FUNDAMENTALS OF OPTICS

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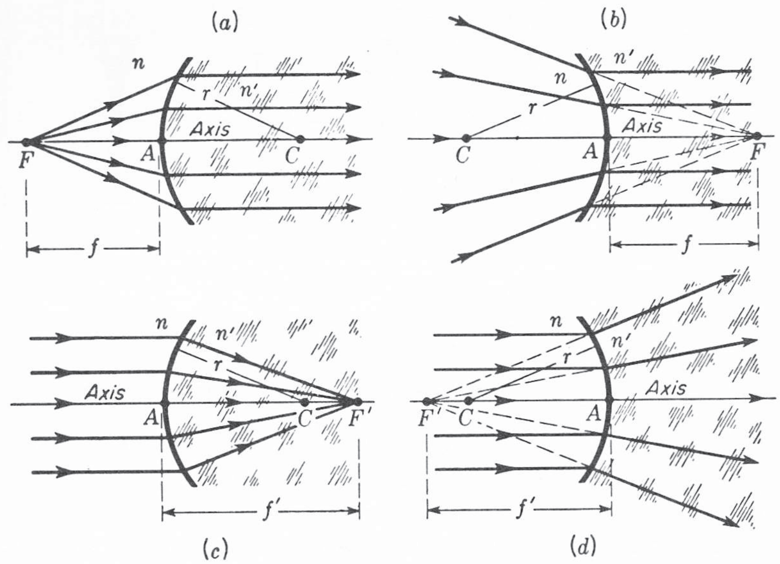

FIGURE 3B
The focal points F and F' and focal lengths f and f' associated with a single spherical refracting surface of radius r separating two media of index n and n'.

In optical diagrams it is common practice to show incident light rays traveling from left to right. A convex surface therefore is one in which the center of curvature C lies to the right of the vertex, while a concave surface is one in which C lies to the left of the vertex.

If we apply the principle of the reversibility of light rays to the diagrams in Fig. 3B, we should turn each diagram end-for-end. Diagram (*a*), for example, would then become a concave surface with converging properties, while diagram (*b*) would become a convex surface with diverging properties. Note that we would then have the incident rays in the denser medium, i.e., the medium of greater refractive index.

3.2 IMAGE FORMATION

A diagram illustrating image formation by a single refracting surface is given in Fig. 3D. It has been drawn for the case in which the first medium is air with an index $n = 1$ and the second medium is glass with an index $n' = 1.60$. The focal lengths f and f' therefore have the ratio 1:1.60 [see Eq. (3a)]. Experimentally it is observed that if the object is moved closer to the primary focal plane, the image will be formed farther to the right away from F' and will be larger, i.e., magnified. If the object is moved to the left, farther away from F, the image will be found closer to F' and will be smaller in size.

All rays coming from the object point Q are shown brought to a focus at Q'.

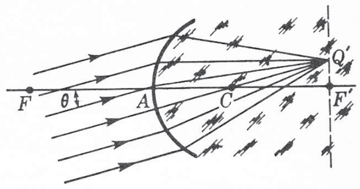

FIGURE 3C
How parallel incident rays are brought to a focus at Q' in the secondary focal plane of a single spherical surface.

Rays from any other object point like M will also be brought to a focus at a corresponding image point like M'. This ideal condition never holds exactly for any actual case. Departures from it give rise to slight defects of the image known as *aberrations*. The elimination of aberrations is the major problem of geometrical optics and will be treated in detail in Chap. 9.

If the rays considered are restricted to *paraxial rays*, a good image is formed with *monochromatic light*. *Paraxial rays* are defined as *those rays which make very small angles with the axis and lie close to the axis throughout the distance from object to image* (see Sec. 2.12). The formulas given in this chapter are to be taken as applying to images formed only by paraxial rays.

3.3 VIRTUAL IMAGES

The image $M'Q'$ in Fig. 3D is a real image in the sense that if a flat screen is located there, a sharply defined image of the object MQ will be formed on the screen. Not all images, however, can be formed on a screen, as is illustrated in Fig. 3E. Light rays from an object point Q are shown refracted by a concave spherical surface separating the two media of index $n = 1.0$ and $n' = 1.50$, respectively. The focal lengths have the ratio 1:1.50.

Since the refracted rays are diverging, they will not come to a focus at any point. To an observer's eye located at the right, however, such rays will appear to be coming from the common point Q'. In other words, Q' is the image point corresponding to the object point Q. Similarly M' is the image point corresponding to the object point M. Since the refracted rays do not come from Q' but only appear to do so, no image can be formed on a screen placed at M'. For this reason such an image is said to be *virtual*.

3.4 CONJUGATE POINTS AND PLANES

The principle of the reversibility of light rays has the consequence that if $Q'M'$ in Fig. 3D were an object, an image would be formed at QM. Hence, if any object is placed at the position previously occupied by its image, it will be imaged at the position previously occupied by the object. The object and image are thus interchangeable, or conjugate. Any pair of object and image points such as M and M'