TOPIC 3.5

How does light behave when it moves from one medium to another?

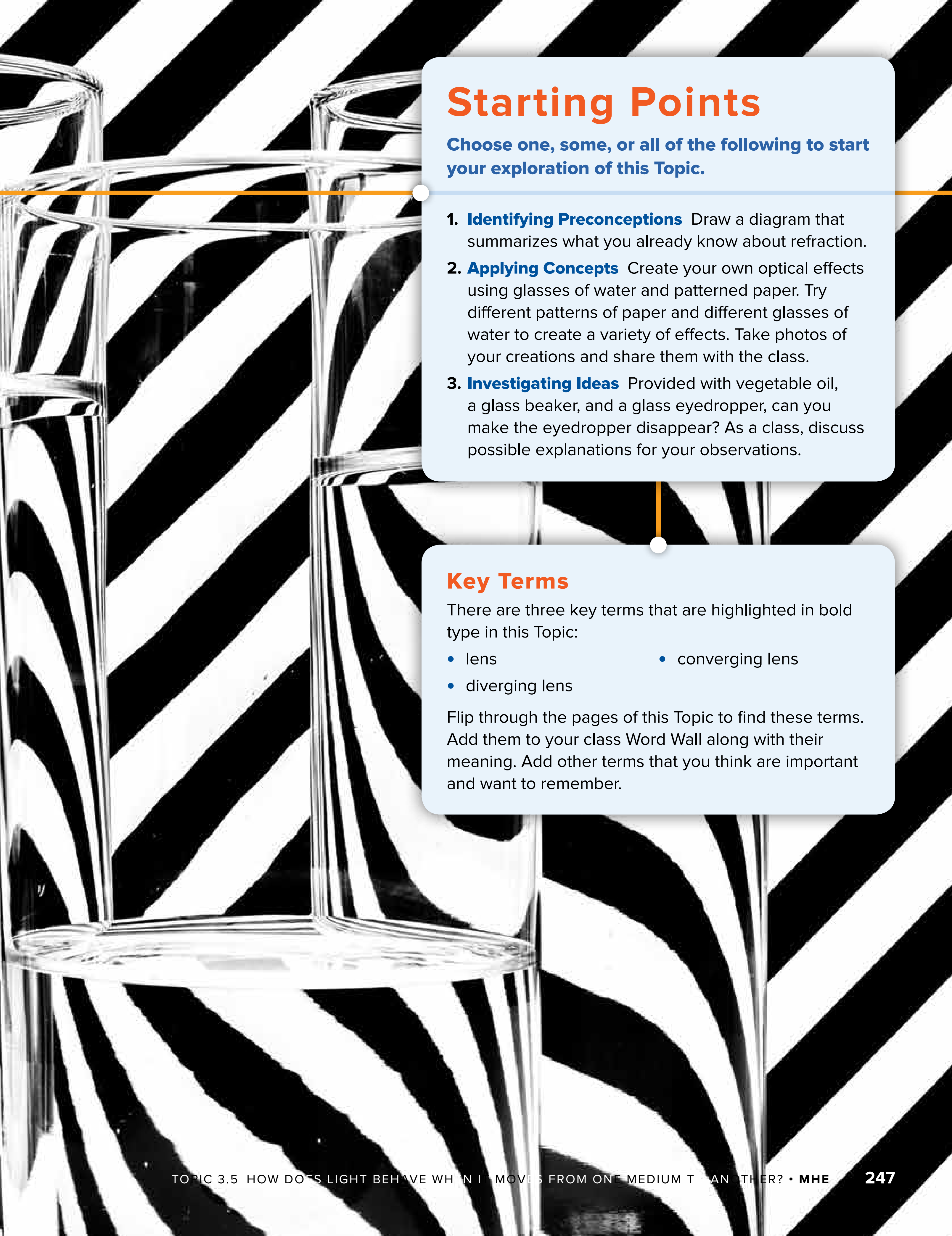
Key Concepts

- Light changes direction and speed when it moves from one medium to another.
- Light refracts as it passes through lenses.
- Refraction plays a role in human vision.
- Many technologies take advantage of light's behaviour when it moves from one medium to another.

Curricular Competencies

- Contribute to care for self, others, community, and the world
- Observe, measure, and record data using equipment
- Communicate ideas, findings, and solutions to problems
- Transfer and apply learning to new situations

The photo on these two pages shows several glasses of water placed in front of diagonally striped paper. It was taken with a normal camera lens. What do you think is responsible for the effect you see? The answer lies in how light behaves when it travels from one medium to another. You already know that refraction causes the path of light to bend when it travels from one medium to another. Refraction can trick your brain. Think back to the pencil placed in half a glass of water. It appeared broken due to refraction. In this photo, refraction is creating the same effect. It is causing the brain to "see" some of the diagonal lines where they are not.



Starting Points

Choose one, some, or all of the following to start your exploration of this Topic.

1. **Identifying Preconceptions** Draw a diagram that summarizes what you already know about refraction.
2. **Applying Concepts** Create your own optical effects using glasses of water and patterned paper. Try different patterns of paper and different glasses of water to create a variety of effects. Take photos of your creations and share them with the class.
3. **Investigating Ideas** Provided with vegetable oil, a glass beaker, and a glass eyedropper, can you make the eyedropper disappear? As a class, discuss possible explanations for your observations.

Key Terms

There are three key terms that are highlighted in bold type in this Topic:

- lens
- converging lens
- diverging lens

Flip through the pages of this Topic to find these terms. Add them to your class Word Wall along with their meaning. Add other terms that you think are important and want to remember.

CONCEPT 1

Light changes direction and speed when it moves from one medium to another.

Activity

Visualizing Refraction

When light travels from one medium to another, both its speed and direction may change. To visualize this, consider this analogy. What happens if you are riding a bicycle and hit some soft mud? Fill in the blanks below to explain what happens. Compare your answers with others in the class.

The front wheels suddenly ____________, but the back wheels keep travelling at the same ____________. As a result, the bicycle ____________.

You have already learned that light travels in a straight line through the same medium. You also know that when light travels from one medium to another, for example, from air to water, its path refracts (bends). What causes this refraction?

Refraction: Light Travels at Different Speeds and Changes Direction

Refraction occurs because light travels at different speeds in different media. For example, light travels at a different speed through air than it does through water. (Light, and all other types of electromagnetic radiation, only travel at the same speed—3.00×10^8 m/s—in a vacuum.) When light changes speed as it moves from one medium to another, the direction in which it travels also changes.

Describing Refraction Using the Wave Model and Ray Model of Light

It is helpful to use the wave model and ray model of light to visualize why the path of light changes direction when light changes speed. To see how these models fit together, look at **Figure 3.36**. Scientists often choose a specific part of a wave to follow and call it a *wave front*. As you can see in **Figure 3.36**, the crests of the waves are wave fronts. The ray (red arrow) shows the direction in which the waves are travelling. It is perpendicular to the wave fronts.

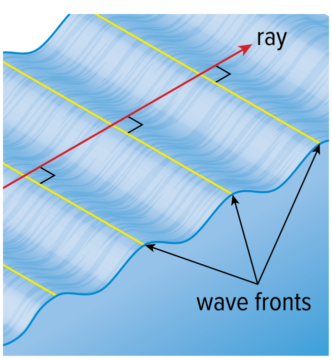
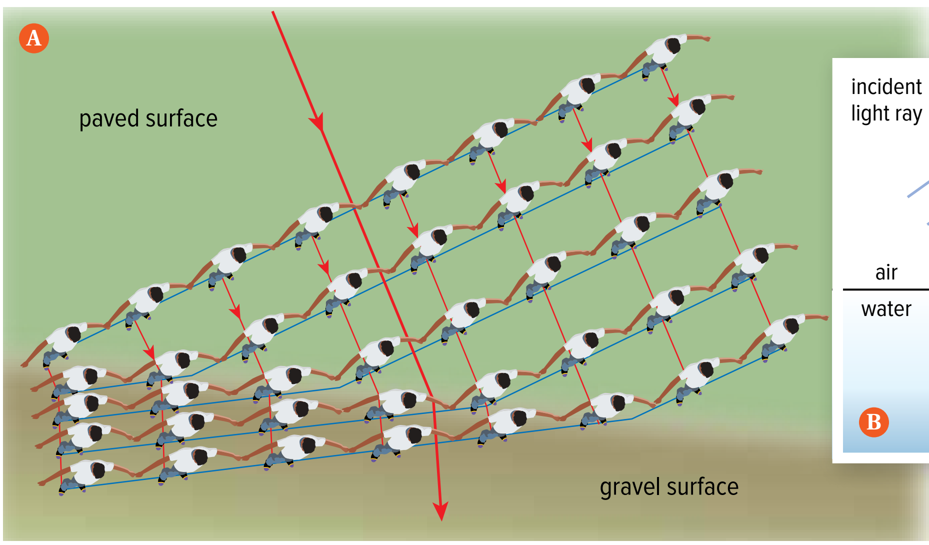
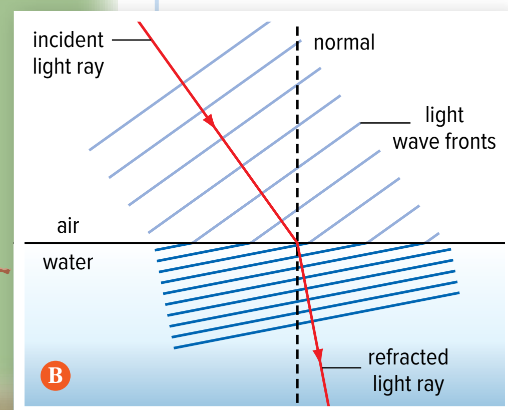


Figure 3.36 All the points on a wave front move together in the direction in which the wave itself is moving.

Try to visualize what happens when a wave front of light reaches the surface between two media. Imagine each wave front as a line of roller skaters holding hands. **Figure 3.37A** shows the movement of the skaters as they go from a paved surface to a gravel surface. As each skater reaches the gravel, he or she slows down. The slower skaters "pull" the line back and cause a bend in the line, representing the wave front. As a result, the direction in which the skaters move changes. This is what happens when a light wave moves from one medium to another: its speed and direction change (**Figure 3.37B**).

Figure 3.37 A When some of the skaters slow down, the direction of the line changes. The larger red arrow shows the direction in which the skaters are moving. B This visual shows how light waves behave in a similar way when they pass from one medium to another.





Did you notice that when the skaters and light waves slowed down, their direction turned toward the normal? When the speed of a wave slows down in the second medium, the direction of the wave is bent toward the normal. To predict if a wave will slow down or speed up when going from the first to the second medium, you need to know the density of the two media.

Light travels more slowly in a more dense medium than in a less dense medium. Therefore, the following statements are true.

- When light travels from a less dense to a more dense medium, the ray bends toward the normal.
- When light travels from a more dense medium to a less dense medium, the ray bends away from the normal.

Connect to Topic 2.2 on pages 114–115

Before you leave this page . . .

1. Come up with another analogy that you could use to visualize how refraction occurs.

CONCEPT 2

Light refracts as it passes through lenses.

Activity

Make a Simple Lens

1. Obtain a 10 cm by 10 cm piece of transparent material, a sheet of newspaper, a medicine dropper, and some water. Lay the transparent material on the newspaper. Place one drop of water on the transparent material. Observe the shape of the water drop.
2. Choose a word on the newspaper. Place the drop of water over it. Compare how the word looks through the drop and without it.
3. Add three more drops to the first drop of water. Observe the shape of the water drop. Then observe the word through the larger amount of water.
4. When you are finished, answer the questions below.
   a) How did the single drop of water affect the appearance of the word?
   b) How did the effect in step 2 compare with the one in step 3?
   c) How do you think the shape of the water drop affected the word's appearance?

A **lens** is a transparent object that causes light to refract and has at least one curved side. Lenses come in a wide variety of sizes and shapes and are made of different types of materials (**Figure 3.38**).

lens a transparent object that causes light to refract and has at least one curved side

Two Types of Lenses: Converging and Diverging

The terms plane, concave, and convex are used to describe lenses as well as mirrors, but lenses have two sides. Either side can be plane, concave, or convex, but at least one side must be curved. All lenses fit into one of two categories. They are either converging lenses or diverging lenses.

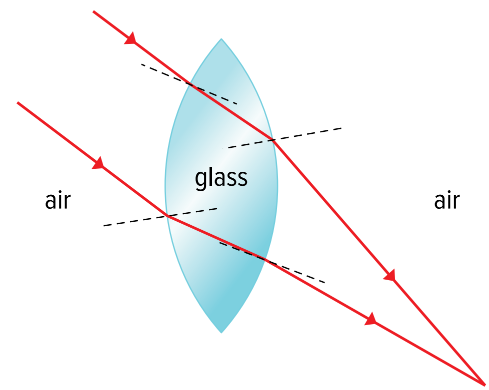
Figure 3.38 These lenses are made of glass, plastic, and even liquid.

Converging Lenses

Converging lenses bring parallel light rays toward a common point. Converging lenses have one or two convex surfaces. They are thicker in the centre. Figure 3.39 shows how parallel rays are brought together by a lens that is convex on both sides.

converging lens a lens that brings parallel light rays toward a common point

When rays strike the left side of the lens, they move from a less dense medium (air) to a more dense medium (the material that forms the lens). The rays refract toward the normals. This causes them to converge slightly.



When the light rays leave the lens, they move from a more dense medium to a less dense medium. When they do this, they refract away from the normals. At first, it might seem that this would cause the rays to separate. However, because of the overall shape of the lens, the final result is that the rays converge after passing through the lens.

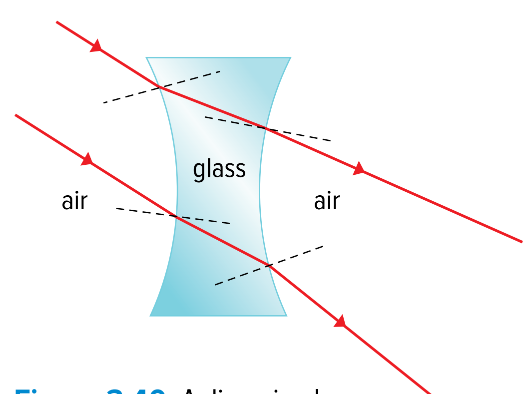
Figure 3.39 A converging lens

Diverging Lenses

Diverging lenses cause parallel rays to spread away from a common point. Diverging lenses have one or two concave surfaces. They are thinner in the centre than on the edges. Figure 3.40 shows how parallel light rays refract when they enter and leave a lens that is concave on both sides.

diverging lens a lens that spreads parallel light rays away from a common point

When rays strike the left side of the lens, they move from a less dense medium (air) to a more dense medium (the material that forms the lens). This means that the rays refract toward the normals. Due to the curvature of the surface, the rays diverge slightly.



When the light rays leave the lens, they move from a more dense medium to a less dense medium. When they do this, they refract away from the normals. Because of the overall shape of the lens, the final result is that the rays diverge.

Figure 3.40 A diverging lens

Before you leave this page . . .

1. What characteristic makes one lens converging and another diverging?

CONCEPT 3

Refraction plays a role in human vision.

The human eye can focus on objects at different distances and form images more accurately than a camera. However, none of this would occur without refraction. It is refraction that makes image formation in the eye possible.

The Front of the Eye Refracts Light

Refraction and focusing take place at the front of the eye. The refracted light forms an image at the back of the eye. The brain interprets the image. Follow the yellow rays in **Figure 3.41** to see what happens as light travels from an object or light source through the eye. Notice how light is refracted more than once before it strikes the back of the eye.

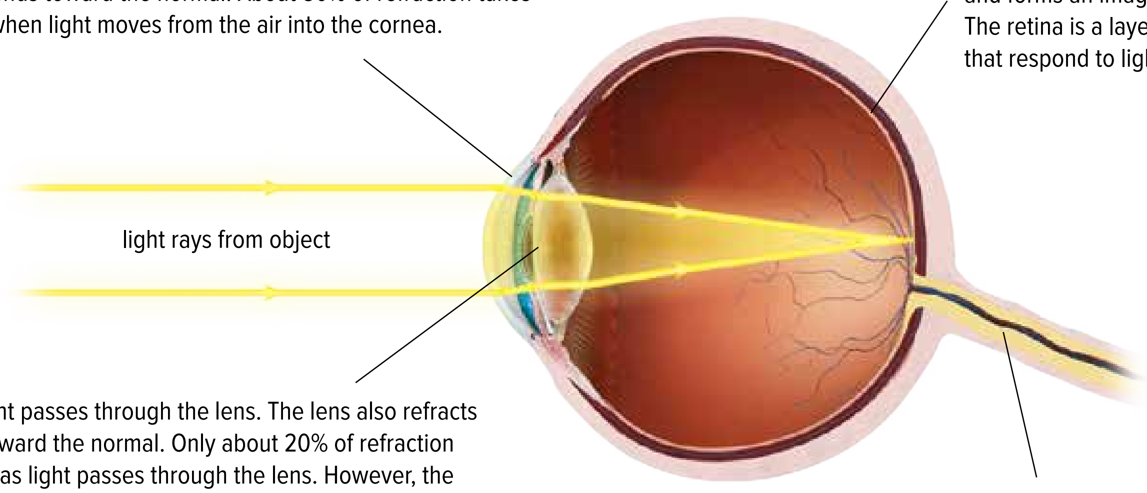


Figure 3.41 This diagram shows the path of light from a source or object through the human eye.

Figure 3.42 shows how the lens in the eye focuses on near and distant objects. A circular muscle that goes around the lens contracts and relaxes to change the shape of the lens. This lets the lens refract light to a different extent and focus light from both near and distant objects on the retina.

Connect to Investigation 3-I on page 258

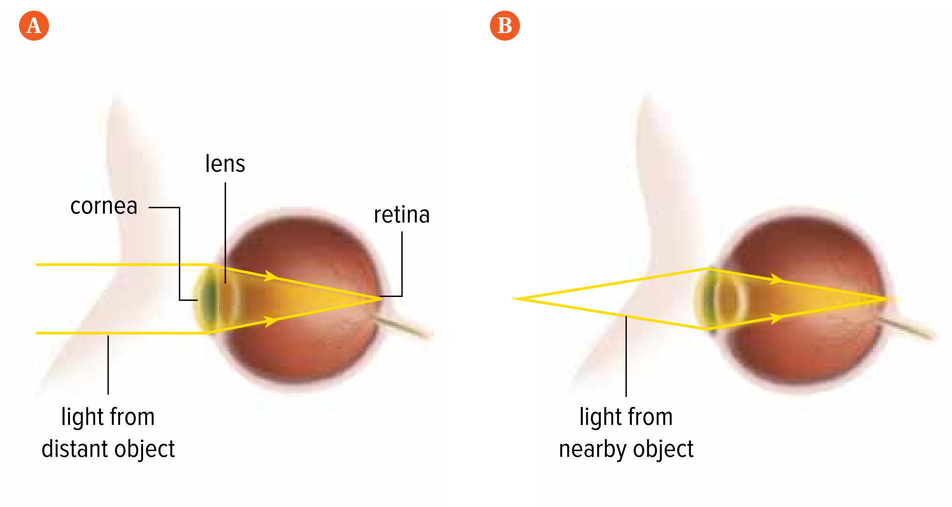


Figure 3.42 In A, the muscle that goes around the lens is relaxed. The lens retains its normal shape. It focuses a distant object correctly on the retina. In B, the muscle is contracted. This make the lens shorter and thicker. It becomes more curved to focus nearby objects.

Extending the Connections

The Back of the Eye Absorbs Light

The retina is a layer of cells that respond to light. It contains two types of cells that absorb incoming light. How are these cells involved in human vision? What roles do they play in vision problems such as red-green colour-blindness?

Before you leave this page . . .

1. Explain how the lens can focus images of both distant objects and nearby objects on the retina.
2. As a person ages, the lenses of the eyes become stiff. The muscles around the lenses can no longer make them change shape. How might this affect a person's vision?

CONCEPT 4

Many technologies take advantage of light's behaviour when it moves from one medium to another.

Activity

Modelling Cataracts

1. Your teacher will provide you with a pair of safety glasses and Parafilm tape. Cover the glasses with the Parafilm tape and put them on. How do the glasses affect your vision?
2. Your teacher will assign you a series of tasks to complete while wearing the glasses. How do the glasses affect your ability to complete the tasks?
3. Find out more about the risks and benefits of cataract surgery. Based on your experience in this activity, would you choose to have the surgery? Why or why not?

Technology has taken advantage of the refraction of light since the first lenses were constructed over a thousand years ago. A few modern technologies in which refraction plays an important role are described here.

Artificial Lenses

A cataract is the clouding of the lens of the eye. Cataracts usually occur after age 40. However, they can occur at a much younger age, and even in infants and children. When cataracts affect a person's vision, a surgeon can remove the cloudy lenses and insert artificial ones. Artificial lenses cannot change shape like natural lenses. This means the eye can only focus on distant objects. However, new artificial lenses are being developed. One is shown on the left. When the circular muscle around the lens relaxes (A), the eye focuses on distant objects. When the muscle contracts, it presses on the lens. Hinges in the lens bend (B), moving the lens back slightly. The eye focuses on objects at arm's length. The person will probably still need glasses to focus on close objects.

Heads-Up Display

A heads-up display or HUD refracts light from a projector through a prism. This makes an image (a computer display) appear in front of the user's eyes. The image appears as an overlay that hovers over the user's view of the real world. One application of a HUD is wearable head gear. This tool is used by pilots, scuba divers, alpine skiers, and others who benefit from its visual display. Users can check important information like speed, distance, depth, and altitude without taking their eyes from the view in front of them. Imagine snowboarding down a slope at Whistler and knowing your speed, altitude, and even direction—all without taking your eyes off the run!

Wavefront Technology

Wavefront technology was first developed to find irregularities in mirrors and lenses in telescopes. Today, eye doctors use it to map irregularities in the cornea and lens. Wavefront technology tracks how a wave front of visible light refracts as it passes through the eye. A machine called a wavefront analyzer directs light waves into a patient's eyes. Then it measures how the waves travel back through the eye and out of the pupil after they bounce off the retina. Wavefront technology helps doctors perform laser eye surgery. It is also used to diagnose and measure vision problems. Wavefront technology may one day make eye chart tests a thing of the past.

Extending the Connections

Beyond Human Vision

Binoculars, microscopes, digital SLR cameras, and some telescopes—these are technologies that enhance human vision in some way. Did you know they all rely on refraction? Choose one of these devices and find out how.

Before you leave this page . . .

1. Describe how new artificial lenses may allow people to see better.
2. Why do you think wavefront technology is an improvement over eye tests that use traditional eye charts?
3. Suggest another use for a HUD.

TAKE Action

Make a Difference

How Can You Help Bring Better Vision to the World?

Giving a person sight is an incredible gift. It's even more incredible if the gift comes right to you in the form of the Flying Eye Hospital. Many people in developing nations have had their vision improved or restored in just this way. The Flying Eye Hospital looks like your average airplane, but it's actually home to a mobile eye hospital and teaching centre. The gift of sight isn't just given to each patient. Its effects also spill over into the patient's family and community to change many lives for the better.

Third World Eye Care Society Canada (TWECS) is another organization that is helping people see in developing nations. The B.C.-based group distributes old eyeglasses to people in countries where poverty or lack of eye care services results in great need. The group also runs eye care projects. Eye doctors, opticians, and other volunteers all play a role in restoring vision through this organization.

Evaluate and Communicate

1. You can help people with vision problems right here in B.C. For example, CNIB runs local volunteer programs. Find out how volunteers are making a difference for visually impaired people in B.C.
2. Some organizations have stories on their websites in which volunteers describe their experiences. Write your own volunteer story that describes how you have made or would like to make a difference in your community as a volunteer.

Apply and Innovate

3. Create a plan to collect old eyeglasses in your community and get them to people who need them. Write down any questions that develop as you create your plan, and try to answer them. Then share your plan with your class. If you like, carry out your plan.

Check Your Understanding of Topic 3.5

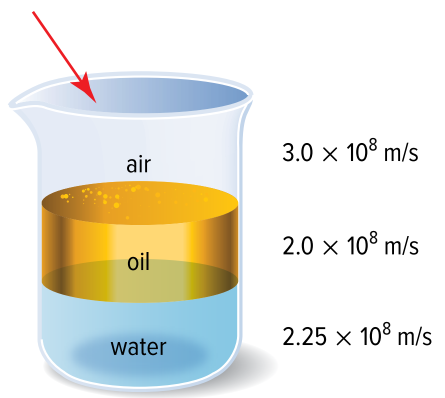
QP Questioning and Predicting PC Planning and Conducting PA Processing and Analyzing E Evaluating
AI Applying and Innovating C Communicating

Understanding Key Ideas

1. Draw a labelled diagram to show how the human eye senses light from a source. PA

2. Explain how vision depends on reflection, refraction, absorption, and transmission of light. PA AI

3. The diagram shows a beaker of cooking oil and water with a light ray about to enter the oil. The speed of light for the three media are shown beside the beaker. PC PA



   a) Use the information on the speed of light to rank the three media in terms of density. Explain why you ranked each medium as you did.
   b) Based on your answers to part a), explain how the path of light changes as it moves from one medium to the next.

4. Is the statement below true or false? Justify your response. PA E

   Light can travel across the boundary between two media without refracting if both media have the same density.

5. Society has benefited from the development of a range of vision-related devices and technologies. Describe two examples that take advantage of refraction. AI C

Connecting Ideas

6. Diverging lenses are needed to correct for nearsightedness, but the front of the eyeglasses is convex. How can a lens have one convex side but still be a diverging lens? Use a sketch to show your reasoning. (Hint: Reread the paragraph on diverging lenses.) E AI C

Making New Connections

7. Photovoltaic cells convert solar energy into electrical energy. How could the efficiency of photovoltaic cells be increased by using lenses? Use a diagram to support your answer. PA AI E C

8. HUDs can provide useful information in a very convenient way. QP PA AI E
   a) Describe how a HUD could help you carry out a task in your daily life.
   b) Predict a possible negative consequence associated with this technology.

9. Scientists believe that the eye of a living colossal squid is larger than a soccer ball. This makes the squid eye about 100 times larger than a human eye. The colossal squid lives near Antarctica, at a depth of at least 1000 m. Suggest how having such a large eye could help this giant thrive in the dark ocean depths. PA AI

INVESTIGATION

3-1

STRUCTURED INQUIRY AND GUIDED INQUIRY

Skills and Strategies

- Questioning and Predicting
- Planning and Conducting
- Processing and Analyzing
- Evaluating
- Applying and Innovating
- Communicating

Safety

- Be careful not to drop the lenses.
- Do not touch the light source. It may be hot.
- Do not shine light directly into anyone's eyes.

What You Need

- variety of lenses
- projector
- screen
- ruler or measuring tape

Exploring Vision Problems

Refraction plays a role in correcting vision problems.

Question

How can you correct vision problems?

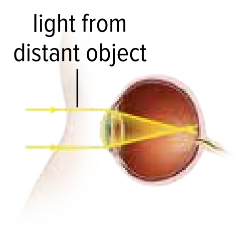
Procedure: Part A—Structured

1. Read the information about vision problems below.

Most people with poor vision have *refractive errors*. When light is refracted by the eye, it does not form a clear image on the retina. Two common refractive errors are myopia and hyperopia.

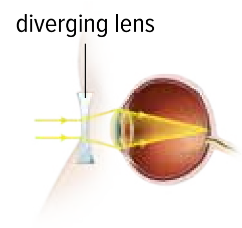
Myopia (nearsightedness): Inability to focus on distant objects.

A



Myopia: The cornea and lens refract light from a distant object. The rays converge to form an image, but the eyeball is too long and the image forms in front of the retina. The rays have spread out again when they reach the retina, so the image is blurry.

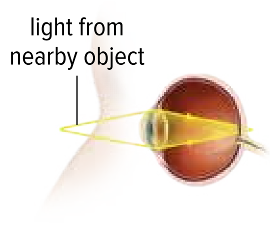
B



Myopia after corrective lenses: A diverging lens spreads out the rays before they reach the cornea. When the eye refracts the light, the image falls on the retina.

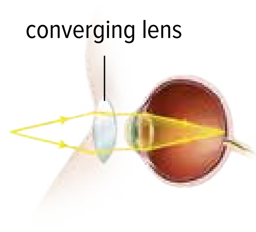
Hyperopia (farsightedness): Inability to focus on nearby objects.

A



Hyperopia: The cornea and eye lens refract light from a nearby object, but the eyeball is too short. The rays reach the retina before they meet, so the image is blurry.

B



Hyperopia after corrective lenses: A converging lens brings the rays closer together before they reach the cornea. When the eye refracts the light, the image falls on the retina.

2. Two patients are visiting an optometrist. (An optometrist is trained to diagnose and prescribe lenses for vision problems.) For each patient, use the information in step 1 to
   a) identify the vision problem
   b) explain the cause of the problem
   c) describe what the light rays are doing in the patient's eyes (assume each eye has the same problem)
   d) recommend the type of lens that would help correct the problem

   Patient 1: A 56-year-old female is having trouble reading books. She plays violin and has no problem reading the sheet music on her music stand.

   Patient 2: A 14-year-old male is having problems reading digital white boards at school. He also has trouble seeing the ball when playing lacrosse.

3. Laser surgery can change the curvature of the cornea to correct for refractive errors. Should the curvature of the cornea be increased or decreased for
   a) hyperopia? b) myopia?

   Explain your reasoning.

Procedure: Part B—Guided

4. You have access to several different lenses, a screen, and a projector. The projector will be out of focus, representing a refractive error.
   a) Draw a sketch of a cross-section of each lens that shows how light rays refract as they pass through the lens.
   b) Identify each lens as converging or diverging.
5. Use the lenses to form a clear image on the screen. You can adjust the distance between the lens and screen.
6. Draw a sketch of each image you produce under the sketch you made of that lens in step 4.
7. For each lens, measure and record the distance between the lens and the screen that produced the clearest image.

Process and Analyze

1. In Part A, what might be another explanation for the condition that Patient 1 is experiencing?
2. In Part B:
   a) Which type of lens produced clear images when the distance between the lens and the screen was the shortest? What type of refractive error could the lens correct?
   b) Which type of lens produced clear images when the distance between the lens and the screen was the longest? What type of refractive error could the lens correct?
   c) Use the term refraction to explain your observations.

Apply

3. When you focus a digital SLR camera, you change the distance between the lens and the charge-coupled device (CCD), the light-sensitive part of the camera. In the human eye, the distance between the lens and the retina is fixed. How do the muscles in your eye accomplish the same result that the camera does by moving the lens?