24.7 ABERRATIONS OF LENSES AND MIRRORS

Aberrations are ways in which real lenses and mirrors deviate from the behavior of an ideal lens or mirror.

Chromatic Aberration

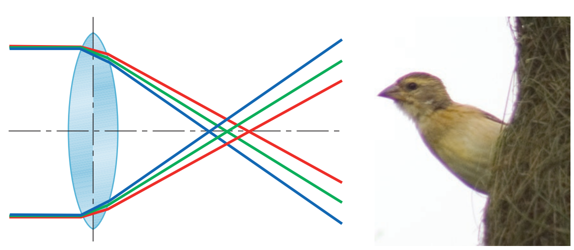
When light composed of several wavelengths passes through a lens, the various wavelengths are refracted by differing amounts because the index of refraction depends on wavelength; this lens defect is called **chromatic aberration** (Fig. 24.22). One way to minimize chromatic aberration is to make lenses from low-dispersion glass or polymer, for which the change in the index of refraction across the visible spectrum is small. An even better way is to use two lenses—one converging and one diverging. One of the lenses is made from a low-dispersion material and the other from a higher-dispersion material. Through careful design, the chromatic aberration of one is largely reversed by the other. Mirrors do not exhibit chromatic aberration because they rely on reflection, not refraction, to form images.

Monochromatic Aberrations

Monochromatic aberrations occur even for a single wavelength of light. They are not caused by dispersion, and are therefore present in mirrors as well as lenses. Recall that the thin lens and mirror equations are only *approximately* valid, because we used small-angle approximations to derive them. These approximations were justified by the assumption that the rays were paraxial—nearly parallel to the principal axis and not too far away from it. The actual path of a ray deviates from what the paraxial approximation predicts, giving rise to monochromatic aberrations.

For an object on the principal axis, the refracted or reflected rays cross the axis at different points, depending on how far from the axis the rays strike the lens or mirror (Fig. 24.23). This defect, which blurs the image, is called **spherical aberration**. A simple fix for spherical aberration is to place an aperture before the lens or mirror so that only rays traveling close to the principal axis can reach the lens. Unfortunately, the trade-off is that less light passes through the lens—the image formed is sharper but less bright.

Spherical aberration can be reduced by using lenses or mirrors with surfaces that are not spherical or by using multiple lens systems. For mirrors, spherical aberration can be avoided by using a *parabolic* mirror. A parabolic mirror focuses parallel rays



(a)

Figure 24.22 (a) In a dispersive medium, the index of refraction depends on wavelength. As a result, the focal length of a lens depends on wavelength. Usually, as shown here, the index of refraction decreases with increasing wavelength. Then if the image sensor of a camera is placed at the correct location for green light, it will be a little too close to the lens for red light and a little too far for blue. (b) Photo of a Baya Weaver (*Ploceus philippinus*) taken near Bangalore, India. The violet fringe around the bird is caused by chromatic aberration.

to a point even if they are not paraxial. Large astronomical reflecting telescopes use parabolic mirrors. Since light rays are reversible, if a point light source is placed at the focal point of a parabolic mirror, the reflected rays form a parallel beam. Searchlights and automobile headlights use parabolic reflectors to send out fairly parallel rays in a well-defined beam of light.

When the object is not on the principal axis, other aberrations come into play. Some of them, such as field curvature and distortion, deform the shape or size of the image. Others, such as coma and astigmatism, make the image blurry. (Note that the term *astigmatism* is used in two different senses. Here, it is a monochromatic aberration present even in symmetric lenses and mirrors. Astigmatism of the eye is caused by an asymmetric cornea.)

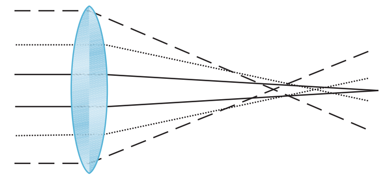


Figure 24.23 Spherical aberration of a converging lens with a point object at infinity. In effect, the lens has different focal lengths for rays that strike the lens at different distances from the principal axis.