5.3 Using Lenses to Form Images

A lens is a piece of transparent material that can bend, or refract, light rays in useful ways to help form a well-focussed image. Concave lenses are thinner in the middle than at the edge. They are used to diverge light rays. Convex lenses are thicker in the middle than at the edge. They are used to converge light rays.

Key Terms

concave lens
convex lens
focal length
lens

Light rays refract through a piece of glass in a predictable way. Recall from Section 5.1 that when a light ray passes from air into a denser material, such as glass, it bends *toward* the normal. When the light ray passes out of the glass, back into the air, it bends *away from* the normal. Using these facts about light it is possible to design and construct lenses. A **lens** is a curved piece of transparent material, such as glass or plastic, that refracts light in such a way as to converge or diverge parallel light rays. The image that a lens forms depends on the shape of the lens. Like curved mirrors, a lens can be convex or concave.

5-8 Observing Light Rays

Find Out ACTIVITY

In this activity, you will observe how light rays refract as they pass through lenses.

Materials

- ray box
- concave lens
- convex lens
- printed page

What to Do

1. Shine the ray box at a concave lens. Observe how the rays are affected. Draw your observations.
2. Look through the concave lens at some printed text. Observe the appearance of the print. Draw your observations.
3. Shine the ray box at the convex lens. Observe how the rays are affected. Draw your observations.
4. Look through the convex lens at some printed text. Observe the appearance of the print. Draw your observations.

What Did You Find Out?

1. Compare what you observed about the appearance of the text with each of the two lenses.
2. Which type of lens would be best used as a magnifying glass? Why?
3. What might the other kind of lens be used for?

Concave Lenses

Concave lenses are lenses that are thinner in the middle than at the edge. As shown in Figure 5.22, light rays that pass through a concave lens diverge. The rays are refracted outward, and never meet at a focal point. The image formed is always upright and smaller than the actual object (see Figure 5.23 and Table 5.1). Concave lenses are used in some types of eyeglasses and some telescopes, and are often used in combination with other lenses.

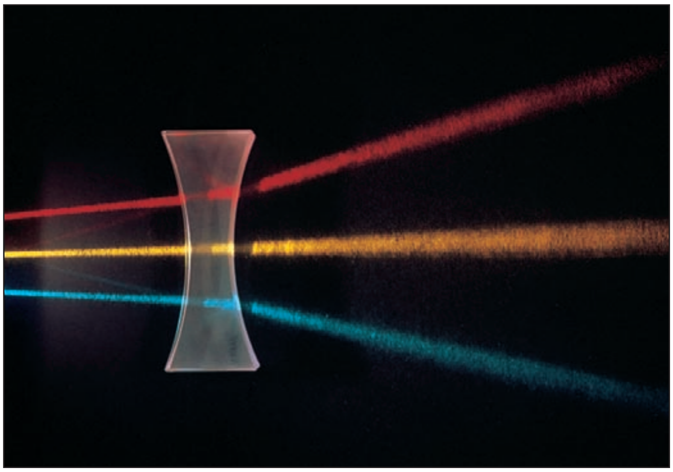


Figure 5.22 Light rays diverge when they pass through a concave lens.

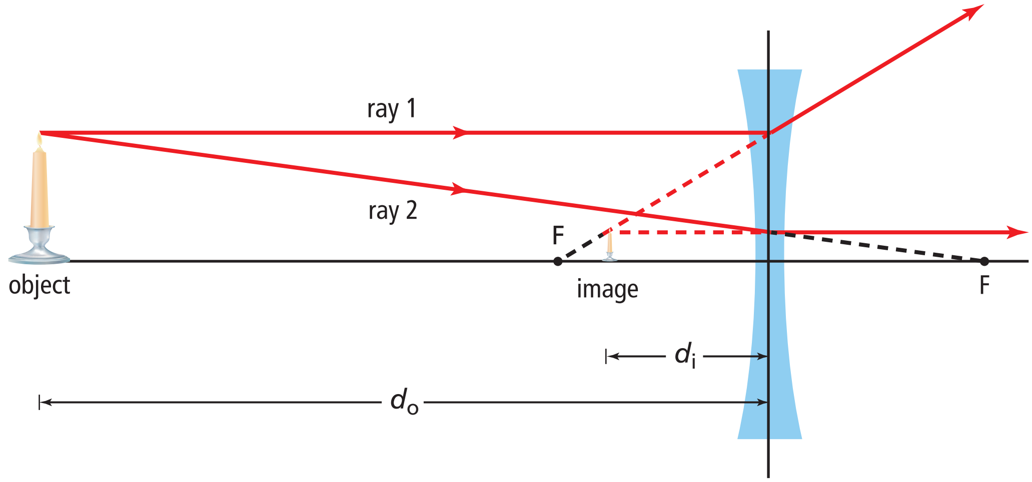


Figure 5.23 Concave lenses produce images that are upright and smaller compared to their objects.

Table 5.1 Images Formed by Concave Lenses	
Distance of Object from Lens	**Type of Image Formed**
Any location	Smaller, upright

Did You Know?

Lenses have been made and used for hundreds of years. In 1303, French physician Bernard of Gordon wrote of the use of lenses to correct eyesight. Around 1610, Galileo used two convex lenses to make a telescope, with which he discovered the moons of Jupiter.

internet connect

Raindrops take on a spherical shape as they fall, which gives them the shape of a convex lens. A drop of water sitting on a glass slide has a nearly spherical shape. Investigate whether a water droplet or a glass bead of the same size would make a good magnifying lens. Start your search at **www.bcscience8.ca.**

Convex Lenses

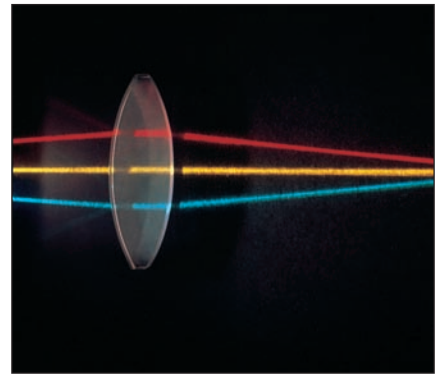


Figure 5.24 Light rays converge when they pass through a convex lens.

Convex lenses are lenses that are thicker in the middle than at the edge. As shown in Figure 5.24, light rays that pass through a convex lens come together, or converge. When parallel rays strike a convex lens from one side, they will all come together at the focal point of the lens. Light passing through the thicker, more curved areas of the lens will bend more than light passing through the flatter areas. A light ray that passes straight through the centre of the lens is not refracted. The image formed by a convex lens depends on the positions of the lens and the object (see Figure 5.25).

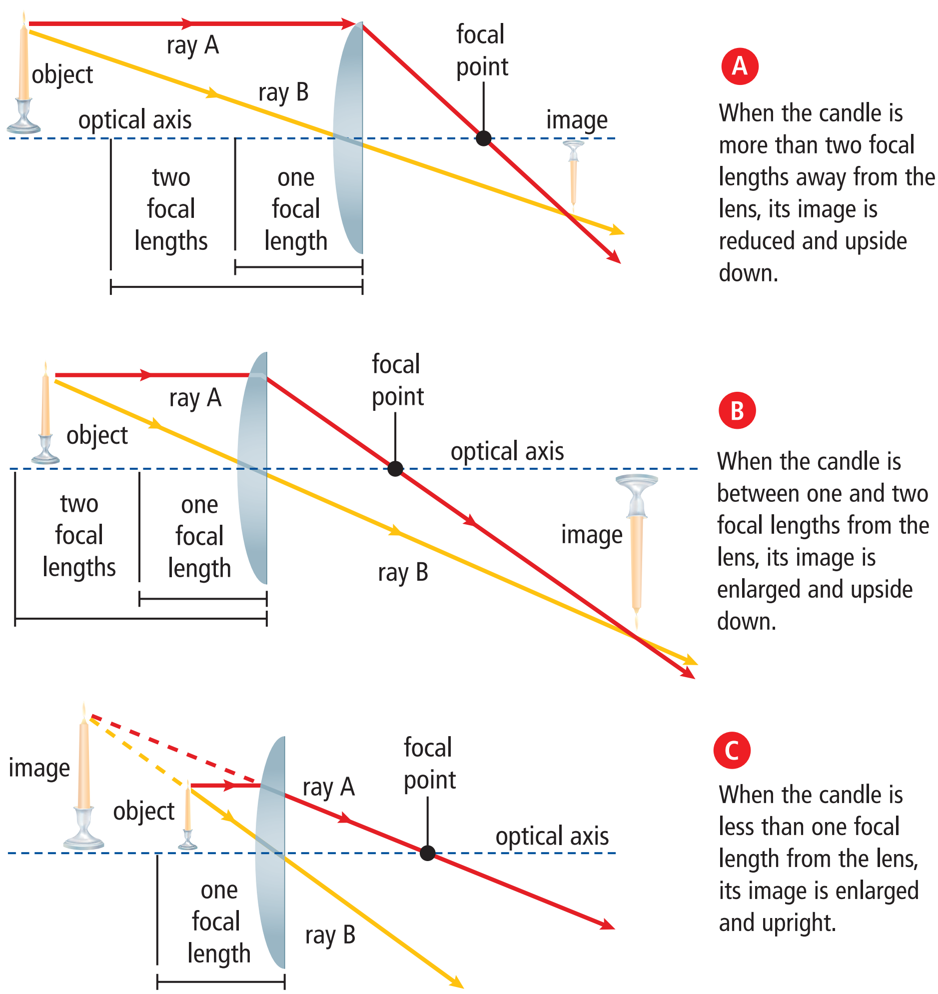


Figure 5.25 An image formed by a convex lens may be inverted, or flipped upside down.

Focal Length in Convex Lenses

Convex lenses and concave mirrors share a similar property in that the light rays converge at the focal point. The distance from the centre of the lens or mirror to the focal point is called the **focal length** (see Figure 5.26). There is a mathematical relationship linking the distance of the object in front of the lens to the distance of the image formed by the lens.

- If the object is more than two focal lengths in front of the lens, the image is smaller than the object and inverted.
- If the object is moved closer to the lens so that it is one to two focal lengths away, the image is larger than the object and still inverted.
- If the object is very close, less than one focal length away, the image appears to be located on the other side of the lens and is both upright and larger than the object.

As summarized in Table 5.2, the type of image a convex lens forms depends on where the object is relative to the focal point.

Suggested Activities

Find Out Activity 5-9 on page 194
Find Out Activity 5-10 on page 195

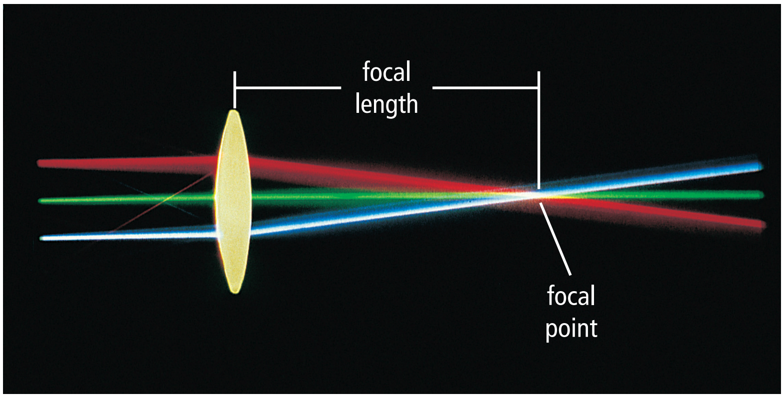


Figure 5.26 The focal length of a convex lens

Table 5.2 Images Formed by Convex Lenses

Distance of Object from Lens	Type of Image Formed
More than two focal lengths	Smaller, inverted
Between one and two focal lengths	Larger, inverted
Object at focal point	No image
Less than one focal length	Larger upright

Reading Check

1. What happens to parallel light rays that strike a concave lens?
2. What happens to parallel light rays that strike a convex lens?
3. What type of image is formed by a concave lens?
4. What determines the type of image that is formed by a concave lens?

Explore More

Eyeglasses would more correctly be called "eyeplastics" these days. Glass refracts well but is heavy and can shatter. The highest quality of plastic in widespread use for glasses is polycarbonate plastic. Find out what properties it has that makes it so useful in lenses. Start your search at **www.bcscience8.ca.**

5-9 Make a Model of a Projector

Find Out ACTIVITY

In this activity, you will examine how an image is affected when seen through a beaker full of water. You will also use a lens to project the image of a light filament onto a screen. A light filament is the twisted wire inside a light bulb.

Safety

- Make sure the electrical cord does not get wet.
- Be careful not to burn yourself with the light bulb.

Materials

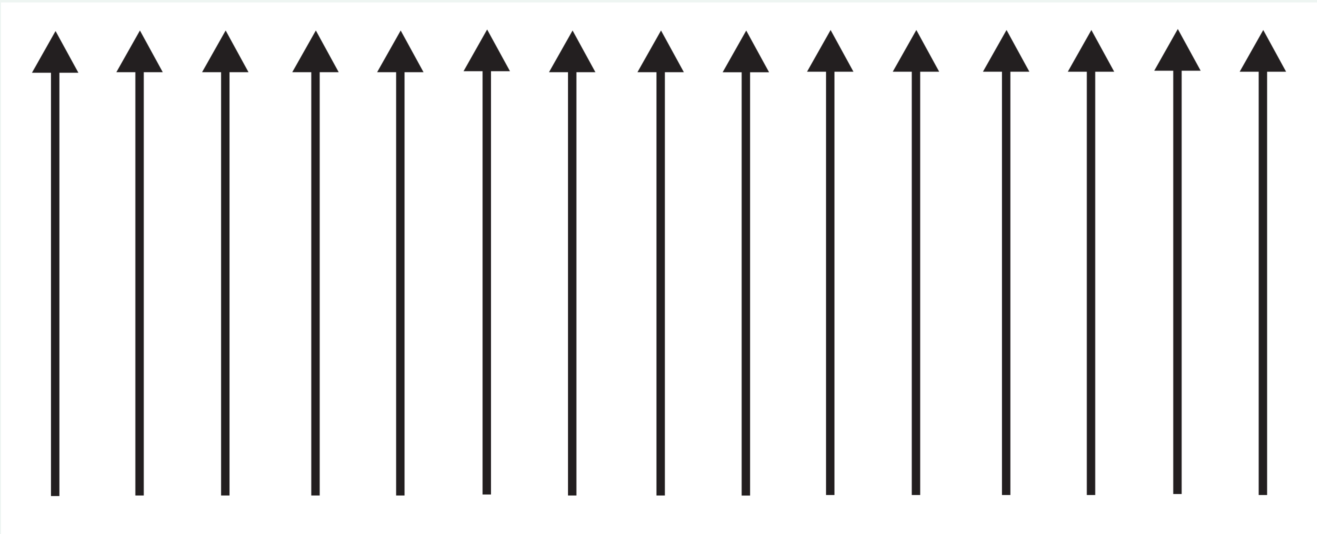
- sheet of paper
- felt pen
- beaker
- water
- convex lens
- unfrosted light bulb

What to Do

1. Draw a series of arrows on a sheet of paper, as shown, and then view the arrows through a beaker full of water. Move the paper left and right and then compare this to the movement of arrows seen through the beaker.
2. Darken the room and turn the light bulb on. Hold the convex lens between the unfrosted light bulb and a plain piece of paper.
3. Move the lens back and forth between the light bulb and the piece of paper. Keep adjusting the distance until you see a sharp image of the filament. Note the size of the image compared to the actual size of the filament.

What Did You Find Out?

1. In step 1:
   (a) How did the orientation of the projected image of the arrows compare with the actual arrows side to side, and up and down?
   (b) How did the projected image of the arrows compare with the actual arrows in terms of size?
2. In step 3:
   (a) How did the orientation of the projected image of the filament compare with the actual filament side to side, and up and down?
   (b) How did the projected image of the filament compare with the actual filament in terms of size?
3. How is the beaker of water like a double convex lens?



5-10 Pinhole Camera

Conduct an INVESTIGATION

Inquiry Focus

Skill Check

- Observing
- Classifying
- Modelling
- Explaining systems

Safety

- Never look directly at the Sun with any camera, including the one constructed in this activity.

Materials

- 2 tubes of different diameters (from wrapping paper, paper towels, aluminum foil or plastic wrap) or make 2 tubes using tape and paper
- adhesive tape (with frosty appearance, not clear)
- scissors
- aluminum foil
- pushpin

A tiny hole can act like a lens.

Question

Can a pinhole camera be used to make an image of a bright object such as a light filament or a television screen?

Procedure

1. Obtain two tubes of different diameters so one can slide inside the other.
2. Completely cover one end of the smaller diameter tube with adhesive tape by placing overlapping strips of tape together. The tape is the screen that the image will be projected on.
3. Completely cover one end of the larger diameter tube with aluminum foil and use tape to hold it in place. Use a pushpin to poke a hole in the foil. The hole in the foil acts like a lens.
4. Slide the smaller tube into the larger tube keeping the tape screen and the aluminum foil on the same side. Begin by sliding the tape right up against the foil.
5. You have just made a camera! Point your camera at a bright object such as a bare light bulb or a television that is turned on. CAUTION: Never look directly at the Sun through any camera, including this one.
6. Slide the smaller tube away from the foil until the image comes into focus. A darkened room may be helpful for this. Is the image in the same orientation as the object or is it inverted?
7. Rotate the camera as you view an image. Does the image rotate with the camera?
8. Clean up and put away the equipment you have used.

Analyze

1. How would the letter *d* appear if viewed through your camera?
2. Explain, using a ray diagram, why the image formed in the camera is inverted.

Conclude and Apply

1. Passing through a forest on a bright day, you notice that on the ground right under some leaves there are many tiny images of the Sun. Explain how these images form.

Wild, Weird, Wonderful

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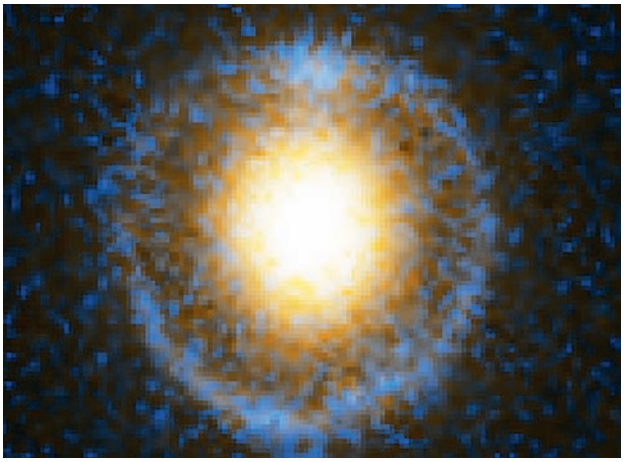
Gravitational Lenses

Imagine that there is a region deep in space that you would like to explore with your telescope, but the distance is just too great to see anything. What if you discovered that halfway between you and the object there was a huge magnifying glass that focussed the light from the distant object right at Earth?

All objects have mass, and where there is mass there is gravity. Gravity not only holds you to Earth and keeps the Moon from flying out of its orbit, it also attracts light. The effect is small for small objects like humans, planets, and individual stars. But gravity can refract light rays passing by a galaxy by a huge amount. When gravity causes many light rays to come together at one point, then we have a lens—a gravitational lens.

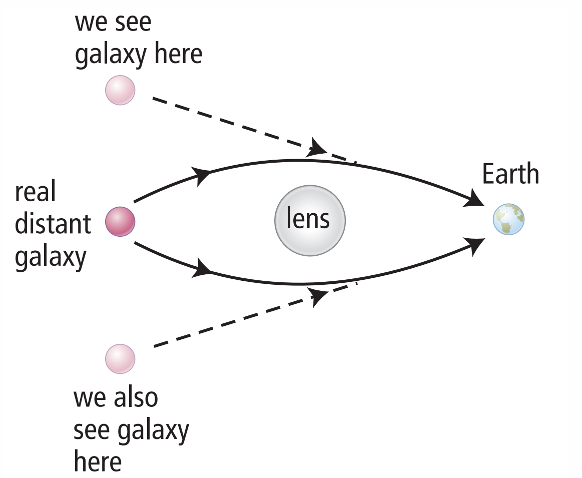
The photograph at the bottom left shows an Einstein ring. The gravitational lens is the bright galaxy in the centre. The blue ring is the distorted image of another galaxy that is on the far side of the lens. The lens is actually in front of the distant blue-coloured galaxy. Light from the blue galaxy passes on all sides of the lens and is pulled together again as it arrives at Earth.



An Einstein ring

A white galaxy

The photograph above shows what appear to be two smaller white galaxies on either side of the lens. Actually it is one galaxy that is as far behind the lens as we are in front of it. It may seem strange that we get two images, but some light travels above the lens and other light from the same source travels below the lens. The light from the white galaxy has been travelling through space for a very long time. It took two billion years to reach the lens, and another two billion years to reach Earth.



What appears to be two galaxies is actually only one galaxy.

Check Your Understanding

Checking Concepts

1. What is a lens?
2. (a) Make a sketch of three parallel light rays passing through a concave lens.
   (b) Make a sketch of three parallel light rays passing through a convex lens.
3. Describe the image formed by a concave lens.
4. As an object comes closer to a convex lens what happens to:
   (a) the size of the image?
   (b) whether the image is upright or upside down?
   (c) the location of the image?
5. List two factors that affect the way that light is refracted through a lens.
6. List two uses of convex lenses.
7. List two uses of concave lenses.

Understanding Key Ideas

8. What is the difference between the way parallel light rays are affected by a concave mirror and a concave lens?
9. Does a concave lens affect light more like a concave mirror or a convex mirror? Explain your answer.
10. Explain why a drop of water placed on the page of a book magnifies printing beneath it.
11. Reading glasses help people to see small print. What sort of lens would be used in them?

Pause and Reflect

The archer fish is a remarkable hunter that catches insects that are resting on branches or reeds up to 2 m above the water. The archer fish sights the insect from beneath the water and then shoots a stream out of its mouth at the insect. Light refracts when it passes from air into water, so the insect appears to be in a different place than it really is. Yet the archer fish is deadly accurate. How do you think this is possible?

Chapter Review

Prepare Your Own Summary

In this chapter, you investigated how optical systems make use of mirrors and lenses. Create your own summary of the key ideas from this chapter. You may include graphic organizers or illustrations with your notes. (See Science Skill 10 for help with using graphic organizers.) Use the following headings to organize your notes:

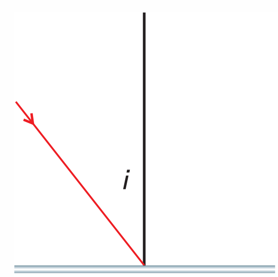
1. The Ray Model of Light
2. Convex Mirrors
3. Concave Mirrors
4. Convex Lenses
5. Concave Lenses

Checking Concepts

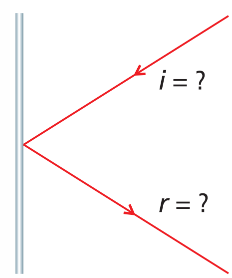
1. State the law of reflection.
2. Use a ray diagram to explain why a light appears dimmer the farther the observer is from it.
3. What is the difference between reflection and refraction?
4. How is an opaque object different from a translucent object in terms of its ability to transmit light?
5. How does the direction of a ray of light change as it passes from air into water?
6. (a) What are the three basic shapes of mirrors?
   (b) With which shape of mirror do light rays converge?
7. How does the reflection from a convex mirror appear to make objects seem smaller?

Understanding Key Ideas

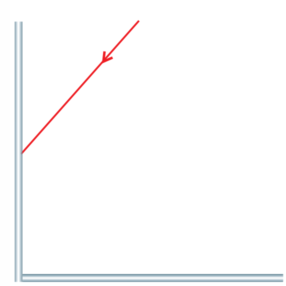
8. Draw a diagram of a light ray reflecting off the surface of a flat mirror. Label the normal, the incident ray, the reflected ray, the angle of incidence, and the angle of reflection.
9. Copy the diagrams below into your notebook. Complete the missing parts of each diagram.



r = ?
Draw the reflected ray.



Draw the normal.



Draw the two reflected rays. Compare the directions of the light striking and bouncing off the mirror.

10. Making reference to the normal line, describe the change in the direction of a light ray that travels from:
(a) air into water
(b) glass into air

11. Draw a diagram to show how an image the same size as an object can be produced by reflection from a flat mirror.

12. As an object moves closer to a convex lens, what happens to the size and orientation of the image?

13. Draw a ray diagram to show what happens to light rays as they pass through:
(a) a convex lens
(b) a concave lens

14. (a) How does the relative thickness of a convex lens affect its ability to refract light?
(b) Draw a thin and a thick convex lens. Show how light rays pass through each of them.

15. Draw ray diagrams to illustrate the difference between opaque, translucent and transparent.

16. Copy the following table into your notebook. For each of the following examples, decide what kind of lens or lenses need to be used in the light fixtures. Use a diagram to show how the lens is affecting the light.

Light Fixtures	Type of Lens	How the Lens Affects Light Rays
(a) A reading light that lights one spot in the room while leaving other areas dark		
(b) An outdoor light that spreads an even illumination over a wide area		
(c) A flashlight that spreads a diffuse, dim light over a wide area, while shining a bright focussed beam in the middle		

17. A magnifying glass contains a lens that can focus the light from the Sun at a single point on the ground.
(a) What shape of mirror can also do this?
(b) Draw a ray diagram to show parallel light from the Sun striking this mirror and to show where the light rays converge.
(c) Which is better for focussing the Sun's light at a point on the ground, a lens or a mirror? Explain.

18. Decide whether each of the following is opaque, translucent, or transparent. Explain your reasons.
(a) your tooth
(b) your skin
(c) your fingernail
(d) the lens of your eye

Pause and Reflect

Suppose you have been given a concave mirror and you have been asked to find its focal point. Describe a procedure that you could use to do this.