12.1 Characteristics of Lenses

Key Terms
lens
converging lens
diverging lens
chromatic aberration

A **lens** is a transparent object with at least one curved side that causes light to refract. Like mirrors, lenses have surfaces defined as concave and convex, and you can predict characteristics of images produced by lenses, such as in a camera.

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

You may have focussed a camera while taking pictures and observed the lens moving in and out. This type of focussing is not convenient in applications such as cellphone cameras and instruments such as an endoscope (see page 466). An electronics company has developed a liquid lens, shown in **Figure 12.1**. The lens can change shape and, as you will learn in this section, the shape changes the focal length of the lens. As a result, the liquid lens does not need to move in and out to focus on objects that are nearby or far away.

The liquid lens consists of two liquids sealed in a transparent tube. The liquids have different indices of refraction, and they will not mix together. The shape of the surface between the liquids determines the focal length of the lens. Once the lens is placed in its holder, electrical leads send a potential difference across the tube. The potential difference alters the lens properties such that the shape of the surface between the two fluids changes. The precise shape of the surface, and therefore the focal length of the lens, is controlled by the potential difference.

Figure 12.1 This tiny lens is only 3 mm in diameter and 2 mm thick. It fits into the holder on the left. The wires on the end of the holder connect to a battery. The battery potential difference can change the focal length of the lens.

Describing Lenses

Figure 12.2 Reading stones such as this were used mostly by nuns, monks, and scholars because, around 1000 C.E., they were almost the only people who knew how to read.

The first known lenses that were developed to magnify print on a page were "reading stones," like the one shown in **Figure 12.2**. The reader moved the stone across the page and read a few words at a time. As scientists learned more about refraction and lenses, they developed a wide variety of lenses for many applications. To understand the applications, you need to learn some of the basic properties of lenses.

The terms *plane*, *concave*, and *convex* are used to describe lenses as well as mirrors, but lenses have two sides. Either side can be plane, concave, or convex. For example, reading stones have one convex side and one plane side. There are many possible shapes for lenses. Fortunately, you do not have to learn about each individual shape. You need only be concerned with the overall effect that lenses have on parallel rays of light that pass through them. One class of lenses causes parallel light rays to spread away from a common point, or *diverge*. The other class of lenses causes parallel light rays to come together, or *converge*, toward a common point. **Figure 12.3** shows different combinations of surfaces for lenses.

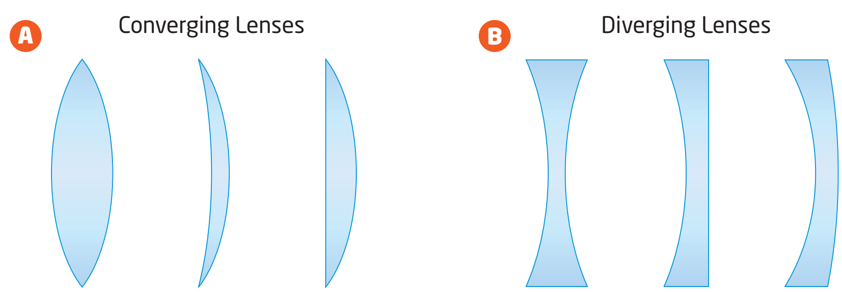


Figure 12.3 **A** Converging lenses have one or two convex surfaces and are thicker in the centre than on the edges. **B** Diverging lenses have one or two concave surfaces and are thinner in the centre than on the edges.

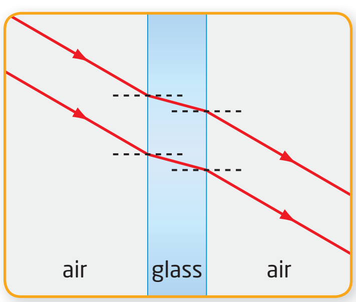


Figure 12.4 When parallel light rays pass through a flat piece of glass like a window pane, the rays shift to the side but do not change their direction relative to each other. This is called lateral displacement.

There is one combination of surfaces that causes light rays to neither converge nor diverge. **Figure 12.4** shows what happens to light rays that pass through a piece of glass that has two plane sides that are parallel to each other, like a window pane. Recall from Chapter 11 that when light travels from a medium with a low refractive index to a medium with a high refractive index, the rays bend toward the normal. Therefore, when light rays enter a piece of glass with a plane surface, the rays bend toward the normal. On the far side of the glass, the rays will bend away from the normal by the same amount that they first bent toward the normal. All rays shift to the side (are laterally displaced), but when they leave the glass, they are travelling in the same direction as when they entered. Because there has been no change in the direction of the rays relative to each other, such a piece of glass (or other transparent material) cannot be considered a lens. However, this information is important to keep in mind when studying lenses.

Converging Lenses

Converge means "to bring together." **Converging lenses** bring parallel light rays toward a common point as shown in **Figure 12.5A**. The shape that most easily illustrates how parallel rays are brought together is a lens that is convex on both sides, or *biconvex*. When rays are incident on the surface on the left side of the lens, they move from a fast medium to a slow medium. Thus, the rays refract toward the normals, causing the rays to converge slightly. When the light rays leave the second surface of the lens, they move from a slow medium to a fast medium, and refract away from the normals. Because of the direction of the normals at this surface, the rays continue to converge.

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

Suggested Investigation

Inquiry Investigation12-A, Image Characteristics of a Converging Lens, on page 512

Diverging Lenses

Diverge means "to spread out in different directions." **Diverging lenses** cause parallel rays to spread away from a common point. A good example of a diverging lens is a lens that is concave on both sides, or *biconcave*. **Figure 12.5B** shows how parallel light rays refract at each surface of a biconcave lens. Note that **Figure 12.5** also shows the axis of symmetry. You may recall from earlier studies that the *axis of symmetry* is a line that divides a shape into two congruent parts that can be matched by folding the shape in half.

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

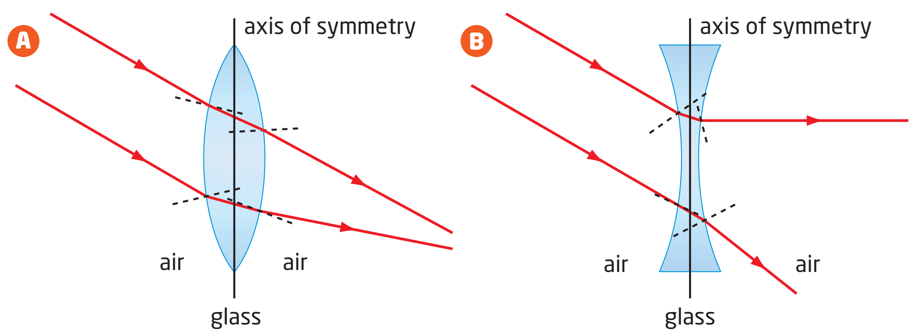


Figure 12.5 In **A**, when parallel rays exit a converging lens, they are travelling toward each other. In **B**, when parallel rays exit a diverging lens, they are travelling away from each other.

Learning Check

1. What properties of a piece of glass or plastic make it a lens?
2. Compare the shapes of converging and diverging lenses in **Figure 12.3**.
   a. What characteristic makes one lens converging and another diverging?
   b. Make a sketch of a converging lens and of a diverging lens. Give both lenses one plane side.
3. Sketch a lens with one convex side and one plane side. Show how two parallel rays would refract as they pass through this lens.
4. Depending on the type of vision correction a person needs, contact lenses can be converging or diverging. However, each of the two sides must have a specific shape because the lens must fit on the surface of the eye. What must be the shape—convex, concave, or plane—of the inside of a contact lens? Explain.

Study Toolkit

Word Families *Converging* and *diverging* belong to the same word family. A table like the one on page 486 can help show the meanings of these two words.

Focal Point and Focal Length of Lenses

The principal axis of a lens is a straight line that passes through the centre of the lens, normal to both surfaces of the lens, as with mirrors. When rays that are parallel to the principal axis pass through a converging lens, the rays intersect at a point. As with a concave mirror, this point is called the focal point (*F*), as shown in **Figure 12.6A**. After parallel rays pass through a diverging lens, the rays diverge. Only by tracing the rays backward do we see that they converge to a point. This point is a virtual focus, as shown in **Figure 12.6B**. Because light can pass through a lens from either side, there are actually two focal points for a lens. These two focal points are the same distance from the centre of the lens. The distance from the centre of the lens to the focal point is the focal length (*f*).

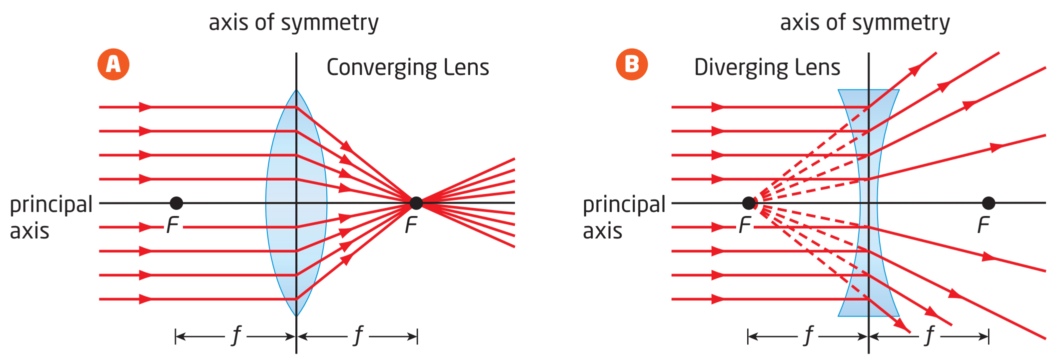


Figure 12.6 In **A** and **B**, notice that the focal point is symbolized by a capital *F*, and the focal length is symbolized by a lower-case *f*. In **B**, the dashed lines indicate that there are no actual rays travelling along these paths.

The position of the focal point for a lens depends on both the index of refraction of the lens material and curvature. Lenses with the same shape but with higher indices of refraction bend rays more, making the focal point closer to the lens. Lenses with larger curvatures but with the same index of refraction have the same effect, as shown in **Figure 12.7**.

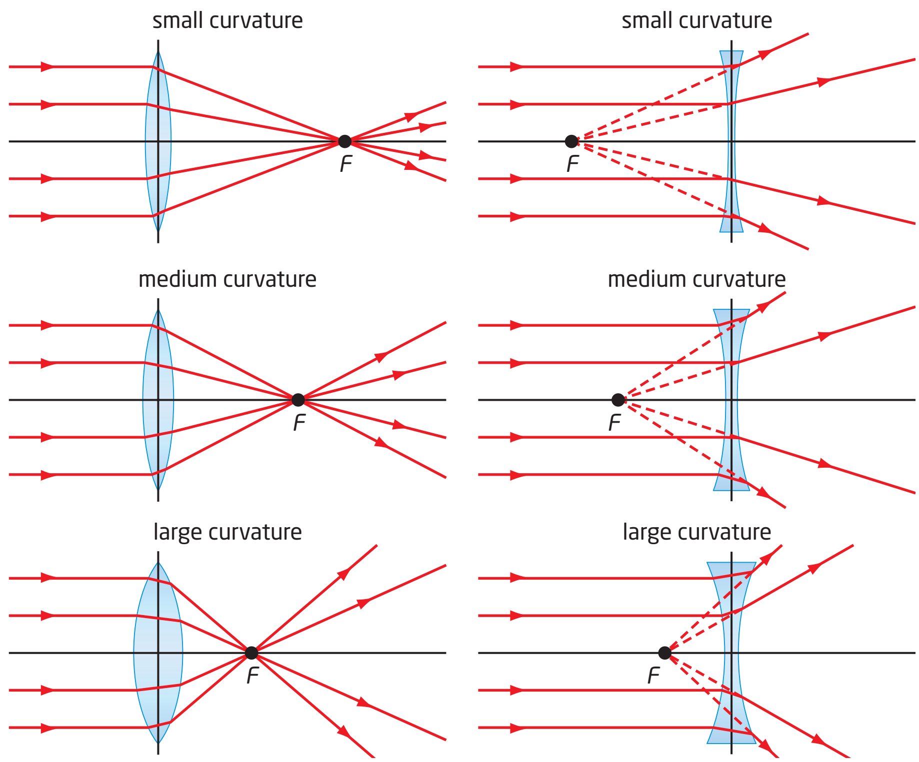


Figure 12.7 If the index of refraction of three different lenses is the same, then the relative focal lengths are determined by the curvature of the lens for both converging and diverging lenses.

Activity 12-2

Hocus Focus

In this activity, you will compare different converging lenses and determine image characteristics and focal lengths.

Materials

- several different converging lenses
- sheet of paper
- metric ruler

Procedure

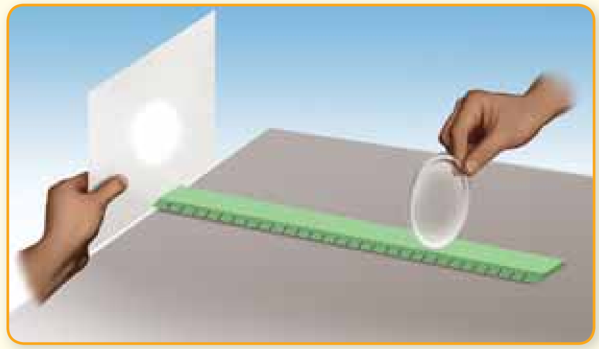
1. In your notebook, make a table with the headings shown below to record your results. Give your table a title.

Description of Lens	Description of Image	Maximum Thickness of Lens (mm)	Focal Length (cm)

2. Find a location where you can use a distant, bright light source, such as an open window on the far side of the classroom. In one hand, hold a converging lens. In the other hand, hold a sheet of paper to act as a screen.

3. Point the lens toward the light source, and support the paper screen so that the lens is between the screen and the light source. As you look through the lens, move the screen back and forth until you see a focussed image of the light source on the screen.

4. Measure the distance from the centre of the lens to the paper screen. Record this measurement in your table.



Record the distance from the paper screen to the lens.

5. In your table, describe the image you see on the screen. Describe the lens by noting whether each lens surface is the same shape. Measure the thickness of the lens at its centre.

6. Repeat steps 3 to 5 for other converging lenses.

Questions

1. Write a sentence describing the image formed by a converging lens when the object is far from the lens.

2. How does the thickness of a converging lens affect its focal length?

Effect of Large Lens Curvature

Figure 12.8 shows an image taken with a fish-eye lens. A fish-eye lens has a very short focal length.

Figure 12.8 A fish-eye lens drastically distorts the image, but it brings a much larger area into view.

Thick and Thin Lenses

Recall from Chapter 10 that spherical aberration occurs when light rays from an object strike a curved mirror far from the principal axis and fail to form a clear image point. Lenses produce spherical aberration for the same reason. If the lenses are very thin, the effect is not noticeable. (The lenses in **Figure 12.6** on page 490 represent the ideal thin lenses.) For thick lens, only light rays that pass through the lens *near the principal axis* meet at the focal point and give a sharp image.

Chromatic Aberration

Look at **Figure 12.9A**. Rays that are farther from the principal axis of a converging lens do not pass through the focal point. The same condition applies to diverging lenses.

The edges of lenses are similar in shape to prisms, so the edges of lenses disperse the light into colours, as shown in **Figure 12.9B**. Compare the edges of the lens with **Figure 11.8** on page 453 to review the way that prisms cause dispersion. When applied to a lens, this dispersion of light is called **chromatic aberration**. An example of chromatic aberration is shown in **Figure 12.9C**. Spherical and chromatic aberration in thick lenses reduces the quality of images in cameras.

chromatic aberration the dispersion of light through a lens

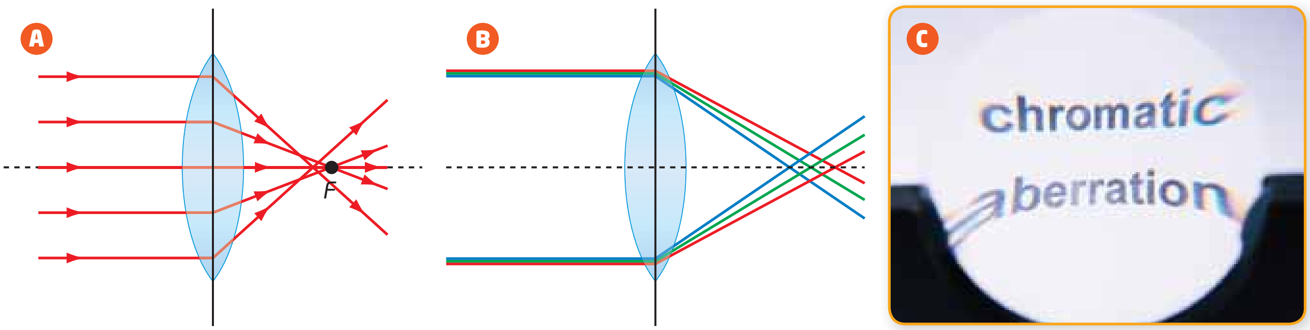


Figure 12.9 In **A**, a single thick lens with spherical surfaces cannot focus all parallel rays at the same point. In **B**, as a result of dispersion, different colours of light are focussed at different points. In **C**, chromatic aberration is most visible along the edges of objects.

Spherical and chromatic aberration can be partially corrected by combining one or more lenses, especially if the lenses are made of materials with different indices of refraction. **Figures 12.10A** and **B** show some combinations of lenses that partially correct for spherical and chromatic aberration. High-quality lenses for expensive cameras usually use a combination of many lenses to reduce aberration as much as possible, as seen in **Figure 12.10C**. Aberrations are not significant if lenses are very thin. When learning about ray diagrams and formulas for lenses, you will consider thin lenses only.

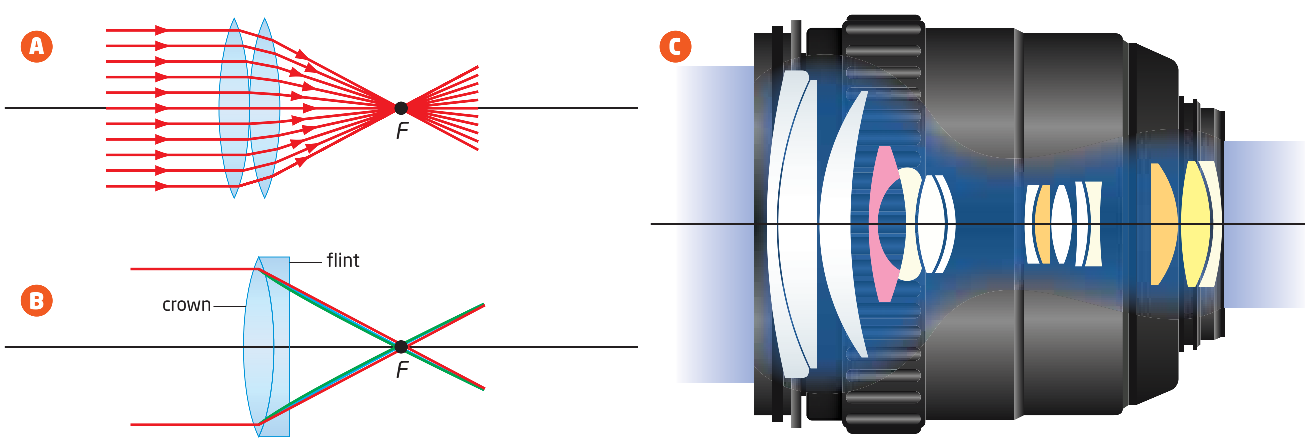


Figure 12.10 Diagram **A** shows that two separate lenses that are thinner than a single lens can reduce spherical aberration. Diagram **B** shows how a combination of lenses made of different types of glass can reduce chromatic aberration. Diagram **C** shows one way to reduce spherical and chromatic aberration in high-quality cameras. As you can see, a combination of many lenses is necessary.

Section 12.1 Review

Section Summary

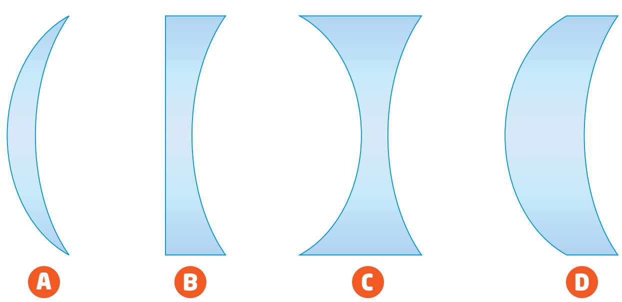
- Lenses are classified as either converging or diverging, depending on how they affect parallel light rays that refract through them.
- Converging lenses have one or two convex surfaces and are thicker in the centre than on the edges. Diverging lenses have one or two concave surfaces and are thinner in the centre than on the edges.
- The focal point of a converging lens is the point at which parallel rays meet after passing through the lens. The focal point of a diverging lens is the point from which the diverging rays appear to have come after parallel rays have passed through the lens.
- With thick lenses, rays that are farther from the principal axis do not pass through the focal point. This causes spherical aberration.
- Different colours of light have different indices of refraction. Therefore, they focus at different points. This causes chromatic aberration.

Review Questions

K/U **1.** Why are lenses *not* categorized according to whether their sides are concave, convex, or plane?

C **2.** Define the terms *converging lens* and *diverging lens*. Use a diagram to illustrate your definitions.

K/U **3.** Classify each of the lenses below as either converging or diverging.



C **4.** Make a sketch that shows how to find the focal point of a diverging lens. Include the focal length of the lens.

K/U **5.** Why do lenses have two focal points on the principal axis instead of one?

A **6.** The photograph on the right has an aberration. Where is the aberration greatest? Why?

C **7.** Using a diagram, show and explain what chromatic aberration is and why it occurs. Describe how high-quality cameras eliminate chromatic aberration. Refer to **Figure 12.10C**.

T/I **8.** Explain why spherical aberration affects images formed in mirrors and lenses but chromatic aberration only occurs with lenses.