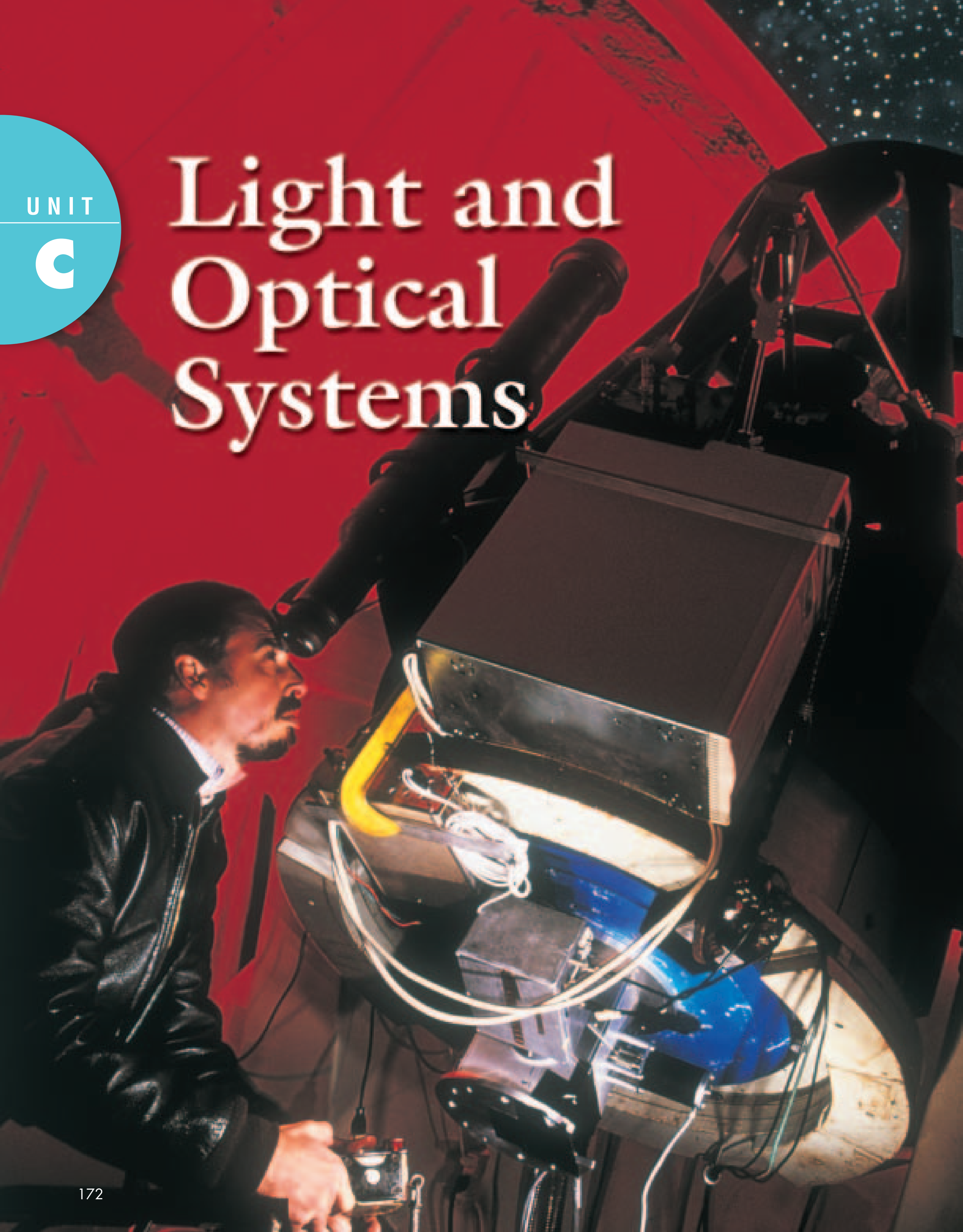
UNIT C

Light and Optical Systems



In this unit, you will cover the following sections:

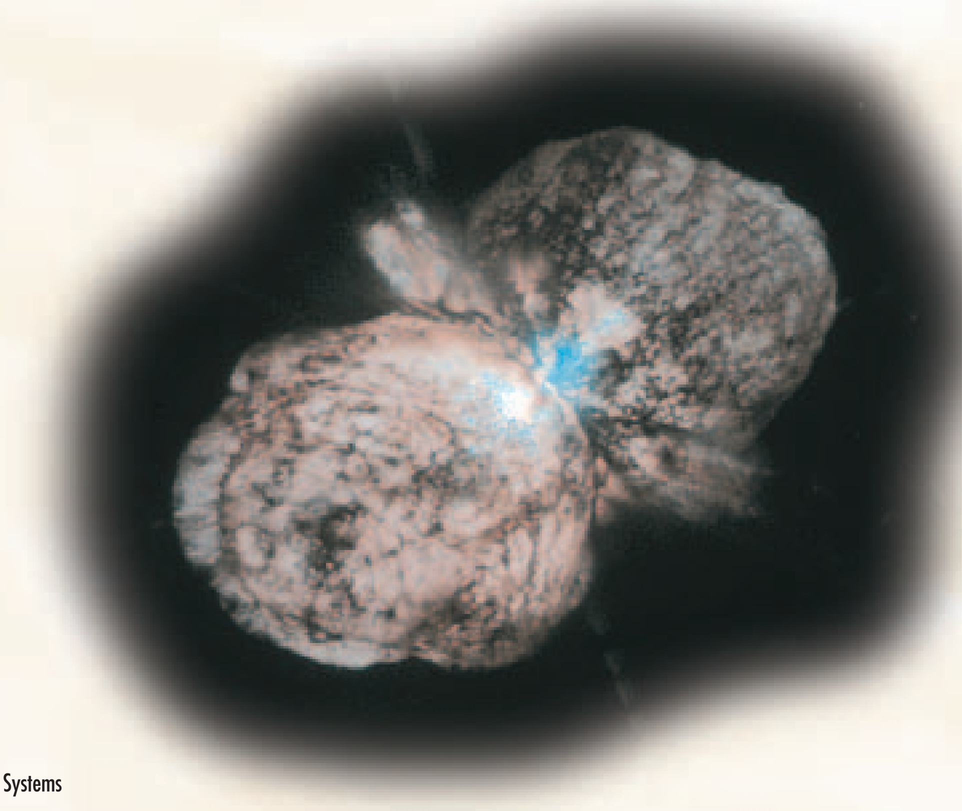
** Extension material*

Exploring

Optical Wonders

What do the Hubble Space Telescope (left) and the capsule endoscope (right) have in common?

Have you ever wanted to know what a star looks like up close? How about seeing inside the human body? Our eyes can't see details of distant stars or through human flesh. However, with a little help from optical devices, you can see amazing images from across the galaxy or inside a living, breathing human being.



An exploding star, Eta Carinae. This star is an exploding dust cloud 13 billion kilometres across!

The optical devices on the previous page were designed to overcome the limitations of our eyes. The Hubble Space Telescope was put into orbit by the space shuttle. It has a large mirror to collect and focus the light from distant stars. It can produce much higher quality images than ground-based telescopes because light does not have to travel through the interference of Earth's atmosphere. This unique telescope continues to send never-before-seen images back to astronomers on Earth.

The capsule endoscope is a new optical invention that is swallowed like a pill. This small package has its own light source and a miniaturized video imager that can transmit pictures by radio signal to a video recorder outside the body. The doctor can then see high-quality images of the inside of the patient's digestive tract on a television screen.

The inside of a person's stomach as seen by a capsule endoscope.

Give it a TRY ACTIVITY

TWISTED RAYS

Make a strip of paper about 2 cm wide and about 20 cm long. Using a black marker, draw a line of arrows one after the other along the length of the paper strip. All the arrows should point the same way. Fill a glass or beaker with water and place it in front of you. Then hold the strip about 15 cm behind the glass with the arrow side facing you. Look through the glass and move the strip from side to side.

- What do you see?
- Discuss with your classmates possible explanations for what you see.

Focus On THE NATURE OF SCIENCE

As you work through this unit, you will be reading and doing activities about light and optical systems. At the end of the unit, there is a project that will require you to apply the principles of light and optics. Use the following questions to help guide your reading and study.

1. **What do we know about the nature of light?**
2. **What technologies have been developed that use light?**
3. **What principles of light do these technologies show?**

1.0

Our knowledge about light and vision comes from explanations, inventions, and investigations.

Key Concepts

In this section, you will learn about the following key concepts:

- microscopes and telescopes
- contribution of technologies to scientific development

Learning Outcomes

When you have completed this section, you will be able to:

- identify challenges in explaining light and vision
- analyze how microscopes, telescopes, and other optical devices use the properties of light
- describe how the development of optical devices contributed to other discoveries in science
- investigate light beams and identify phenomena that show the nature of light

Have you noticed that you can't see a thing in a completely dark room? Why is light necessary for vision? Why can your eyes see what is directly in front of you but not what is around a corner? The answer is in the form of energy that is almost always around you. It's light! Our eyes are able to see an object only if light is emitted from the object or bounces off it. Since light travels in straight lines from its source, there must be a direct path for light to strike your eyes to make vision possible. The way vision works is just one of the interesting features of the nature of light.

There are many natural events that make us curious about light. How is a rainbow formed? On hot days, why do roads appear to be wet? Why does the sun seem brighter at noon than at sunset? People have been studying light for thousands of years to try and explain these and other aspects of light.

For Web links relating to 1.0, visit **www.pearsoned.ca/scienceinaction**

1.1 The Challenge of Light

Figure 1.1 Archimedes' plan to destroy the Roman fleet using light reflected off mirrors

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Years Away
Astronomers use a unit of measurement called a light year. But it's not a unit of time. It actually measures the distance that light travels in space in one year, about 9 460 500 000 km!

Since the earliest times, people have put light to work. Mirrors and lenses were used in China and ancient Greece. The Greek scientist Archimedes even developed a plan to reflect light from mirrors to burn enemy ships in the Syracuse harbour, Figure 1.1.

But even though the Greeks and Chinese used light, they didn't have a clear idea about what light was or how we experienced light. Over the centuries many people have asked questions, have done experiments, and have tried to explain how light works. Explaining light properly has taken centuries, and even now, scientists still have questions about light.

Early Light Ideas

In ancient Greece, many people studied light. In the sixth century B.C., a mathematician called Pythagoras tried to explain how we see light. He thought light consisted of beams. These beams came from a person's eyes in straight lines, and the sense of sight occurred when these beams touched the objects a person was looking at.

There was a problem with this theory. If it were true, then we would be able to see in the dark. In spite of this problem, Pythagoras's theory was accepted for many years.

Continued on page 180 →

Figure 1.2 How Pythagoras viewed vision

Inquiry
Activity

LIGHT UP YOUR LIFE

Before You Start ...

Working in groups, you will experiment with light. There will be six stations to visit. It doesn't matter in which order you visit the stations.

The Question

What are some properties of light?

Procedure

At each station, do the investigation and write down what you observed about light.

Figure 1.3 Station A

Station A

- Put three coloured filters: blue, red, and green, separately over three light sources of equal brightness (three flashlights or ray boxes). Shine each coloured light source at a white screen.
- Overlap (mix) two different coloured lights together in different combinations. What happens?
- Keep a chart of your combinations and results.
- Lastly, overlap all three coloured lights together on the screen. What do you observe?

Station B

- Look at your image in a flat mirror. If you step back from the mirror, how does your view change? Can you see more or less of yourself?

Station C

- Look at a sheet of graph or lined paper using a **convex lens** (thicker in the middle than at the edges) and a **concave lens** (thinner in the middle).
- What happens to the distances between the lines when you move each lens further away from the paper?
- What happens when you move each lens closer to the paper?

Figure 1.4 Station C

Station D

- This is a demonstration station. Your teacher will turn the lights off and shine a laser through a container filled with water mixed with a little cornstarch.
- As your teacher holds the laser below the waterline (Figure 1.5, left) and shines the laser through the water at different angles, observe the laser and the light beam in the water. What do you notice?
- If your teacher then holds the laser above the waterline (Figure 1.5, right) and shines the laser through the water at various angles, do you notice anything different?

Caution!
Lasers are used in grocery store scanners and CD players, but they are very dangerous. Make sure you are not in the path of the laser beam. Laser light can permanently damage your eyes.

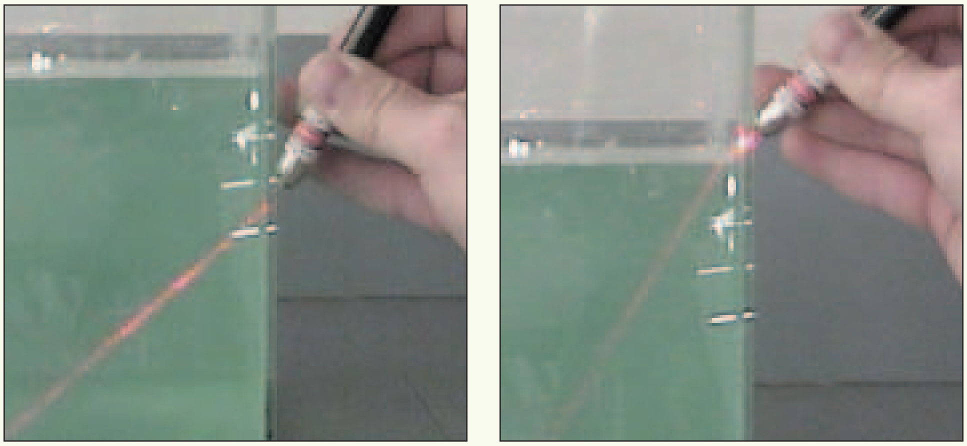

Figure 1.5 Station D

Station E

- Shine a light source through a glass, tissue paper, and a book.
- What happens to the light in each case?
- Shine a light through other materials.

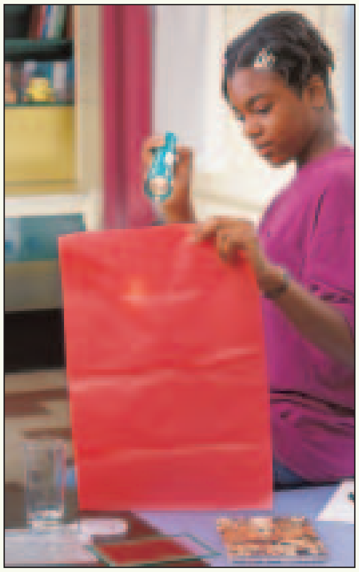

Figure 1.6 Station E

Station F

- Using solar-powered devices, can you find a way to show that light is energy?
- Try changing the amount of light that reaches the devices to see how the level of power varies.

Figure 1.7 Station F

More Light Ideas

Other Greeks looked into how light worked. Euclid discovered that when you shine a beam of light onto a flat mirror, the angle between the incoming beam and the mirror is equal to the angle between the reflected beam and the mirror. He also suggested that light travels in straight lines. In about the first century A.D., the astronomer Ptolemy described how light beams bend when they go from air to glass.

Light Ideas in the Middle Ages

In about A.D. 1000, a great Arab scientist called al-Haytham took up the study of light. He studied the work of Euclid and Pythagoras and wrote a book on optics. He was the first to accurately describe how vision worked. He showed that light bounces off objects and then travels to the eye, showing that light does not come from the eyes but rather light travels to the eyes. Because al-Haytham's explanation was so detailed, Pythagoras's theory was abandoned. Al-Haytham studied many other properties of light, and tried to explain how rainbows were formed but didn't have much success.

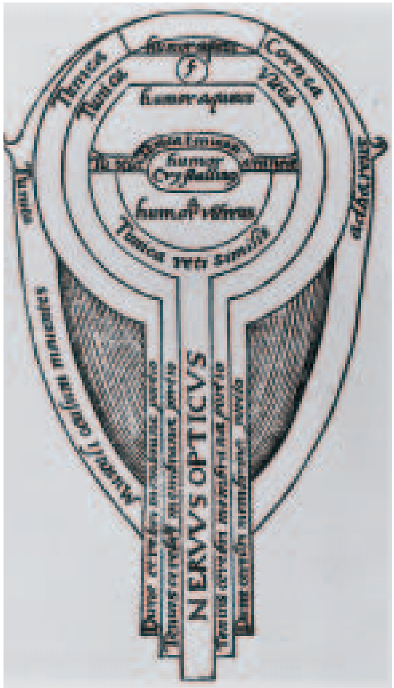

Figure 1.8 al-Haytham's diagram of the eye

Newton's Light Experiment

The English scientist Sir Isaac Newton also was fascinated by light, and he was especially interested in the colours of a rainbow. A French thinker called Descartes had proposed that sunlight was somehow changed or modified to form coloured light. By shining a light through a prism, Newton showed that white light is actually a mixture of different colours of light. As the light passed through the prism, it split up into many separate colours. Passing the rainbow colours through a second prism, Newton showed that the separate colours combined back into white light.

A Speedy Discovery

All of the early scientists understood that beams of light travelled, but they didn't know how fast they travelled. In the past, people didn't have instruments to record very high speeds, but they thought that light must travel extremely fast. The first reasonably accurate measurement was made by Ole Romer in 1676. His measurement was refined in the 1920s by a scientist named Albert A. Michelson. He placed two mirrors on the tops of two mountains in California and measured the distance between the two mirrors, which was 35.4 km. He then sent a beam of light from one mirror to the other. He used extremely accurate timing devices to measure how long it took the beam to reach the second mountain. By dividing the distance by the time, he calculated the speed of light as it travels through Earth's atmosphere to be 299 798 km/s.

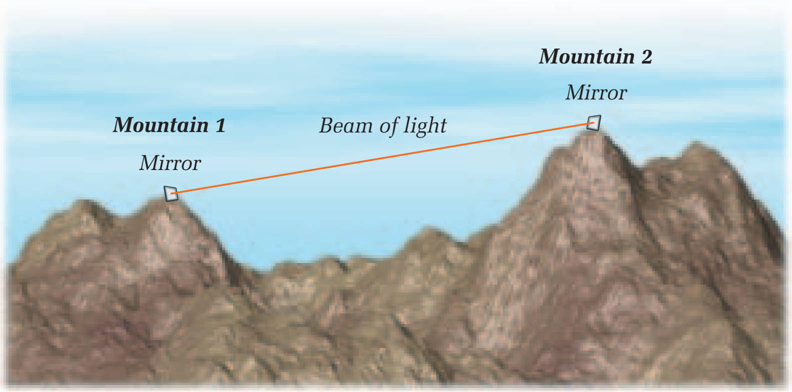

Figure 1.9 Timing a beam of light as it travelled from one mountain to another was the first accurate measurement of the speed of light.

Some Properties of Light

Over the years, many different people have contributed to our knowledge of light and how we perceive it. We now know about some of its basic properties.

- Light travels in straight lines.
- Light can be reflected.
- Light can bend.
- Light is a form of energy.

As you work through this unit, you will encounter these and other characteristics of light and study them in more detail.

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How Fast?
Michelson found out how fast light travels through Earth's atmosphere. Find out how fast light travels in other substances such as water, space, and other materials.

Check and Reflect

1. What did Ptolemy discover about light?
2. What was Pythagoras's theory of how we see?
3. What was the problem with Pythagoras's theory?
4. What did al-Haytham try to explain?
5. Based on Michelson's measurement of the speed of light, if the distance between the sun and Earth is 149 596 000 km, how long does it take light to travel from the sun to Earth?

1.2 Optical Devices

Figure 1.10 Astronomers use telescopes to explore the universe.

Scientists, craftsmen, and hobbyists learned they could take advantage of the tendency of light to reflect off surfaces and bend (refract) through others. How could these properties of light be used in inventions?

An **optical device** is any technology that uses light. An optical device can be as simple as a mirror, or as complex as the Hubble Space Telescope. The invention of optical devices has led to big improvements in our daily lives, and has allowed huge scientific advances. Here we will take a brief look at some of these optical devices and the impact they have had.

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In Focus

Did you know we have been wearing optical devices for 700 years? Alessandro della Spina, an Italian monk, made the first eyeglasses to correct vision around A.D. 1300. The glasses pictured here were made in the 15th century.

MICROSCOPES

It is believed that the father and son team of Hans and Zacharias Jansen of the Netherlands first built a microscope in about 1595. The first microscopes might have been very simple in design, but they led to incredible discoveries.

Antonie van Leeuwenhoek, a Dutch amateur scientist, experimented with a simple microscope of his own design in the 17th century. He looked at things like pond water, blood, and the plaque scraped from his own teeth. The things he saw astounded him! He wrote about his discoveries of “little animalcules,” which were really the first descriptions of microscopic items such as bacteria, protozoa, algae, and red blood cells.

Van Leeuwenhoek’s discoveries shocked the scientific world. Up until then, people had no idea there were organisms so small you couldn’t see them. As curiosity about this hidden world grew, more scientists started using microscopes. The invention of the microscope led to a whole new branch of science: microbiology. Microbiology is the study of micro-organisms.

All **microscopes** allow you to see great detail by combining the power of at least two lenses. These two lenses are the eyepiece and the objective (see Toolbox 11: Using a Microscope). When a light source shines through the specimen, a large image is produced that you can see by looking through the eyepiece. Microscope designs have improved greatly since van Leeuwenhoek's day, but they all use the same basic principle.

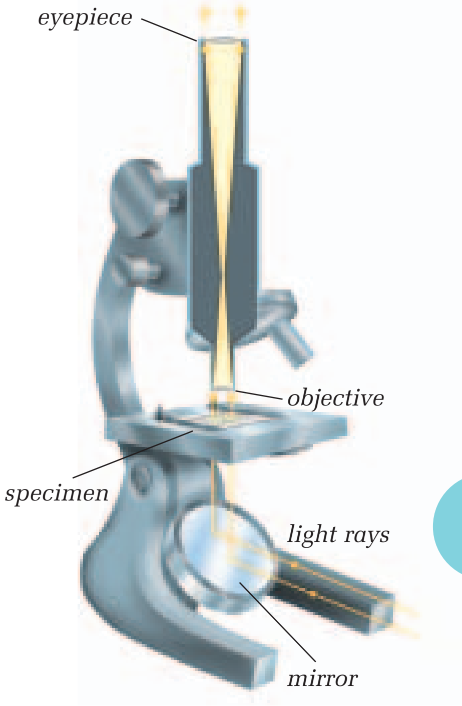

Figure 1.11 A microscope uses lenses to create an enlarged image of a tiny object.

Telescopes

The earliest astronomers, people who study stars and planets, were fascinated by the movement of stars and planets in the night sky. Even though people used single lenses to get a slightly closer look at the stars, it was the invention of the **telescope** that revolutionized astronomy. The first telescope was made in the Netherlands in the late 17th century. When the great Italian scientist Galileo heard about the telescope, he built one himself in one day. It didn't magnify very well, but Galileo was so impressed with it, he made more, stronger telescopes.

Figure 1.12 Galileo made astonishing discoveries about the solar system once he started using a telescope.

Using these telescopes, Galileo made amazing astronomical discoveries. He discovered mountains and craters on the moon, small objects circling Jupiter, and he discovered that Venus had phases just like the Moon.

There were two characteristics of telescopes that allowed him to see so much. Telescopes both magnify and collect light. The magnifying power of his telescopes allowed him to see Venus, and the light-collecting ability of the microscope allowed him to see the faint objects around Jupiter.

Types of Telescopes

Telescopes provide enlarged images of distant objects by using lenses and mirrors, or a combination of both, to collect light from distant objects and bring it to your eyes. Usually telescopes are used to collect light from space, allowing astronomers to see objects that they could not see with the unaided eye.

There are two main types of telescopes: refracting telescopes and reflecting telescopes.

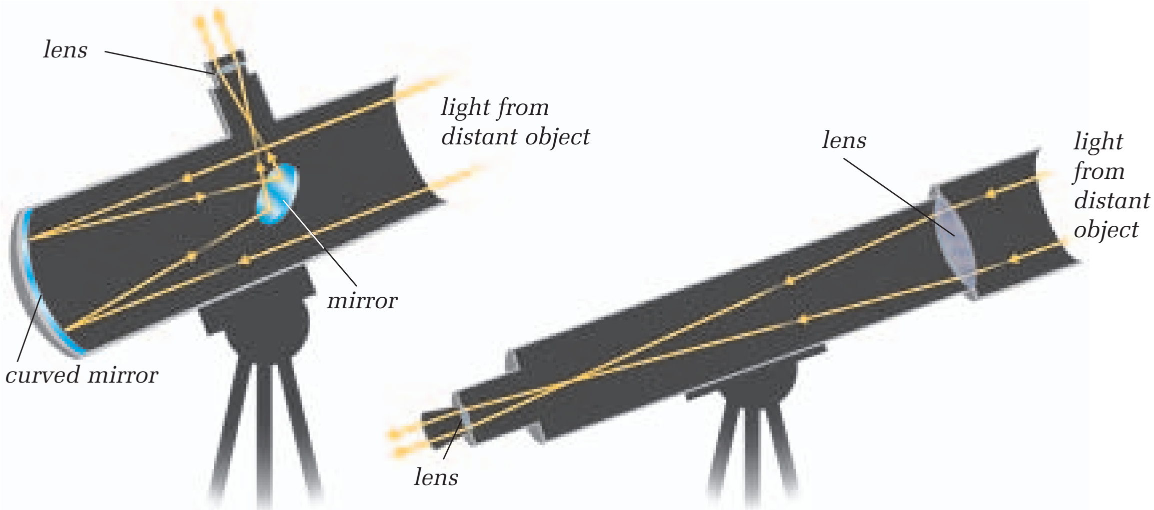

Figure 1.13 Refracting telescopes (right) use a combination of lenses; reflecting telescopes (left) use lenses and mirrors to form an image.

Refracting telescopes have two lenses, one on each end of a long tube. The larger lens is the objective lens that gathers light and focusses the rays toward the eyepiece, which in turn allows you to see the object larger than it appears with the unaided eye.

Reflecting telescopes use a large circular mirror that curves inward. This curved surface gathers light extremely well. Another mirror inside the telescope directs light to the eyepiece, which leads to your eye.

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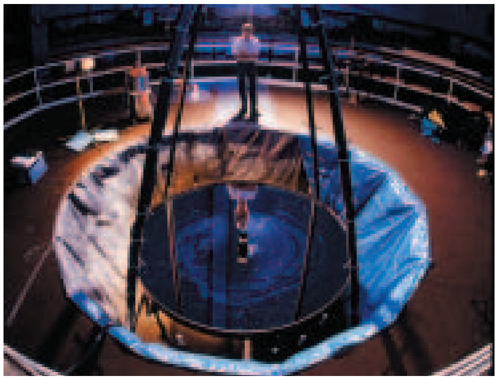
Liquid Mirrors

This telescope mirror looks solid, but it's actually made of liquid. Find out why astronomers are using liquid mirrors and how they work.



Inquiry Activity

Make a Pinhole Camera

You have read about various optical devices. Here is a chance to make and investigate your own optical device.

Materials & Equipment

- paper or styrofoam cup
- pin
- rubber band
- wax paper
- light bulb

Figure 1.14 Step 2

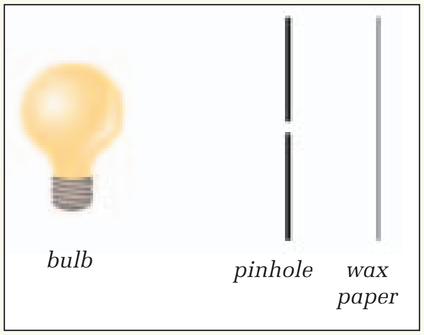


Figure 1.15 Copy this diagram into your notebook.

The Question

How does a pinhole camera work to form an image?

Procedure

1. Use the pin to make a tiny hole in the centre of the bottom of the cup.
2. Place a piece of wax paper over the open end of the cup using the rubber band to hold it in place.
3. Turn off the room lights. Point the end of the cup with the hole toward the light bulb.
4. Look at the image formed on the wax paper.

Collecting Data

5. Make a drawing of the image that appeared on the wax paper.
6. Move the pinhole camera closer, then farther away from the light bulb. Note the results.

Analyzing and Interpreting

7. What do you think is happening to produce the image on the wax paper?
8. Reproduce the drawing in Figure 1.15 in your notebook.
9. Use a ruler to draw a straight line (#1) that starts at the top of the bulb and goes through the pinhole to the screen. Now draw another line (#2) that starts at the bottom of the bulb and also goes through the pinhole.
10. Remember that line #1 represents light from the top of the bulb, and line #2 represents light from the bottom of the bulb. Does this diagram help explain the drawing you made in step 5?

Forming Conclusions

11. Write a summary sentence or two that answers the question: "How does a pinhole camera work to form an image?" Include at least two diagrams that illustrate the images formed by objects at different distances from the camera.

Binoculars

You can buy telescopes for home use, but they can be large and difficult to move around. You might want to use **binoculars** instead. They are simply two short refracting telescopes fixed together. Binoculars are not as powerful as telescopes but they are much more convenient.

Figure 1.16 Binoculars have two reflecting prisms on each side.

Light Interactions

Investigating how light interacts with objects can reveal interesting information about the nature of light. Light tends to travel straight, but will bounce and bend predictably when it strikes various substances. In the next section, you will learn more about how light bounces off, is absorbed by, and bends in different substances.

Check and Reflect

1. What optical device would you use to view the peak of a nearby mountain and why? Is there another device you could use?
2. How is a microscope similar to a refracting telescope? How is it different?
3. Compare and contrast refracting and reflecting telescopes.
4. How does a microscope work?

Assess Your Learning

1. What did Euclid discover about light?
2. Describe three properties of light.
3. Could a mirror be called an optical device? Explain why or why not.
4. Why was the invention of the telescope so important?

Focus On: THE NATURE OF SCIENCE

Scientific knowledge results from the shared work of many people over time, and new interpretations are made as new evidence is gathered. Reflect on what you've learned in this section.

1. How did Pythagoras contribute to scientific knowledge?
2. How did al-Haytham build on Pythagoras's ideas?
3. How did Newton change scientific ideas about how coloured light is formed?

2.0 Light behaves in predictable ways.

Key Concepts

In this section, you will learn about the following key concepts:

- transmission and absorption of light
- reflection and refraction
- images

Learning Outcomes

When you have completed this section, you will be able to:

- describe how light is reflected, transmitted, and absorbed
- identify materials that are good absorbers, reflectors, and transmitters of light
- measure and predict angles of reflection and refraction
- describe how the refraction of light varies through different materials
- demonstrate the formation of images using a convex lens

Have you ever been window-shopping on a bright day? The glare from the glass can be quite annoying. What is glare? Glare is light reflected from the glass. You may have had to cup your hands around your eyes in order to see into the store. When you block out the sunlight with your hands, it makes it easier to see the light coming through the glass from inside the store.

You may have noticed another annoying problem 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 once again easy to see.

Depending on the situation, light will reflect, transmit, or both. Is it possible to tell what will happen when light strikes a surface? Does light behave in regular, predictable ways? In this section, you will find out.

For Web links relating to 2.0, visit www.pearsoned.ca/scienceinaction

2.1 Light Travels in Rays and Interacts with Materials

A popular attraction at fairs and carnivals is a mirror maze. It's fun because you can't tell whether you're looking at a person or their reflection, and so you can't tell where a person is actually standing.

When you think about it, the whole way you relate to the world is based on the assumption that light moves from objects to your eyes in straight lines. Suppose this assumption was false: then a person who appears to be right in front of you might actually be behind you. It would truly be a wild world if light twisted and turned at will. Life would be like a mirror maze all the time!

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The Closest Star

The star closest to us (apart from the sun) is Alpha Centauri. Rays from this star take 4.3 years to reach our eyes. If astronauts travelled to this star at the same speed at which they travelled to the moon, the trip would take several thousand years!

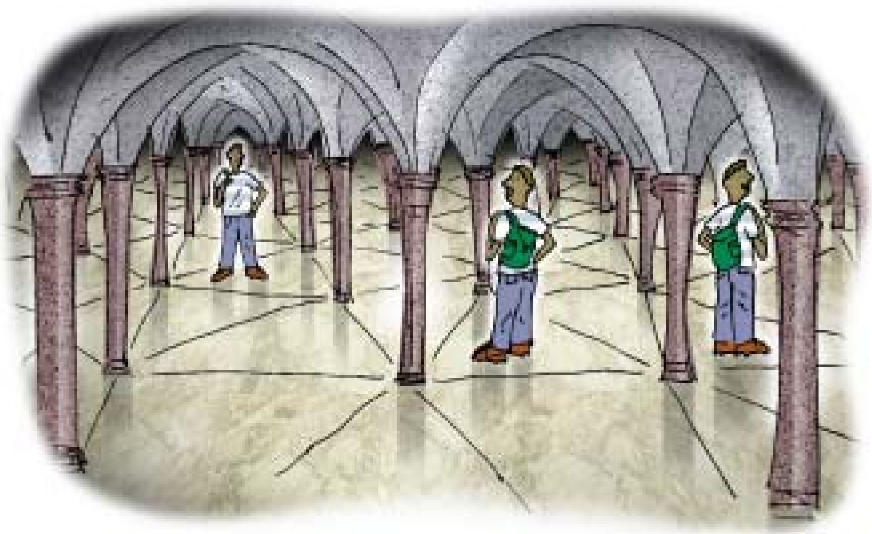

Figure 2.1 A mirror maze is fun because it's confusing.

Give it a TRY ACTIVITY

PENCIL SHADOWS

Place a gooseneck lamp on a table and hold a pencil in an upright position about 20 cm from the lamp. Make sure the light bulb is higher than the top of your pencil. Look at the shadow created by the pencil. Have your partner place a metre-stick so that it touches the top of the lamp, the top of the pencil, and the tabletop. Look at where the metre-stick touches the tabletop.

- Where is the pencil shadow in relation to the end of the metre-stick on the table surface?
- Repeat the procedure holding the pencil at different angles. Do the results change?
- What does this tell you about how light travels?

Ray Diagrams

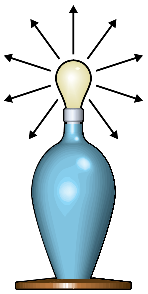

Figure 2.2 A simple ray diagram

Scientists use **ray diagrams** to show how light travels. The light travelling from a source is shown as straight lines called rays. Each ray ends with an arrow to indicate the direction of travel. Although ray diagrams are useful, they don't show the complete picture. Light rays travel away from a light source in every direction. To show all the light rays, you would have to draw millions of arrows, not just the few rays as in Figure 2.2. But ray diagrams are useful because they can illustrate how light behaves in different situations.

Ray diagrams can help explain why the brightness, or **intensity**, of a light changes with distance. Figure 2.3 shows the same number of rays leaving the light source, but fewer hit your eyes as you move farther away.

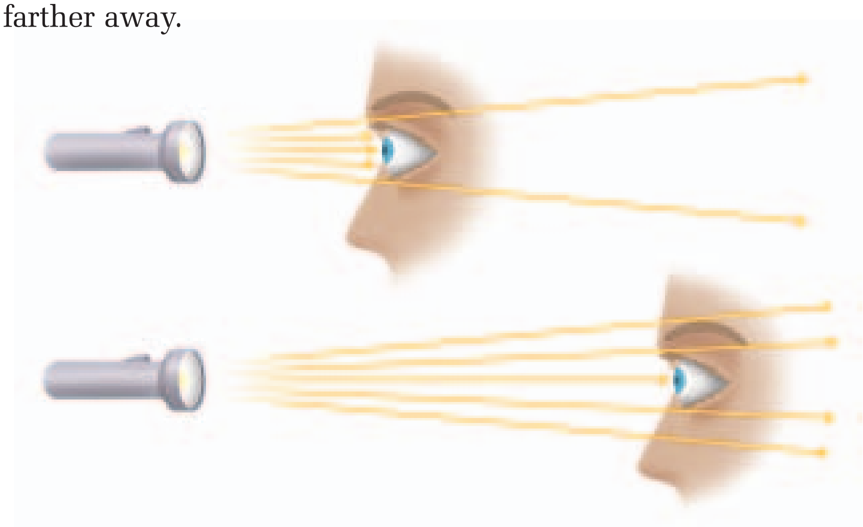

Figure 2.3 Fewer light rays reach your eyes the farther you are from a light source.

Ray diagrams also help explain shadows. If light hits an object, it can't go any farther. So if an object gets between the light and our eyes, we perceive this lack of light as a shadow.

Figure 2.4 A shadow is created by the absence of light.

LIGHT INTERACTS WITH MATERIALS

When light strikes objects, it behaves in different ways depending on the type of material each object is made of. **Transparent** materials, such as glass or clear plastic, can transmit light, meaning light travels straight through them. That's why you can see clearly through a window pane.

Translucent materials allow some, but not all, light to pass through. A frosted window pane is a good example of a translucent material. Some light can pass through, but you can't see what's on the other side of the frosted glass in any detail.

Opaque materials do not allow any light to pass through them. They absorb or reflect the light that hits them. Since light cannot get through an opaque object, a shadow is created behind it. Wood, metal, and brick are examples of opaque objects.

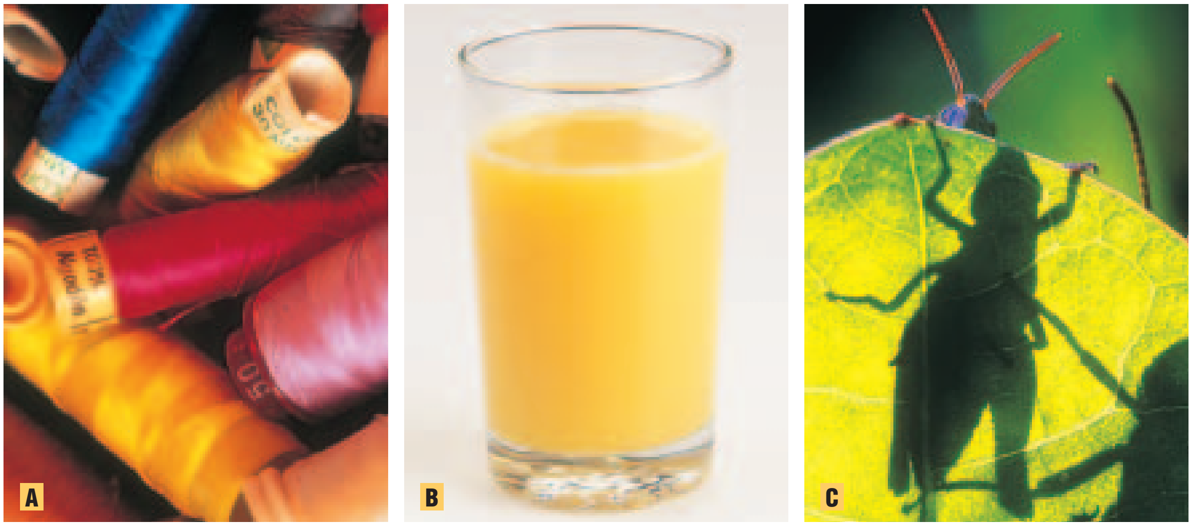

Figure 2.5 Light of various colours reflects off the spools of thread, A, and does not pass through; the spools are opaque. The glass is transparent, B, allowing you to see the juice inside. The leaf is translucent, C; some light from behind the insect passes through the leaf, but you can't see the insect through the leaf.

You may have a pencil or pen in your hand right now. So if you can see your pencil, then light must be coming from the pencil to your eyes. But where is the light from the pencil coming from? Pencils and other opaque objects are **non-luminous**, meaning they don't produce light. The light that gets to your eyes from the pencil (or from any other opaque object) is actually light reflected from a light source. A light source is **luminous**; it produces light. Light from a light source (the sun, a lamp) bounces or reflects off the pencil and hits your eyes. The same thing happens when light hits every opaque object in the room. That's why you can see your surroundings.

Inquiry Activity

LIGHT REFLECTION

The Question

What material is the best reflector of light?

The Hypothesis

Based on the question and the materials you have collected, form a hypothesis for this investigation.

Materials & Equipment

- light source
- light meter
- ruler
- large selection of sample materials such as coloured construction paper, wax paper, cloth, pieces of wood, tin foil, glass, and plastic

Procedure

1. Organize the materials you have chosen to test for reflectivity. Predict which materials you think will reflect the best and which the worst.
2. In step 3, you will shine the light source onto the materials and make a **qualitative** measure of reflectivity. This type of measure is one in which *you* decide on characteristics and attributes. For example, you may choose to rank the materials against each other from "least reflective" to "most reflective." In step 4, you will use a light meter to obtain a **quantitative** measure of reflectivity. This type of measure determines an amount using numbers and units.

Figure 2.6 Testing different materials

Collecting Data

3. Hold the light source 15 cm away and shine it directly onto one of your chosen materials. Looking from behind and to the side of the light source, observe how much the light reflects from the material. In a table, record the reflectivity of the material. Repeat for the other materials. Make sure that the distance between the object and the meter stays the same.
4. Next, aim the light meter at the material so that it receives the reflected light. Hold the meter just to the side of the light source, so no light from the source strikes the meter directly. In a table, record the meter reading. Repeat for the other materials.

Analyzing and Interpreting

5. Decide on the best way to present your findings. For example, you might generate a list, or use a bar graph, or create a computer spreadsheet.
6. Which materials reflected the best? Did this agree with your prediction? Why or why not?
7. Which materials reflected the worst? Did this agree with your prediction? Why or why not?
8. Were there any instances where your qualitative results did not match your quantitative measures? If there were discrepancies, explain.

Figure 2.7 Constuction workers wear reflective clothing. How do you think this helps keep them safe?

Forming Conclusions

9. Write a summary sentence or two that answers the questions: "What material is the best reflector of light?" and "What properties of a material would make an ideal reflector?"

Types of Reflection

Regular reflection occurs when light rays hit a smooth surface. The incoming rays travel parallel to one another. When these rays strike a smooth surface, they all bounce off in the same direction, and so the reflected rays stay 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 if they had travelled directly from the source to your eyes without reflecting. Regular reflection produces a clear image but your eyes must be in the direct path of the reflected rays in order to see the reflected image.

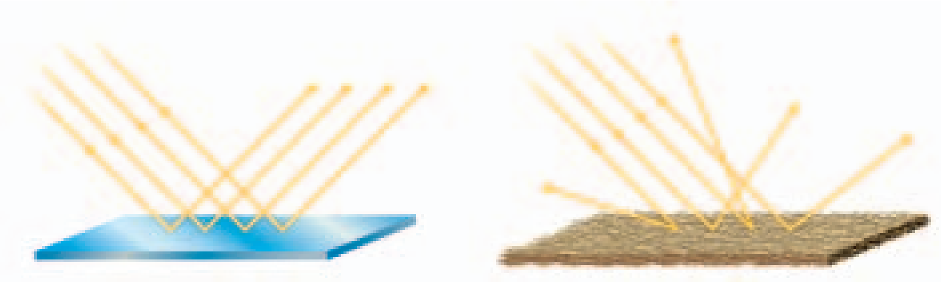

Figure 2.8 Regular reflection (left) and diffuse reflection (right)

When light rays strike a rough or uneven surface, **diffuse reflection** occurs. When the light rays hit the surface, they reflect, but due to the rough surface, each of the rays is reflected at a different angle. So the reflected rays do not remain parallel. Some surfaces, such as a kitchen counter, may appear to be smooth, but they actually have very small bumps that scatter light rays in many directions. Because the light is scattered, you can see the kitchen counter from any position.

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When the Moon Turns Red

During a full lunar eclipse, Earth (an opaque object) passes between the moon and the sun, and casts a shadow over the moon. If Earth completely blocked the sun's light to the moon, you would expect the moon to disappear completely. However, the moon doesn't disappear; it appears orange or "blood red." Use the Internet and other sources to find out why the moon turns red.

Check and Reflect

1. Explain how you could change the direction of a ray of light. Include a diagram in your answer.
2. A basketball does not give off light. Explain, with the help of a ray diagram, how you are able to see a basketball.
3. What happens to light when it hits a translucent object?
4. Which would make a better reflector, a piece of metal or a piece of wood? Explain why.
5. Explain, with the help of ray diagrams, why the shadow created by your hand on a wall grows bigger when you move your hand toward the light source.

2.2 The Law of Reflection

Figure 2.9 Is this photograph printed upside down? What is real and what is reflection? Shiny smooth surfaces make excellent reflectors.

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Making Mirrors

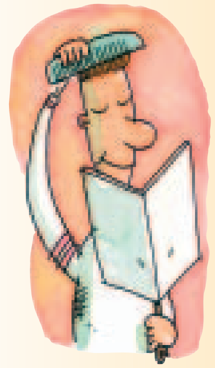
Today, most mirrors are made of glass with a thin film of silver applied to the back. Two-way mirrors are specially designed to reflect 50 percent of the light and transmit the other 50 percent. So, on one side of the mirror, people see a reflection like that in an ordinary mirror. However, people on the other side can see right through. This works only if the room on the reflective side is brighter than the viewing room.

As you have just learned, a smooth surface allows all of the **incident** (incoming) **rays** to bounce off as a parallel beam, giving a regular reflection. The shinier and smoother the surface, the better the reflection. Still water, mirrors, glass, or even polished metal will allow you to see your image. **Plane mirrors** (flat mirrors) provide the clearest reflections. Using plane mirrors, you can investigate how reflected light behaves.

Give it a **TRY** — ACTIVITY

WHICH SIDE IS WHICH?

Look at your face in a mirror. Wink your right eye. Which eye does your reflection wink? Now, set two mirrors at right angles (90°) to each other. Tape them together so they will stand safely. Look directly into the corner of the two mirrors, so that one eye falls on each mirror. Now wink at your reflection. Which eye does your reflection wink now? Have some fun by using the mirror to guide your finger to one of your eyebrows, or to comb your hair.



- Can you explain the difference in reflections in the mirror and the 90° mirrors?

Inquiry Activity

The Law of Reflection

The Question

What rule can you make that describes how light reflects off a mirror?

Materials & Equipment

- pencil
- paper
- ruler
- protractor
- modelling clay
- plane mirror
- ray box

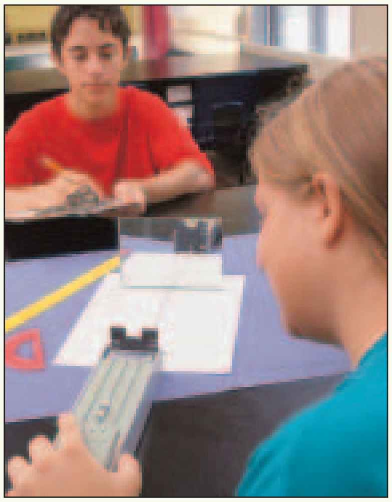


Figure 2.10 Step 3

Procedure

1. Draw a horizontal line. Use a protractor to draw a line perpendicular to it (90°). This is the **normal**. This should make a "T" on your page.
2. Use the modelling clay to hold your mirror upright. Place the mirror on the horizontal line you have drawn. The normal should now be perpendicular to the reflective surface of the mirror.
3. Darken the room and shine a ray of light (the incident ray) at the mirror that is parallel to the normal. Where is the reflected ray?
4. Move the light source so that the incident ray hits the mirror at an angle. Make sure the light beam hits the mirror where the normal meets the mirror. Where is the reflected ray?
5. Using your ruler, draw the incident ray and the reflected ray. Show the direction of the light rays using arrows.
6. Repeat the procedure using several different angles of incidence. For each repetition, use a different colour of pencil to draw the incident and reflected rays.

Collecting Data

7. Measure the angles of incidence and angles of reflection using a protractor. Make sure you measure both angles from the normal, as in Figure 2.11, and not from the mirror surface.

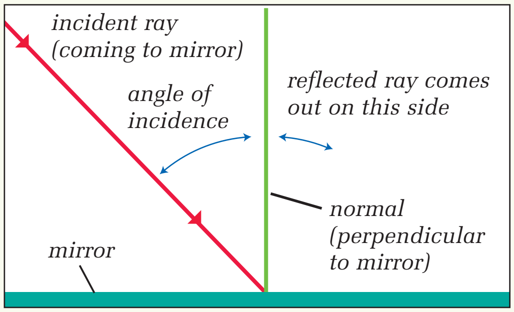


Figure 2.11 The angle of incidence is measured from the normal.

HINT
Use the abbreviations "i" for angle of incidence, and "r" for angle of reflection. Then state your angle as an equation, for example, "i = 37°."

Analyzing and Interpreting

8. How does the angle of incidence compare with the angle of reflection?
9. What happens to the angle of reflection when you increase the angle of incidence?

Forming Conclusions

10. Now that you have an idea of how light reflects, how could you use this information? Give an example of building a device that might require knowledge of the law of reflection.

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Mirrors on the Moon

In 1969 and 1971, astronauts on the Apollo missions placed special mirrors on the surface of the moon. It doesn't matter at what angle a laser light shone from Earth hits these mirrors. The beam will always reflect back in exactly the same direction from which it came. Find out more about these special mirrors. How do they work? Why were they placed on the moon?

The Law of Reflection

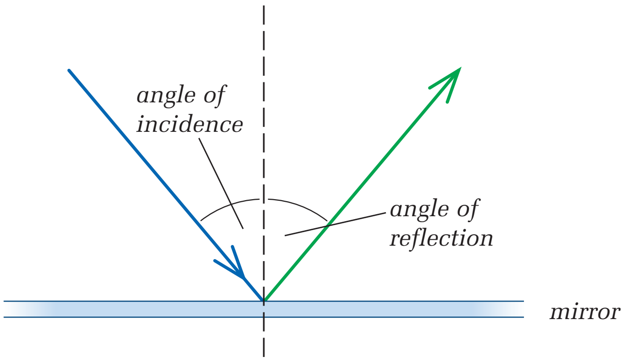
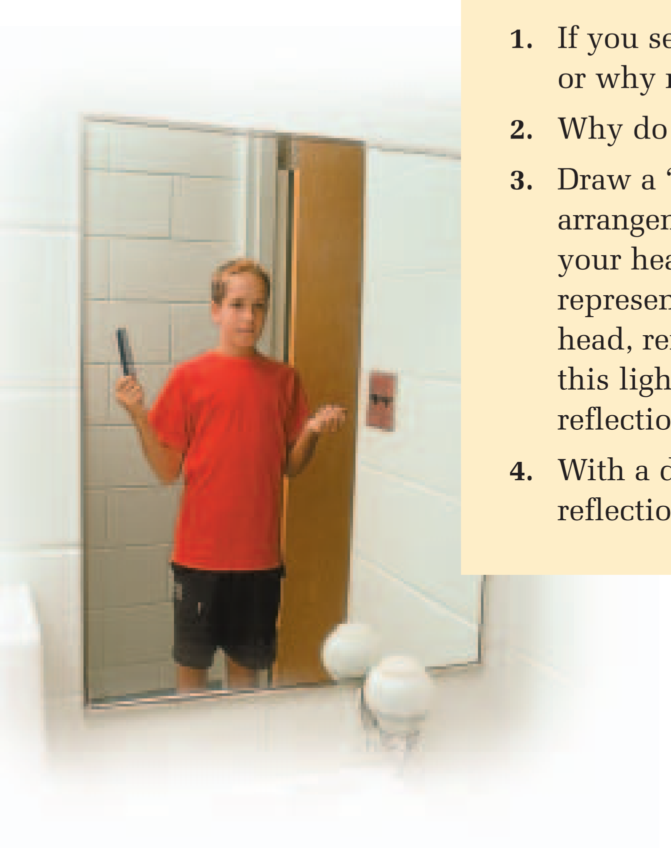


Figure 2.12 The law of reflection

When a ray of light hits a plane mirror at an angle, it bounces off the mirror surface at exactly the same angle. If you use straight lines to represent the mirror and rays in a drawing as in Figure 2.12, a line perpendicular to the mirror at the point of reflection is called the **normal**. The angle between the incident ray and the normal is the **angle of incidence**. The angle between the reflected ray and the normal is the **angle of reflection**. According to the **law of reflection**, the angle of incidence is equal to the angle of reflection.

Check and Reflect

1. If you see someone in a mirror, can they see you? Explain why or why not. Use a ray diagram if necessary.
2. Why do you think mirrors are so useful in magic acts?
3. Draw a "view from above" ray diagram that illustrates an arrangement of mirrors that would allow you to see the back of your head while looking straight ahead. (Hint: Draw a circle to represent your head. Draw a light ray leaving the back of your head, remembering to include the arrow.) How can you direct this light ray to your eyes? Mark the angles of incidence and reflection on your diagram.
4. With a diffuse reflection, do you think light rays obey the law of reflection?



2.3 Reflecting Light with Curved Mirrors

Figure 2.13 Fun-house mirrors distort your reflection.

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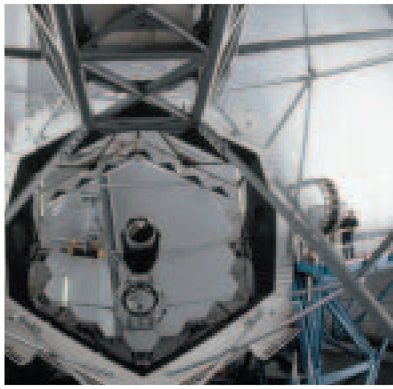
That's a Big Mirror!
The largest telescope mirror is located in the Keck Observatory in Hawaii. The concave mirror is 10 m wide! Astronomers are planning to build bigger mirrors up to 100 m wide.



Standing in front of a fun-house mirror at the carnival can make you look pretty weird. The strange image you see is produced by flat, outward-curved, and inward-curved sections in the same mirror. 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. Let's take a close look at two types of curved mirrors.

Concave Mirrors

A **concave mirror** has a surface that curves inward like a bowl. Like any other mirror, concave mirrors obey the law of reflection. However, when parallel light rays approach a curved surface and strike at different points on the curve, each ray will reflect at a slightly different direction. These rays all head to a common point, called the **focal point**.

As you can see from Figure 2.14, concave mirrors are good at collecting light and bringing it to a single point. This is why concave mirrors are ideal for reflecting telescopes where you want to gather as much dim light as possible.

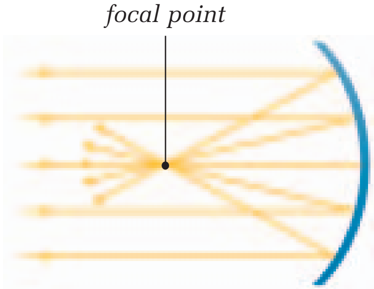


Figure 2.14 Concave mirrors reflect parallel rays of light back through the focal point.

Imagine a light bulb at the focal point, sending rays out in all directions. By reversing the direction of the arrows in Figure 2.14, you can see that the light rays would leave the mirror as parallel rays. That's why you will find concave mirrors in flashlights and car headlights. The concave mirror directs most of the light rays out in front of the flashlight or car, exactly where you need them.

Give it a TRY — ACTIVITY

CONCAVE MIRROR IMAGES

Place an object in front of a concave mirror to produce a clear, focussed image. Observe the image carefully. Is it upside down or upright, bigger or smaller? Record your observations.

Predict what the image will look like when the object is placed at the following locations: a) closer to the mirror, b) farther away from the mirror, and c) very far from and very close to the mirror.

At each location, will the image be bigger, smaller, upright or upside down, or will there be any image at all? Record your predictions and then test them by moving the object. Were your predictions correct? Record your observations.

CONCAVE MIRROR IMAGES

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 upside-down image. 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, the image becomes upright and enlarged.

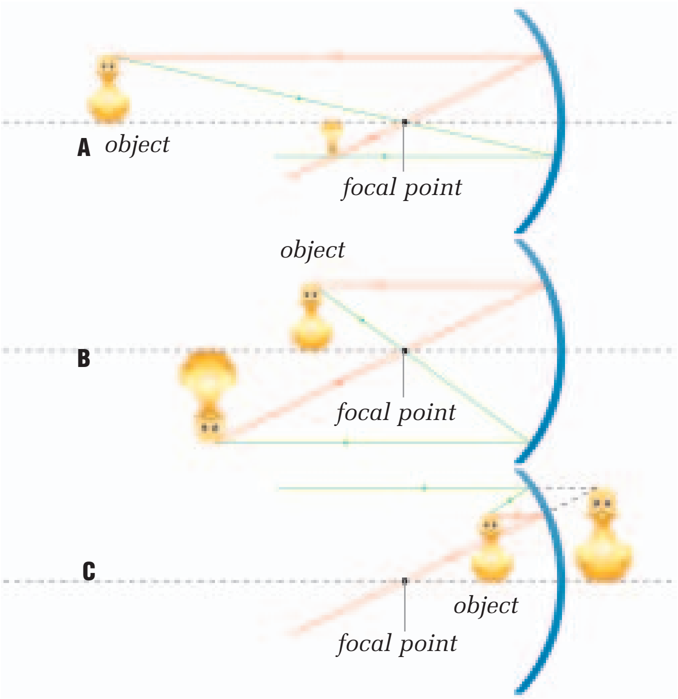
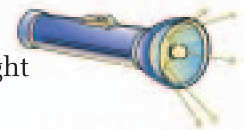
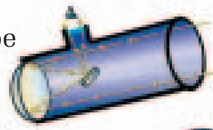


Figure 2.15 If an object is farther from the focal point, the image is upside down, as in A and B. If the object is between the focal point and the mirror, the image appears upright and enlarged, as in C.

Device		Use of Concave Mirror
Flashlight		To produce a parallel beam
Telescope		To collect a large amount of 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)

Convex Mirrors

A mirror with a surface curved outward is called a **convex mirror**. As you might expect, it does the opposite of a concave mirror. Instead of collecting light, it spreads out light rays.

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 the warning "Objects in mirror are closer than they appear."

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It's a Wide, Wide View

Find out about uses for convex mirrors. Try drawing ray diagrams to prove that convex mirrors can be useful in certain situations.

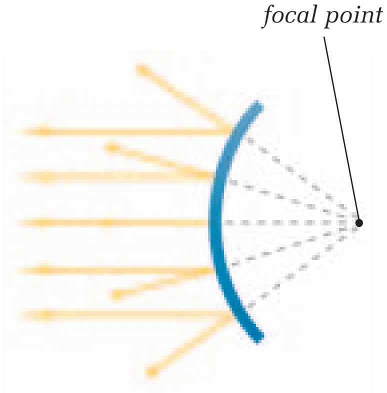

Figure 2.16 A convex mirror reflects parallel rays of light as if they came from a focal point behind the mirror.

Check and Reflect

1. Do curved mirrors obey the law of reflection? Explain.
2. Someone has left a shiny metal bowl outside in the sun. Which may have the potential to damage your eyes: looking at the outside of the bowl or the inside of the bowl? Explain.
3. An object is held extremely close to a concave mirror. Describe how the image will appear. Draw a ray diagram to explain.
4. If you look in a convex mirror, would your image ever appear smaller? Explain why or why not.
5. Describe one practical use of a concave mirror.

2.4 Transparent Substances Refract Light

Figure 2.17 Catching salmon in water is challenging.

*info***BIT**

Pumpkin Sun

When the sun is near the horizon, the rays from the lower edge of the sun bend, or refract, more than the rays from the upper edge as they pass through Earth's atmosphere. This makes the sun look slightly oval instead of round.

British Columbia has some beautiful rivers where grizzly bears hunt for salmon. The grizzlies have to be patient, though. Often they will grab for a salmon and miss, especially when the salmon is in deep water. The closer to the surface the fish is, the easier it is for the grizzly to catch. Why is this so? It has to do with how light behaves in water.

If you tried to catch a fish with your hands, you would face the same problem as the grizzly bear. A fish in the water is not where it appears to be. The problem is that light bends when it leaves the water. When a light ray strikes a boundary where two different substances meet (often referred to as the interface) at an angle, it will change direction.

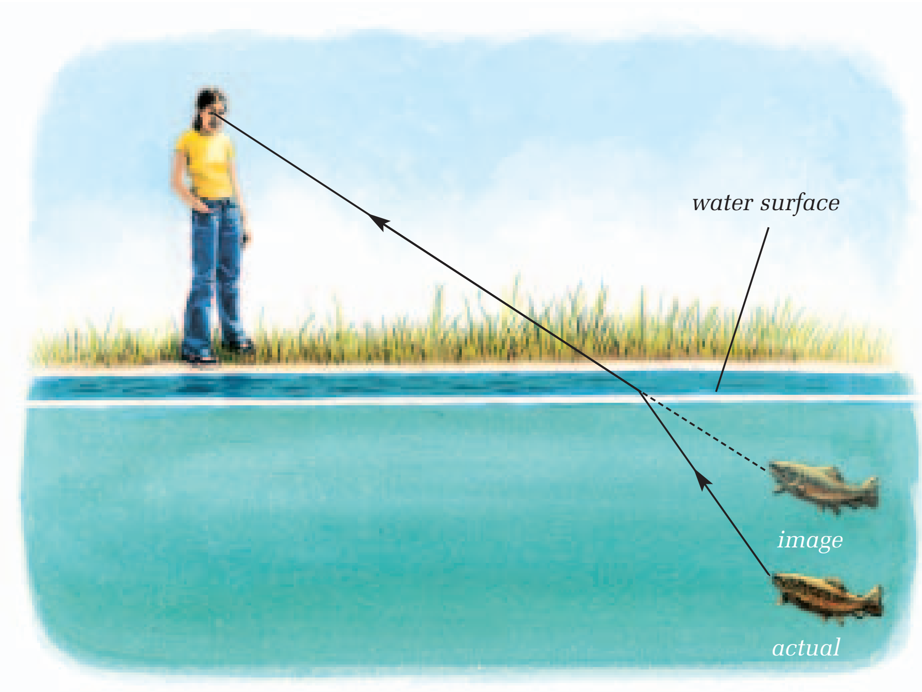

Figure 2.18 The fish is not where it appears to be.

Figure 2.18 shows the light rays coming from the fish bending as they leave the water. Our eyes assume that light travels in straight lines. If you trace the light rays that reach the eye backward in a straight line, you will find that they do not lead to the fish. Instead, the light from the fish in deep water appears to be coming from shallower water, thus fooling you into grabbing where the fish is not.

How Light Refracts

When light travels at an angle from one medium (substance) to another, it bends or refracts. You might be surprised to learn that **refraction** is due to changes in the speed of light. In space, light travels at around 300 000 km/s. Space is a vacuum, and there are no particles to get in the way of light and slow it down. However, just like a student trying to move from class to class when the hallways are full, it's impossible to move at top speed when particles (students) get in the way. What happens when light suddenly slows down as it hits a medium? If it strikes a medium of different density at an angle, it refracts.

How does this happen? Imagine light travelling like the line of skaters in Figure 2.20. Initially, they are all travelling at the same speed. In front of skaters C, D, and E, lies a patch of rough ice that will cause them to slow down. If the rest of the skaters continue to skate at the original speed, the result is a bend in the line. The same thing happens with light. When part of a beam of light slows down and the rest keeps going, the beam of light will bend.

Figure 2.19 This object is not really bent.

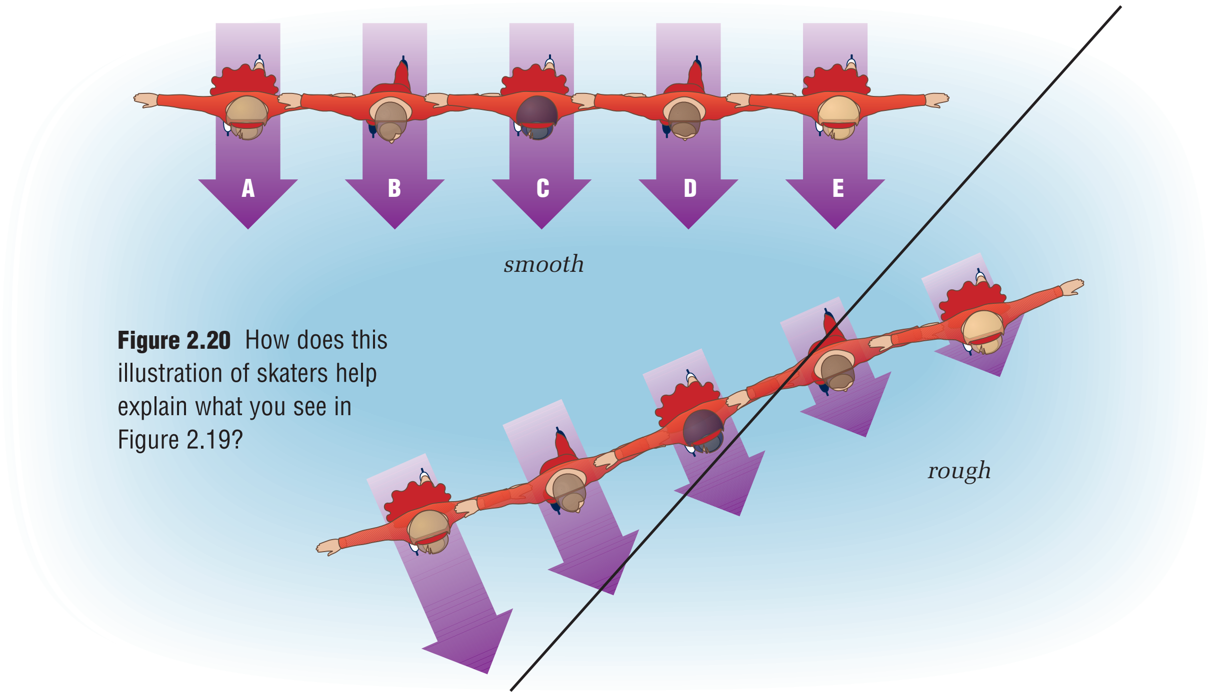

Figure 2.20 How does this illustration of skaters help explain what you see in Figure 2.19?

Inquiry
Activity

FROM AIR TO SOLIDS

Materials & Equipment

- glass block
- paper
- pencil
- ruler
- protractor
- ray box with a single slit opening
- transparent plastic block

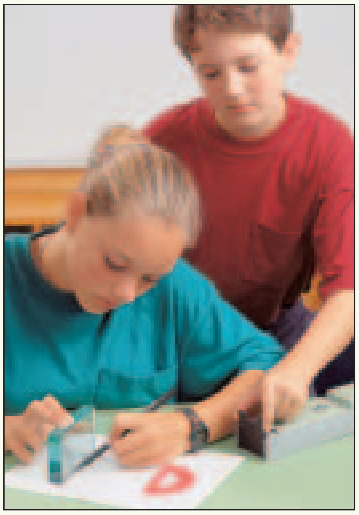

Figure 2.21 Tracing around the glass block

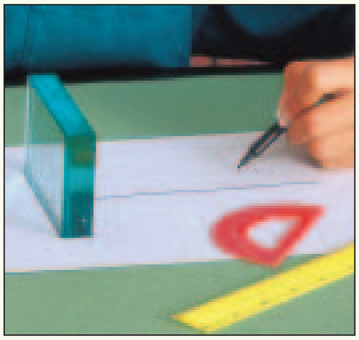

Figure 2.22 Drawing the normal

The Question

What happens to light when it passes from air through different transparent solids?

Procedure

1. Place the glass block on a piece of paper and trace around it as in Figure 2.21. Mark a point near the middle of the front edge of the block and draw a normal at right angles to this point, Figure 2.22.
2. Direct a ray of light from the ray box so that it shines along the normal. The point where the ray enters the block is the point of incidence.
3. Mark the exit point where the ray leaves the glass. Join the incident and exit points. This is the refracted ray.
4. Adjust the ray box so that the light ray strikes the glass at the same point of incidence, but this time at an angle from the normal.
5. Again, trace the incident ray, and mark the point where it leaves the block. Draw the refracted ray again and make sure to label them.
6. Repeat steps 4 and 5, each time using different angles for the incident ray.

Collecting Data

7. Complete each refracted ray on the paper using a ruler to join the point of incidence to the exit point. Make sure all rays, incident and refracted, are labelled correctly. Add arrows to the rays to indicate their direction.
8. Use your protractor to determine the angle of incidence and the angle of refraction in each case. Note that these angles are measured from the normal. Organize all the angles in a table with the headings "angle of incidence" and "angle of refraction" and list the rays in order by their angle of incidence.
9. Repeat steps 1 through 8 with the plastic block and a new sheet of paper. Predict how refraction will change using the plastic block. Use the same angles of incidence you used for the glass block.

Analyzing and Interpreting

10. How does the incident angle compare with the refracted angle?
11. What happened when the ray entered the block along the normal?
12. What happened to the refracted ray as the angle of incidence was increased?
13. How did the refraction of rays in glass and plastic compare?

Forming Conclusions

14. What two factors affect how much light is refracted?
15. Which of the two substances, glass or plastic, refracts light more?

REFRACTION IN DIFFERENT MEDIA

Light bends when it hits a new medium at an angle. The denser the new medium, the more the light slows down, and so the more it refracts. A diamond is much more dense than water, and so a diamond refracts light more than water does.

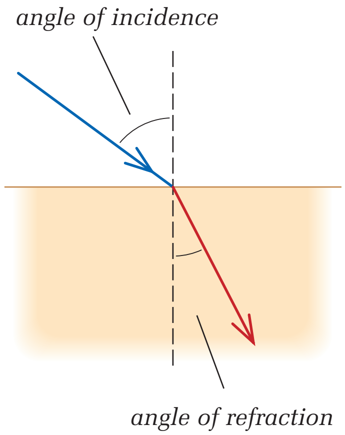

Figure 2.23 Ray diagram showing refraction

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Wet Road Ahead!

Have you ever been on a car trip on a hot sunny day and the road ahead seems wet? What you see is an optical illusion called a mirage. Investigate the role refraction plays in causing mirages.

CHECK AND REFLECT

1. What happens to light rays when they pass from one medium into another medium? Explain the process of refraction.
2. How does the type of medium affect refraction?
3. When would it be easier for a bear to catch a fish: as the fish swims or when it jumps in the air? Use your knowledge of how light travels in air and water to explain.
4. Why do objects at the bottom of an aquarium filled with water appear closer than they actually are?
5. The archer fish fires jets of water with its mouth at unsuspecting bugs on branches above the water. Explain in terms of how light travels, why these fish almost always "shoot" when they are directly beneath a bug. Why don't they shoot at an angle?

Figure 2.24 Question 5

2.5 Lenses Refract and Focus Light

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Wow! That's Intense!

Convex lenses bend parallel light rays to a single point. As a result, the concentrated light energy at that point is hot enough to burn skin and can start fires. Be very careful handling convex lenses, especially in sunlight.

In section 1.0, you learned that microscopes, telescopes, and binoculars take advantage of lenses to manipulate light. What is it about lenses that make them great at collecting and moving light around? The answer lies in their shape and the material they're made of.

A **lens** is a piece of curved glass or other transparent material. It is smooth and regularly shaped so when light strikes it, the light refracts in a predictable way. The most useful aspect of lenses is that the light rays that refract through them will sometimes form images.

Figure 2.25 A magnifying glass is a convex lens.

Concave Lenses

A **concave lens** is thinner in the centre than at the edges. As parallel rays pass through a concave lens, they are refracted away from the centre of the lens. So as light passes through a concave lens, the light rays diverge or spread out, and they will never meet on the other side of the lens.

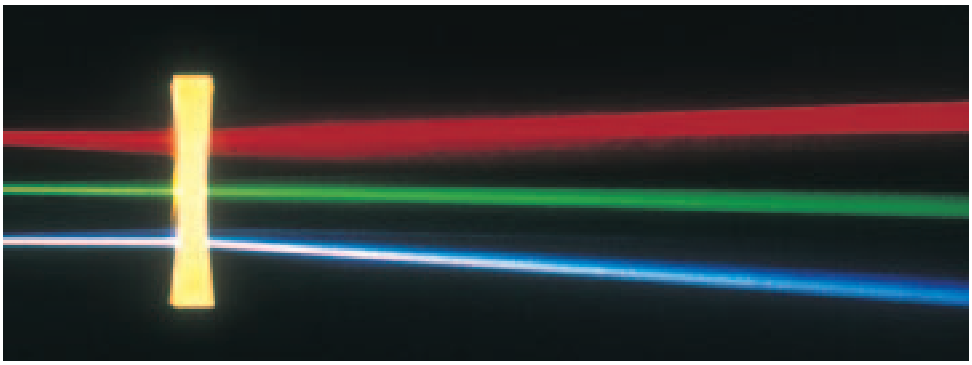

Figure 2.26 Concave lenses spread light out.

Convex Lenses

A **convex lens** curves outward and is thicker in the middle than at the edges. The technical name for a convex lens that curves outward on both sides is a double convex lens, but it's usually just called a convex lens. As parallel light rays travel through a convex lens, they are refracted toward the centre of the lens. So as light passes through a convex lens, the rays move toward each other. The light rays cross at the focal point of the lens. (By changing the curvature of the lens or the substance it is made of, you can alter the focal point.)

The ability to bring light rays together makes a convex lens useful for two reasons. First, it can act as a light collector, much like a concave mirror. This is why a convex lens is used in a refracting telescope. It collects and focusses starlight. (Look back at the diagram of a refracting telescope on page 184.) Second, a convex lens forms a **real image**. The light rays actually meet at a point, and the image can be projected onto a screen.

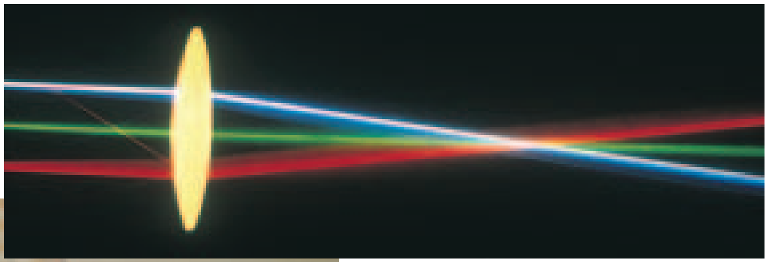

Figure 2.27 Convex lenses bring light rays together.

Figure 2.28 A real image can be projected onto a screen.

Depending on how close the object is to the convex lens, you can project images that are smaller or larger than the object. However, as you can see in Figure 2.28, there is one drawback to convex lenses. The image is upside down!

Inquiry
Activity

Checking Out Images

Materials & Equipment

- cardboard stand
- sheet of unlined white paper
- tape
- light bulb and socket
- battery and wires
- convex lens
- modelling clay (to support the lens)
- metre-stick

The Question

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

The Hypothesis

Based on the question, form a hypothesis for this investigation.

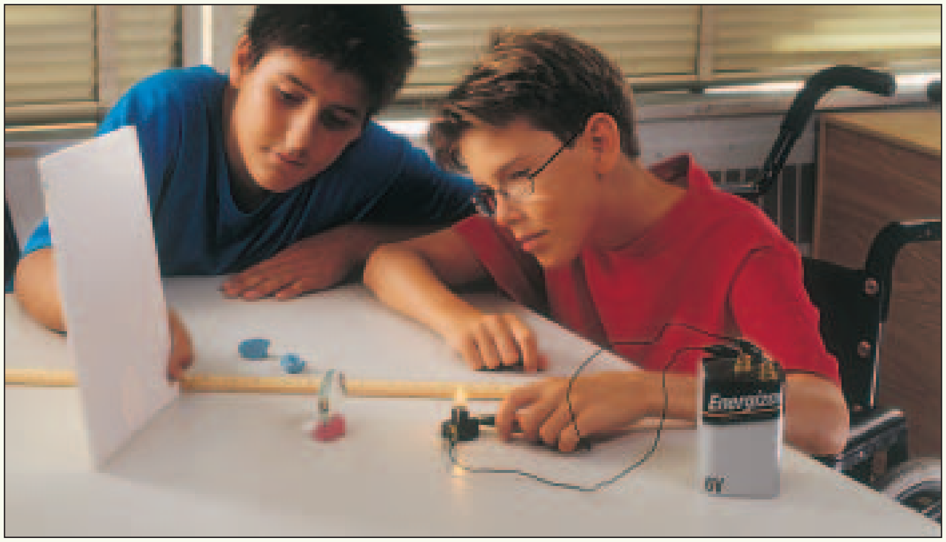

Figure 2.29 Finding the focal length of the lens

Procedure

1. Measure the height of the glass part of the bulb.
2. Tape the paper onto the cardboard stand. This is your "screen."
3. If your teacher has provided you with the focal length of the lens, you may skip this step. If you don't know the focal length of the lens, do the following to find the focal length:
   - Place the lens in between the stand and the lit bulb.
   - Move the screen and the bulb slowly inward, then outward, keeping the lens in the middle. At a particular distance, an upside-down bulb of the same size as the actual bulb will come into focus on the screen. Be patient! If you don't get the image the first time, keep trying.
   - Measure the distance between the bulb and lens. Divide this value by 2. This is the approximate focal length of the lens.
4. Record the bulb height and focal length in your notebook.
5. You are going to collect data on the size of the image of the bulb, as well as the distance of the bulb from the lens. Draw a data table like the one on the following page.

Distance from bulb to lens (cm)	Image position (upright or upside down)	Size of image (cm)

6 Place the bulb more than twice the focal length away from the lens. Move the screen until the image comes into focus.

Collecting Data

7 Record the following in your data table:
- distance from the bulb to the lens
- the position of the image (upright or upside down)
- the size of the image

8 Place the bulb just over one focal length away from the lens. Move the screen until the image comes into focus. Record the results as in step 7.

9 Repeat step 7 again but this time place the bulb less than one focal length away from the lens. Move the screen to attempt focus. If you cannot get an image on the screen, bend down and look at the bulb through the lens. Can you see an image of the bulb in the lens? If you see an image through the lens, estimate its size.

Analyzing and Interpreting

10 Is the image formed by a convex lens always upside down? If not, under what conditions is the image upright?

11 What happens to the size of the image as the bulb moves toward the lens? What happens to the image position?

12 What happens when the bulb is placed inside the focal length of the lens?

Forming Conclusions

13 Write a summary paragraph explaining how lens placement affects image size and location.

Applying and Connecting

Convex lenses are often used in projectors. You may have used a projector to give a slide or film presentation. What happens to the size of the image as the projector is moved closer to the screen? Explain this in terms of what you have learned about convex lenses. How do you think projectors overcome the "upside-down" problem?

Extending

Try repeating this experiment using lenses of different focal lengths.

Figure 2.30 Using a projector

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The Fresnel Lens

In 1822, Augustine Fresnel (pronounced Fray-nell) invented a lens that was much more efficient at collecting and directing light rays than other lenses used at the time. Find out more about the structure and function of Fresnel lenses.

Image Formation with a Convex Lens

The formation of an image by a convex lens depends upon how far the object is from the lens. The ray diagrams in Figure 2.31 help illustrate this. If the object is farther away than the focal point of the lens, as in diagrams A and B, the image appears upside down and smaller or bigger. Both of these images are real images. In diagram C, the image will appear upright and bigger, and forms on the same side of the lens as the object. When you use a magnifying glass, the object you're looking at appears to be bigger on the other side of the glass.

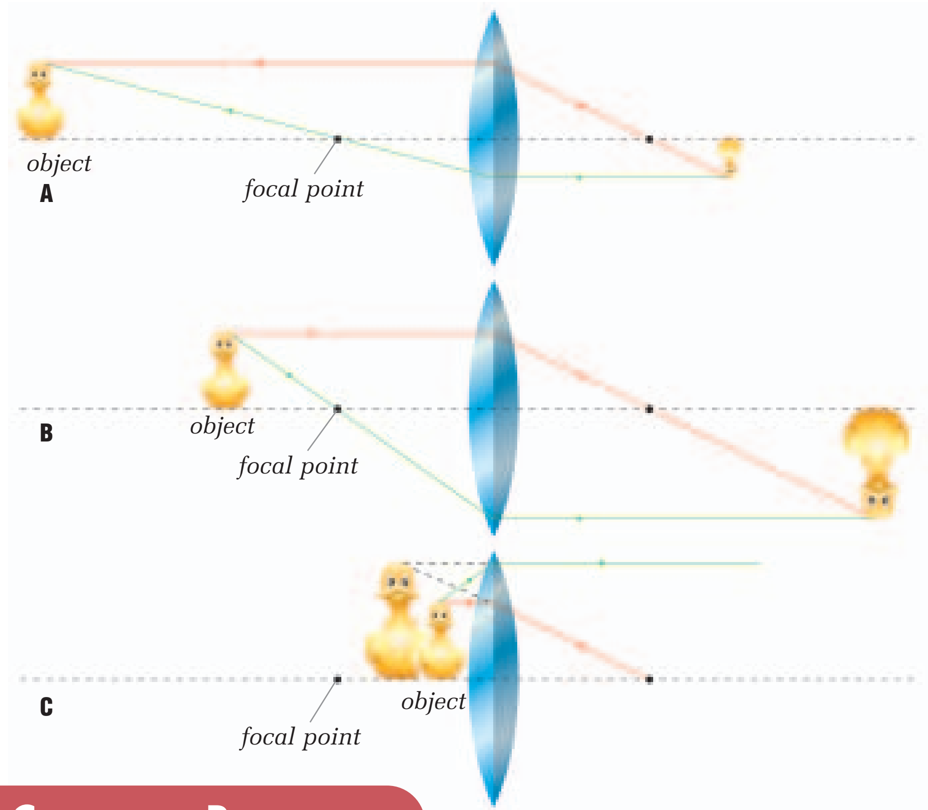


Figure 2.31 The formation of an image with a double convex lens depends on where you put the object.

Check and Reflect

1. Why are lenses useful for moving light around?
2. Draw a ray diagram that shows the path light rays take through a concave lens.
3. What kind of image is formed when an object is placed at the focal point of a convex lens?
4. Figure 2.32 shows the view through glass building bricks. How do these bricks let light through but still protect your privacy?
5. Suppose you wanted to examine closely the leaf of a plant. What type of lens would you choose? Would you use a lens combination? Explain.

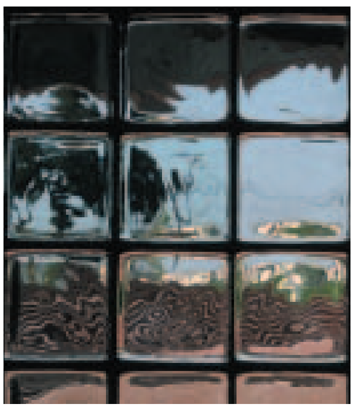


Figure 2.32 Question 4

Experiment ON YOUR OWN

LENS SWITCH-A-ROO

Before You Start ...

You now know how the size and position of images formed by a convex lens can change depending on the position of the object. Would the images be different if you used two convex lenses?

The Question

How does image formation vary when two convex lenses are used?

Design and Conduct Your Experiment

TOOLBOX

1 Make a hypothesis.
2 Decide on the materials and equipment you will need to test your hypothesis.
3 Are there any safety aspects you need to consider?
4 Plan your procedure. What steps do you have to go through to collect the data you need?
5 Write up your procedure and show it to your teacher.
6 Decide what your data collection table should look like and construct it.
7 Before you start your investigation, make predictions about the size and locations of the images.
8 Carry out your investigation and compare your results with your hypothesis. Was your hypothesis correct? If not, how would you explain your experimental result?
9 Compare your results with classmates who investigated similar questions. Were your results similar?

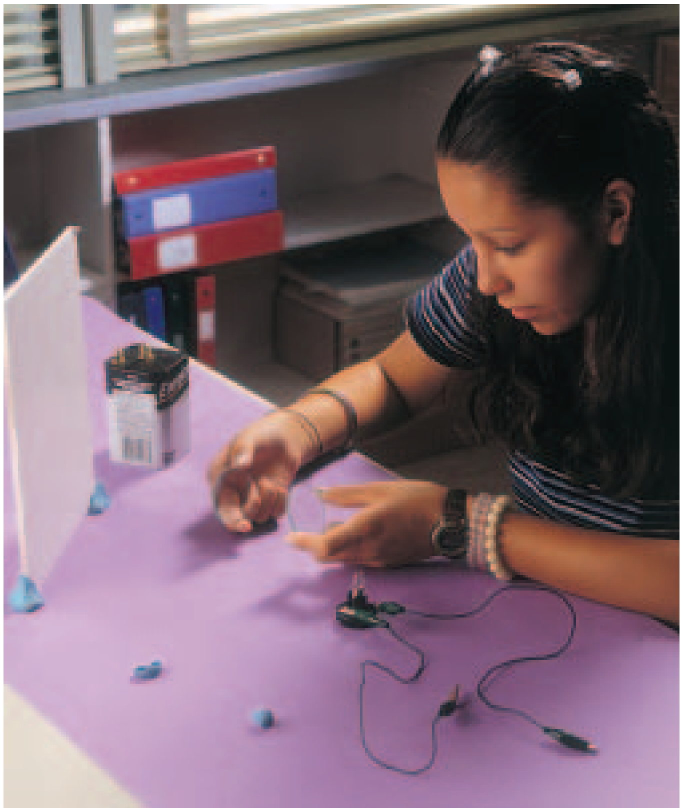


Figure 2.33 Think about how you will conduct your experiment.

10 Compare your experimental procedure with classmates who investigated similar questions. Identify some strengths and weaknesses of the different ways of collecting and displaying data.
11 Are there any questions or problems that came up during your experiment that would take more investigation to answer?
12 Outline how you would design an experiment to look into these questions or problems.

Careers and Profiles

Say Cheese!

Ray Boudreau is a professional photographer. His portfolio includes everything from corporate executives to members of the Royal Canadian Air Farce. In fact, he took many of the photographs that appear in this unit.

Q: When did you first become interested in photography?

A: My interest in photography began when I was 11 years old. A friend of the family gave me a little Kodak printing kit. After using it for the first time, I was hooked on it.

Q: What's the most challenging part of your job?

A: Each picture I take has its own photographic problem which I have to solve. It's a problem-solving business. Using my photographic knowledge to solve problems is fun for me.

Figure 2.34 Ray Boudreau is setting up for a photograph that appears in Cells and Systems.

The camera Boudreau uses can be fitted with different lenses.

Each photographic lens uses a combination of convex and concave lenses.

Q: What was your most challenging photo?

A: I had to photograph the city of Toronto for the cover of a magazine. I rented a wide-angle lens and we went up in a helicopter. I was strapped in and I hung out of the helicopter and photographed the buildings from as close as we could get. The wide-angle lens made the tops of the buildings look really big and the bottoms look really small.

1. Do you think a photographer has to know about light and optical systems to do his or her job?
2. If you were a photographer, what part of the job would you find challenging?

Assess Your Learning

1. Use a labelled diagram to illustrate the law of reflection.
2. As Figure 2.35 indicates, it is possible to build a spy device with a long tube or milk carton. This could also be used to see over a crowd at a parade. Using a diagram, explain how mirrors are arranged in this device to make it an effective "spy tool." Make sure to indicate how rays of light would travel through the device.

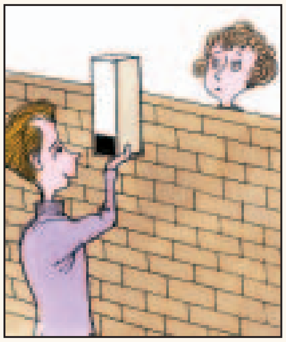


Figure 2.35 Question 2

3. Design a reading light that someone could use without bothering others in the room. (Hint: How could a mirror help?)
4. If you wanted to block out all of the light from your bedroom, what type of material would you use on the window? What would you use if you wanted to block out half of the light?
5. In Figure 2.36, the doll in the tank of water illustrates light from the doll reaching your eyes by three different paths. Explain what is happening to the light rays on those three paths.

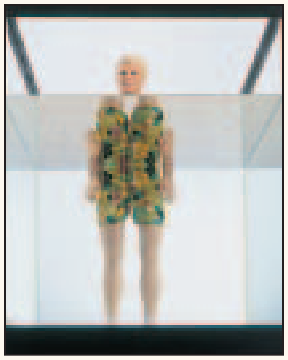


Figure 2.36 Question 5

6. Describe how you would project a bigger image with a double convex lens.
7. Why should the pages of a book be slightly rough rather than very glossy?
8. Trace Figure 2.37 into your book. Assume the light ray moved from substance A to B. Add an arrow to the light ray, draw a normal, and label the angles of incidence and refraction.

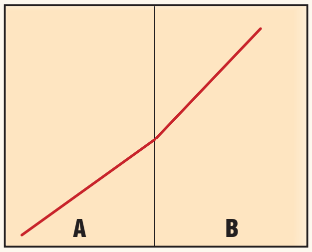


Figure 2.37 Question 8

Focus On THE NATURE OF SCIENCE

Scientists strive to gain knowledge of the natural world. Reflect back on what you have learned about how light behaves.

1. Why do you think it is important to learn how light reacts in nature?
2. How has the development of different types and applications of lenses and mirrors helped us to better understand our world?
3. How does an understanding of how light travels aid in the development of new technologies?

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

Key Concepts

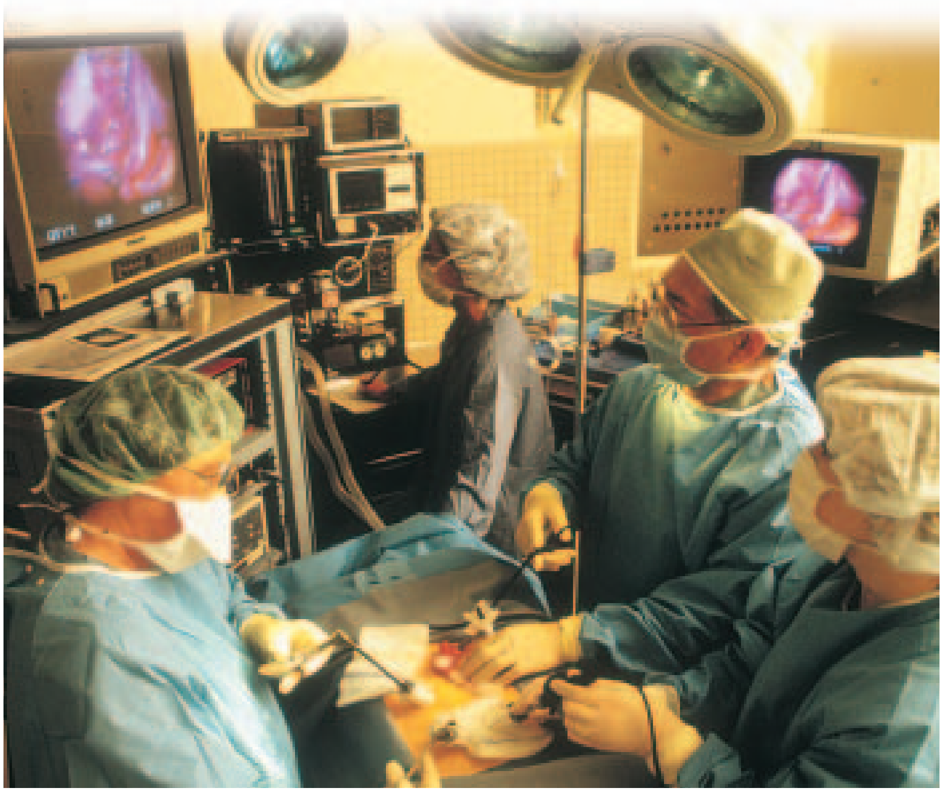
In this section, you will learn about the following key concepts:

- electromagnetic spectrum
- transmission and absorption of light
- colour and wavelength
- sources of light

Learning Outcomes

When you have completed this section, you will be able to:

- describe the characteristics and composition of sunlight
- explain the wave properties of light and the electromagnetic spectrum
- describe some of the technological applications of electromagnetic radiation
- recognize the dangers associated with certain forms of radiation
- evaluate, compare, and contrast different artificial and natural light sources
- describe how primary colours can be added to produce different colours and white light



The medical profession has changed incredibly in the last two centuries. Doctors have a number of different tools they can use to see inside the body without having to operate.

The endoscope is a combination camera/light source. The light is delivered through a thin, flexible fibre-optic cable. It allows the doctor to illuminate the inside of the digestive system and examine the structures clearly to identify any problems. The doctor views the image on a TV screen and can even perform operations this way.

Visible light is just one form of energy used by doctors to advance medical treatment. Lasers are used to make incisions in surgery. X-rays are used to view dense structures inside the soft tissue of our body. Gamma rays are used to treat cancer. Even microwaves have been used to shrink certain enlarged tissues. What do all of these forms of energy have in common?

For Web links relating to 3.0, visit **www.pearsoned.ca/scienceinaction**

** Extension material*

3.1 The Wave Model of Light

An important part of science is developing models. Models are based on what we observe about the characteristics and properties of something. They help make it easier to understand complex concepts. Scientists commonly use the **wave model of light**.

Waves and light have two big similarities: they are both a form of energy, and they travel out in all directions. If waves describe light, then you need more information about how waves behave.

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Tsunami!
In 1771, a tidal wave, or tsunami, hit the coast of Japan. It was possibly 85 m high and had enough energy to toss a 750-t rock 2.5 km inland.

Properties of Waves

__wavelength__—the distance from the crest of one wave to the crest of the next

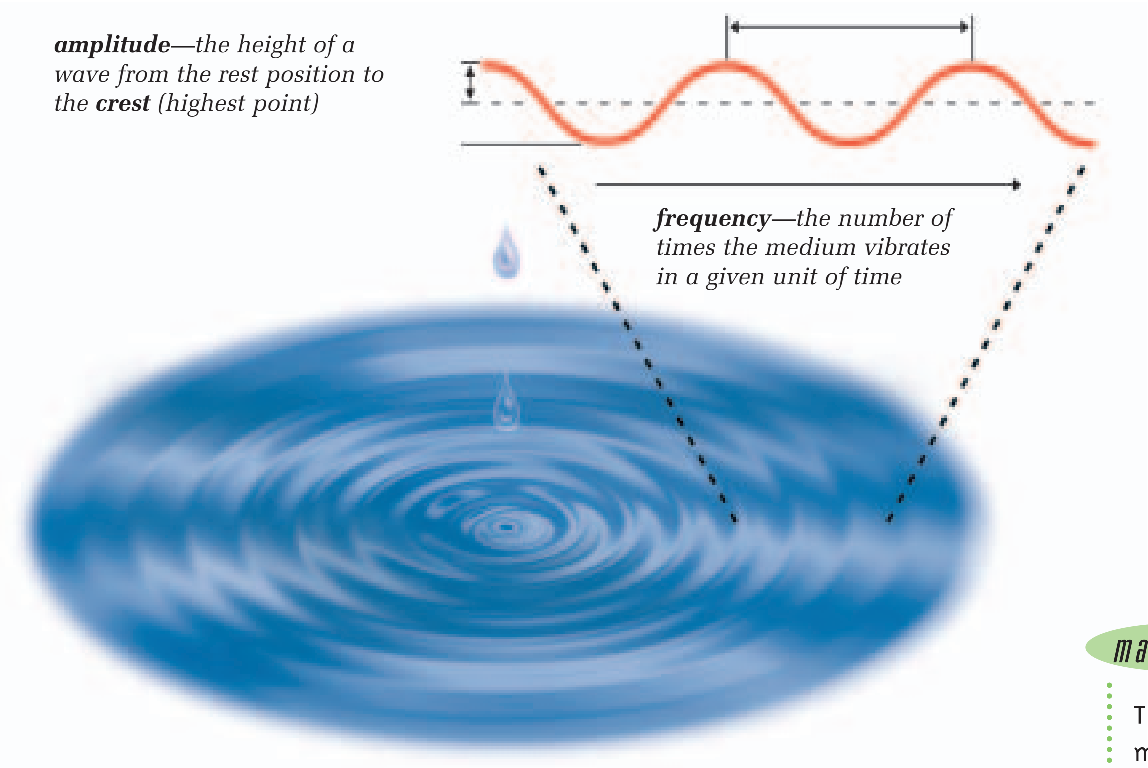

Figure 3.1 All waves have an amplitude, wavelength, and frequency.

All waves have a wavelength, but the wavelengths can vary widely. Think about sitting in the bath. You've probably created waves just for the fun of it. Suppose you were making one new wave every second. Would it take more or less energy to create three waves per second? It takes more energy.

When you create more waves per second, the frequency of the waves increases. As the frequency increases, you'll notice that the crests of each wave are closer to one another. So as more energy is put into making waves, the frequency of waves increases and the wavelength shortens.

mathLink

There is a mathematical relationship between the speed, wavelength, and frequency of a wave.

speed = wavelength × frequency

If the speed of a wave on a rope is 50 cm/s and its wavelength is 10 cm, what is the frequency of the wave?

Light Waves

As you learned in the first section, rainbows have fascinated people, especially scientists, for thousands of years. How are the colours of a rainbow formed? You always need sunlight to create a rainbow, so there must be some relationship between the white light of the sun and the coloured light of a rainbow.

Figure 3.2 Sunlight and raindrops are needed to form a rainbow.

Give it a **TRY** — **Activity**

What Is White Light Made Of?

Shine a light through a prism so that the light leaving the prism falls on an unlined piece of paper. What colours do you see? As you hold the prism and light steady, your partner will use coloured pencils to draw the colours on the piece of paper. Switch places with your partner. Again, trace the colours you see onto the piece of paper.

- What colours do you see on the paper? What is the order of the colours?
- Is it difficult to see where one colour ends and the next begins?
- Did the order of the colours on the paper ever change?
- The term *spectrum* means a range. How do you think this term is related to what you observed?

When you shine sunlight or white light through a prism as in Figure 3.3, the light refracts, and splits up into the colours of the rainbow. These colours form the **visible light spectrum**. Each colour of light is refracted at a different angle. So white light is made up of many different colours of light.

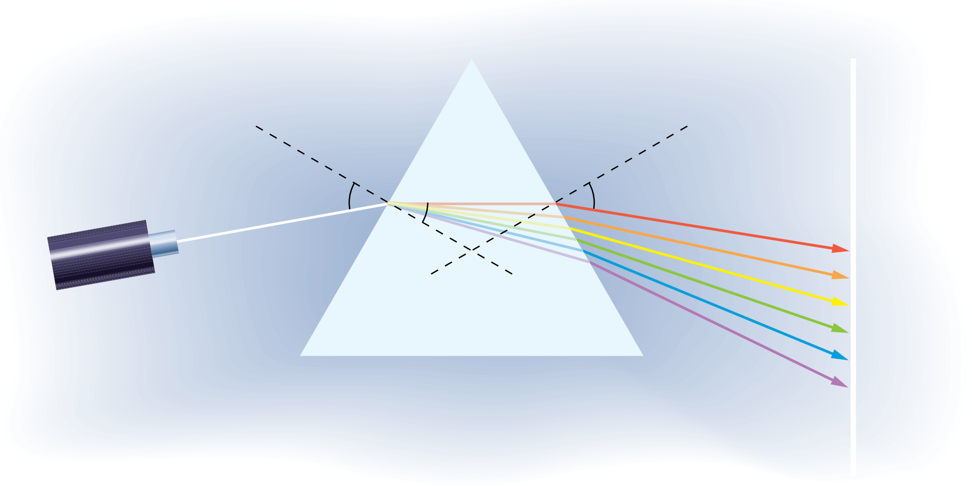

Figure 3.3 Refraction of white light through a prism. Each colour of light that makes up white light refracts at a slightly different angle.

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Two Pots of Gold?

When rainbows form, sometimes a secondary rainbow appears outside the first. Find out how the secondary rainbow occurs. Is the order of colour in the secondary rainbow the same as the first?

The colours of the spectrum can be explained using the wave model. Figure 3.4 shows that each colour of light in the visible light spectrum has a slightly different wavelength.

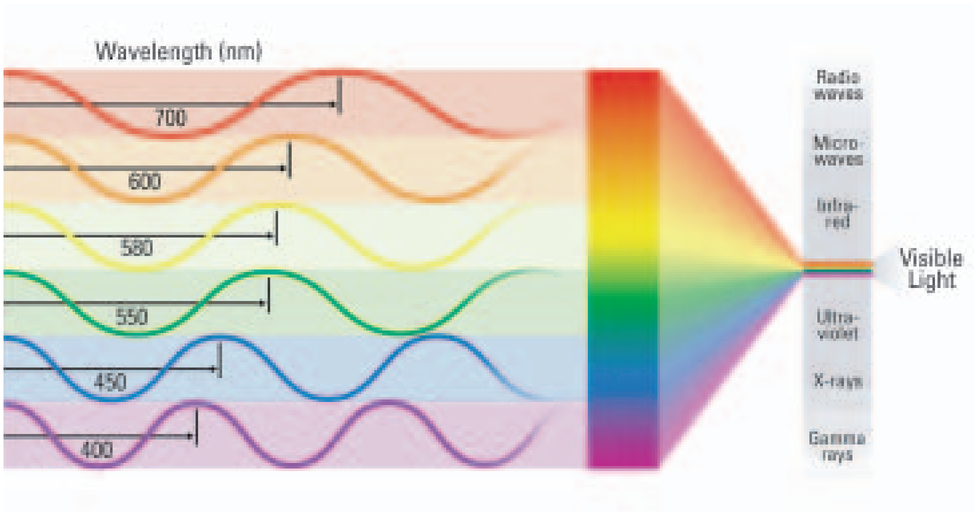


Figure 3.4 The visible spectrum has red light on one end, violet on the other, and all the other colours in between. Red light has a wavelength of 700 nm (nanometre)—as you move through the other colours, the wavelength shortens to 400 nm for violet light. These wavelengths are very tiny. A nanometre is one-billionth of a metre, so 700 nm = 0.000 000 7 m.

Check and Reflect

1. What properties do light and the waves in your bath share?
2. Create a concept map that links frequency, amplitude, and wavelength.
3. On a piece of graph paper, draw a diagram of a wave with an amplitude of 4 cm and a wavelength of 10 cm.
4. Draw a diagram to explain what happens to white light as it passes through a prism.

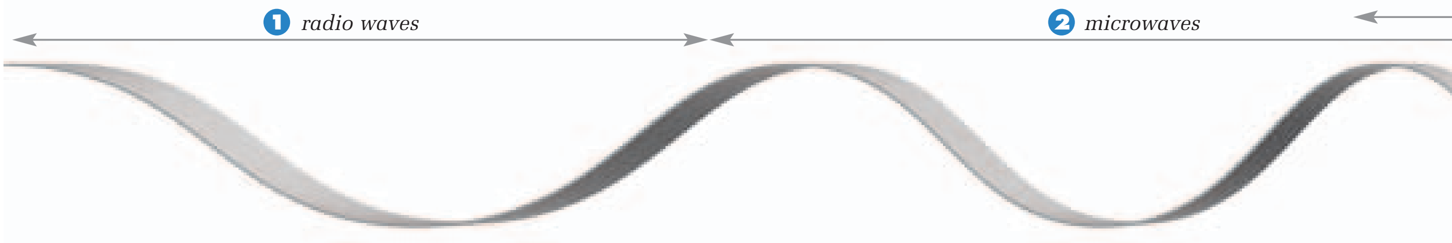
3.2 The Electromagnetic Spectrum

Imagine you are out for a walk in the park. The sun is shining down and there's not a cloud in the sky, but actually you are being drenched! Not by rain, but by energy. In addition to visible light, the sun sends out lots of different types of energy. Most of them you cannot see or feel.

The Invisible Spectrum

There is a whole world of energy that lies beyond our sense of

Uses of the Electromagnetic Spectrum



1 Radio waves are vital to communications around the world. Different wavelengths within the spectrum of radio waves are used to separate modes of communication. For example, FM radio waves are longer than AM radio waves. Searchers for extraterrestrial intelligence use radio antennas to scan space for radio signals that would indicate life on other worlds. They haven't found anything—yet.

2 Microwaves are shorter than radio waves. This means that the frequency of microwaves is higher than radio waves, and they carry more energy. When microwaves are used to heat food, they make the water particles in the food vibrate. This causes the food to heat up.

3 Infrared waves can't be seen but they are felt as heat. Special equipment can sense infrared radiation and detect hotter and cooler areas. Images of infrared radiation are called thermograms.

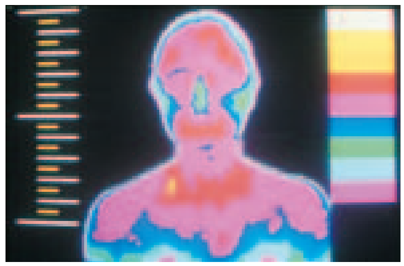


Figure 3.5 Electromagnetic radiation strikes Earth in many different forms.

vision. The wavelengths that make up visible light are just a small part of a very large range of **electromagnetic radiation**. The wave model works perfectly to explain the invisible parts of the **electromagnetic spectrum** (Figure 3.5). At the end of the spectrum with longer wavelengths than visible light, you find the low-frequency radio waves, microwaves, and infrared radiation. At the other end of the spectrum where the wavelengths are shorter and frequencies higher than visible light, you find ultraviolet radiation, X-rays, and gamma rays. Human eyes are not sensitive to either end of the electromagnetic spectrum that lies beyond visible light, so these rays remain invisible.

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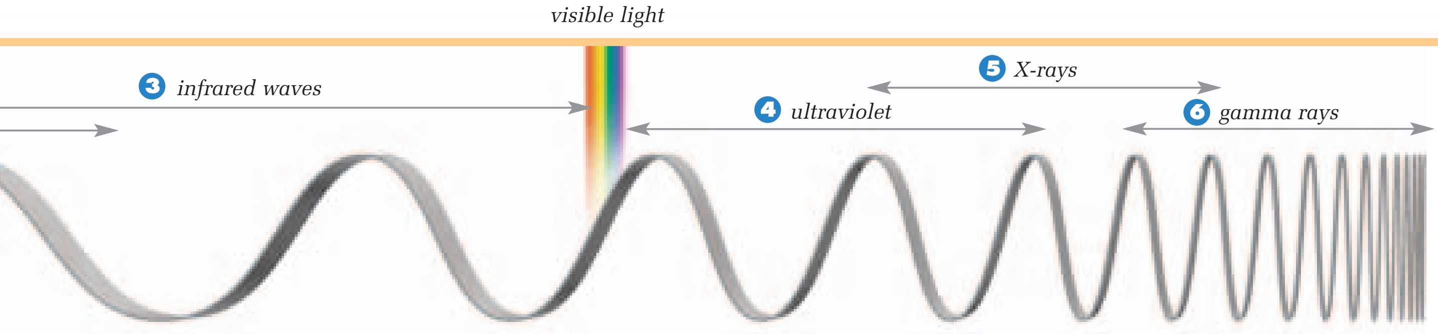
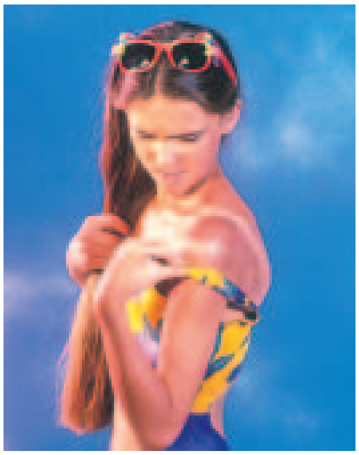
Not on the Same Wavelength

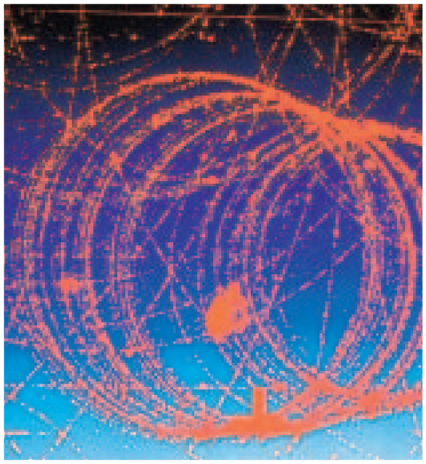
The longest wavelengths in the electromagnetic spectrum are long radio waves, at 100 km. The shortest are gamma rays, at 0.000 000 000 0001 mm



4 **Ultraviolet** (UV) **light** carries more energy than visible light and can burn the skin, increasing the risk of skin cancer. Most of the sun's UV rays are absorbed by Earth's ozone layer but it is still advisable to wear sunblock creams when outdoors. A sunblock provides an opaque layer that prevents UV rays from reaching your skin.



5 **X-rays** and 6 **gamma rays** both represent extremely high-energy radiation. Both these rays can penetrate tissues. Lower energy X-rays have difficulty passing through bone, making them useful for medical imaging. Gamma rays are used to kill cancer cells. Doctors always use very short bursts of these rays because long-term exposure can cause cancer. This is why X-ray technicians protect themselves and other parts of your body with lead aprons that X-rays cannot penetrate.



Cloud chamber showing radiation trails

Applications of Electromagnetic Radiation

Although we cannot see the invisible parts of the electromagnetic spectrum, these waves can be transmitted, reflected, and absorbed, just like visible light.

Radio Waves

Radio waves can be used in medicine to produce images of tissues deep inside the body. A magnetic resonance imaging (MRI) device sends short bursts of radio waves into the body. With the help of a magnetic field, the radio waves energize atoms and make them line up. When the radio pulses are turned off, the atoms return to their original orientation, releasing radio waves back to the machine. Different types of tissue release energy at different rates. The MRI uses these radio waves to construct a computer image of the tissue.

Figure 3.6 Magnetic resonance imaging is useful for examining the brain and spinal cord.

Microwaves

You may have heard the term ***radar*** before. The word is actually an acronym for **ra**dio **d**etection **a**nd **r**anging. Older radar devices used radio waves. Today, radar devices send out short bursts of microwaves in order to detect objects. Like visible light, microwaves obey the law of reflection, so some of the waves sent out by radar reflect off objects and return to the radar receiver. By knowing the speed of the microwaves and the time it took them to return, the receiver calculates how far away the object is. Radar is now an indispensable technology, allowing us to track ships, airplanes, and even weather systems.

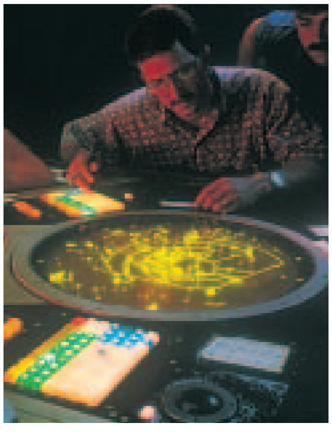


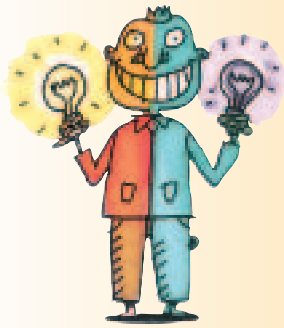
Figure 3.7 Air traffic controllers use radar to monitor planes landing and taking off at airports.

Give it a TRY ACTIVITY

GIVE IT A GLOW

Your teacher will provide you with a variety of materials and two light sources: a regular bulb and a black light bulb. The regular bulb emits infrared radiation (heat) as well as light. The black light bulb emits mostly ultraviolet light. Darken the room as much as possible and turn on the regular light bulb. One by one, hold the materials up to the light and note the appearance of each. Record your observations. Repeat the process using the black light.

- Which substances appear different under the regular light?
- Which substances appear different under black light?
- Why do you think that certain substances glow in the presence of ultraviolet radiation and not in the presence of infrared radiation? Discuss possible explanations with your classmates.



Ultraviolet Rays

Ultraviolet (UV) light is also a form of electromagnetic radiation. UV light has a higher frequency than visible light, so it carries more energy. Because the energy of UV rays is great enough to kill living cells, UV light can cause skin damage that can lead to cancer. This high energy level is useful to hospitals and food processing plants, which use ultraviolet lamps to kill micro-organisms on equipment.

Small doses of ultraviolet light can be beneficial to humans. Skin cells produce vitamin D, which keeps teeth and bones healthy. In order to create the vitamin, the cells need small amounts of UV light. Some babies are born with jaundice, a liver condition that causes yellowing of the skin. To treat the condition, newborns are placed under ultraviolet lamps.

Figure 3.8 This baby is being treated for jaundice under an ultraviolet light. The baby's eyes are covered because too much ultraviolet light could damage them.

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What's Cooking?

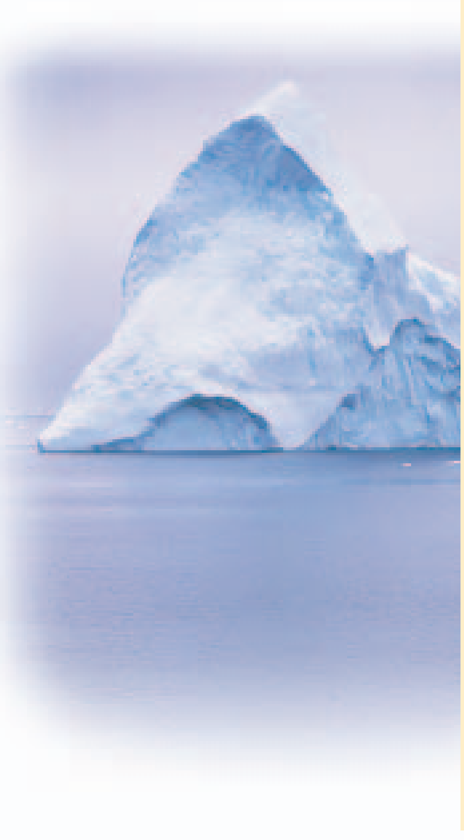
The microwave oven is an extremely useful application of microwave radiation. Did you know that the discovery that microwaves could cook food happened purely by accident? Use the Internet and other sources to find out more about the development of the microwave oven.

Gamma Rays

Gamma rays have the shortest wavelengths and highest frequency of the electromagnetic spectrum, and they contain the greatest amount of energy. Gamma rays can penetrate the body to a much greater extent than X-rays, and they can cause serious illness. But, like ultraviolet light, small amounts of gamma radiation can treat illnesses. Small doses of gamma rays are used in radiation therapy to kill cancer cells.

Figure 3.9 A person undergoing radiation therapy

Check and Reflect



1. Make a comparison chart of X-rays, radio waves, and visible light. How are they the same? How are they different?
2. Is the statement "the sun only gives off visible light" correct? Why or why not?
3. Why is it a good idea to wear a hat and sunblock creams when spending time in the sun?
4. Explain how radio waves can be used to determine the position of icebergs at sea.
5. Electromagnetic radiation can be used to treat cancer. What type of radiation would you use if you were the oncologist (cancer specialist)? Explain.
6. Many people operate their home electronics with remote controls. Using what you have learned about electromagnetic radiation, explain how a remote control might work.
7. When you go to the dentist, he or she sometimes takes X-rays of your teeth. Why does the technician put a lead apron over you, and why does he or she go behind a metal screen when taking the X-ray picture?

3.3 Producing Visible Light

Figure 3.10 Without sunlight, there would be no life on Earth.

Of the wide spectrum of electromagnetic radiation, visible light is probably the most important to us. Think about how often you are exposed to visible light. Where does most of it come from? How is it produced?

Look at the photos in Figure 3.11 and classify them as natural or artificial light sources. Artificial light sources are human made. Check how your classmates have classified the photos. Do you agree with them?

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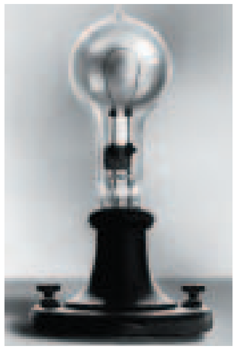
Bamboo Light



Thomas Edison was one of the first to design light bulbs in the late 1800s. His first bulbs didn't last that long, though. Edison used pieces of bamboo for the filament of the first light bulbs; these filaments would burn out after about 30 hours. Today, filaments are made of tungsten.

Figure 3.11 Natural and artificial light sources

Figure 3.12 Think how short winter days would be without any artificial light.

Artificial Sources of Light

Can you imagine how different your life would be without artificial sources of light? Think about how many times a day you flip on a switch and are greeted with light. Why is it now so easy to produce artificial light? What types of devices produce light?

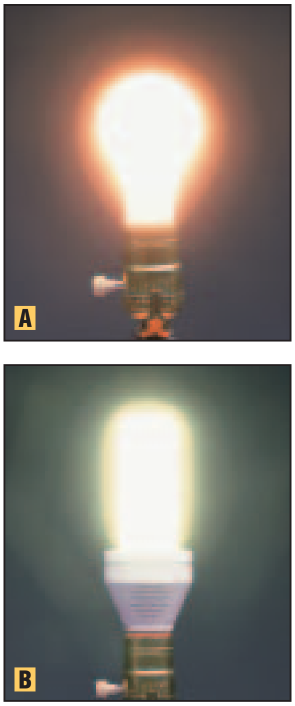


Figure 3.13 An incandescent bulb, A, and a fluorescent bulb, B

Incandescent Light

At the heart of an **incandescent** bulb, there is a filament (thin piece of wire). When you turn it on, electrical energy flows through the filament, heating it to extremely high temperatures. As electricity flows through the filament, it causes the wire to glow white-hot. The light you see from the bulb is the filament glowing.

Fluorescent Light

A **fluorescent** 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 **phosphor**. Electricity passes through a fluorescent bulb many times per second. Each time it passes through, it makes the gas in the bulb emit ultraviolet radiation. This ultraviolet radiation strikes the phosphor on the inside of the bulb, which then glows and emits visible white light. The emission of white light in this way is called fluorescing.

Phosphorescent Light

Phosphorescence is slightly different from fluorescence. In fluorescent lights, the phosphor emits light only while the ultraviolet light is hitting it. However, some substances have the ability to store energy from the radiation that hits them, and they can emit light for a long time after the source of radiation has stopped. This ability to emit light is known as **phosphorescence**. Phosphorescent materials are often used in novelty items because they will glow in the dark for some time after being energized by light. This also explains why glow-in-the-dark toys will eventually grow dim but can be re-energized simply by being held under a lamp for a few minutes.

Incandescent vs. Fluorescent Lights

Choosing an artificial light source depends on a number of things. Convenience, appearance, and durability all contribute to the choice of what light to use. The cost of operating the light is another factor. It may make sense to use a more expensive device if it costs less to run and lasts longer. These are some factors to consider when choosing between incandescent and fluorescent light bulbs.

Figure 3.14 Fluorescent lights are commonly used in offices and public buildings.

TRY This at Home — **ACTIVITY**

The Look of Light

Check out the lighting around your home. You probably have incandescent and perhaps some fluorescent or halogen lights as well. Compared with sunlight, how would you describe the light from each of these light sources? Warm? Cool? Does each one have a slightly different colour? Look at objects lit by these lights. Do their colours appear different? If so, how are they different? Record your observations. Do the same thing with lights in public places such as malls and parking lots.

Inquiry Activity

Comparing Different Types of Light Bulbs

The Question

Which type of light bulb gives off the most heat?

The Hypothesis

Form a hypothesis for this investigation.

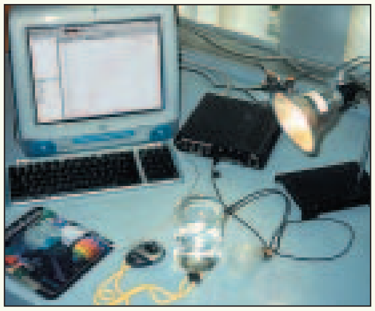


Figure 3.15 If available, consider using a computer interface.

Materials & Equipment

- light bulbs: 60-W incandescent, 60-W halogen, and 15-W fluorescent (or any other variety of light bulbs that give off similar amounts of light)
- gooseneck lamps
- thermometer
- beaker
- water at room temperature
- test tube
- felt marker
- timer

Caution!
After bulbs have been turned on, do not touch them even after they have been turned off! They can reach very high temperatures. If there are not enough lamps for each group, your teacher will change the bulbs for you.

Procedure

1. Screw each of the three bulbs into a gooseneck lamp. Your teacher may have done this for you already by setting up lamps in different parts of the room. Do not turn them on yet.
2. Make a table for recording temperature data for each bulb. You will be taking readings every 30 s for 5 min.
3. Use the felt marker to draw a line about halfway up the test tube. Fill the tube with water from the beaker up to the mark.
4. Put the thermometer into the test tube. With one hand, hold the test tube around its top rim. Use your other hand to support the thermometer.
5. Have your partner start the timer and turn on the lamp. Hold the water-filled part of the test tube about 2 cm in front of the bulb you are testing. **Make sure the lamp is facing forward, NOT upward (see Figure 3.15). Never hold water above a lamp or light socket**. Be careful not to bump the bulb with your test tube. Very gently move the thermometer up and down in the water during the trial, to ensure it heats evenly.

Collecting Data

6 Every 30 s, record in your table the temperature shown on the thermometer. Continue doing this for 5 min.

7 Repeat the procedure described in steps 4 and 5 for the other two light bulbs. Before doing so, replace the water in the test tube with water from the beaker and let the thermometer cool down. Record temperatures in your table.

Analyzing and Interpreting

8 Construct a graph, using time as your manipulated variable and temperature as the responding variable. Plot the data for each of the bulbs on your graph.

Forming Conclusions

9 Write a summary statement that answers the question “Which type of light bulb gives off the most heat?”

10 The bulbs you tested produce similar amounts of light, but different amounts of heat. Where does the energy for the production of the heat come from?

Applying and Connecting

What type of lighting would you recommend for your school? an office building?

Figure 3.16 What lighting will keep this chick warm?

Energy-Efficient Light Bulbs

Most light bulbs should really be called “heat bulbs” because they produce far more heat than light, or more infrared radiation than visible light energy. Incandescent bulbs produce about 95% heat and only 5% light. When you were a child, you may have used an incandescent bulb to bake cakes in a toy oven! Fluorescent bulbs are much more efficient than incandescent bulbs, but they still release up to 80% of their energy as heat.

Natural Sources of Light

The most important natural source of light on Earth is the sun. There are, however, other natural sources of visible light. If you've ever walked through a meadow on a warm summer evening, you may have seen points of light flickering on and off. This flickering light is produced by fireflies. When living organisms produce their own light, it's called **bioluminescence**.

The firefly has a light-producing organ, or **photophore**, on the underside of its abdomen. The light produced by the photophore is created by a chemical reaction. Unlike electric light, this chemical light is very efficient because it gives off no waste heat. Because of this, bioluminescent light is often called cool light.

Fish that live deep in the ocean have to create their own light because no sunlight can reach that far down. Some produce light in the same way as fireflies do, but other fish have bacteria in their photophores that do the light-producing chemical reaction for them. The black sea dragon and the angler fish have a special long spine with a bulb on the end of it, filled with light-producing bacteria. The spine acts as a fishing rod, and the bulb as a lure, attracting smaller fish into their waiting jaws. Flashlight fish use light from their photophores to keep their school together as they swim. They can quickly turn their photophores off if a predator approaches.

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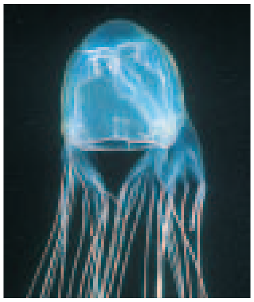
Glowing Organisms



Some algae, jellyfish, insects, crustaceans, fish, bacteria, and even earthworms produce light by bioluminescence. Find out more about species that produce light. Prepare a report on the organism and exactly how and why it produces light.

Figure 3.17 A flashlight fish

Check and Reflect

1. Explain how an incandescent light bulb works.
2. Your watch dial may have glow-in-the-dark numbers. Is this phosphorescence or fluorescence? Explain your answer.
3. Why would a business choose fluorescent instead of incandescent lights?
4. What is bioluminescence?