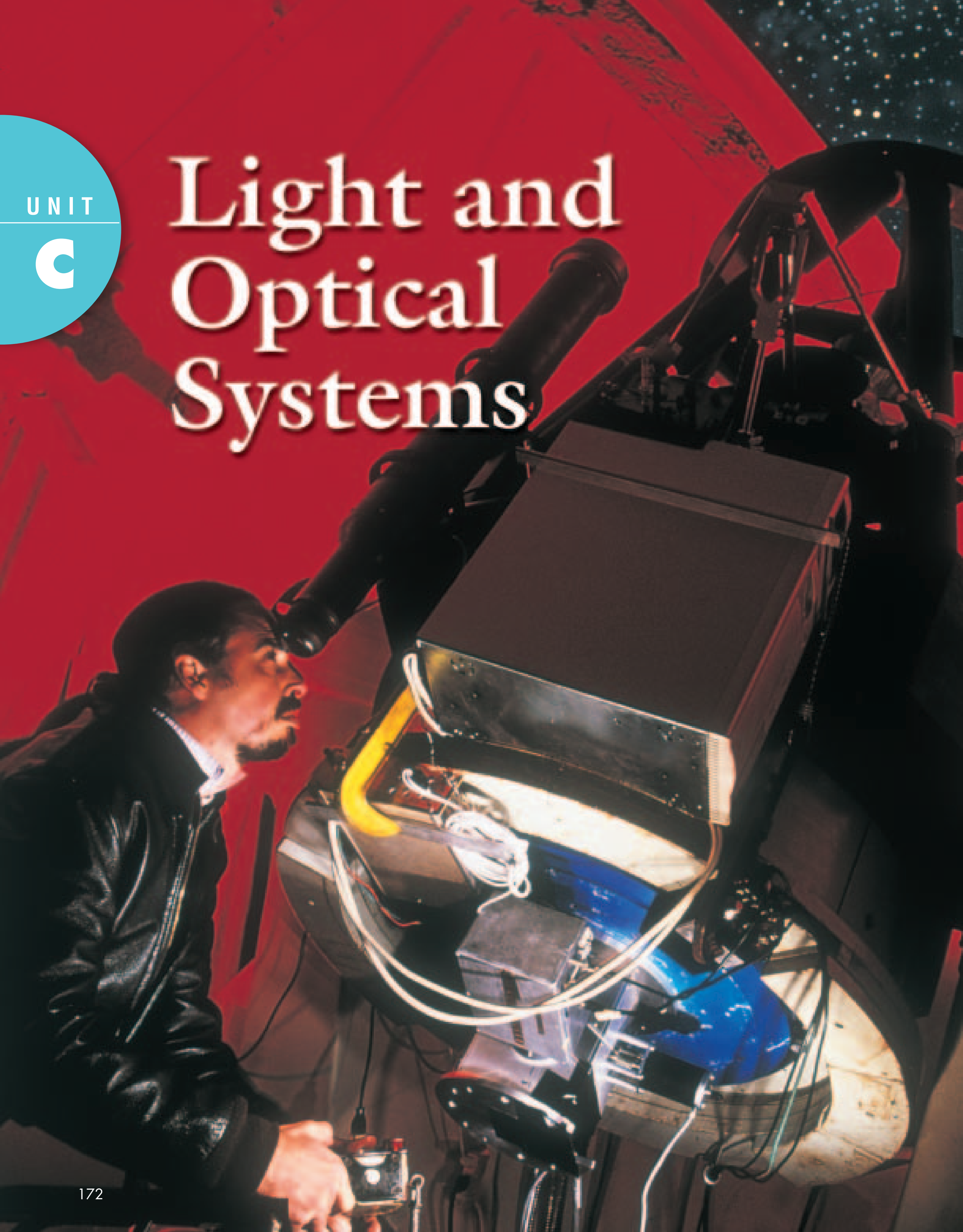
UNIT C

Light and Optical Systems



In this unit, you will cover the following sections:

1.0

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

1.1 The Challenge of Light

1.2 Optical Devices

2.0

Light behaves in predictable ways.

2.1 Light Travels in Rays and Interacts with Materials

2.2 The Law of Reflection

2.3 Reflecting Light with Curved Mirrors

2.4 Transparent Substances Refract Light

2.5 Lenses Refract and Focus Light

3.0

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

3.1 The Wave Model of Light

3.2 The Electromagnetic Spectrum

3.3 Producing Visible Light

3.4 The Colours of Light

4.0

Eyes and cameras capture images using the properties of light.

4.1 Image Formation in Eyes and Cameras

4.2 Other Eyes in the Animal Kingdom

4.3 Image Storage and Transmission

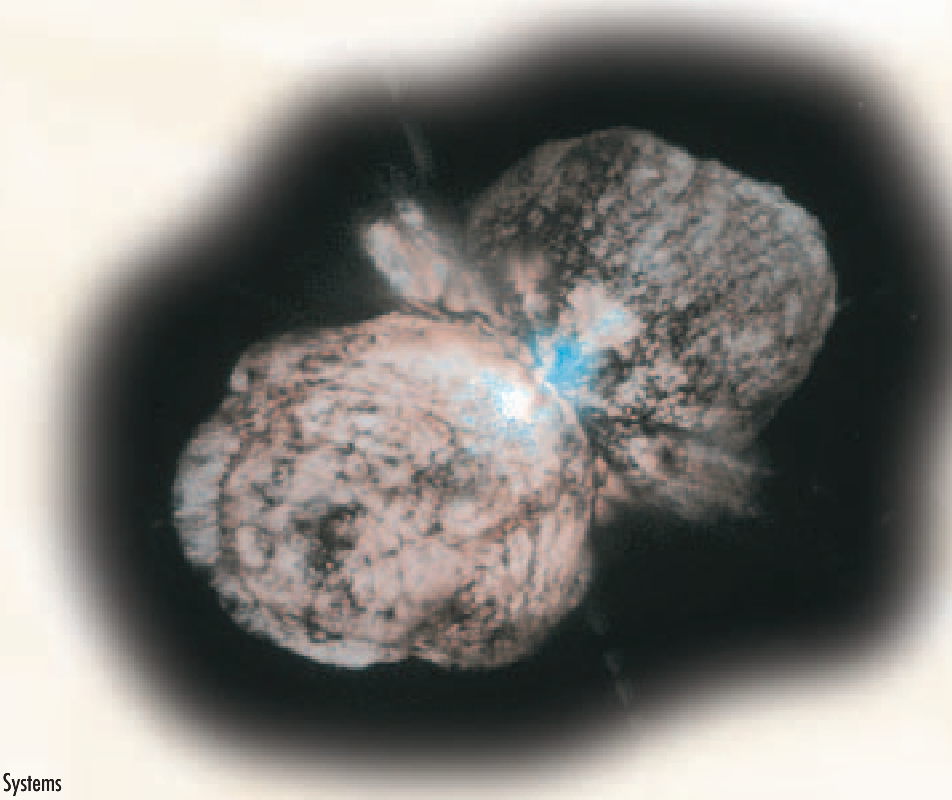
** Extension material*

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

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.

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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!

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.

Figure 1.2 How Pythagoras viewed vision

Continued on page 180 →

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.

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?

Figure 1.3 Station A

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.

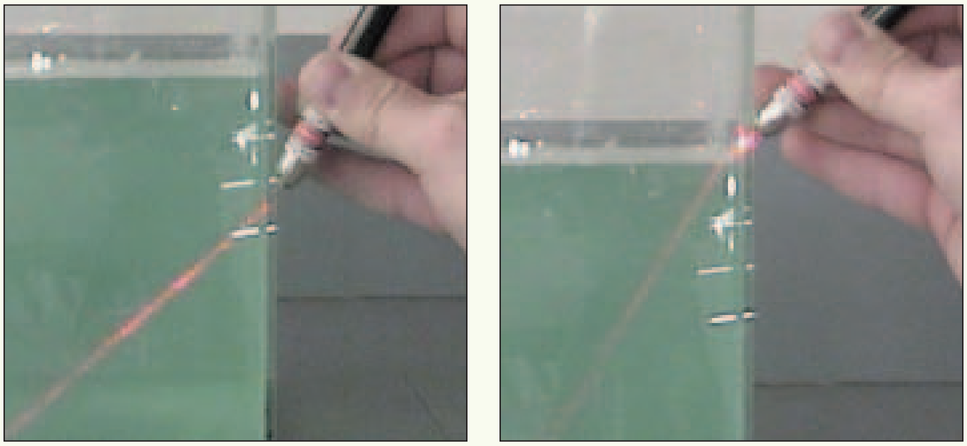

Figure 1.5 Station D

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.

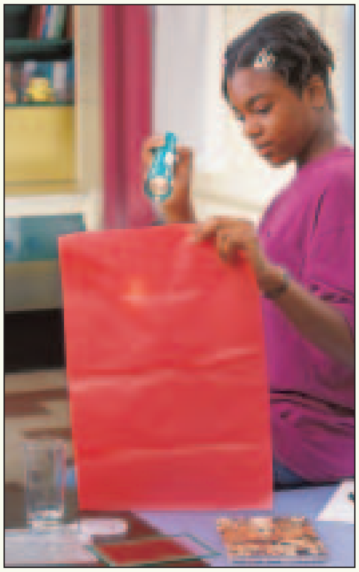

Figure 1.6 Station E

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.

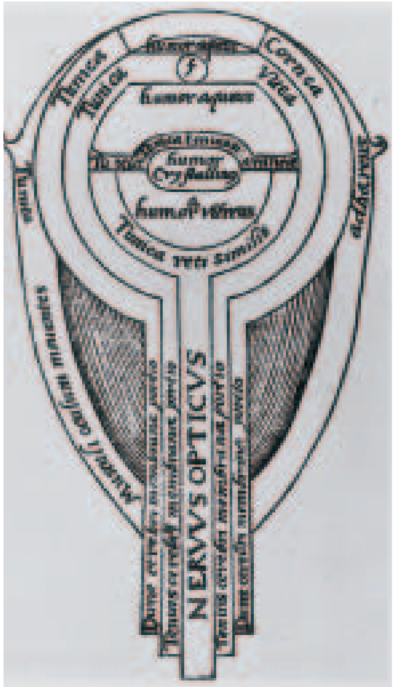

Figure 1.8 al-Haytham's diagram of the eye

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

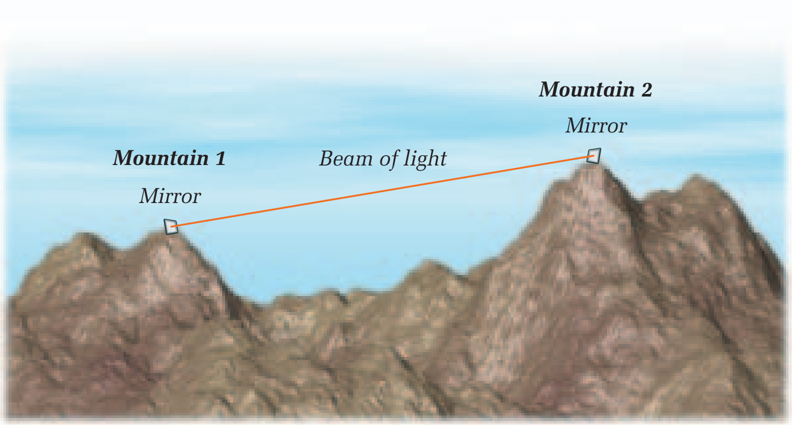

Figure 1.9 Timing a beam of light as it travelled from one mountain to another was the first accurate measurement of the speed of light.

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.

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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.

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.

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.

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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.

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.

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.

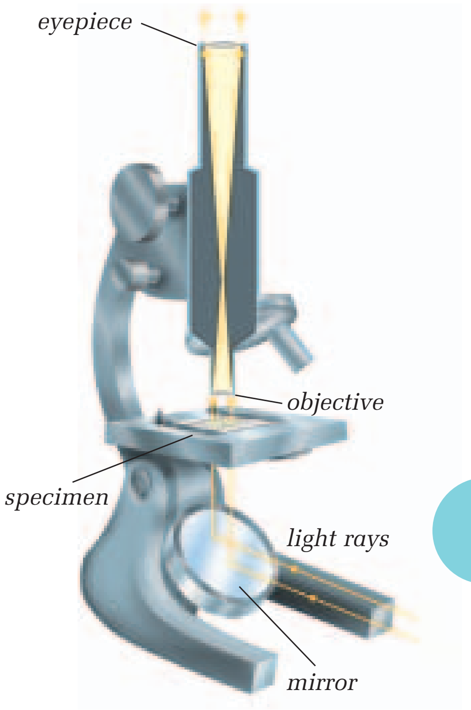

Figure 1.11 A microscope uses lenses to create an enlarged image of a tiny object.

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.

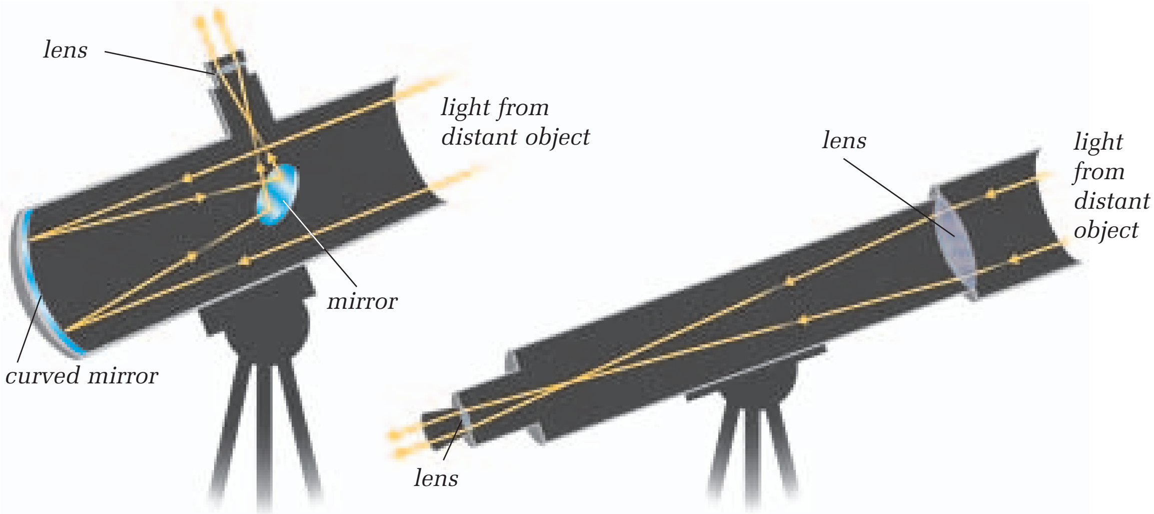

Figure 1.13 Refracting telescopes (right) use a combination of lenses; reflecting telescopes (left) use lenses and mirrors to form an image.

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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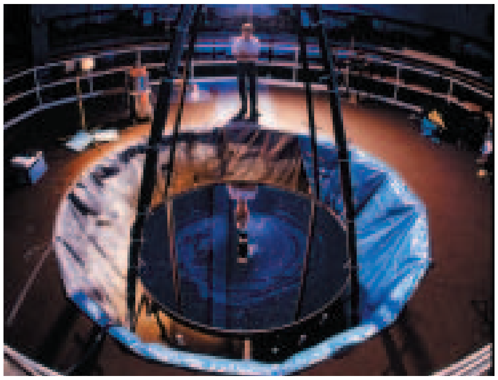
Liquid Mirrors

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.

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.

Materials & Equipment

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

Figure 1.14 Step 2

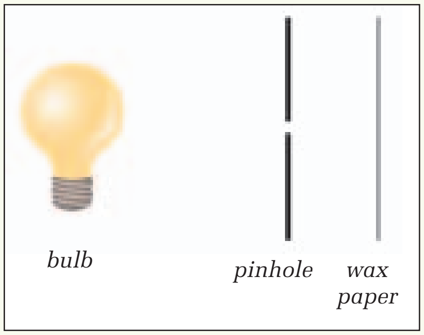


Figure 1.15 Copy this diagram into your notebook.

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!

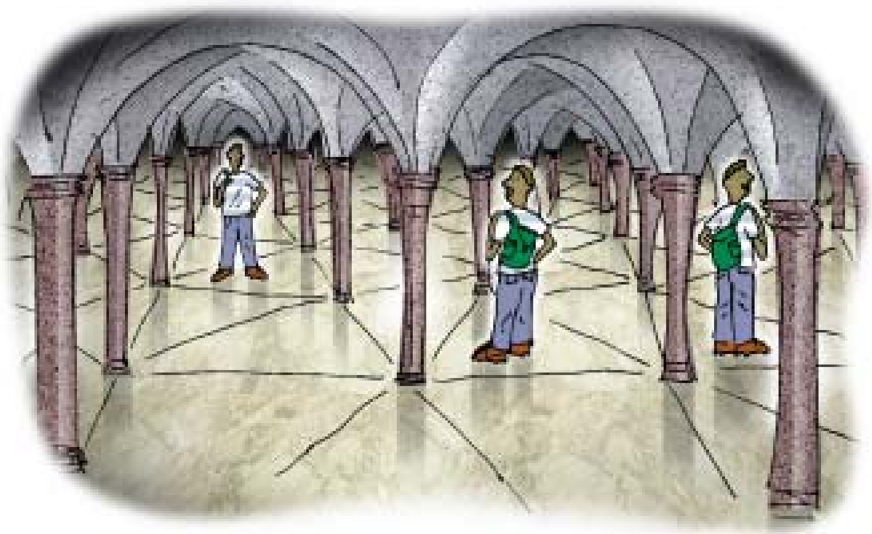

Figure 2.1 A mirror maze is fun because it's confusing.

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?

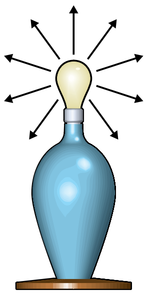

Figure 2.2 A simple ray diagram

Ray Diagrams

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.

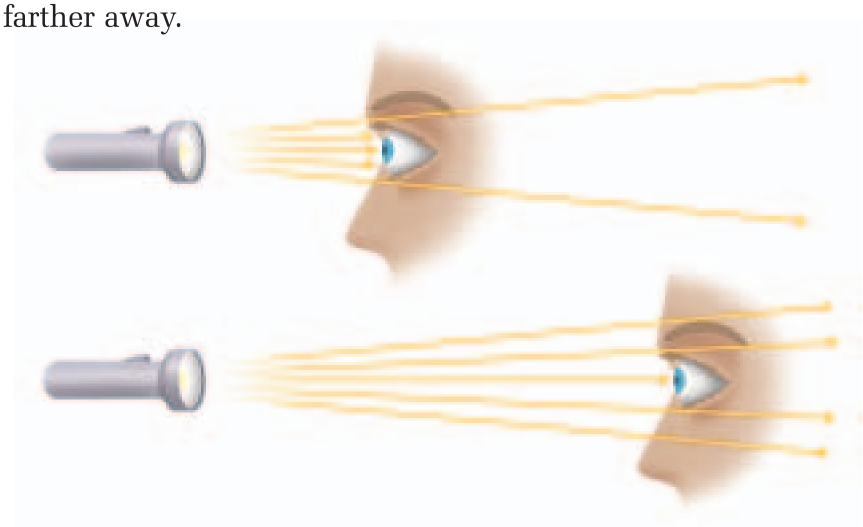

Figure 2.3 Fewer light rays reach your eyes the farther you are from a light source.

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.

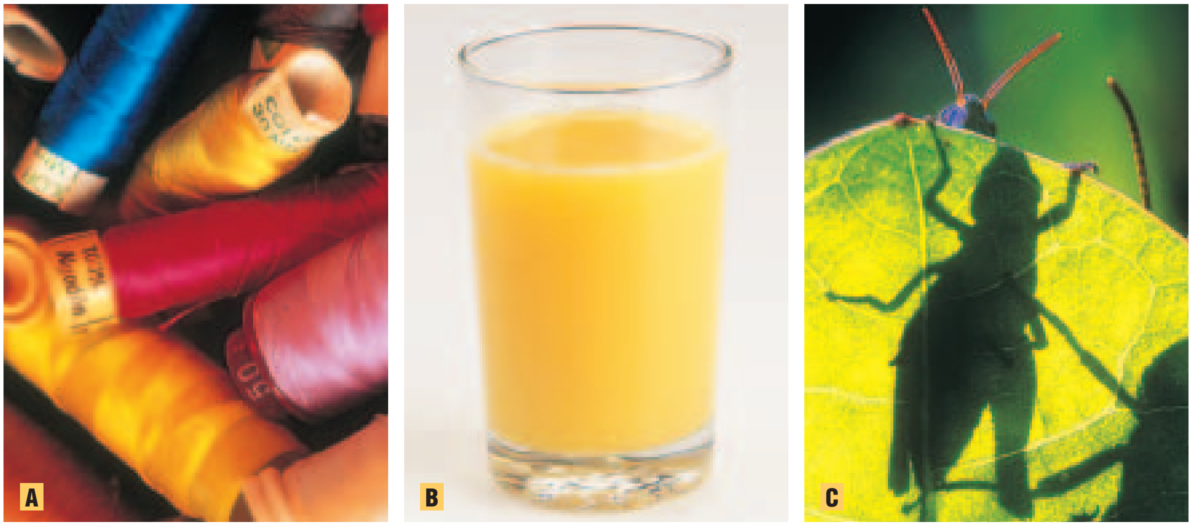

Figure 2.5 Light of various colours reflects off the spools of thread, A, and does not pass through; the spools are opaque. The glass is transparent, B, allowing you to see the juice inside. The leaf is translucent, C; some light from behind the insect passes through the leaf, but you can't see the insect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

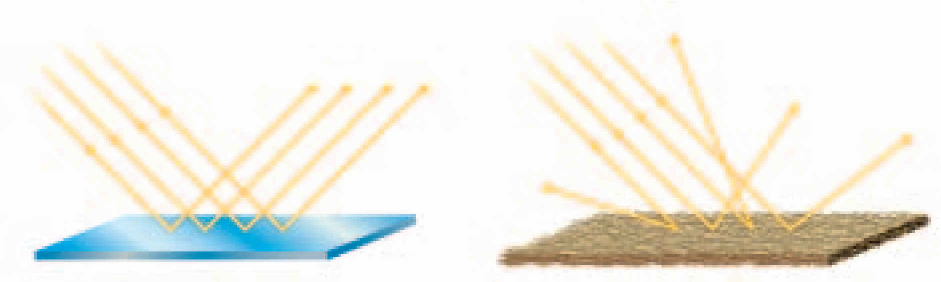

Figure 2.8 Regular reflection (left) and diffuse reflection (right)

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.

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.

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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.

2.2 The Law of Reflection

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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.

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

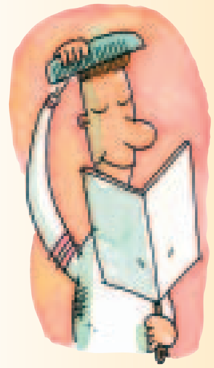
As you have just learned, a smooth surface allows all of the **incident** (incoming) **rays** to bounce off as a parallel beam, giving a regular reflection. The shinier and smoother the surface, the better the reflection. Still water, mirrors, glass, or even polished metal will allow you to see your 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

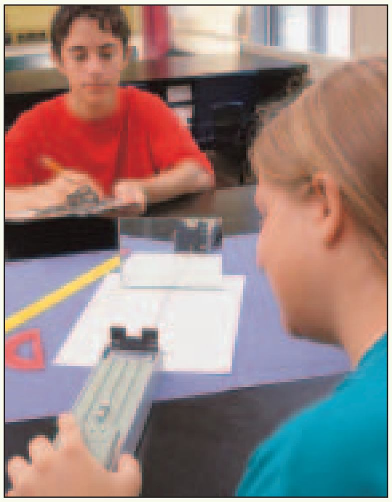


Figure 2.10 Step 3

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.

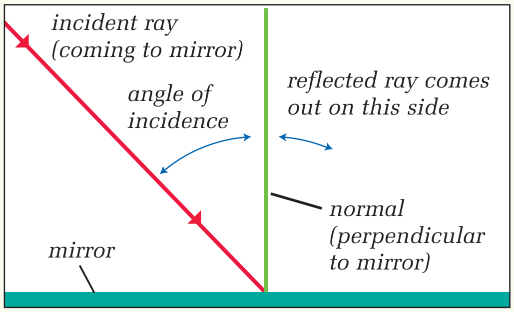


Figure 2.11 The angle of incidence is measured from the normal.

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

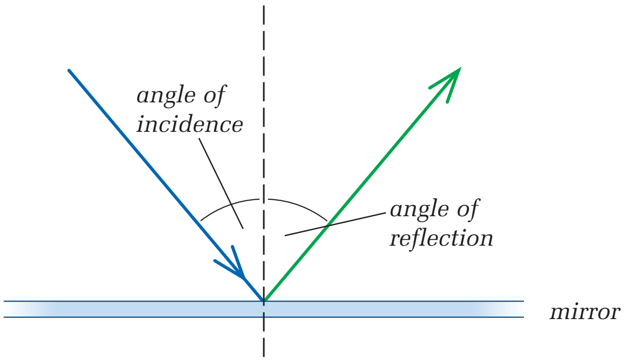
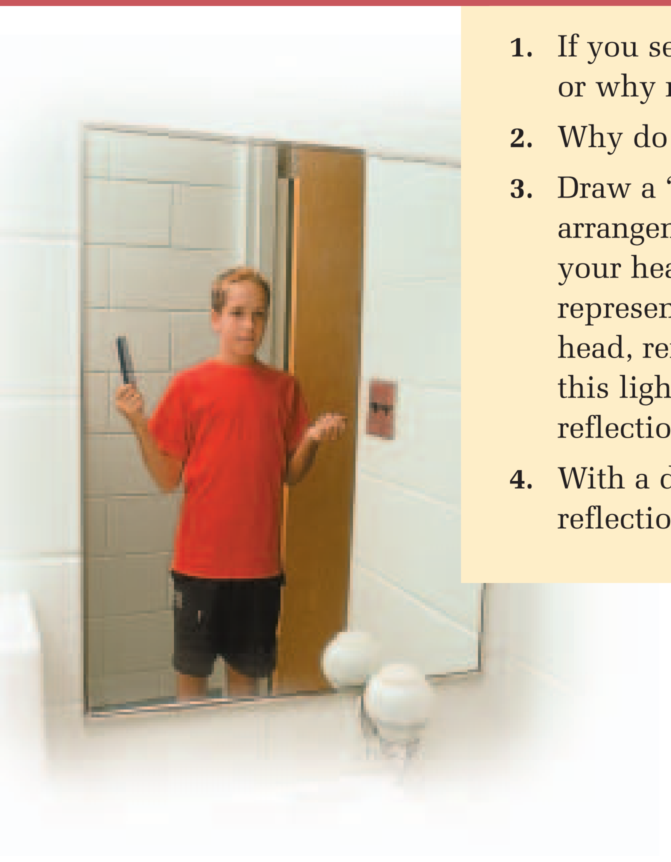


Figure 2.12 The law of reflection

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

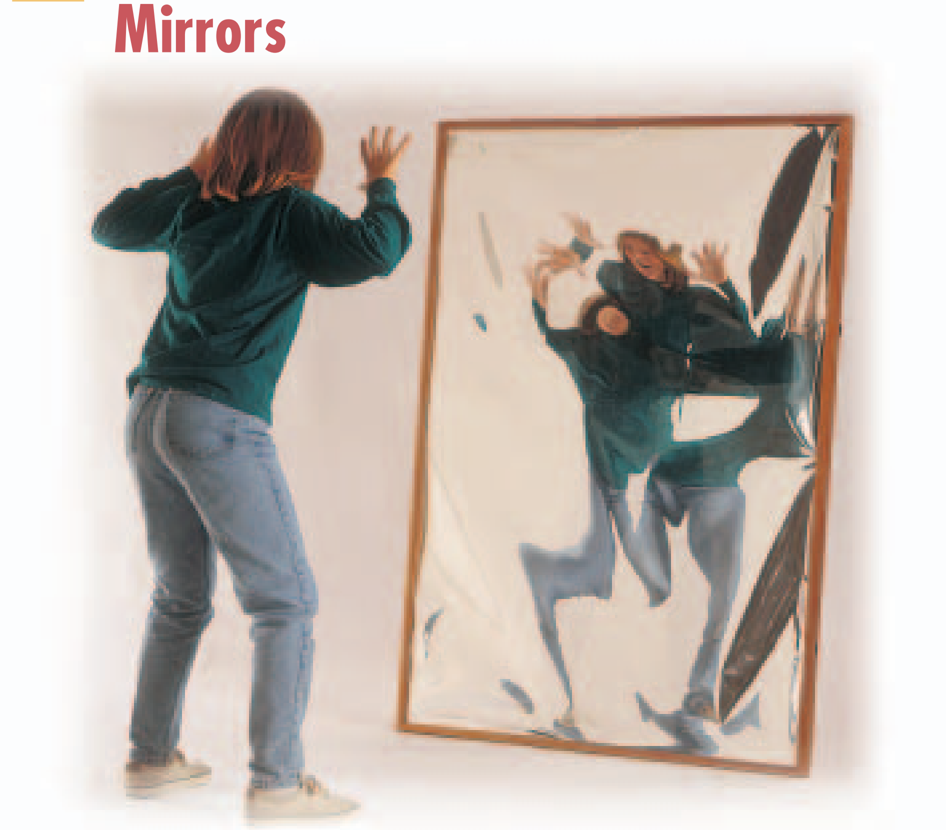


Figure 2.13 Fun-house mirrors distort your reflection.

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.

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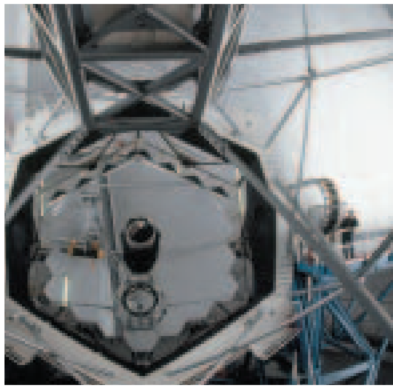
That's a Big Mirror!
The largest telescope mirror is located in the Keck Observatory in Hawaii. The concave mirror is 10 m wide! Astronomers are planning to build bigger mirrors up to 100 m wide.



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.

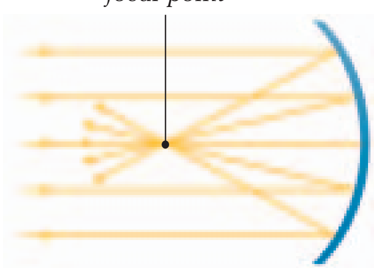


Figure 2.14 Concave mirrors reflect parallel rays of light back through the focal point.

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.

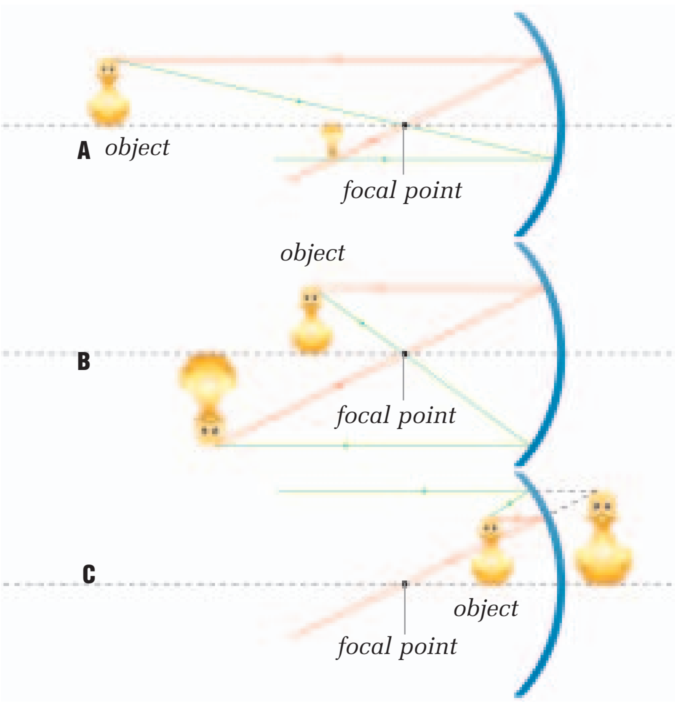
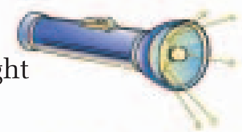
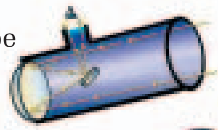


Figure 2.15 If an object is farther from the focal point, the image is upside down, as in A and B. If the object is between the focal point and the mirror, the image appears upright and enlarged, as in C.

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.

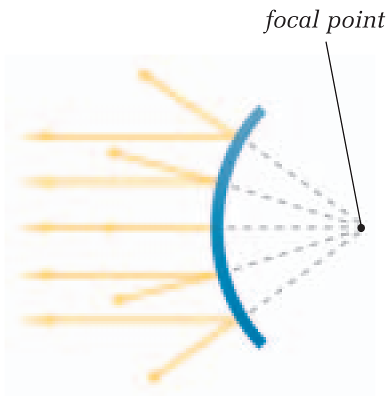

Figure 2.16 A convex mirror reflects parallel rays of light as if they came from a focal point behind the mirror.

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

*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.

Figure 2.17 Catching salmon in water is challenging.

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.

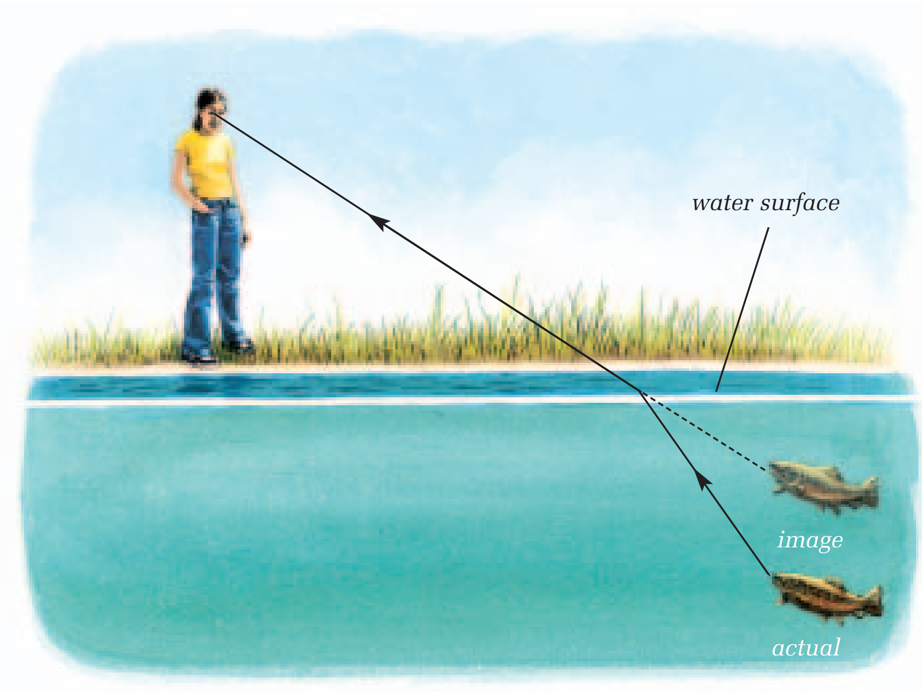

Figure 2.18 The fish is not where it appears to be.