الفصل السادس

Aberrations

A precise analysis of image formation requires tracing each ray, using Snell's law at each refracting surface and the law of reflection at each reflecting surface. This procedure shows that the rays from a point object do not focus at a single point, with the result that the image is blurred. The departures of actual images from the ideal predicted by our simplified model are called aberrations.

Spherical Aberrations

Spherical aberrations occur because the focal points of rays far from the principal axis of a spherical lens (or mirror) are different from the focal points of rays of the same wavelength passing near the axis. Figure 1 illustrates spherical aberration for parallel rays passing through a converging lens. Rays passing through points near the center of the lens are imaged farther from the lens than rays passing through points near the edges.

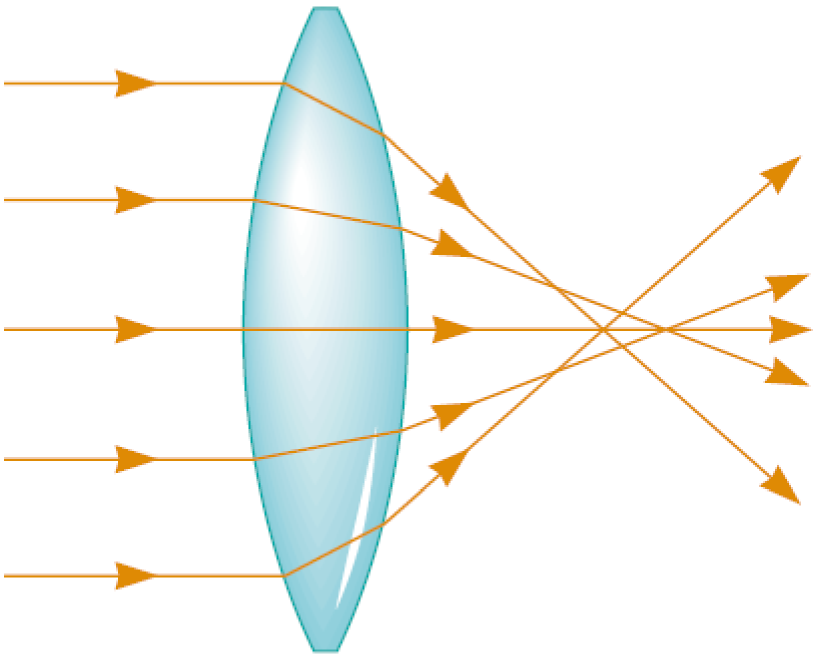


Figure 1: Spherical aberration caused by a converging lens.

Many cameras have an adjustable aperture to control light intensity and reduce spherical aberration. (An aperture is an opening that controls the amount of light passing through the lens.) Sharper images are produced as the aperture size is reduced because with a small aperture only the central portion of the lens is exposed to the light; as a result, a greater percentage of the rays are paraxial. At the same time, however, less light passes through the lens. To compensate for this lower light intensity, a longer exposure time is used.

In the case of mirrors, spherical aberration can be minimized through the use of a parabolic reflecting surface rather than a spherical surface. Parabolic surfaces are not used often, however, because those with high-quality optics are very expensive to make. Parallel light rays incident on a parabolic surface focus at a common point, regardless of their distance from the principal axis. Parabolic reflecting surfaces are used in many astronomical telescopes to enhance image quality.

Chromatic Aberrations

The fact that different wavelengths of light refracted by a lens focus at different points gives rise to chromatic aberrations. For instance, when white light passes through a lens, violet rays are refracted more than red rays (Fig. 2). From this we see that the focal length of a lens is greater for red light than for violet light. Other wavelengths (not shown in Fig.2) have focal points intermediate between those of red and violet.

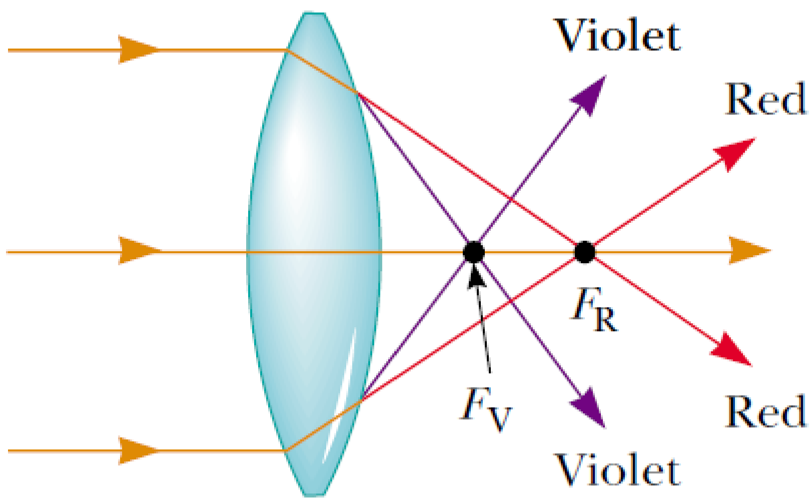


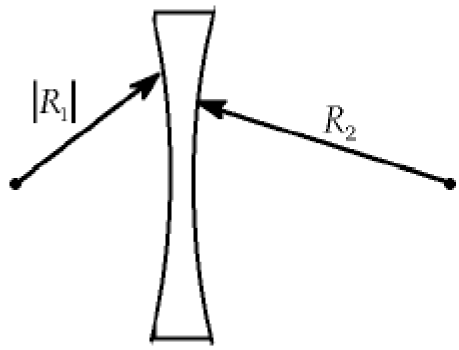
Figure 2. Chromatic aberration caused by a converging lens. Rays of different wavelengths focus at different points.

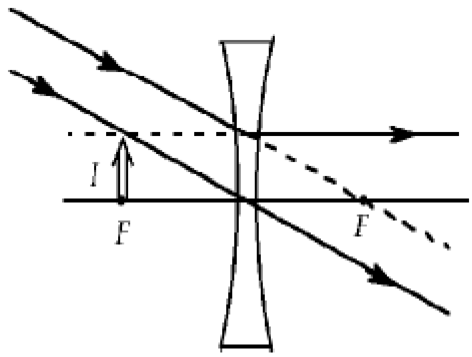
Chromatic aberration for a diverging lens also results in a shorter focal length for violet light than for red light, but on the front side of the lens. Chromatic aberration can be greatly reduced by combining a converging lens made of one type of glass and a diverging lens made of another type of glass.

Example: Explain why a mirror cannot give rise to chromatic aberration.

Answer: Chromatic aberration arises because a material medium's refractive index can be frequency dependent. A mirror changes the direction of light by reflection, not refraction. Light of all wavelengths follows the same path according to the law of reflection, so no chromatic aberration happens.

Example : The magnitudes of the radii of curvature are 32.5 cm and42 cm for the two faces of a biconcave lens. The glass has index of refraction 1.53 for violet light and 1.51 for red light. For a very distant object, locate and describe (a) the image formed by violet light, and (b) the image formed by red light.





(a) The focal length of the lens is given by

$$\frac{1}{f} = (n-1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) = (1.53 - 1.00)\left(\frac{1}{-32.5\text{ cm}} - \frac{1}{42.5\text{ cm}}\right)$$

$$f = -34.7\text{ cm}$$

Note that R1 is negative because the center of curvature of the first surface is on the virtual image side.

When $p = \infty$

the thin lens equation gives $q = f$.

Thus, the violet image of a very distant object is formed

at $\boxed{q = -34.7\text{ cm}}$.

The image is $\boxed{\text{virtual, upright and diminshed}}$.

(b) The same ray diagram and image characteristics apply for red light.

Again, $q = f$

and now $\frac{1}{f} = (1.51 - 1.00)\left(\frac{1}{-32.5\text{ cm}} - \frac{1}{42.5\text{ cm}}\right)$

giving $f = \boxed{-36.1\text{ cm}}$.

ASTIGMATISM

This defect of the image occurs when an object point lies some distance from the axis of a concave or convex mirror. The incident rays, whether parallel or not, make an appreciable angle ϕ with the mirror axis. The result is that, instead of a point image, two mutually perpendicular line images are formed. This effect is known as astigmatism and is illustrated by a perspective diagram in Fig. 6N.

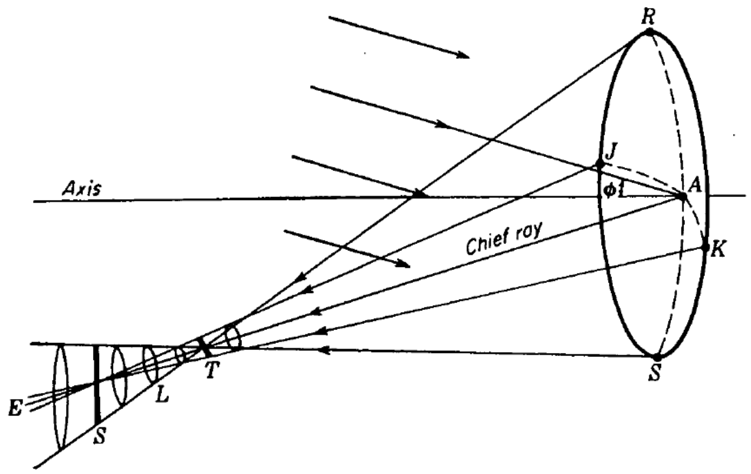


Figure 6N : Astigmatic images of an off-axis object point at infinity, as formed by a concave spherical mirror. The lines *T* and *S* are perpendicular to each other.

If the positions of the *T* and S images of distant object points are determined for a wide variety of angles, their loci will form a paraboloidal and a plane surface respectively, as shown in Fig. 6o. As the obliquity of the rays decreases and they approach the axis, the line images not only come closer together as they approach the paraxial focal plane but they shorten in length. The amount of astigmatism for any pencil of rays is given by the distance between the *T* and S surfaces measured along the chief ray.

Equations giving the two astigmatic image positions are*

$$\frac{1}{s} + \frac{1}{s'_T} = -\frac{2}{r\cos\phi} \qquad \frac{1}{s} + \frac{1}{s'_S} = -\frac{2\cos\phi}{r}$$

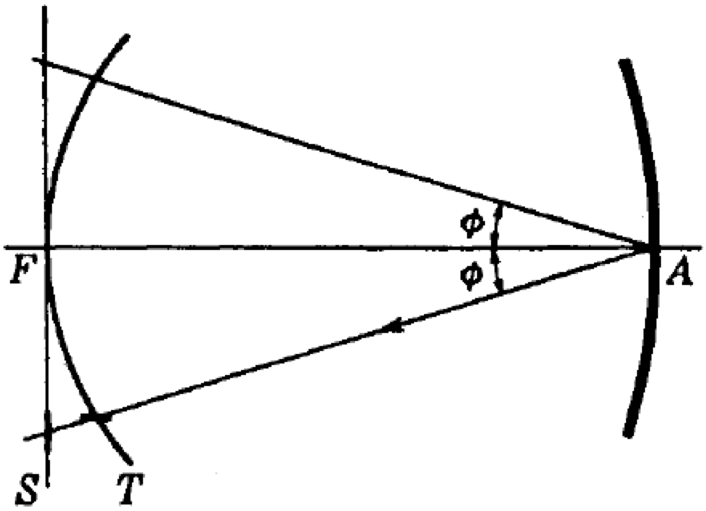


Figure 6O: Astigmatic surfaces for a concave spherical mirror.