LESSON 18

Getting Things Into Focus

MOSS PHOTOGRAPHY.COM

No, it's not a Cyclops! How does this transparent object produce this effect?

INTRODUCTION

Can you recall what happens to light as it enters and leaves a transparent rectangular block? What term did you use to describe this process? Many transparent objects do not have flat sides like the block you investigated in Lesson 17. How do you think light behaves when it strikes transparent objects with curved surfaces? How do such transparent objects affect the appearance of other objects that are viewed through them? In this lesson, you will conduct and design some inquiries to discover the answers to these questions.

OBJECTIVES FOR THIS LESSON

Make observations through transparent objects with curved surfaces.

Classify transparent objects with curved surfaces.

Investigate how light behaves when it passes through transparent objects with curved surfaces.

Getting Started

1. One member of your group should collect the plastic box of materials. Divide the round transparent objects between the pairs in your group so that each pair has three different transparent objects.

2. Examine the objects. Discuss the following with your partner.

   Where have you previously seen objects like these?

   Do these objects refract light? What evidence do you have for your answer?

   Do objects like these have a particular name?

3. Sort the objects into two groups.

   What characteristics did you use to sort the objects?

4. Be prepared to share your answers to these questions with the class.

MATERIALS FOR LESSON 18

For you

1 copy of Student Sheet 18.1: Examining Images Made by Convex Lenses
1 copy of Student Sheet 18.2: Investigating Refraction in Convex Lenses
1 copy of Student Sheet 18.3: Investigating a Concave Lens

For you and your lab partner

3 transparent objects
1 metric ruler, 30 cm (12″)
1 white screen
1 wide-slit ray box mask
1 no-slit ray box mask
1 comb

For your group

1 ray box
1 ray box lid
1 60-W clear halogen lightbulb
1 bulb holder
1 extension cord

INTRODUCING LENSES

Transparent objects with curved surfaces like the ones you have just observed are called lenses. Like the block you used in Lesson 17, lenses refract light. Lenses with surfaces that curve outward are called "convex" lenses. Lenses with surfaces that curve inward—like a cave—are called "concave" lenses. Some lenses have a combination of surfaces with different shapes and are named accordingly. For example, a lens with one flat side (or plane) and one convex side is called a "plano-convex" lens. Can you think of any places where you have seen lenses being used?

Inquiry 18.1
Examining Images Made by Convex Lenses

PROCEDURE

1. Place the thicker of the convex lenses on this page. Have your partner hold the ruler so that one end touches the page next to the lens. Keeping your eye at the end of the ruler, pick up the lens and move it slowly toward your eye (see Figure 18.1).

2. Look for any changes in the appearance of the letters on the page as you move the lens. Make any measurements you consider appropriate. Record your responses to A–G on Student Sheet 18.1: Examining Images Made by Convex Lenses.

   A. Record your observations and measurements.

Figure 18.1 *Keeping your eye at the end of the ruler, pick up the lens and move it slowly toward your eye. What do you observe through the lens?*

3. Hold the lens about an arm's length from your body. Look through the lens across the room or out the window.

   B. Describe what you observe through the thick convex lens.

4. Allow your partner to make the same observations by repeating Steps 1–3.

5. Hold up the white screen so that light from the window (or a brightly lit object) shines though the lens and onto the screen. Move the lens toward and away from the screen (see Figure 18.2).

   C. Describe what you observe on the screen.

6. Obtain the clearest image possible on the screen.

   D. Record the exact distance (in centimeters or millimeters) from the lens to the screen.

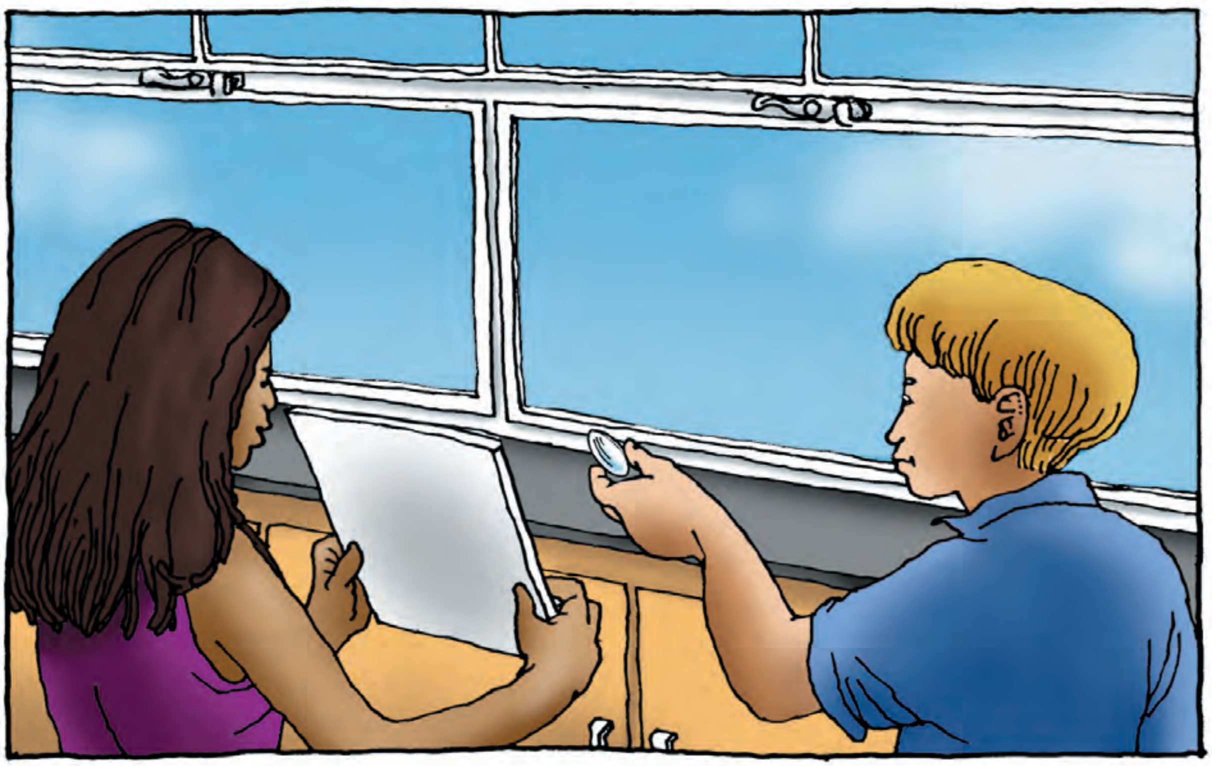


Figure 18.2 *Hold up the white screen so that light shines though the lens and onto the screen. Move the lens toward and away from the screen.*

7. Before answering E, discuss your findings with your group. Here are some suggested points to consider in your discussion.

How did the lens affect the appearance of the size of the letters on the page?

How did the appearance of the letters change as you moved the lens away from the page?

At what distance from the page did the letters look biggest?

What happened to the orientation of the letters as you moved the lens away from the page (and how far from the page did this occur)?

What happened to the size of the letters as you moved the lens away from the page?

What did you observe when you looked at distant objects through the lens?

What did you observe on the screen?

E. List how many images you could make using this lens. For each image, describe its characteristics (magnified or reduced, upright or inverted, real or virtual) and how you made it.

8. Now take out the thinner of the two convex lenses.

F. Investigate the thin convex lens in the same way. Record your observations and measurements.

G. Write a paragraph comparing your results from the two lenses.

9. Be prepared to contribute your observations and ideas to a class discussion on convex lenses.

Inquiry 18.2
Investigating Refraction in Convex Lenses

PROCEDURE

1. Using your knowledge of refraction and your observations from Inquiry 18.1, discuss with your partner how light rays may behave when they enter and leave a convex lens. Be prepared to share your ideas with the class.

2. Set up the apparatus shown in Figure 18.3. (You will work in pairs, but will share a ray box with the other pair in your group.) Record your responses to A–I on Student Sheet 18.2: Investigating Refraction in Convex Lenses.

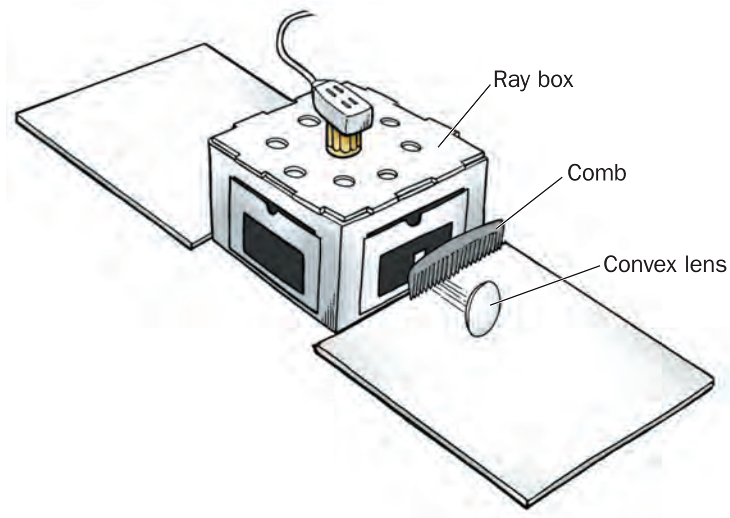


Figure 18.3 *Set up the apparatus as shown. You will need to adjust the position of the comb and lens to get the rays to pass through the lens.*

3. Use the apparatus to investigate what happens to rays of light when they strike each of the two convex lenses.

   A. Design a table for recording your observations and measurements.

4. Discuss your observations with your group. As a group, discuss and then record your answers to the following questions:

   B. Were all the rays that struck a particular lens refracted through the same angle?

   C. What happened to the light rays after they left the lenses?

   D. At what distances did this happen?

   E. Compare this distance with the one you measured for D of Inquiry 18.1. Comment on your comparison.

   F. How can your observations help you explain the inverted image you obtained on the screen in Inquiry 18.1?

SAFETY TIP

Do not touch the lightbulb. It is hot and may cause painful burns.

5. Read "How a Convex Lens Focuses Light."

6. Use the reader and your observations to answer these questions:

G. Determine the focal lengths of the thick and thin convex lenses.

H. Is there a relationship between focal length and the curvature of the convex lens? If so, what is it?

I. What is the relationship between focal length and the distance at which the lenses produced focused images of distant objects on a screen?

7. Read "How a Convex Lens Forms an Image."

HOW A CONVEX LENS FOCUSES LIGHT

When you moved the lenses toward and away from the screen or the page, you found that you could obtain a clear image with the lenses only in certain positions. This clear image is said to be in focus or focused. The distance between the convex lens and the object when the image of the object comes into focus depends on the shape of the convex lens.

In Inquiry 18.2, you discovered that parallel rays are refracted by a convex lens so that they come together (converge) at a point on the other side of the lens. This point at which light rays converge and cross over is called the focal point of the lens. The distance between the middle of the lens (its optical center) and the focal point is called the focal length of the lens. You can determine the approximate focal length of a lens by measuring the distance between the lens and a focused image of a distant object (for example, the inverted image you observed on the white screen).

Some Important Features of a Convex Lens

Use this diagram to help you understand how a convex lens works.

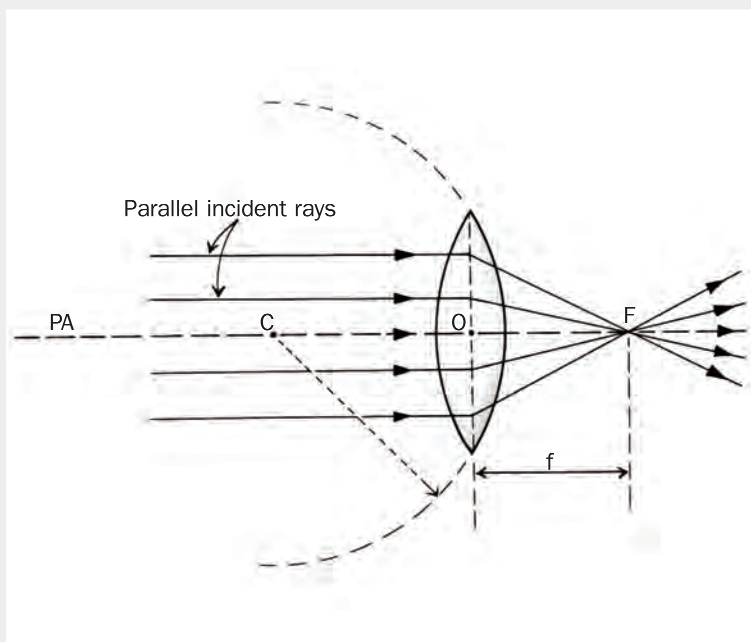
O *(optical center): Light rays passing through this point do not change direction.*

C *(center of curvature): This point is the center of the sphere of which the lens surface is a part. Your lenses have two centers of curvature, one for each curved surface. Only one center of curvature is shown in this illustration.*

PA *(principal axis): This line connects the center of curvature and the optical center of the lens.*

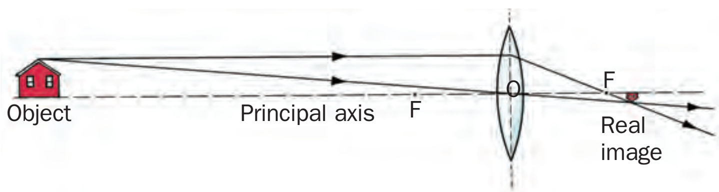
F *(focal point): This is the point on the principal axis through which all light rays traveling parallel to the principal axis of a convex lens meet.*

f *(focal length): This is the distance between the focal point and the optical center.*



HOW A CONVEX LENS FORMS AN IMAGE

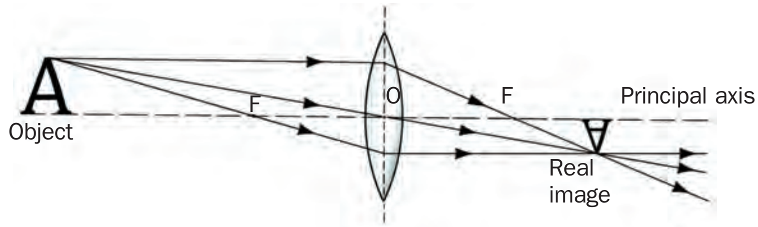
Look at the ray diagram. It shows how an image of a distant object—like the scene outside a window—is focused on the screen by a convex lens.



The formation of an image of a distant object by a convex lens

The rays reflected from a distant object—the house—are almost parallel to one another (and to the principal axis). These parallel rays are refracted so that they pass through or near the focal point. Rays passing from the object through the optical center are not refracted. Look closely at the ray diagram. You will notice that the place where these rays cross (only two rays are shown on the diagram) determines where the image is formed. The image is formed just beyond the focal point of the lens. (In fact, for a distant object, the place where the image is formed is very close to the focal point of the lens.) The image is called a "real image" because light reflected from the object really exists and can be detected at this point in space. Because it is a real image it can be projected onto a screen. The image is inverted because the light rays that produce the image have crossed over at the focal point of the lens.

Objects closer to the lens—like the letter A in this ray diagram—are brought into focus farther from the focal point. However, the image is still real and inverted.

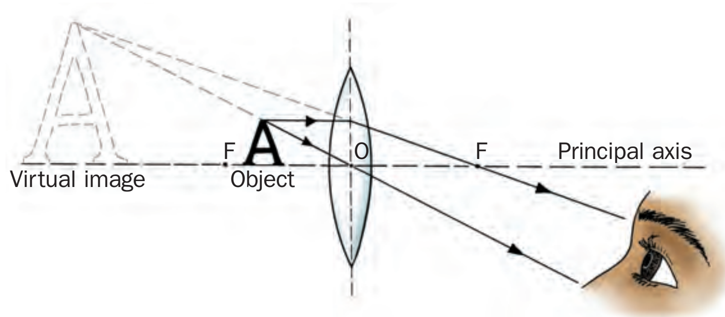


The formation of an image when an object (in this case, the letter A) is closer to a convex lens

This image is the same as the inverted image you may have observed when you looked at a page of your Student Guide through the lenses in Inquiry 18.1.

What would happen if an object were really close to the lens—inside its focal length? Would the image produced be a real or virtual one? Would it look bigger or smaller than the object? Look at the ray diagram below. It explains how a person would see an object (the solid letter A) observed in this way.

The rays appear to come from a point behind the object. The image is magnified, upright, and virtual. Where in the previous lessons have you encountered such an image?



The formation of an image when the object (the solid letter A) is very close to a convex lens (that is, within the focal length of the convex lens)

Inquiry 18.3
Investigating a Concave Lens

PROCEDURE

1. Working with your partner, investigate the image(s) the concave lens can produce.

   A. On Student Sheet 18.3: Investigating a Concave Lens, describe the image(s) produced by a concave lens.

2. Predict what will happen if you shine light rays through the lens.

   B. Draw a diagram of your prediction.

3. Using the equipment available, devise your own procedure to test your prediction.

   C. Record your observations.

4. Discuss your observations with members of another group. Work with them to answer the following questions about the concave lens:

   D. What does this lens do to incident light rays?

   E. Does this lens have a focal point—a point where the rays come together (or appear to come together) and cross over? If so, can you observe it, or can you suggest where it could be?

   F. What are the characteristics of the image produced by a concave lens? (Is it upright or inverted, magnified or reduced, real or virtual?)

5. Share your ideas in a short class discussion about concave lenses, then read "How a Concave Lens Forms an Image."

REFLECTING ON WHAT YOU'VE DONE

1. Discuss with your partner the characteristics of convex and concave lenses.

   A. Working with your partner, complete Table 1 on Student Sheet 18.3.

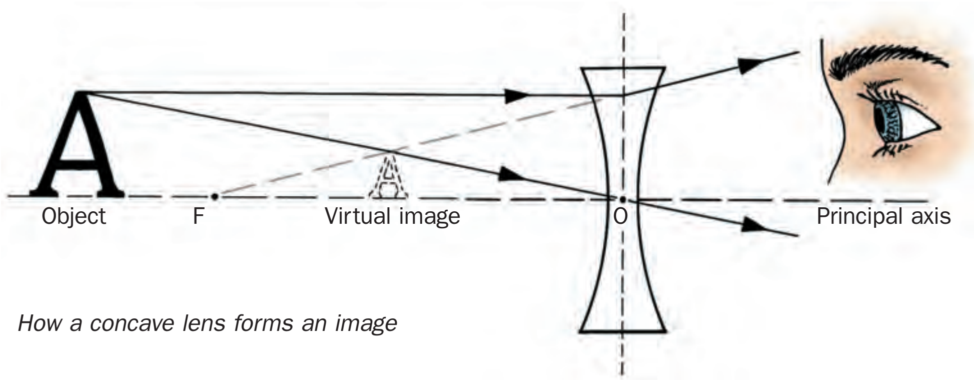
2. Read and discuss with your class "A Colored Blur."

SAFETY TIP

Turn off the ray box immediately after you finish using it. Allow the ray box to cool.

HOW A CONCAVE LENS FORMS AN IMAGE

Look at the ray diagram. It shows how a concave lens forms an image.



How a concave lens forms an image

As parallel rays from an object pass through the concave lens, they are refracted and diverge. To an observer looking at the object through the lens, the image is smaller than the object. No light from the object is focused where the image appears to be. The image produced by a concave lens is therefore a virtual image. When observing a distant object through a concave lens, the image of the object appears to be very near the focal point of the lens. Concave lenses only produce reduced, upright virtual images.

A Colored Blur

When you used lenses to look at the letters on the page, did you notice something odd about the color of the image? Did you see a colored blur? Have you seen this effect before?

When white light passes from one transparent material to another, the wavelengths that make up the white light are refracted by slightly different amounts. This causes the white light to split into different colors—something that is useful when you are using a prism to observe the spectrum of white light. But what if you want to use a lens to observe a clear, accurately colored image? When light passes through the lens, different colors in the light are refracted by slightly different amounts. These different colors therefore focus at slightly different distances from the lens. This creates a colored blur—called a chromatic aberration—around the image.

Many modern lenses (in cameras and telescopes, for example) are specially designed to reduce chromatic aberrations by making different colors focus at the same point. These lens are called achromatic lenses. (The term "achromatic" means without color.) This photograph shows chromatic aberration produced by an inexpensive hand lens when it is used to observe a printed page.

JEFF MCADAMS, PHOTOGRAPHER, COURTESY OF CAROLINA BIOLOGICAL SUPPLY COMPANY

MOVIE PHYSICS

In a movie theater, you watch a real image projected onto a screen. How is this done?

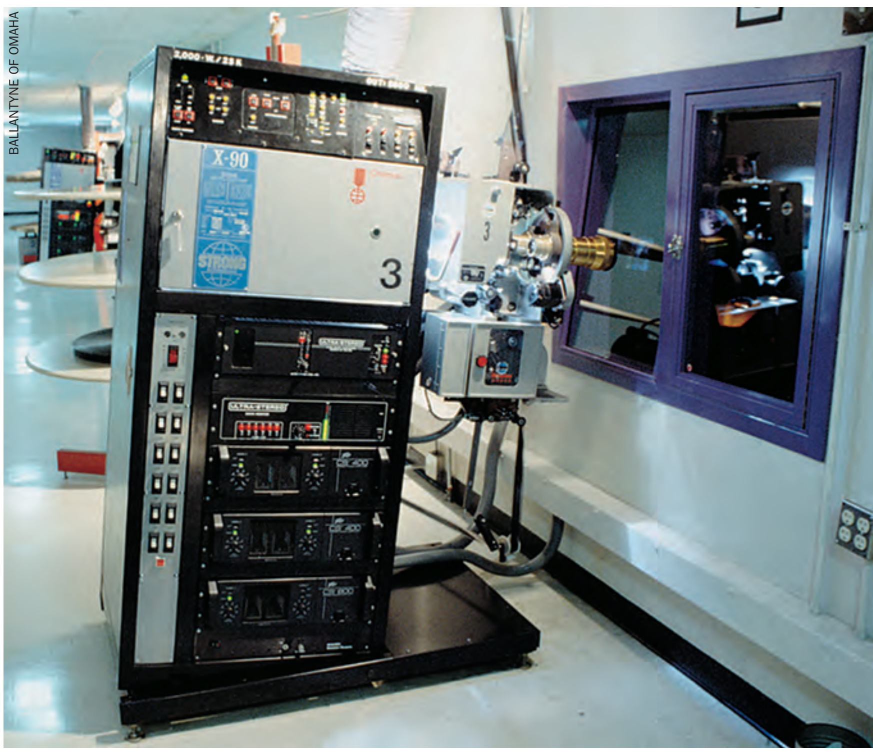
As the movie theater lights dim, voices hush. In the dark you can hear an occasional cough or the rustle of candy wrappers and smell the aroma of buttered popcorn. The screen lights up. Welcome to the world according to Hollywood—a world of make-believe made from moving images and digital sound. Hold on tightly to your seat. The movie is about to start.

What is the physics behind watching a movie? While a movie character often begins in someone's imagination, the character's image on the screen is a real image. Light rays shined onto the movie screen produce the image we see as a moving picture. But how is such a big, clear, and moving image produced?

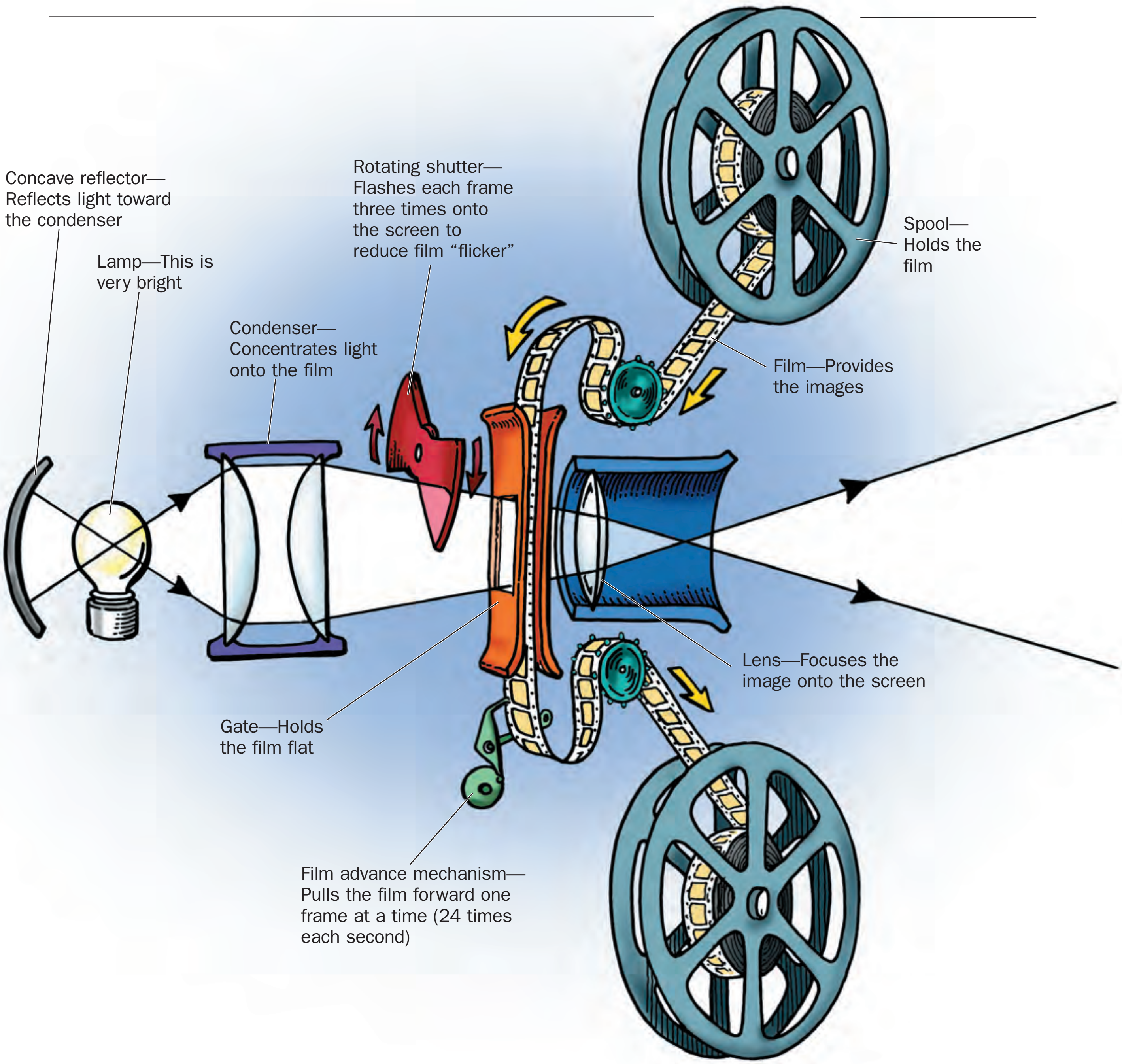
Projecting the Best Image

When you made your pinhole camera you projected an image onto a screen. The image was small, dim, and upside down. A projector at the back of the movie theater is a more complex optical device. It uses a very bright light source and lenses to project a big, bright image onto the screen.

Let's see how a movie projector works by following the light from its source in the projector to the image on the movie screen. The film—a long strip of transparent pictures—is positioned in the middle of the projector. Behind the film is a very bright lamp sitting inside a concave reflector. White light from the lamp is concentrated though two lenses—called a condenser—onto the film. The rays emerging from the



A modern movie projector is a complex piece of machinery that combines advanced optics and electronics.



A lot goes on inside a movie projector. Follow the light from the lamp through the film and the lens.

condenser pass through the film. The transparent pictures on the film act like a series of multicolored filters. The filtered light, carrying the image on the film, then passes through a series of lenses that spreads the light out and focuses it onto the movie screen.

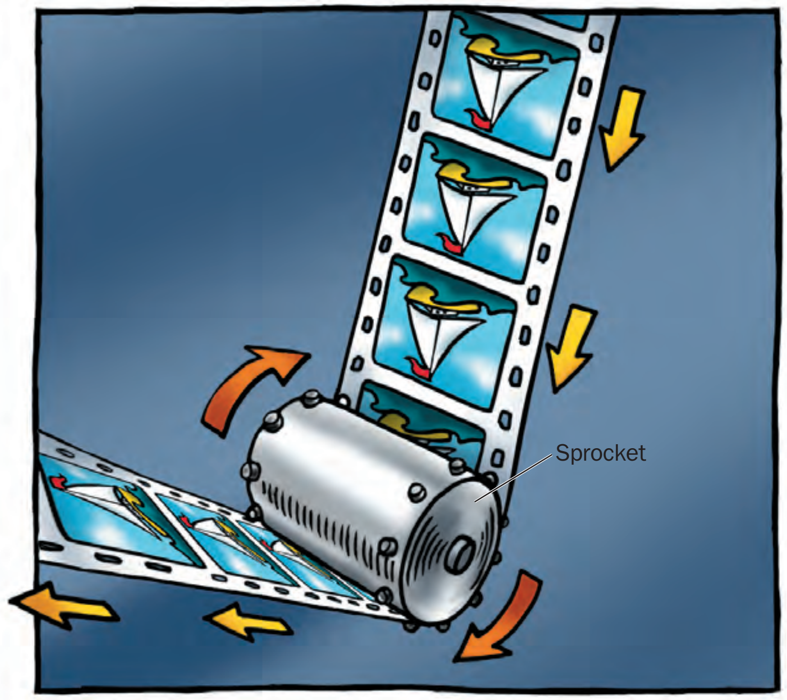
Look carefully next time you are in a movie theater. You will see this spreading beam of light emerging from the projector booth. Because the projector is far from the screen at the opposite end of the theater, the light can spread out. When the light strikes the screen, the image produced is therefore many times larger than the original tiny picture on the film. The movie screen then reflects some of the light that forms this image to your eyes.

Making Movies Move

The thousands of images that make up the moving picture we see on the screen are stored on a long piece of transparent film. This film is wound on a reel and runs continuously through the movie projector. The film is fed into the projector upside down and reversed left to right. When light rays shining through the film pass through the lenses of the projector, they cross. The picture on the screen therefore appears to the audience as right-side up.

The projector uses sprocket gears that fit into the small holes in the edges of the film to feed 24 of these separate images past the lens each second. A shutter flashes each of these images onto the screen three times. (This means 72 pictures are projected each second. This flash rate is so fast that our eyes do not notice the images flickering on the screen.) Our eyes and visual system interpret these pictures as moving. Movies are an example of an optical illusion. You will look at optical illusions in more detail in Lesson 24.

Next time you go to a movie, check out the physics of the movie theater. It may prove to be as exciting as the film! ☐



The film is fed into the projector upside down and reversed left-to-right. When inverted by the projector, it appears on the screen in its correct orientation.