Chapter 26 Geometrical Optics

The Reflection of Light: Mirrors:

Mirrors produce images because the light that strikes them is reflected, rather than absorbed. Reflected light does much more than produce dramatic and beautiful pictures, however. For example, it allows our sense of vision to be remarkably useful. When we "see" an object, light from it enters our eyes and evokes the sensation of vision. Some objects themselves produce the light that we see, like the sun, a flame, or a light bulb. Most objects, though, reflect into our eyes light that originates elsewhere, and if it were not for reflection, we would not be able to see them. Much more practical applications of light reflection range from measuring the speeds of automobiles to reading price information from bar codes at the supermarket.

Basic Terms

Wave front

Wave fronts are surfaces on which all points of a wave are in the same phase of motion.

Plane wave

If the wave fronts are flat surfaces, the wave is called a plane wave.

Ray

Rays are lines that are perpendicular to the wave fronts and point in the direction of the velocity of the wave.

Reflection

When light reflects from a smooth surface, the reflected light obeys the law of reflection, which states that (a) the incident ray, the reflected ray, and the normal to the surface all lie in the same plane, and (b) the angle of reflection equals the angle of incidence.
Images

A virtual image is one from which rays of light do not actually come, but only appear to do so. A real image is one from which rays of light actually emanate.

Mirrors

(a) A plane mirror forms an upright, virtual image that is located as far as the object is in front of it. In addition, the height of the image and the object are equal.
(b) A spherical mirror has the shape of a section from the surface of a sphere.

Principal axis

The principle axis of a mirror is a straight line drawn through the center of curvature and the middle of the mirror's surface.

Paraxial ray

Rays that lie close to the principle axis are known as paraxial rays.

Radius of curvature

The radius of curvature $R$ of the mirror is the distance from the center of curvature to the mirror.

Focal point

(a) The focal point of a concave spherical mirror is a point on the principal axis, in front of the mirror. Incident paraxial rays that are parallel to the principle axis converge to the focal point after being reflected from the concave mirror.

(b) The focal point of a convex spherical mirror is a point on the principal axis behind the mirror. For a convex mirror, paraxial rays that are parallel to the principal axis seem to diverge from the focal point.

Refraction of Light: Lenses

Light can travel through many different media, such as solids, liquids, and gases, although it does so at different speeds. When light passes from one medium, such as air, into another medium, such as glass, the difference in speeds leads to a change in the direction of travel. This directional change or bending lies at the heart of some remarkable effects, depending on
the nature of the materials and their shapes. The change in direction of travel is also responsible for rainbows and the sparkle of diamonds. It is the basis for the important field of fiber optics. Countless applications and devices are made possible through the property of the refraction of light.

**Basic Terms**

**Refraction**

When light strikes the interface between two media, part of the light is reflected and the remainder is transmitted across the interface. The change in the direction of travel as light passes from one medium into another is called refraction.

**Index of refraction**

The *index of refraction* $n$ of a material is the ratio of the speed of light $c$ in vacuum to the speed of light $v$ in the material: $n = c/v$.

**Snell's law of refraction**

Snell's law of refraction states that (1) the refracted ray, the incident ray, and the normal to the interface all lie in the same plane, and (2) the angle of refraction $\theta_2$ is related to the angle of incidence $\theta_1$ by

$$n_1 \sin(\theta_1) = n_2 \sin(\theta_2)$$

where $n_1$ and $n_2$ are the indices of refraction of the incident and refracting media, respectively. The angles are measured relative to the normal.

**Critical angle**

When light passes from a medium of larger refractive index $n_1$ into one of smaller refractive index $n_2$, the refracted ray is bent away from the normal. If the incident ray is at the critical angle, the angle of refraction is 90°. The critical angle can be determined from Snell's law and given by
\[
\sin(\theta_c) = \frac{n_2}{n_1}
\]

**Total internal reflection**

When the angle of incidence exceeds the critical angle, all the incident light is reflected back into the medium from which it came, a phenomenon known as total internal reflection.

**Brewster angle**

When light is incident on a nonmetallic surface at the Brewster angle \(\theta_B\), the reflected light is completely polarized parallel to the surface. The Brewster angle is given by

\[
\tan(\theta_B) = \frac{n_2}{n_1}
\]

where \(n_1\) and \(n_2\) are the refractive indices of the incident and refracting media, respectively. When light is incident at the Brewster angle, the reflected and refracted rays are perpendicular to each other.

**Lens**

The lenses used in optical instruments, such as eyeglasses, cameras, and telescopes, are made from transparent materials they refract light. They refract the light in such a way that an image of the source of the light is formed. Depending on the phenomenon of refraction in forming an image, lenses are classified into two types: **converging lenses** and **diverging lenses**. (a) With a converging lens, paraxial rays that are parallel to the principal axis are focuses to a point on the axis by the lens (see Figure 26.30). (b) With a diverging lens, paraxial rays that are parallel to the principal axis appear to originate from its focal point after passing through the lens (see Figure 26-31).

**Focal point**

(a) The **focal point** of a converging lens is a point on the principal axis. Incident paraxial rays that are parallel to the principle axis converge to the focal point after passing through the lens.

(b) The **focal point** of a diverging lens is a point on the principal axis. Incident paraxial rays that are
parallel to the principal axis seem to originate from the focal point after passing through the lens.

**Focal length**

The distance from the focal point to the lens along its principal axis.

**Ray diagram**

The image produced by a converging or a diverging lens can be located using a technique called *ray diagram*. See Figure 26-33, 26-34, 26-35 for the detailed constructing steps.

**Thin-lens equation**

The *thin-lens equation* can be used with either converging or diverging lenses that are thin, and it relates the object distance $d_o$, the image distance $d_i$, and the focal length $f$ of the lens:

$$\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f}$$

**Magnification equation**

The magnification $m$ of a lens is the ratio of the image height $h_i$ to the object height $h_o$. The magnification is also related to $d_o$ and $d_i$ by the *magnification equation*:

$$m = -(d_i/d_o)$$