CHAPTER 11

Mirrors and Lenses

KEY IDEAS

- Light reflects off surfaces in a predictable way.
- Optical devices produce images that can have different characteristics.
- Mirrors produce images by reflecting light.
- When light passes through a transparent material, it may change direction.
- Lenses produce images by refracting light.

LEARNING TIP

Read the Key Ideas. This will you give you the specific information that you need to pay attention to as you read the chapter. As you read the Key Ideas, ask yourself, "What do I already know about this topic?"

The effects of reflection and refraction are used to design a variety of optical devices. Mirrors and lenses change our view of the world. In the photograph, you can see a soccer ball as it would normally appear to your eyes, and as its reflection would appear in different mirrors. What happens when light hits a mirror? How do mirrors work?

In this chapter, you will investigate the behaviour of light as it reflects off or passes through different materials. Understanding how light behaves has led to the development of technologies that allow us to see better and farther, and to see objects that are too small to be seen with the unaided eye.

Reflecting Light off a Plane Mirror

Mirrors—dentists use them to examine your teeth, drivers use them to monitor traffic, decorators use them to make rooms seem larger, and you use them to check that you don't have the remains of your lunch on your nose. Regular, flat mirrors are called **plane mirrors.** (Here, the word *plane* means "a flat, two-dimensional surface," just as it does in mathematics.) In this Investigation, you will study how light reflects off a plane mirror.

You will use a protractor to measure angles in this Investigation. Whenever you measure an angle, always estimate its value first. Then, you can check that the result of your measurement makes sense.

INQUIRY SKILLS

● Questioning	○ Hypothesizing
● Predicting	○ Planning
● Conducting	● Recording
● Analyzing	● Evaluating
● Communicating	

Question

(a) Write a question that will be answered in this Investigation.

Prediction

(b) Look at **Figure 1**. Make a prediction about the relationship between the angle of incidence and the angle of reflection.

LEARNING TIP

For help with writing a question and a prediction, see "Questioning" and "Predicting" in the Skills Handbook section **Conducting an Investigation**.

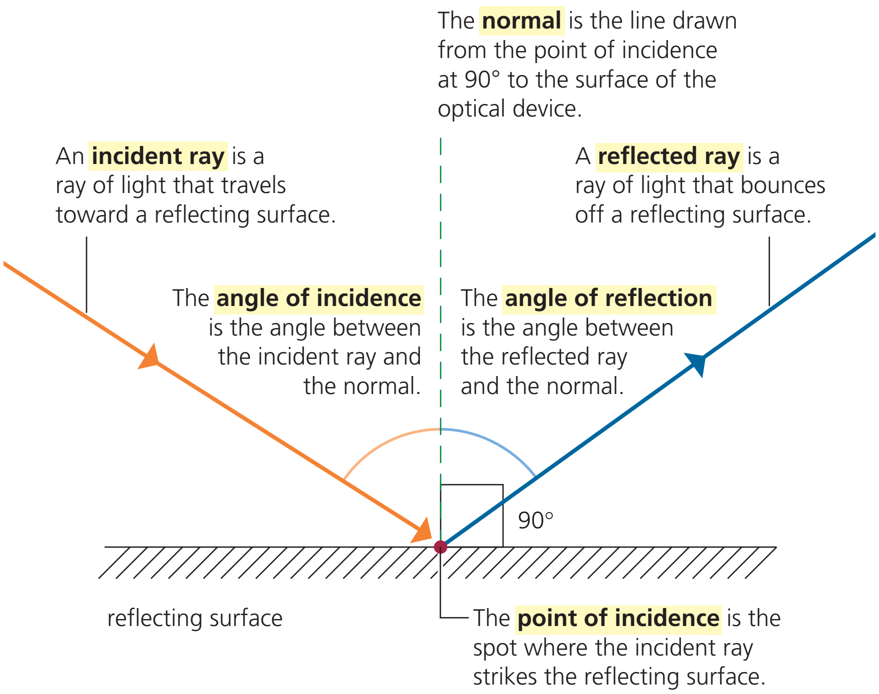


Figure 1
Vocabulary related to the reflection of light: Light travels in straight lines and can be represented using rays.

LEARNING TIP

Figure 1 contains important vocabulary. Take your time looking at **Figure 1** and making connections between the labels and what the diagram shows.

Do not touch the light bulb in the ray box or look directly into the light. Handle mirrors carefully to avoid breakage.

Experimental Design

You will trace the path of a ray from a ray box as the ray reflects off a plane mirror.

Materials

- ray box with single-slit window
- plane mirror that can stand by itself
- ruler
- sharp pencil
- plain paper
- protractor

Procedure

1. Aim a narrow ray of light from the ray box toward the mirror. Move the ray box so that the incident ray hits the mirror at the same point but with different angles of incidence. Observe the reflected ray each time you move the ray box. Record your observations.

Step 1

2. Draw a straight line, AB, on a piece of paper. The line should be longer than the mirror. Mark a point near the middle of AB. This will be your point of incidence. Place the plane mirror so that its reflecting surface (not the glass surface) lies along AB.

Step 2

3. Aim a light ray at the point of incidence. Move the ray box until the reflected ray is lined up with the incident ray. Draw three small dots along the middle of the light ray. Remove the ray box and the mirror. Use a ruler to connect the dots to the point of incidence with a broken line. What is this line? Label it.

Step 3

4. Return the mirror to its original position. Aim a light ray toward the point of incidence. Make sure that the angle of incidence is large. Mark small dots along the middle of the incident ray and reflected ray.

Step 4

Procedure (continued)

5. Remove the mirror and the ray box. Use a ruler to join the dots for each ray to the point of incidence. Label the rays, and show their directions with arrows. Use your protractor to measure the angle of incidence and the angle of reflection in your diagram. Record the sizes of the angles in your diagram.

6. Repeat steps 4 and 5 on a new piece of paper for several different angles of incidence.

Analysis

(c) Summarize your results in a table.

(d) Where is the reflected ray when the incident ray travels along the normal to a plane mirror?

(e) What are the angles of incidence and reflection in this Investigation?

(f) Scientists use two laws to describe how light reflects from a plane mirror. The first law of reflection compares the angle of incidence with the angle of reflection for light rays hitting a mirror. Based on your observations, write your version of the first law of reflection.

Evaluation

(g) Did your evidence support your prediction? Explain.

(h) Did your observations provide evidence that allowed you to answer the question you wrote at the beginning of this Investigation? If so, write the answer. If not, revise the question.

(i) Where might errors occur in this Investigation? How would these errors affect your conclusion?

(j) When conducting this Investigation, did you and your partner share the recording and physical work equally? How might you work differently with a partner or a group in upcoming Investigations?

PERFORMANCE TASK

Knowing the laws of reflection means that mathematics can be used in the design of optical devices. Are there features of your chosen optical device that can be described mathematically?

11.2 Reflecting Light off Surfaces

When shooting hoops outdoors, have you ever tried bouncing the ball on the grass instead of the asphalt? When the ball bounces off a smooth driveway or a gym floor, you can predict the direction it will travel. But when it bounces off the grass, you cannot predict where it will go. The same is true of light, as shown in **Figure 1**.

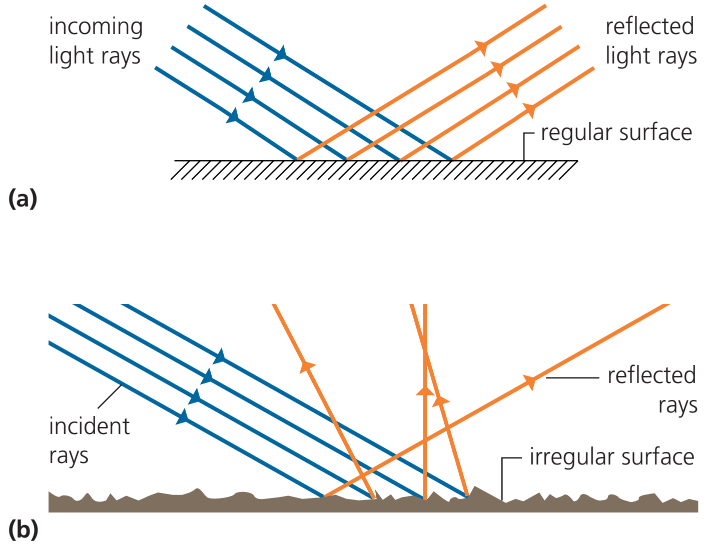


Figure 1
Light acts somewhat like a basketball when it hits a surface. If the surface is smooth and regular **(a)**, like a mirror, you can predict the direction of the reflected light more easily than if the surface is irregular **(b)**.

Specular Reflection

You've learned that a smooth, shiny surface reflects light more predictably than a rough, dull surface. The reflection of light off a smooth, shiny surface is called **specular reflection.** When light reflects off a smooth, shiny surface, you can see an image. For example, specular reflection occurs off mirrors, shiny metal, and the surface of still water (**Figure 2**).

Figure 2
Which way is up? Turn the book upside down and see if that helps you decide.

The Laws of Reflection

You have used rays to represent light as it travels from a ray box to a mirror and as it is reflected in a straight line off the mirror. Experiments like yours always yield the same results. When experimental results are consistent, scientists create "laws" to summarize the results. They have created two **laws of reflection**:

- The angle of incidence equals the angle of reflection.
- The incident ray, normal, and reflected ray all lie in the same plane.

The laws of reflection can be used to learn why the eye sees an image in a plane mirror (**Figure 3**). When you look in a mirror, you see an image that appears to be behind the mirror. If you extended the reflected rays behind the mirror, the image is where the rays appear to come from. For each set of incident and reflected rays, the angle of incidence equals the angle of reflection.

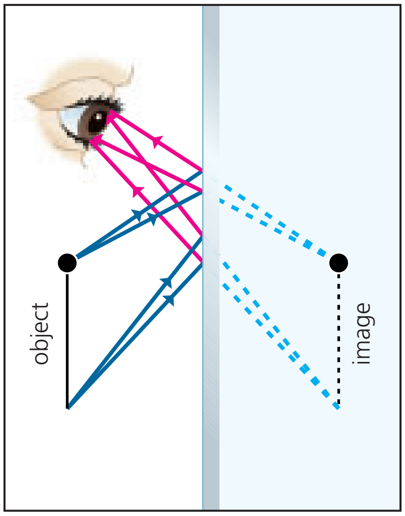


Figure 3
Your eye can see an image in a plane mirror.

Diffuse Reflection

Most surfaces are not regular. You cannot see a reflected image in cardboard or broccoli. When light hits an irregular surface, you see **diffuse reflection** as the reflected light scatters in many directions.

Both direct light from a source and reflected light from a regular surface can strain the eyes. A room with a bright light source and mirrors on every wall would be very hard on the eyes. The glare from a transparent glass lamp would also be hard on the eyes. Diffuse light is easier on the eyes. Homes, schools, and places of work are designed with this in mind. Ceilings are often coated with an irregular surface, such as stucco, that causes diffuse reflection. Lamps often have frosted bulbs that diffuse the light. Lampshades diffuse the light even more.

Figure 4 shows how indirect lighting and irregular surfaces help to diffuse the light in a room. In indirect lighting, the light bulbs cannot be seen. The light from the bulbs reflects off the ceiling or walls before it reaches your eyes.

LEARNING TIP

Check your understanding of specular and diffuse reflection. Explain how they are different in your own words to a partner.

Figure 4
How many examples of diffuse reflection and specular reflection of light can you find in this photograph?

TRY THIS: Specular and Diffuse Reflection

Skills Focus: predicting, observing, communicating

In this activity, you will use shiny aluminum foil to study specular and diffuse reflection.

(a) Predict what will happen when you shine a flashlight on three pieces of aluminum foil, as shown in **Figure 5**.

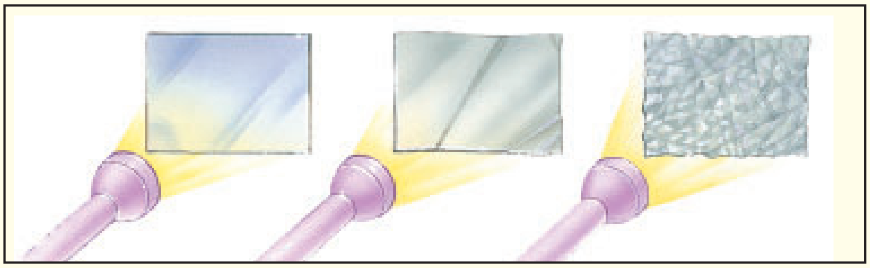


Figure 5

1. Set up the materials, and make your observations. You will see the effect best if the room is dark.

(b) Explain your observations using a diagram.

2. Repeat step 1, but use three different fabrics instead of the aluminum foil. Choose fabrics that are the same colour and have smooth, textured, and very rough surfaces.

(c) Write a brief report to summarize your findings.

11.2 CHECK YOUR UNDERSTANDING

1. In your own words, describe specular reflection and diffuse reflection.
2. Draw a ray diagram that shows a plane mirror and an incident ray with an angle of incidence of 37°. Then, draw the reflected ray. Draw ray diagrams using angles of incidence of 77° and 0°, as well.
3. (a) What is the largest possible angle of incidence for a light ray travelling toward a mirror?

   (b) What is the smallest possible angle of incidence?
4. Give examples of how an interior designer might benefit from a knowledge of diffuse reflection. Choose an example of direct light and an example of indirect light in your home. Briefly summarize their effectiveness.

PERFORMANCE TASK

Is specular or diffuse reflection important in your optical device? Is it a problem or an advantage?

Describing Images

11.3

When your teacher shows you slides, you see images produced by the projector on the screen. When you look at the letters in this sentence, an image of the letters forms at the back of your eyes. An image is the likeness of an object. An **optical device** produces an image of an object.

Real and Virtual

Images can be real or virtual. What does this mean? A **real image** can be placed on a screen. A **virtual image** cannot be placed on a screen. A virtual image can be seen only by looking at or through an optical device.

The four main characteristics listed in **Table 1** are generally used to study and compare images. These characteristics are used to describe the image in **Figure 1**.

LEARNING TIP

Make connections to your prior knowledge. What do you already know about real and virtual images? Is there any new information here?

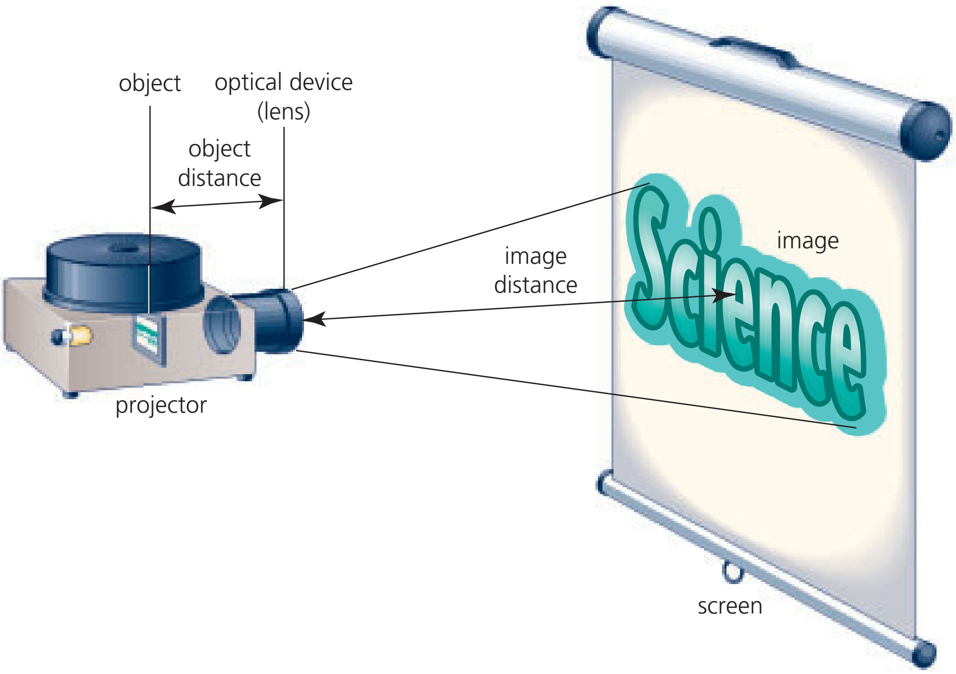


Figure 1
A slide projector shows a real image on a screen. The image is larger than the object viewed and is upright. It is closer to the optical device than to the object.

LEARNING TIP

Refer to **Table 1** when you complete the Try This activity on this page.

Table 1 Characteristics of Images

Characteristic	Possible descriptions
size	• smaller than the object viewed • larger than the object viewed • same size as the object viewed
attitude	• upright (right-side up) • inverted (upside down)
location	• several choices • examples: on the side of the lens opposite the object; closer to the optical device than to the object
type	• real image (can be placed on a screen) • virtual image (can be seen only by looking at or through an optical device)

Do not look at the Sun or any other bright source of light with a pinhole camera. The light could damage your eyes.

TRY THIS: Images in a Pinhole Camera

Skills Focus: creating models, observing

You can use a homemade pinhole camera to investigate images. A pinhole camera is a box with a tiny hole at one end and a viewing screen at the other end. It can be as small as a shoebox or as large as a box for packing a new refrigerator. You can even stand inside a large pinhole camera to view the images! **Figure 2** shows how to make a small pinhole camera.

1. Aim the pinhole toward the object you want to see and look at the screen.

(a) What are the characteristics of the image of an object that is a few metres away from the camera?

(b) What happens to the image as the camera gets closer to the object?

(c) What happens if a second pinhole is made about 1 cm below the first pinhole?

(d) Draw a diagram to show how an image is formed in a pinhole camera.

(e) Is the image that is seen in a pinhole camera real or virtual? Why?

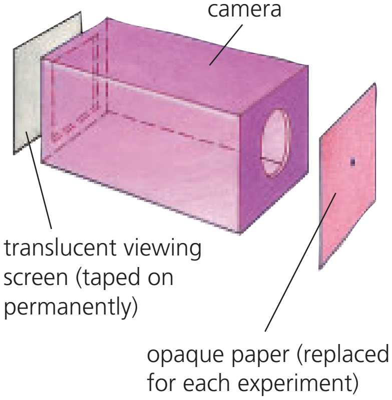


Figure 2
This type of pinhole camera is easy to make. Aim the pinhole toward the object you want to see, and look at the screen.

11.3 CHECK YOUR UNDERSTANDING

1. Describe the characteristics of the image you see when your teacher uses an overhead projector.
2. The screen in a pinhole camera must be translucent rather than transparent or opaque. Why?

Viewing Images in a Plane Mirror

Everyone uses mirrors. When you look in a plane mirror, you see an image of the object, not the object itself. As you learned in Section 11.3, an image can be described using four characteristics: size, attitude, location, and type.

INQUIRY SKILLS

○ Questioning	● Hypothesizing
● Predicting	○ Planning
● Conducting	● Recording
● Analyzing	● Evaluating
● Communicating	

Question

What are the characteristics of an image seen in a plane mirror?

Prediction

(a) Predict what you will discover in this Investigation.

Hypothesis

(b) From your experience with mirrors, write a hypothesis that explains the image seen in a plane mirror.

LEARNING TIP

For help with writing a prediction and a hypothesis, see "Predicting" and "Hypothesizing" in the Skills Handbook section **Conducting an Investigation**.

Experimental Design

You will view images in mirrors and draw diagrams to help you describe these images.

Handle mirrors carefully to avoid breakage.
To avoid injury, handle pins with care.

Materials

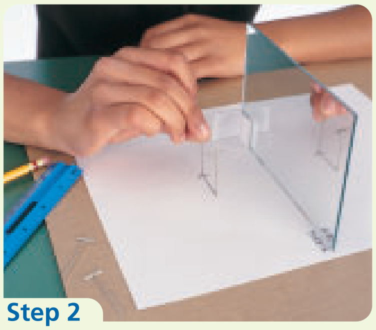
- safety goggles
- large plane mirror
- plain paper
- flat cardboard
- ruler
- small plane mirror (or MIRA)
- four pins

Procedure

1. Look into a large plane mirror. What is the size of the image compared with the size of the object (you)? What is the attitude of your image?

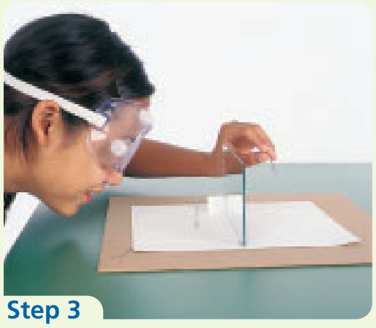

Step 1

2. Put on your safety goggles. Place a piece of paper on the cardboard. Draw a straight line that is a little longer than the small mirror. Label this line *mirror*. Place the reflecting surface of the mirror along this line. Draw an arrow that is about 2 cm or 3 cm long in front of the mirror. Label the arrow *object*. Stick a pin vertically through each end of the arrow.


Step 2

3. Move around a pin behind the mirror until the pin is exactly where the image of the first pin appears to be. Check by looking at the image from several viewpoints. When you are sure of the location, stick the second pin into the paper and cardboard behind the mirror. Repeat this step using a fourth pin for the other end of the arrow. Draw a broken arrow between the two pins, and label it *image*.

4. Check to see if the image of the arrow is real or virtual. Put a piece of paper (a screen) where the image seems to be. If you can see the image on the paper, it is real. If you cannot see the image on the paper, it is virtual. Record your observations.


Step 3

5. Remove the mirror and the pins. On your diagram, measure and label the shortest distance from the mirror line to each end of the object. (This is the object distance.) Measure and label the shortest distance from the mirror line to each end of the image. (This is the image distance.)

Analysis

(b) State the four characteristics of the image in this Investigation.

(c) In step 5, how did the distance from the image to the mirror compare with the distance from the object to the mirror?

Evaluation

(d) Did your observations support your prediction? Explain.

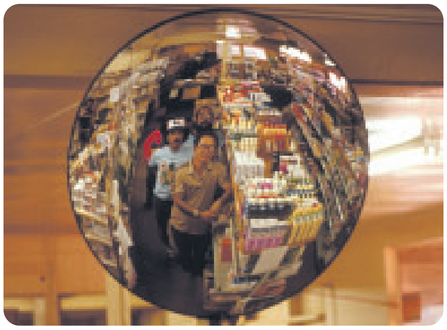
(e) Describe any possible sources of error in this Investigation.

INQUIRY SKILLS

● Questioning	● Hypothesizing
○ Predicting	○ Planning
● Conducting	● Recording
● Analyzing	● Evaluating
● Communicating	

Curved Mirrors

You may have noticed a big curved mirror high in a corner at a local store (**Figure 1**). The store owner uses the convex mirror to watch for shoplifters. A **convex** mirror has the reflecting surface on the outside curve. Why do the images you see in a convex mirror that make it effective for surveillance?



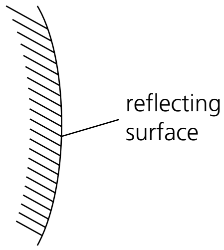


Figure 1
A convex mirror is like the back of a spoon.

The next time you visit a dentist, look closely at the lamp that the dentist uses (**Figure 2**). A concave mirror in the lamp focuses the light into your mouth so that the dentist can work on your teeth. A **concave** mirror has the reflecting surface on the inside curve. What makes a concave mirror effective for working on teeth?

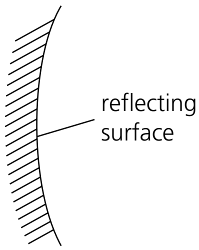


Figure 2
A concave mirror is like the inside of a spoon.

The images you see in curved mirrors look different from the images you see in plane mirrors. In this Investigation, you will explore these differences.

LEARNING TIP

For help with writing a question and a hypothesis, see "Questioning" and "Hypothesizing" in the Skills Handbook section **Conducting an Investigation**.

Do not touch the ray box the light bulb in or look directly into the light.
Handle mirrors carefully to avoid breakage.

Question

(a) What question is being investigated?

Hypothesis

(b) Create a hypothesis for this Investigation.

Experimental Design

You will use a ray box to investigate the properties of curved mirrors.

Materials

- curved mirrors for viewing
- curved mirrors to use with the ray box
- ray box with multiple-slit window and single-slit window
- plain paper
- sharp pencil
- ruler
- protractor

Procedure

1. Have a partner hold a concave viewing mirror close to your eyes. Describe the image you see. Observe the image carefully as your partner slowly moves the mirror away from your eyes. Describe any changes you observe in the image.

Step 1

2. Have a partner hold a convex viewing mirror close to your eyes. Describe the image you see. Observe the image carefully as your partner slowly moves the mirror away from your eyes. Describe any changes you observe. How is the image produced by the convex mirror different from the image produced by the concave mirror in step 1?

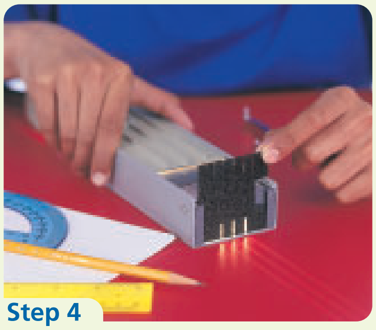
Step 2

3. Use a ray box to aim a narrow ray of light at the surface of a concave mirror. Observe where each ray is reflected. Try several different angles. Record where each ray came from and where it was reflected. Do the laws of reflection apply to concave mirrors?

Step 3

Procedure (continued)

4. Use the ray box with the multiple-slit window to shine three or more parallel rays of light at a concave mirror. Draw a diagram of what you observe. Can a concave mirror focus light rays?



Step 4

5. Repeat steps 3 and 4 using a convex mirror. Can a convex mirror focus light rays?

Analysis

(c) Use your observations and the characteristics of images to describe the images seen in each mirror. Is each image real or virtual?

(i) a concave mirror when the object is close to the mirror

(ii) a concave mirror when the object is far away from the mirror

(iii) a convex mirror when the object is close to the mirror

(iv) a convex mirror when the object is far away from the mirror

(d) In part (c), you had to decide whether the image in each mirror was real or virtual. What evidence did you use to support your decision? Describe how you could demonstrate whether or not each mirror produced a real image. Draw a diagram of the set-up.

Evaluation

(e) Did your observations enable you to answer your question at the beginning of this Investigation? Why or why not?

(f) Did your observations support your hypothesis? Explain.

PERFORMANCE TASK

Concave mirrors can be used to focus light. Are concave mirrors used in your optical device? Are convex mirrors used?

11.6 Using Curved Mirrors

You may not realize it, but curved mirrors are part of your everyday life. Whether you are shopping, riding a school bus, or learning about solar heating, curved mirrors are near. **Figures 1** and **2** show some of the terms that are used to describe curved mirrors.

principal axis: a line through the centre of the mirror that includes the principal focus

principal focus: the position where reflected parallel light rays come together

focal length: the distance from the principal focus to the middle of the mirror

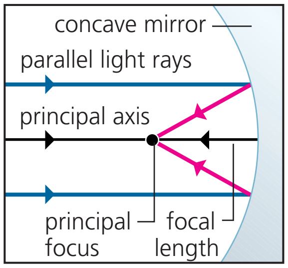
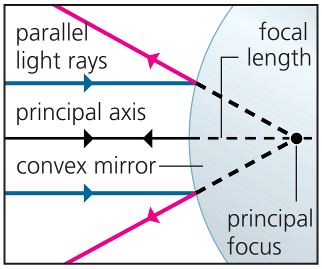


Figure 1



principal axis: a line through the centre of the mirror that includes the principal focus

principal focus: the position where parallel light rays appear to reflect from

focal length: the distance from the principal focus to the middle of the mirror

Figure 2

A concave mirror focuses parallel light rays (**Figure 1**). When an object is beyond the principal focus of a concave mirror, the type of image produced is real. The image is in front of the mirror and can be placed on a screen.

A convex mirror spreads the light rays out (**Figure 2**). Images in a convex mirror are always virtual, because they are behind the mirror and cannot be placed on a screen.

LEARNING TIP

Do not rush when you are looking at illustrations. Look carefully at **Figures 1** to **6** and read the captions. Then check for understanding. Ask yourself, "What does this show? How is this connected to what I am learning?"

Using Concave Mirrors

If you have ever looked through a reflecting telescope, you have used a concave mirror. **Figure 3** shows how a concave mirror gathers light from distant objects and brings it to a focus. The biggest telescopes built, including space telescopes, are based on this design.

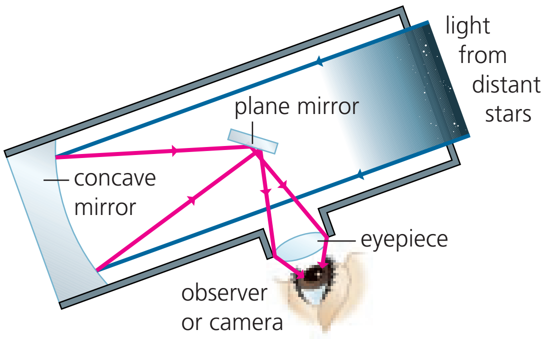


Figure 3
A reflecting telescope creates an image that can be viewed, photographed, or recorded digitally.

Figure 4 shows how a concave cosmetic mirror is used to produce an upright, enlarged image of a nearby object. The person using the mirror must be closer to it than the principal focus.

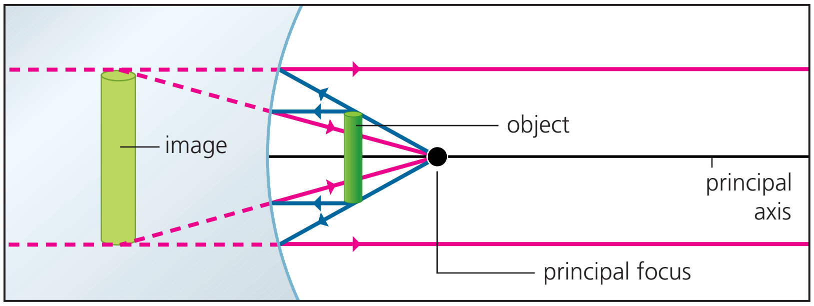


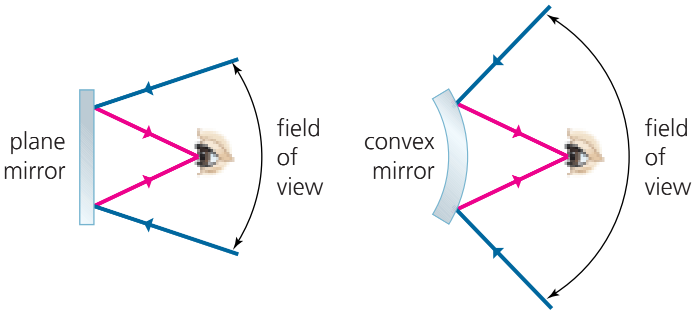
Figure 4
A concave mirror produces an upright, enlarged image when the person using it is closer to the mirror than the principal focus. Could this image be placed on a screen?

Using Convex Mirrors

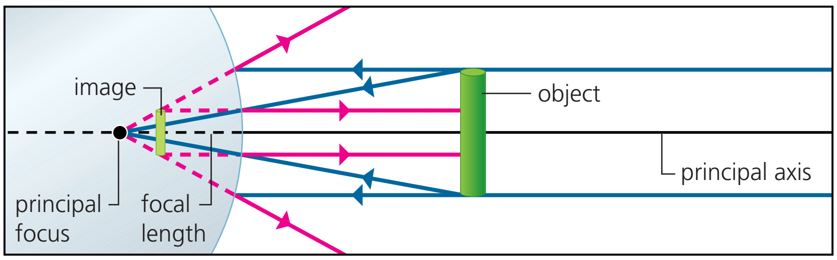
You have probably noticed large surveillance mirrors in many stores. A convex mirror can be used to monitor a very large area because its curved surface reflects light from all parts of a room to a person's eye. Images are always upright and smaller than the object, no matter where the object is located. **Figure 5** shows how a convex mirror produces an image and why it gives a much wider view than any other kind of mirror. **Figure 6** shows another common use of convex mirrors. Can you think of more uses?

LEARNING TIP

Explain the differences between concave and convex mirrors in your own words to a partner.



(a) The reflection in a convex mirror has a much larger field of view than the reflection in a plane mirror.



(b) The characteristics of the image produced by a convex mirror are the same whether the object is near the mirror or far away.

Figure 5

Figure 6
A convex mirror on the front of a school bus allows the driver to see children both beside and in front of the bus.

Table 1 Image Characteristics of Different Mirrors

	Plane mirror	**Concave mirror** (object closer than principal focus)	**Concave mirror** (object beyond principal focus)	**Convex mirror**
Size	• same size as object	• larger than object	• larger than the object but becomes smaller as object distance increases	• smaller than object
Attitude	• upright	• upright	• inverted	• upright
Location	• behind mirror • same distance from mirror as object	• behind mirror • farther from the mirror than the object	• in front of mirror • distance varies depending on distance of object	• behind mirror • farther from the mirror than the object
Type of image	• virtual	• virtual	• real	• virtual

11.6 CHECK YOUR UNDERSTANDING

1. Briefly describe how the principal focus in a concave mirror is the same and how it is different from the principal focus in a convex mirror.
2. How do the characteristics of images in a convex mirror compare to those in a concave mirror
   (a) when the object is close to the mirror?
   (a) when the object is far from the mirror?
3. For each situation, state whether the image produced is real or virtual. Explain how you know.
   (a) A girl is standing close to a cosmetic mirror while applying lipstick.
   (b) An astronomer is looking at an image of the Moon through her telescope, which has a concave mirror.
   (c) A clerk in a drugstore is looking at the image of a customer in a surveillance mirror.
4. Rewrite the following false statements to make them true.
   (a) The image in a convex mirror is always real and upright.
   (b) When an object is inside the principal focus of a concave mirror, its image is inverted and real.
   (c) Real images are always located behind the mirror.
5. Curved mirrors can be used to gather light from the Sun and focus it for solar heating. Draw a diagram that shows how this might work.
6. Do you think the focal length of a concave mirror would increase, decrease, or stay the same if the mirror were made flatter? Use a diagram to help illustrate your explanation.

PERFORMANCE TASK

What is the purpose of the concave and/or convex mirrors in your chosen device?

The Refraction of Light

You have seen that light travels in straight lines through air. What happens when light travels from one material into another? Have you ever noticed that your legs look different when you are standing in a swimming pool? **Figure 1** shows this distorted view. The distortion happens because light bends as it passes from water into air. The bending of light as it travels from one material into another is called **refraction**. **Figure 2** shows some terms that are used to describe refraction.

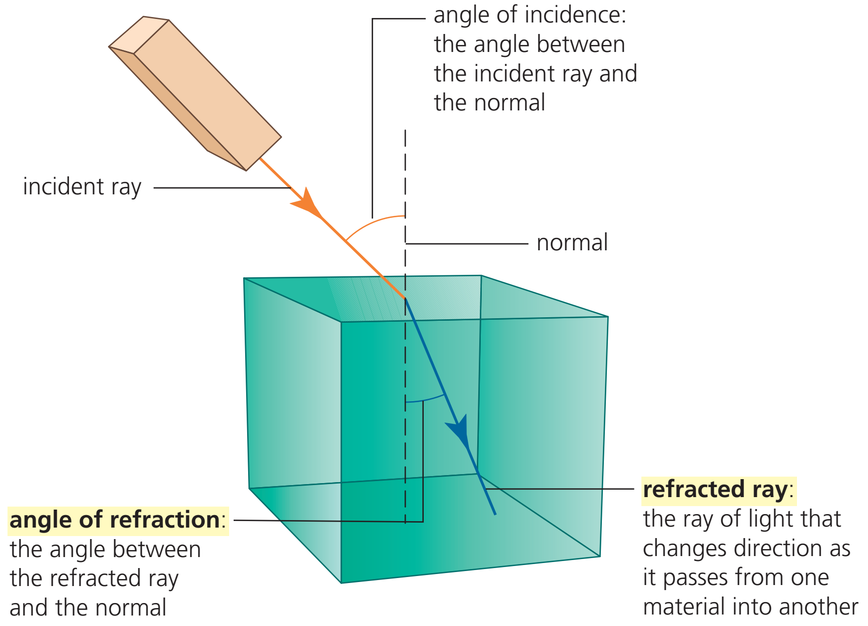


Figure 2
Some terms that are used to describe refraction

Figure 1
Light refracts as it travels from water into air, causing a distorted view. Will light refract the same amount in glycerin or a block of acrylic?

INQUIRY SKILLS

- ● Questioning
- ○ Predicting
- ● Conducting
- ● Analyzing
- ● Communicating
- ● Hypothesizing
- ● Planning
- ● Recording
- ● Evaluating

In this Investigation, you will be using transparent materials to investigate refraction.

LEARNING TIP

For help with this Investigation, see the Skills Handbook section **Designing an Investigation**.

Question

(a) Formulate a question you can use to investigate the refraction of light in transparent materials.

Hypothesis

(b) Create a hypothesis for this Investigation.

Experimental Design

(c) Design an investigation to test your hypothesis. You want to explore refraction as light travels from air into another material, and when light travels from this material back into air. You should test several transparent liquids and at least one solid.

(d) List the materials you will require and the steps you will take, including any safety precautions. Describe how you will record your data.

Materials

- apron
- safety goggles
- thin transparent dishes (containers for liquids)
- ray box with single-slit window

Possible transparent materials:

- water
- glycerin
- mineral oil
- saltwater solution
- sugar-water solution
- solid rectangular prism (acrylic block)

Clean up any spills immediately.
Do not touch the light bulb in the ray box or look directly into the light.

Procedure

1. Show your investigation plan to your teacher. With your teacher's approval, carry out your investigation. Be sure to wear your apron and safety goggles. Record any changes you make to your plan as you proceed. Record your observations.

Analysis

(e) Light travels in straight lines in air. How does it travel in other transparent materials?

(f) Compare the angle of refraction as light travels from air into a liquid or solid with the angle of refraction as light travels from a liquid or solid into air.

(g) List the differences between the materials you tested. Speculate about what property of the materials you tested explains your results.

(h) List the materials you tested in order of least refraction to greatest refraction for light entering from air.

Evaluation

(i) In this Investigation, you used a container to hold the liquids. Did the container affect the results? Support your answer using a diagram.

(j) How could you improve the design of your Investigation?

PERFORMANCE TASK

Is light refracted in your optical device? Why is it necessary to refract the light in this device?

Refracting Light in Lenses

11.8

Your eyes depend on refraction. They make use of a special optical device called a lens. A **lens** is a curved, transparent device that causes light to refract as it passes through. As you read, light reflects off the page, travels to your eyes, and refracts when it enters the lens of each eye. A magnifying glass (**Figure 1**), the lenses in eyeglasses, contact lenses, and camera lenses are all examples of useful lenses.

Figure 1
Lenses have a variety of uses, depending on their size, shape, and other properties. As light passes through this lens, it refracts to create enlarged images.

Why Does Light Refract?

You have seen that light refracts when it travels from one material into another. Why does this happen? Using careful measurements, scientists have discovered that the speed of light differs in different transparent materials. When light travels from air into certain materials, it slows down. This change in speed causes the light to change direction. The same thing happens, for the same reason, if you ride a bicycle from pavement onto sand (**Figure 2**). The new material causes a change in speed and direction.

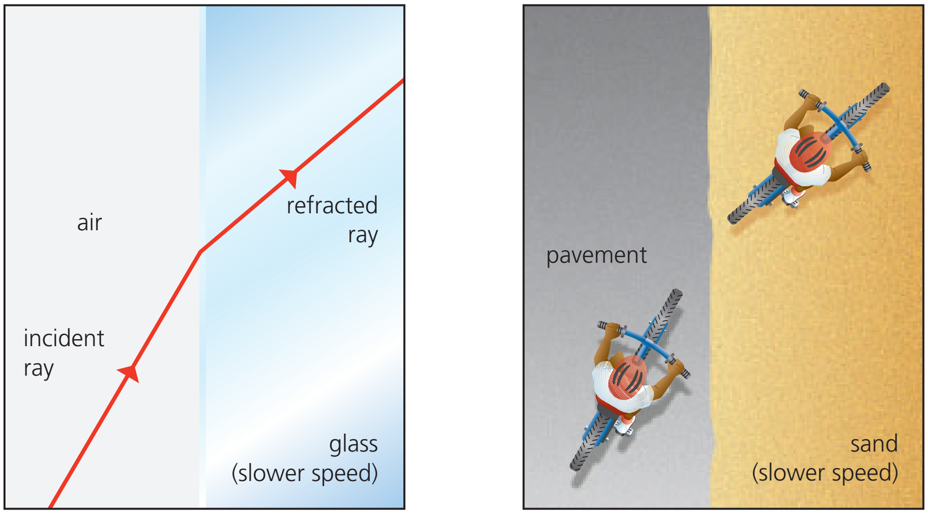


Figure 2
Light refracts when its speed changes, just as a bicycle changes direction when it slows down as it moves from pavement onto sand.

TRY THIS: Exploring Lens Combinations

Skills Focus: observing, controlling variables

How do designers decide which lenses to use in microscopes and other devices? How do they decide what is the best combination to use? You can explore these questions using several glass lenses.

1. Examine several single lenses. Look through them from both sides and from near and far. Look through them at objects nearby and far away.

(a) How do concave and convex lenses compare?

(b) How does the curvature of a lens affect the image?

(c) How does the distance between the lens and the object affect the image?

(d) Does the distance between your eye and the lens affect the image?

2. Combine lenses by putting one in front of the other. Look through your combination of lenses.

(e) What is the best combination for viewing nearby objects?

(f) What is the best combination for viewing objects that are far away?

(g) When using a concave-convex combination, what is the best arrangement for viewing nearby objects? What is the best arrangement for viewing objects that are far away?

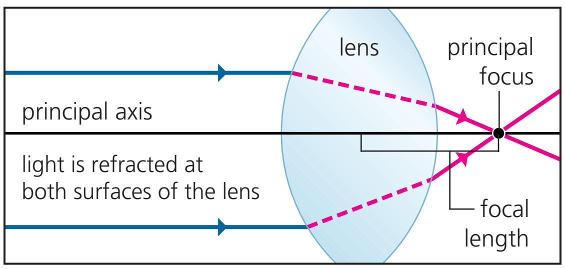
3. Try combining three lenses.

(h) Did you discover any useful combinations of three lenses? Explain.

Do not look at any bright light source through the lenses. Handle lenses carefully to avoid breakage.

Designs of Lenses

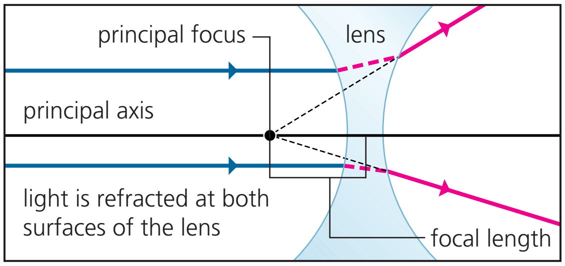
Generally, lenses are convex or concave. A convex lens is thicker in the middle than at the outside edge (**Figure 3**). A concave lens is thinner in the middle than at the outside edge (**Figure 4**). This difference causes different effects and images when light passes through the lenses. Notice, however, in both **Figures 3** and **4**, that a light ray through the middle of a lens does not refract, because it meets the surface at a 90° angle. Does a bicycle continue in the same direction if it moves from one surface to another at a 90° angle?



principal focus: the position where parallel light rays come together

focal length: the distance from the principal focus to the centre of the lens

Figure 3
A convex lens bulges outward, causing light rays to come together, or converge. A convex lens is often called a converging lens.



principal focus: the position where parallel light rays appear to come from

focal length: the distance from the principal focus to the centre of the lens

Figure 4
A concave lens is caved inward, causing light rays to spread apart, or diverge. A concave lens is often called a diverging lens.

The characteristics of convex and concave lenses determine how they are used in different optical devices. For example, if you want to make something look bigger, then you should use a convex lens.

Combining Lenses

Some optical devices, such as microscopes, telescopes, and cameras, use more than one lens. A microscope, for example, has two lenses—the objective lens that is close to the object being viewed, and the eyepiece lens that you look through.

11.8 CHECK YOUR UNDERSTANDING

1. Explain why light bends as it travels from air into water.
2. Light speeds up when it travels from glass into air. Redraw **Figure 2** (on p. 331), showing what happens when light travels from glass into air.
3. Describe the attitude and approximate size of the image when an object is very close to and far from
   (a) a convex lens
   (b) a concave lens
4. Using a diagram, explain whether the focal length would be greater in
   (a) a thick or thin convex lens
   (b) a thick or thin concave lens
5. Is a convex lens more like a convex mirror or a concave mirror in the way that it produces images? Explain your answer.
6. Light refracts more when it passes from air into diamond than to any other common material. What can you conclude about the speed of light in diamond?
7. Make a list of devices that use at least one lens.

11.9 Inquiry Investigation

INQUIRY SKILLS

● Questioning	○ Hypothesizing
● Predicting	● Planning
● Conducting	● Recording
● Analyzing	● Evaluating
● Communicating	

Figure 1
This image was created using a fisheye lens.

Investigating Lenses

Have you ever looked through a peephole in a door to see who is on the other side? Have you ever looked through binoculars at a ball game? Have you ever used a microscope to look at cells? Whether lenses are used to make faraway objects appear clearer or to enlarge small objects, they can produce interesting results (**Figure 1**). In this Investigation, you will use light rays to discover how different lenses produce different types of images.

Question

(a) Write a question about images and lenses that you can investigate.

Prediction

(b) Based on what you have learned, predict an answer to your question.

Experimental Design

You will use a ray box to observe images created by lenses and determine if your prediction is correct.

Look at **Figure 2** to see how you can use two rays, one at a time, to locate the top of the image of an object placed in front of a convex lens. Using two more rays, you can use a similar technique to locate the bottom of the image.

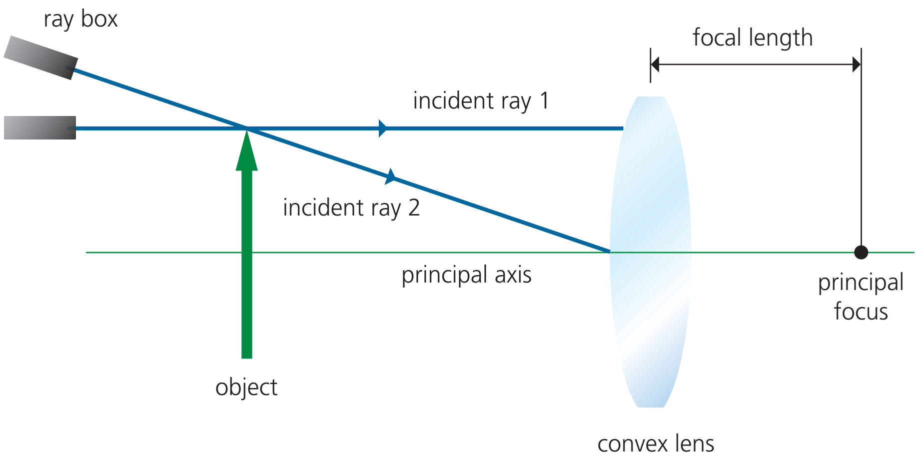


Figure 2
How to find the top of an image

LEARNING TIP

For help with writing a question and a prediction, see "Questioning" and "Predicting" in the Skills Handbook section **Conducting an Investigation**.

(c) Design a procedure to find the image of an object in each position described below, and to decide what type of image it is.

Convex Lens

(i) an object that is 2 times the focal length from the lens

(ii) an object that is 1.5 times the focal length from the lens

(iii) an object that is exactly the focal length from the lens

(iv) an object that is half the focal length from the lens

Concave Lens

(v) an object that is 2 times the focal length from the lens

(vi) an object that is exactly the focal length from the lens

(d) Based on your design, list the steps you will take.

Materials

- ray box with multiple-slit window and single-slit window
- convex and concave lenses to use with the ray box
- plain paper
- sharp pencil
- ruler

Do not touch the light bulb in the ray box or look directly into the light. Handle the lenses carefully to avoid breakage.

Procedure

1. With your teacher's approval, carry out your procedure. For each position in step (c), draw a diagram showing what you discover. (If the rays are spreading apart, extend them with a ruler to find out where they appear to come from.)

Analysis

(e) Describe the steps you would take to determine the focal length of

(i) a convex lens

(ii) a concave lens

(f) Describe the conditions that cause a convex lens to produce

(i) a real image

(ii) a virtual image

(iii) no image

(g) Does a concave lens produce a real image or a virtual image? Explain.

Evaluation

(h) How would you improve your procedure if you were going to do this Investigation again?

PERFORMANCE TASK

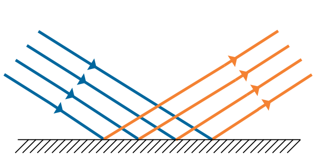
Many optical devices use combinations of lenses. How many lenses are in your device? What kinds of lenses are used? What combination of different lenses is used?

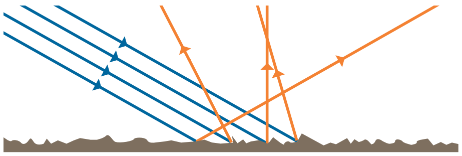
Chapter 11 Review Mirrors and Lenses

Key Ideas

Light reflects off surfaces in a predictable way.

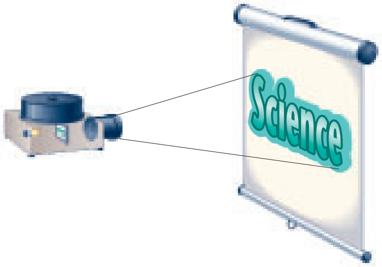
- Reflection off a smooth surface is called specular reflection.
- The first law of reflection states that the angle of reflection is equal to the angle of incidence.
- The second law of reflection states that the incident ray, the normal, and the reflected ray all lie in the same plane.
- Reflection off an irregular surface is called diffuse reflection.





Optical devices produce images that can have different characteristics.

- Real images can be placed on a screen. Virtual images cannot be placed on a screen and can only be seen by looking at or through an optical device.
- Images can be uprighted or inverted; larger than, smaller than, or the same size as the object; and on the same side or the opposite side of the optical devices as the object is located.



Mirrors produce images by reflecting light.

- Plane mirrors produce upright, virtual images that are the same size as the object and located behind the mirror.

Vocabulary

plane mirrors, p. 313

incident ray, p. 313

angle of incidence, p. 313

normal, p. 313

reflected ray, p. 313

angle of reflection, p. 313

point of incidence, p. 313

specular reflection, p. 316

laws of reflection, p. 317

diffuse reflection, p. 317

optical device, p. 319

real image, p. 319

virtual image, p. 319

convex, p. 323

concave, p. 323

principal axis, pp. 326, 332

principal focus, pp. 326, 332

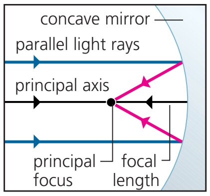
focal length, p. 326

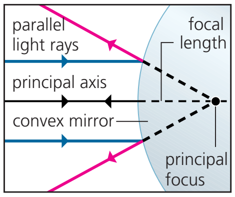
refraction, p. 329

refracted ray, p. 329

- Concave mirrors produce larger, real images when the object is farther than the principal focus. They produce virtual images when the object is nearer than the principal focus.

- Convex mirrors always produce upright, virtual images that are smaller than the object and located behind the mirror.

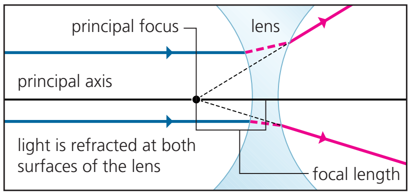




When light passes through a transparent material, it may change direction.

- When light passes from one material to another, its speed may change. This causes the light to refract, or change direction.

- The greater the change in speed, the more light refracts.



Lenses produce images by refracting light.

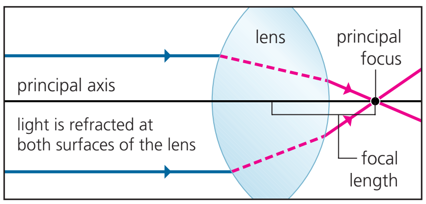
- Lenses are curved transparent materials that refract light.

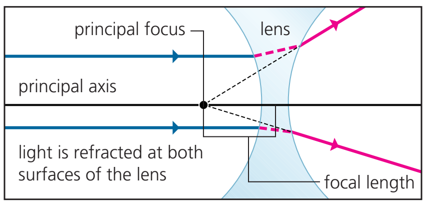
- A concave lens causes light rays to spread apart, or diverge.

- A convex lens causes light rays to come together, or converge.

- Microscopes, telescopes, binoculars, and cameras use mirrors or lenses, or a combination of mirrors and lenses, to observe objects.

- Optical devices are used to make distant objects appear closer, to make smaller objects appear larger, and to capture images of objects.





angle of refraction, p. 329

lens, p. 331

Review Key Ideas and Vocabulary

1. An incident light ray aimed along the normal of a plane mirror
(a) has an angle of incidence of 0°
(b) has an angle of reflection of 0°
(c) is perpendicular to the mirror
(d) reflects back onto itself
(e) all of the above are true

2. The image seen in a convex mirror, compared with the object, is always
(a) smaller, upright, and virtual
(b) larger, upright, and virtual
(c) smaller, inverted, and virtual
(d) smaller, inverted, and real
(e) larger, upright, and real

3. Light travelling from air into glass has an angle of incidence of 45°. The angle of refraction in the glass is most likely
(a) 0°
(b) 45°
(c) bigger than 45°
(d) smaller than 45°
(e) none of the above because all light reflects

4. The statement "the angle of reflection equals the angle of incidence" is considered a law because
(a) experimental results are consistent
(b) it is true only in certain situations
(c) scientists are still searching for a theory
(d) laws are always true
(e) it is the best explanation available

5. Where must you be to see an upright image of yourself in a concave mirror? Where must you be to see an inverted image of yourself?

6. Using the laws of reflection, draw a diagram to show how the eye sees an image in a plane mirror.

7. (a) In **Figure 1**, what are the names of lines A, B, and C?
(b) What is the angle of incidence?

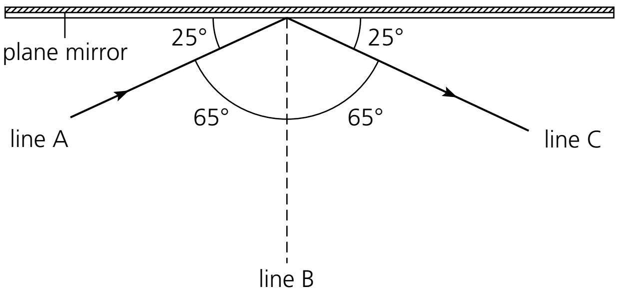


Figure 1

8. Examine **Figure 2**. Match each object in front of the mirror with the image that is the correct size and has the correct attitude.

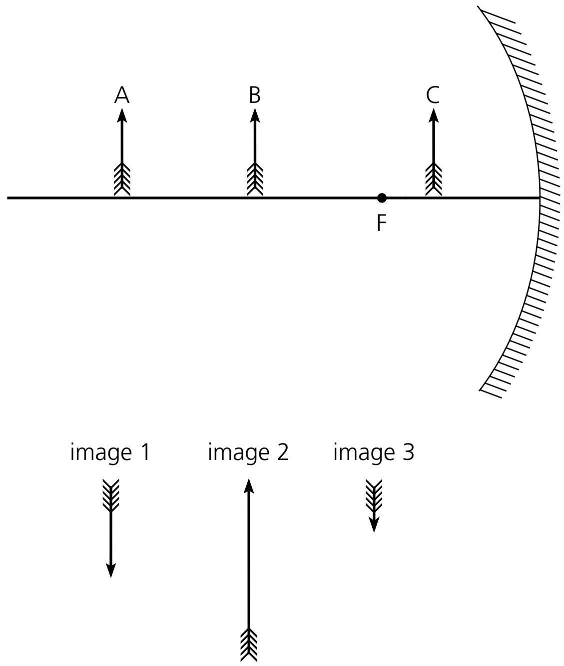


Figure 2

9. (a) What is the refraction of light?
(b) Why does it occur?
(c) How does refraction allow you to see?
(d) How does it affect how you see?

10. If you saw a coin in the water, would you reach for the exact location where the coin appears to be? Explain your answer.

Use What You've Learned

11. Draw a top-view diagram to show how you would place a mirror in order to see around a corner.

12. How could you use a curved mirror to start a campfire on a sunny day? Draw a diagram to illustrate your answer.

13. Satellite dishes are used to reflect energy from a satellite so that it comes to a focus. What type of reflector is a satellite dish? Using your knowledge of reflection from curved surfaces, draw a diagram to show how this device works.

14. Identify 10 ways that the reflection of light is used in everyday situations.

15. Why is the lettering on the front of the ambulance in **Figure 3** printed backward?

Figure 3

16. When a certain liquid is poured into a beaker that contains a block of acrylic, the block disappears from view.
(a) Explain this phenomenon.
(b) Based on the results of Investigation 11.7, what is the liquid?

17. Not all lenses are concave or convex. For example, one type of lens has one concave side and one convex side. Find some examples of other types of lenses, as well as interesting combinations of lenses. Report your findings.

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Think Critically

18. Why is diffuse reflection more important than regular reflection in our everyday lives? Present your evidence in a short paragraph.

19. Name at least two applications of concave and convex mirrors that are not listed in the text. Describe why you think they were chosen for this application.

20. Suppose that you want to buy one of the following devices: a telescope, a microscope, a camera, or binoculars. Make a list of questions you would ask the salesperson in order to help you decide.

21. What problems occur when printing or writing is seen in a mirror? What could you do to read printing when looking in a mirror?

22. What safety problems can occur when using a convex mirror? List situations in which a convex mirror should not be used.

23. Write a paragraph that summarizes your observations about images produced by concave and convex lenses.

Reflect on Your Learning

24. How do you think your everyday life would be affected if concave lenses weren't available? Give examples to illustrate your answer.

25. Write a short paragraph describing examples of how the reflection of light makes the natural world more beautiful and more enjoyable.

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