The rays from a point on a distant object are essentially parallel—see Fig. 23–10. Therefore we can say that *the focal point is the image point for an object at infinity on the lens axis.* Thus, the focal point of a lens can be found by locating the point where the Sun's rays (or those of some other distant object) are brought to a sharp image, Fig. 23–32. The distance of the focal point from the center of the lens is called the **focal length**, f. A lens can be turned around so that light can pass through it from the opposite side. The focal length is *the same* on both sides, as we shall see later, even if the curvatures of the two lens surfaces are different. If parallel rays fall on a lens at an angle, as in Fig. 23–31b, they focus at a point F_a. The plane in which all points such as F and F_a fall is called the **focal plane** of the lens.

Focal length of lens

FIGURE 23–32 Image of the Sun burning a hole, almost, on a piece of paper.

Any lens† that is thicker in the center than at the edges will make parallel rays converge to a point, and is called a **converging lens** (see Fig. 23–29a). Lenses that are thinner in the center than at the edges (Fig. 23–29b) are called **diverging lenses** because they make parallel light diverge, as shown in Fig. 23–33. The focal point, F, of a diverging lens is defined as that point from which refracted rays, originating from parallel incident rays, seem to emerge as shown in Fig. 23–33. And the distance from F to the lens is called the **focal length**, f, just as for a converging lens.

Optometrists and ophthalmologists, instead of using the focal length, use the reciprocal of the focal length to specify the strength of eyeglass (or contact) lenses. This is called the **power**, P, of a lens:

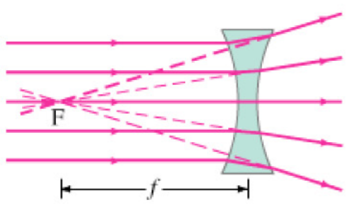
Power of lens

$$P = \frac{1}{f}. \qquad \textbf{(23–7)}$$

Diopters

The unit for lens power is the **diopter** (D), which is an inverse meter: $1\text{ D} = 1\text{ m}^{-1}$. For example, a 20-cm-focal-length lens has a power $P = 1/(0.20\text{ m}) = 5.0\text{ D}$. We will mainly use the focal length, but we will refer again to the power of a lens when we discuss eyeglass lenses in Chapter 25.

FIGURE 23–33 Diverging lens.



The most important parameter of a lens is its focal length f. For a converging lens, f is easily measured by finding the image point for the Sun or other distant objects. Once f is known, the image position can be calculated for any object. To find the image point by drawing rays would be difficult if we had to determine the refractive angles at the front surface of the lens and again at the back surface where the ray exits. We can save ourselves a lot of effort by making use of certain facts we already know, such as that a ray parallel to the axis of the lens passes (after refraction) through the focal point. To determine an image point, we need to consider only the three rays indicated in Fig. 23–34, which uses an arrow (on the left) as the object, and a converging lens forming an image to the right. These rays, emanating from a single point on the object, are drawn as if the lens were infinitely thin, and we show only a single sharp bend at the center line of the lens instead of the refractions at each surface. These three rays are drawn as follows:

RAY DIAGRAM

Finding the image position formed by a thin lens

Ray 1 is drawn parallel to the axis; therefore it is refracted by the lens so that it passes along a line through the focal point F behind the lens, Fig. 23–34a. (See also Fig. 23–31a.)

Ray 2 is drawn on a line passing through the other focal point F′ (front side of lens in Fig. 23–34) and emerges from the lens parallel to the axis, Fig. 23–34b.

Ray 3 is directed toward the very center of the lens, where the two surfaces are essentially parallel to each other; this ray therefore emerges from the lens at the same angle as it entered; as we saw in Example 23–6, the ray would be displaced slightly to one side, but since we assume the lens is thin, we draw ray 3 straight through as shown, Fig. 23–34c.

The point where these three rays cross is the image point for that object point. Actually, any two of these rays will suffice to locate the image point, but drawing the third ray can serve as a check.

†We are assuming the lens has an index of refraction greater than that of the surrounding material, such as a glass or plastic lens in air, which is the usual situation.