Section 3

Refraction and Lenses

Reading Preview

Key Concepts

- Why do light rays bend when they enter a medium at an angle?
- What determines the types of images formed by convex and concave lenses?

Key Terms

- index of refraction
- mirage
- lens
- convex lens
- concave lens

Target Reading Skill

Asking Questions Before you read, preview the red headings. In a graphic organizer like the one below, ask a *what, when, where* or *how* question for each heading. As you read, write the answers to your questions.

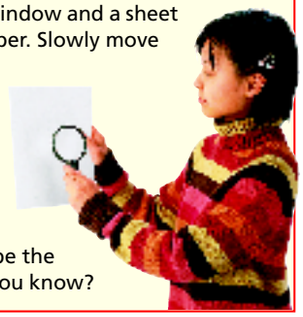
Refraction and Lenses

Question	Answer
When does refraction occur?	Refraction occurs . . .

Lab zone Discover Activity

How Can You Make an Image Appear?

1. Stand about 2 meters from a window. Hold a hand lens up to your eye and look through it. What do you see? **CAUTION:** *Do not look at the sun.*
2. Move the lens farther away from your eye. What changes do you notice?
3. Now hold the lens between the window and a sheet of paper, but very close to the paper. Slowly move the lens away from the paper and toward the window. Keep watching the paper. What do you see? What happens as you move the lens?



Think It Over

Observing How is an image formed on a sheet of paper? Describe the image. Is it real or virtual? How do you know?

A fish tank can play tricks on you. If you look through the side of a fish tank, a fish seems closer than if you look over the top. If you look through the corner, you may see the same fish twice. You see one image of the fish through the front of the tank and another through the side. The two images appear in different places! How can this happen?

FIGURE 13
Optical Illusion in a Fish Tank
There is only one fish in this tank, but refraction makes it look as though there are two.

Lab zone Discover Activity

Skills Focus Observing

Materials hand lens, white paper

Time 10 minutes

Tips You may substitute an overhead fluorescent light for the sunlit scene viewed through a window. Caution students never to look directly at the sun, even on a cloudy day. This activity works best in a darkened room.

L1

Expected Outcome Students should see an image of the window on the paper, including the scenery seen through the window. They should observe that the scenery is upside-down.

Think It Over The image is formed as the rays of light pass through the lens and onto the paper. The image is real. It is inverted and has been projected onto the paper.

Section 3

Refraction and Lenses

Objectives

After this lesson, students will be able to

O.4.3.1 Explain why light rays bend when they enter a medium at an angle.

O.4.3.2 Identify what determines the types of images formed by convex and concave lenses.

Target Reading Skill

Asking Questions Explain that changing a heading into a question helps students anticipate the ideas, facts, and events they are about to read.

Answers

Sample graphic organizer:

Refraction and Lenses

Questions

1. When does refraction occur?
2. What are the types of lenses?

Answers

1. When light rays enter a medium at an angle
2. Concave and convex lenses

All in One Teaching Resources

- Transparency O47

Preteach

Build Background Knowledge

L2

Introducing Lenses

Show students a hand lens, and have them recall a time when the used a hand lens to observe something small in detail. Ask: **How do objects appear through a hand lens?** *(Bigger than they really are)* Point out the convex surfaces of the lens. Tell students they will learn in this section how a hand lens magnifies objects and how other types of lenses change light.

Instruct

Refraction of Light

Teach Key Skills L2

Bending Light Rays

Focus Review refraction of waves.

Teach Tell students that light waves, like other waves, change in speed and bend as they enter a new medium at an angle. Say that some mediums slow and bend light more than others. Ask: **Do you think light waves travel more slowly through water or air?** *(Students might answer correctly that light waves travel more slowly through water.)*

Apply Ask: **What happens when light travels from water into air?** *(Sample answer: Light waves speed up and bend opposite to the way they would when traveling from air into water.)* **learning modality: verbal**

Math Analyzing Data

Math Skill Making and interpreting graphs

Focus Have students read about the index of refraction in the feature.

Teach Call students' attention to the table. Explain that the lower the number for the index of refraction, the faster light travels through the medium and the less it bends when it enters the medium. Ask: **When light moves from air into a new medium, which medium in the table bends light least?** *(Water)*

Answers

1. Diamond causes the greatest change in the direction of a light ray traveling from air.
2. According to the graph, most solids bend light more than liquids (quartz is an exception).
3. You would not expect light to bend if it entered corn oil at an angle after traveling through glycerol, because corn oil and glycerol have the same value for the index of refraction.

Independent Practice L2

All in One Teaching Resources

- Guided Reading and Study Worksheet: *Refraction and Lenses*

Student Edition on Audio CD

Math Analyzing Data

Bending Light

The index of refraction of a medium is a measure of how much light bends as it travels from air into the medium. The table shows the index of refraction of some common mediums.

1. **Interpreting Data** Which medium causes the greatest change in the direction of a light ray?
2. **Interpreting Data** According to the table, which tends to bend light more: solids or liquids?
3. **Predicting** Would you expect light to bend if it entered corn oil at an angle after traveling through glycerol? Explain.

Index of Refraction

Medium	Index of Refraction
Air (gas)	1.00
Water (liquid)	1.33
Ethyl alcohol (liquid)	1.36
Quartz (solid)	1.46
Corn oil (liquid)	1.47
Glycerol (liquid)	1.47
Glass, crown (solid)	1.52
Sodium chloride (solid)	1.54
Zircon (solid)	1.92
Diamond (solid)	2.42

Refraction of Light

Refraction can cause you to see something that may not actually be there. As you look at a fish in a tank, the light coming from the fish to your eye bends as it passes through three different mediums. The mediums are water, the glass of the tank, and air. As the light passes from one medium to the next, it refracts. **When light rays enter a medium at an angle, the change in speed causes the rays to bend, or change direction.**

Refraction in Different Mediums Some mediums cause light to bend more than others, as shown in Figure 14. When light passes from air into water, the light slows down. Light slows down even more when it passes from water into glass. When light passes from glass back into air, the light speeds up. Light travels fastest in air, a little slower in water, and slower still in glass. Notice that the ray that leaves the glass is traveling in the same direction as it was before it entered the water.

Glass causes light to bend more than either air or water. Another way to say this is that glass has a higher index of refraction than either air or water. A material's **index of refraction** is a measure of how much a ray of light bends when it enters that material. The higher the index of refraction of a medium, the more it bends light. The index of refraction of water is 1.33, and the index of refraction of glass is about 1.5. So light is bent more by glass than by water.

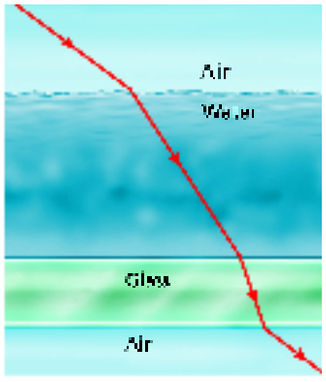


FIGURE 14
Refraction of Light
As light passes from a less dense medium into a more dense medium, it slows down and is refracted.

Prisms and Rainbows Recall that when white light enters a prism, each wavelength is refracted by a different amount. The longer the wavelength, the less the wave is bent by a prism. Red, with the longest wavelength, is refracted the least. Violet, with the shortest wavelength, is refracted the most. This difference in refraction causes white light to spread out into the colors of the spectrum—red, orange, yellow, green, blue, and violet.

The same process occurs in water droplets suspended in the air. When white light from the sun shines through the droplets, a rainbow may appear. The water droplets act like tiny prisms, refracting and reflecting the light and separating the colors.

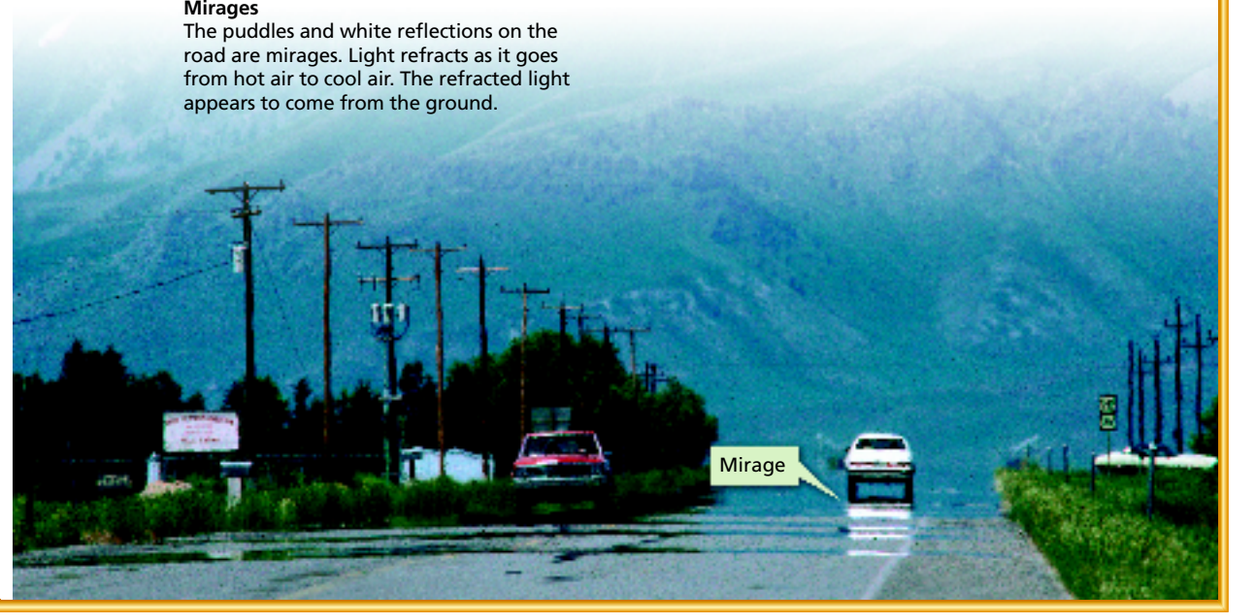
FIGURE 15
Rainbows
A rainbow forms when sunlight is refracted and reflected by tiny water droplets. **Observing** *What is the order of colors in a rainbow?*

Mirages You're traveling in a car on a hot day, and you notice that the road ahead looks wet. Yet when you get there, the road is dry. Did the puddles dry up? No, the puddles were never there! You saw a **mirage** (mih RAHJ)—an image of a distant object caused by refraction of light. The puddles on the road are light rays from the sky that are refracted to your eyes.

Figure 16 shows a mirage. Notice the shiny white areas on the road behind the white car. The air just above the road is hotter than the air higher up. Light travels faster in hot air. So, light rays from the white car that travel toward the road are bent upward by the hot air. Your brain assumes that the rays traveled in a straight line. So the rays look as if they have reflected off a smooth surface. What you see is a mirage.

Reading Checkpoint **What causes a mirage?**

FIGURE 16
Mirages
The puddles and white reflections on the road are mirages. Light refracts as it goes from hot air to cool air. The refracted light appears to come from the ground.



Lab zone Build Inquiry L3

Observing Refraction of Light

Materials light source, 2 prisms, white paper
Time 10 minutes

Focus Have groups of students observe what happens when light passes through two prisms.

Teach Instruct students to pass a beam of light through a prism and onto a piece of white paper to produce a spectrum. Ask: **What do you predict will happen if one color of the spectrum passes through a second prism?** *(Students may predict the colored light will separate into more colors.)* Allow students to test their predictions by using index cards to block all but the red light and then placing a second prism in the path of the red light. *(The second prism will bend the red light, but the color of the light will not change.)*

Apply Encourage students to draw a diagram to show what happened to the light rays when they went through the second prism. **learning modality: visual**

Address Misconceptions L1

Mirage: Image or Imagination?

From movies and television programs, students may have the impression that a mirage is imaginary, or an object that people see that is not really there. Explain that a mirage is an image of a real object formed by the bending of light. **learning modality: verbal**

Differentiated Instruction

English Learners/Beginning L1
Vocabulary: Link to Visual Call students' attention to the inset drawing in Figure 16. Guide students in tracing the light ray from the car to the observer and then along the line of sight from the observer to the mirage. Explain that the light ray bends because it changes speed in air at different temperatures. **learning modality: kinesthetic**

English Learners/Intermediate L2
Comprehension: Use Visuals Use the same strategy, but replace the final question with: **In which direction do light rays first travel from the car?** *(Toward the road)* **How could someone make the mirage disappear?** *(Block light near the car on its way down toward the road or further from the car as the light travels upward.)* **learning modality: kinesthetic**

Monitor Progress L2

Drawing Have students draw a sketch showing what happens to light when it passes at an angle into a medium with a lower index of refraction.

Answers
Figure 15 Red, orange, yellow, green, blue, and violet

Reading Checkpoint Refraction of light

Lenses

Teach Key Concepts L2

Lenses and Refraction of Light

Focus Review what students know about convex and concave mirrors and reflection of light. Then, have them use their prior knowledge to predict how convex and concave lenses might form images.

Teach Ask: **What do you think a convex lens looks like? A concave lens?** *(A convex lens is curved outward. A concave lens is curved inward.)*

Apply Ask: **How do you think the curved surface of a lens affects the transmission of light?** *(Sample answer: It causes light to bend at angles. It creates real or virtual images that may be bigger or smaller than the object.)* **learning modality: verbal**

Use Visuals: Figure 18 L1

Images in Convex Lenses

Focus Have students read the Figure 18 caption.

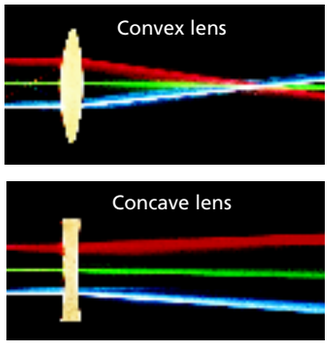
Teach Ask: **How do the two parts of the figure differ?** *(In the top part of the figure, the object is farther from the lens than the focal point; the image is real, larger than the object, and upside down. In the bottom part of the figure, the object is located between the focal point and lens; the image is virtual, larger than the object, and upright.)*

Apply Ask: **What causes the differences in the images?** *(The different positions of the object)* **Which diagram shows how the hand lens forms an image of the ladybug? How do you know?** *(The bottom diagram, because the image is a virtual image)* **learning modality: visual**

All in One Teaching Resources

- Transparency O48

FIGURE 17
Convex and Concave Lenses
A convex lens can focus parallel rays at a focal point. A concave lens causes parallel rays to spread apart.



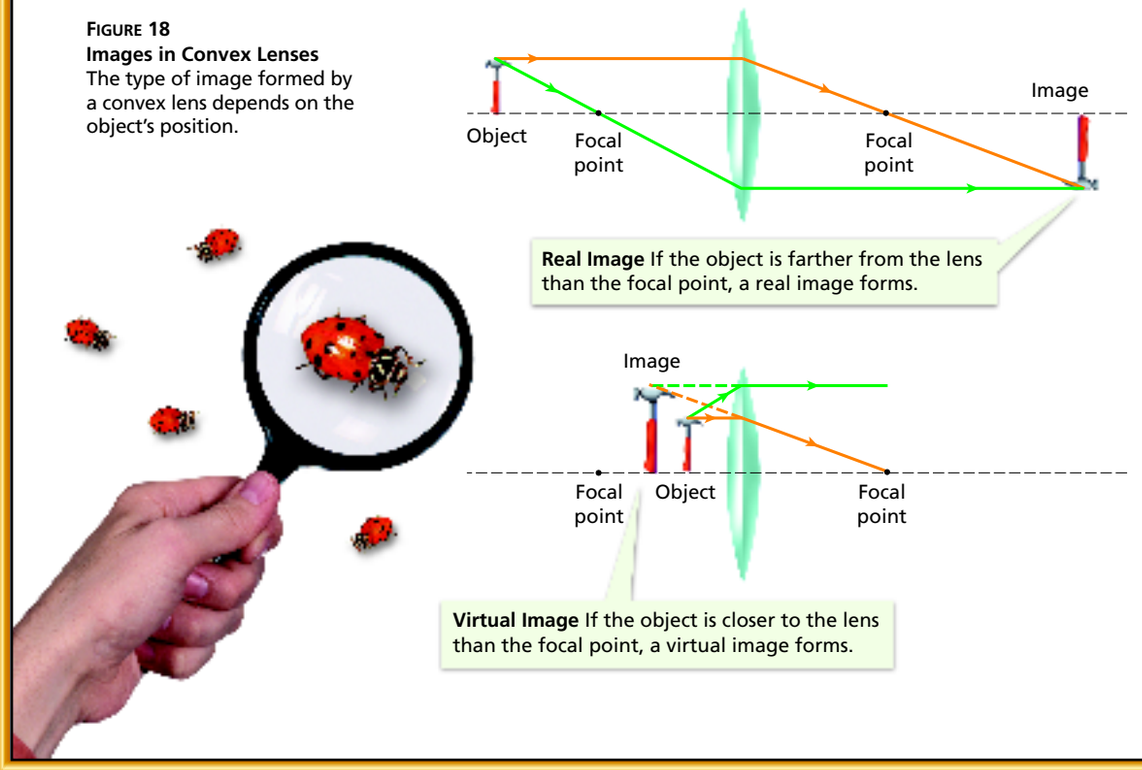
Lenses

Anytime you look through binoculars, a camera, or eyeglasses, you are using lenses to bend light. A **lens** is a curved piece of glass or other transparent material that is used to refract light. A lens forms an image by refracting light rays that pass through it. Like mirrors, lenses can have different shapes. The type of image formed by a lens depends on the shape of the lens and the position of the object.

Convex Lenses A **convex lens** is thicker in the center than at the edges. As light rays parallel to the optical axis pass through a convex lens, they are bent toward the center of the lens. The rays meet at the focal point of the lens and continue to travel beyond. The more curved the lens, the more it refracts light. A convex lens acts somewhat like a concave mirror, because it focuses rays of light.

An object's position relative to the focal point determines whether a convex lens forms a real image or a virtual image. Figure 18 shows that if the object is farther away than the focal point, the refracted rays form a real image on the other side of the lens. If the object is between the lens and the focal point, a virtual image forms on the same side of the lens as the object.

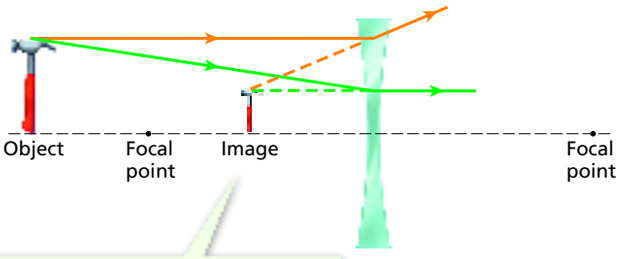
FIGURE 18
Images in Convex Lenses
The type of image formed by a convex lens depends on the object's position.



Differentiated Instruction

English Learners/Beginning L1
Comprehension: Modified Cloze Give students the first paragraph under the heading *Lenses* on this page with blanks instead of important words. Provide them with a list of correct choices. Show students how to fill in the blanks using a sample sentence. Then, have them fill in the blanks in the paragraph. **learning modality: visual**

English Learners/Intermediate L2
Comprehension: Modified Cloze Give intermediate students the same paragraph with the same blanks. For choices, give them a list that contains both correct and incorrect terms. Demonstrate with an example how to fill in the blanks, and then have them fill in the blanks in the paragraph. Ask students to check their choices by comparing it with the paragraph in the book. **learning modality: visual**



Virtual, Reduced Image Wherever the object is placed, a virtual image forms.

FIGURE 19
Images in Concave Lenses
A concave lens produces virtual images that are upright and smaller than the object.
Interpreting Diagrams *Why can a concave lens only form a virtual image?*

Go Online active art

For: Lenses activity
Visit: PHSchool.com
Web Code: cgp-5042

Concave Lenses A **concave lens** is thinner in the center than at the edges. When light rays traveling parallel to the optical axis pass through a concave lens, they bend away from the optical axis and never meet. **A concave lens can produce only virtual images because parallel light rays passing through the lens never meet.**

Figure 19 shows how an image forms in a concave lens. The virtual image is located where the light rays appear to come from. The image is always upright and smaller than the object.

Reading Checkpoint **What is the shape of a concave lens?**

Section 3 Assessment

Target Reading Skill **Asking Questions** Use the answers to the questions you wrote about the headings to help you answer the questions below.

Reviewing Key Concepts

1. **a.** **Identifying** What is a material's index of refraction?
   b. **Relating Cause and Effect** What causes light rays to bend when they enter a new medium at an angle?
   c. **Predicting** If a glass prism were placed in a medium such as water, would it separate white light into different colors? Explain.
2. **a.** **Defining** What is a lens?
   b. **Comparing and Contrasting** Describe the shapes of a concave lens and a convex lens.
   c. **Interpreting Diagrams** Use Figure 18 to explain how you can tell whether a convex lens will form a real or virtual image.

Lab zone At-Home Activity

Bent Pencil Here's how you can bend a pencil without touching it. Put a pencil in a glass of water so that it is half in and half out of the water. Have your family members look at the pencil from the side. Using your understanding of refraction, explain to your family why the pencil appears as it does.

Lab zone At-Home Activity

Bent Pencil L1 Students are expected to explain to their families that the pencil appears to bend because light from the pencil bends when it travels between the air and water. They also might say that the brain assumes light travels in a straight line from the image to the eye, so the pencil is perceived as bent.

Lab zone Chapter Project

Keep Students on Track Make sure students have begun to build their optical instruments. Answer any questions and address any design difficulties they may have. If students are having trouble because their designs are too elaborate, guide them in simplifying their designs.

All in One Teaching Resources

- Transparency O49

Go Online active art

For: Lens activity
Visit: PHSchool.com
Web Code: cgp-5042

Students can interact with the ray diagrams of lenses online.

Monitor Progress L2

Answers

Figure 19 Because parallel light rays passing through the lens never meet

Reading Checkpoint A concave lens is thinner in the center than at the edges.

Assess

Reviewing Key Concepts

1. a. A measure of how much a ray of light bends when it enters that material **b.** One side of the light rays changes speed before the other side. **c.** Yes, because the index of refraction of glass is different than that of water.

2. a. A curved piece of glass or other transparent material that is used to refract light **b.** A concave lens is thicker in the middle; a convex lens is thicker at the edges. **c.** If the object is farther from the lens than the focal point, a real image will form. If the object is closer to the lens than the focal point, a virtual image will form.

Reteach L1

Read aloud the boldface sentences, leaving out one or more important terms in each sentence. Ask students to identify the missing terms.

Performance Assessment L2

Oral Presentation Call on students to define refraction, index of refraction, and mirage. Call on other students to explain how the three terms are related.

All in One Teaching Resources

- Section Summary: *Refraction and Lenses*
- Review and Reinforcement: *Refraction and Lenses*
- Enrich: *Refraction and Lenses*

Lab zone Skills Lab

Looking at Images

Prepare for Inquiry

L2

Skills Objective

After this lab, students will be able to

- control variables by keeping some variables constant and manipulating others
- interpret data by correlating the size of an image with experimental conditions

Prep Time 15 minutes

Time 40 minutes

Advance Planning

Obtain enough convex lenses and light sockets with bulbs and batteries for each group of students. Buy or make cardboard stands.

Safety

Review the safety guidelines in Appendix A.

All in One Teaching Resources

- Lab Worksheet: *Looking at Images*

Guide Inquiry

Invitation

Tell students that convex lenses are used in telescopes and microscopes. Ask: **What do you think convex lenses do?** *(Magnify images of very small or distant objects)*

Introduce the Procedure

Tell students they will use a convex lens to investigate images in this lab.

Troubleshooting the Experiment

- If necessary, demonstrate how to determine the focal length of the lens.
- Lenses with very short focal lengths will not produce clear images at large distances.

Expected Outcome

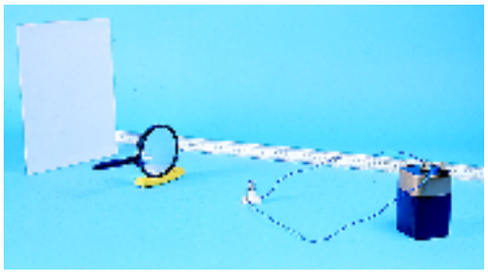
When the light bulb is much farther from the lens than the focal point, the image is real and smaller than the object. The closer to the focal point the bulb is, the larger the real image becomes.

Analyze and Conclude

1. Students kept constant the focal length and the position of the lens. They manipulated position of the bulb and the cardboard. Responding variables were size and location of image.

Lab zone Skills Lab

Looking at Images



Problem

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

Skills Focus

controlling variables, interpreting data

Materials

- tape
- convex lens
- cardboard stand
- blank sheet of paper
- light bulb and socket
- clay, for holding the lens
- battery and wires
- meter stick
- centimeter ruler

Procedure

1. Tape the paper onto the cardboard stand.
2. Place a lit bulb more than 2 m from the paper. Use the lens to focus light from the bulb onto the paper. Measure the distance from the lens to the paper. This is the approximate focal length of the lens you are using.
3. Copy the data table into your notebook.
4. Now place the bulb more than twice the focal length away from the lens. Adjust the cardboard until the image is focused. Record the size of the image on the paper and note the orientation of the image. Record the distance from the bulb to the lens and from the lens to the cardboard.
5. Now, move the bulb so that it is just over one focal length away from the lens. Record the position and size of the image.

Analyze and Conclude

1. **Controlling Variables** Make a list of the variables in this experiment. Which variables did you keep constant? Which was the manipulated variable? Which were the responding variables?
2. **Observing** What happened to the position of the image as the bulb moved toward the lens?
3. **Interpreting Data** Was the image formed by the convex lens always enlarged? If not, under what conditions was the image reduced?
4. **Predicting** What would happen if you look through the lens at the bulb when it is closer to the lens than the focal point? Explain your prediction.
5. **Communicating** Write a paragraph explaining how the distance between an object and a convex lens affects the image formed. Use ray diagrams to help you summarize your results.

Design an Experiment

Design an experiment to study images formed by convex lenses with different thicknesses. How does the lens thickness affect the position and size of the images? *Obtain your teacher's permission before carrying out your investigation.*

Data Table

Focal Length of Lens: ____ cm		Height of Bulb: ____ cm	
Distance From Bulb to Lens (cm)	Distance From Lens to Cardboard (cm)	Image Orientation (upright or upside down)	Image Size (height in cm)

2. As the bulb moved toward the lens, the image moved farther from the lens.

3. No; the image was reduced when the object was farther from the lens than twice the focal length.

4. Students might predict that no image would be projected onto the paper, because the image is virtual when the object is in this position.

5. Students are expected to draw diagrams showing how rays from a bulb are refracted through a convex lens when the object is placed at different distances from the lens. They can use them to explain their results.

Extend Inquiry

Design an Experiment Students' experiments should repeat the procedure in this lab using convex lenses of varying thicknesses.