

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.

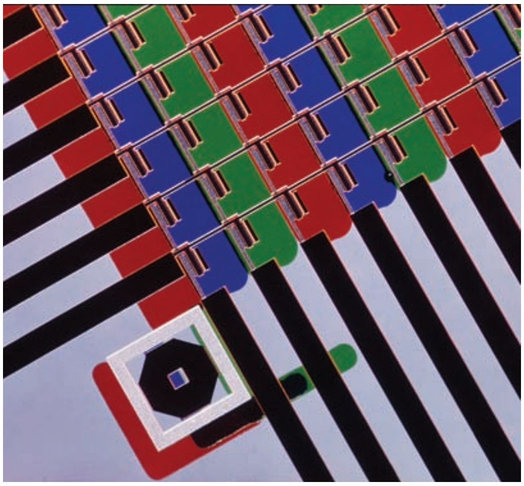


Figure 10.37 A light micrograph of a colour LCD screen, magnification 20× at 6 × 7 cm

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?

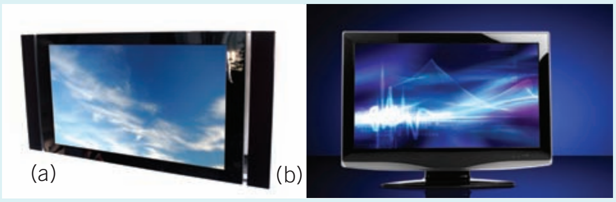


Figure 10.38 (a) Plasma screen and (b) LCD screen. Each type of screen has advantages and disadvantages.

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.

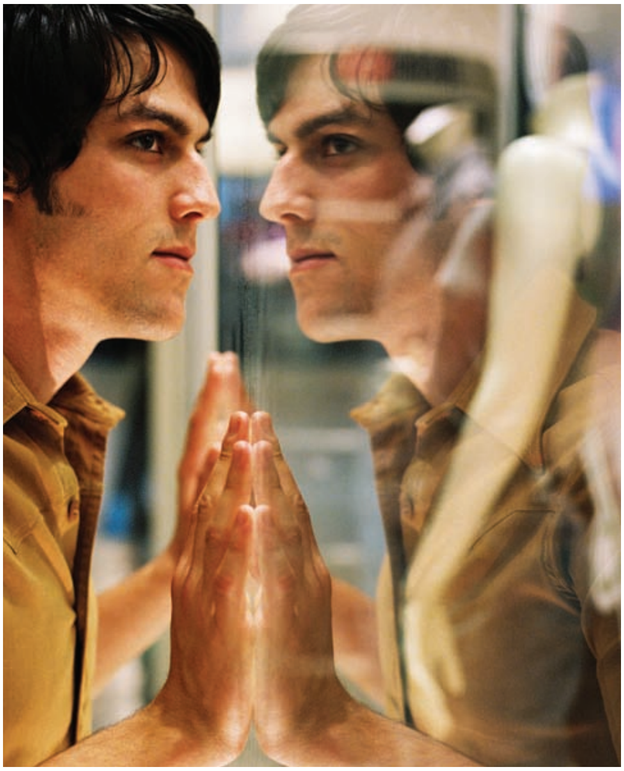


Figure 10.40 A glass window transmits light and reflects light.

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.

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.

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).

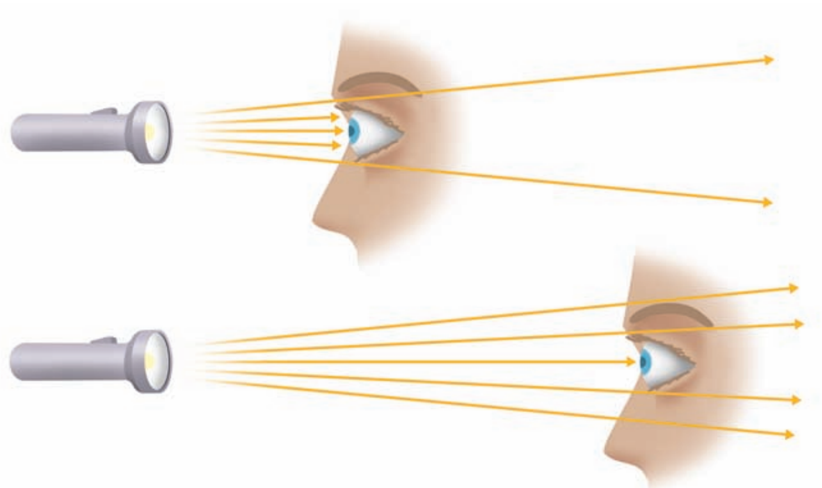


Figure 10.43 Fewer light rays reach your eyes when you are farther from a light source.

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.

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).

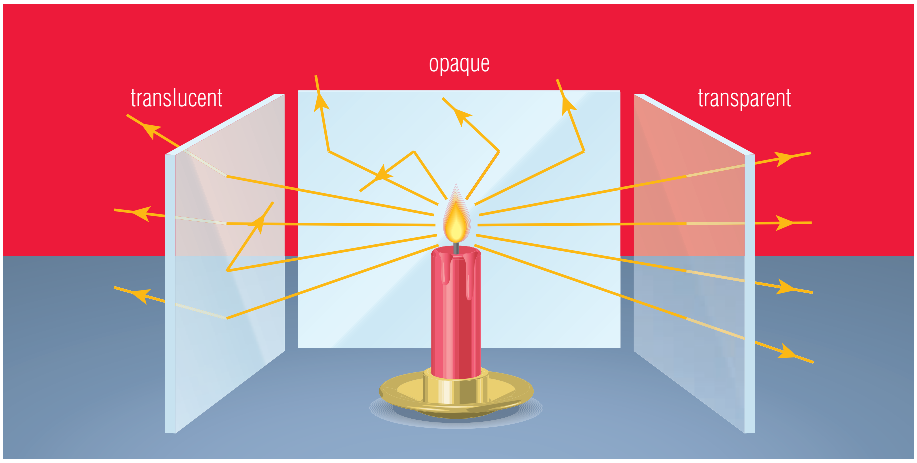


Figure 10.45 Ray diagrams show how light is affected by transparent, opaque, and translucent materials.

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).

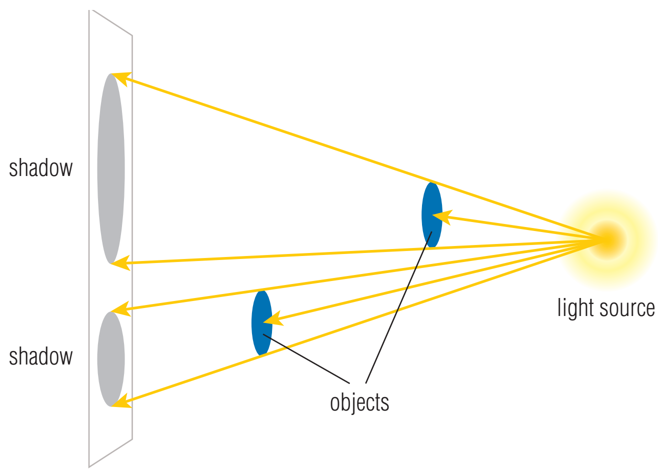


Figure 10.46 The shadow is larger if the object is closer to the light source.

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).

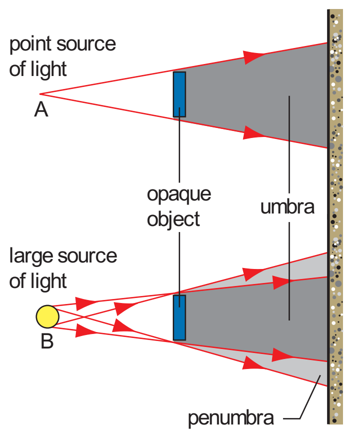


Figure 10.47 A ray diagram illustrates how the umbra and penumbra form in a shadow when the light source is not a point.

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)

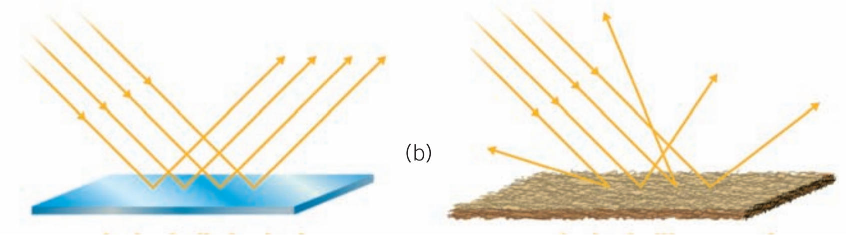


Figure 10.48 (a) Regular reflection and (b) diffuse reflection

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?

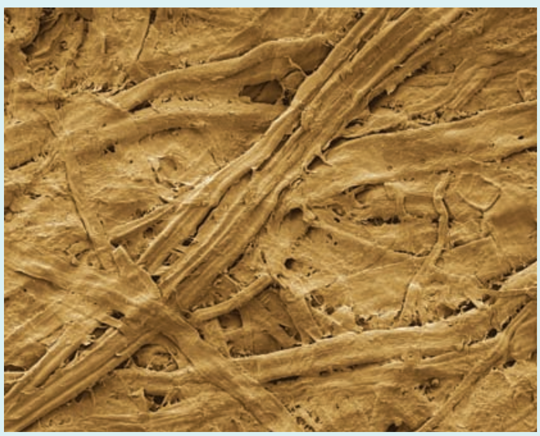


Figure 10.49 Photomicrograph of the surface of a paper towel (magnification 150X)

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

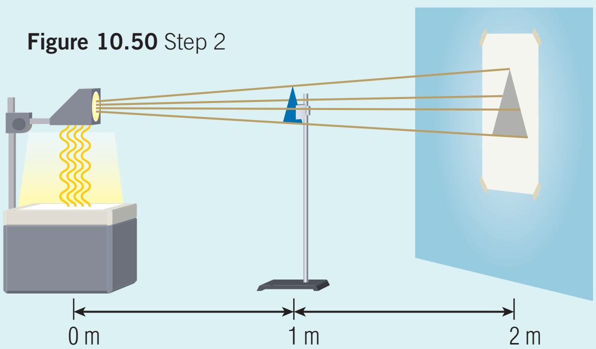
- a bright light source, such as a ray box, flashlight, or overhead projector
- triangle, rectangle, or similar shape cut from cardboard
- retort stand and clamp
- chart paper to trace on
- adhesive tape
- pencil/marker
- material to simulate light rays, such as drinking straws attached end to end, metre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

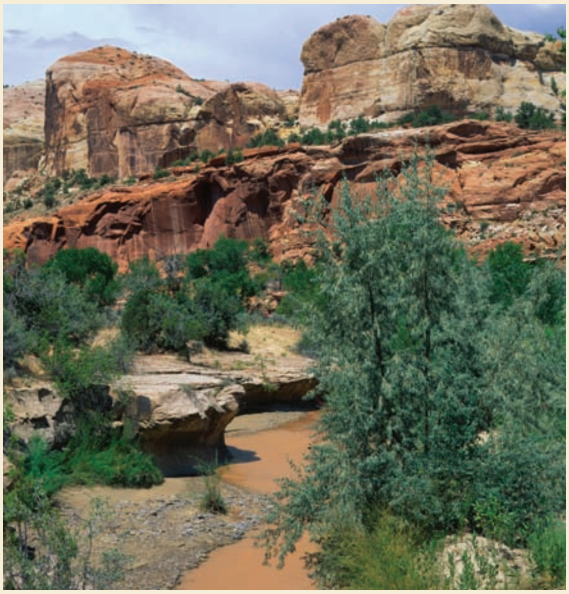
12. Describe how you can use ray diagrams to predict the size and shape of shadows created by opaque objects.

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

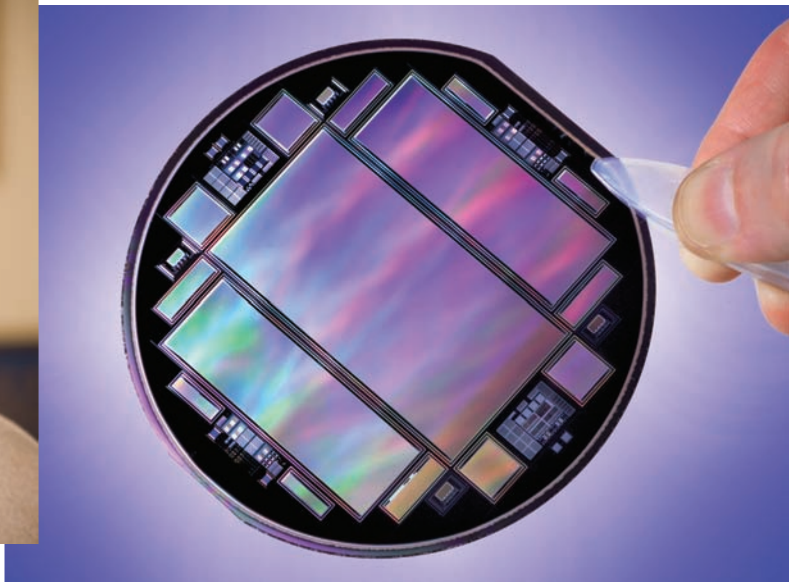


Figure 10.52 A charge-coupled device, part of the Keck telescope in Hawaii

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

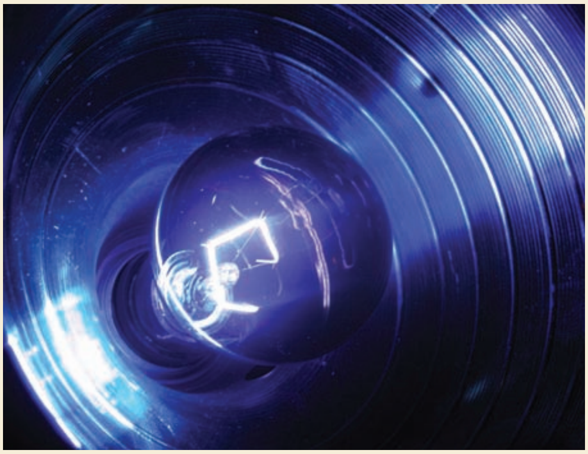
Question 17

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***.