Summary

THE BIG IDEA **Lenses change the path of light.**

30.1 Converging and Diverging Lenses

A lens forms an image by bending parallel rays of light that pass through it.

- A **lens** is a piece of glass or plastic that refracts light.
- A **converging lens,** also known as a **convex lens,** is thicker in the middle, causing rays of light that are initially parallel (straight wave fronts) to meet at a single point.
- A **diverging lens,** also known as a **concave lens,** is thinner in the middle, causing rays of light to appear to originate from a single point.
- The **principal axis** of a lens is a line joining the centers of curvature of its surfaces.
- For a converging lens, the **focal point** is the point at which a beam of light parallel to the principal axis converges.
- The **focal plane** is a plane perpendicular to the principal axis that passes through either focal point of a lens. When the lens of a camera is set for distant objects, the film (or electronic sensor) is in the focal plane behind the lens in the camera.
- The **focal length** of a lens, whether converging or diverging, is the distance between the center of the lens and its focal point.

30.2 Image Formation by a Lens

The type of image formed by a lens depends on the shape of the lens and the position of the object.

- A magnifying glass is simply a converging lens that increases the angle of view and allows more detail to be seen.
- A converging lens will magnify only when the object is between the focal point and the lens. The magnified image will be farther from the lens than the object and right-side up (erect). The image is virtual.
- When the object is far enough away to be beyond the focal point of a converging lens, light originating from the object and passing through the lens converges and can be focused on a screen. An image formed by converging light is called a **real image.**
- A real image formed by converging light is upside down (inverted).
- When a diverging lens is used alone, the image is always virtual, right-side up, and smaller than the object.

30.3 Constructing Images Through Ray Diagrams

The size and location of the object, its distance from the center of the lens, and the focal length of the lens are used to construct a ray diagram.

- **Ray diagrams** show the principle rays that can be used to determine the size and location of an image.
- An arrow is used to represent the object; for simplicity, one end of the object is placed on the principal axis. To locate the position of the image, you only need to know the paths of two rays from a point on the object.
- There are three rays useful for the construction of a ray diagram:
  1. A ray parallel to the principal axis that passes through the focal point on the opposite side.
  2. A ray passing through the center of the lens that is undeflected.
  3. A ray through the focal point in front of the lens that emerges parallel to the principal axis after refraction by the lens.
- In a ray diagram that shows an image formed by a converging lens, all the images that are formed are real and inverted.
- The method of drawing ray diagrams applies also to diverging lenses. The image formed by a diverging lens is always virtual, reduced, and right-side up.

30.4 Image Formation Summarized

A converging lens forms either a real image or a virtual image. A diverging lens always forms a virtual image.

- A converging lens is a simple magnifying glass when the object is within one focal length of the lens. The image is then virtual, magnified, and right-side up.
- When the object is beyond one focal length, a converging lens produces a real, inverted image.
- When an object is viewed with a diverging lens, the image is virtual, reduced, and right-side up.

30.5 Some Common Optical Instruments

Optical instruments that use lenses include the camera, the telescope (and binoculars), and the compound microscope.

- A camera consists of a lens and sensitive film (or light-detecting chip) mounted in a lighttight box. The lens in a camera forms a real, inverted image on the film or chip.
- A simple telescope uses a lens to form a real image of a distant object. A second lens called the **eyepiece** is positioned so that the image produced by the first lens is within one focal length of the eyepiece. The eyepiece forms an enlarged virtual image of the real image.

- A third lens or a pair of reflecting prisms is used in the terrestrial telescope, which produces an image that is right-side up. A pair of terrestrial telescopes, side by side, makes up a pair of *binoculars*.
- A compound microscope uses two converging lenses of short focal length. The first lens in a microscope, called the **objective lens,** produces a real image of a close object. A second lens in a microscope, the eyepiece, forms a virtual image of the first image, further enlarged.

30.6 The Eye

The main parts of the eye are the cornea, the iris, the pupil, and the retina.

- Light enters the eye through the transparent covering called the **cornea.**
- The amount of light that enters is regulated by the **iris,** the colored part of the eye that surrounds the pupil.
- The **pupil** is the opening of the eyeball through which light passes.
- Light passes through the pupil and lens and is focused on a layer of tissue at the back of the eye—the **retina**—that is extremely sensitive to light.
- The *fovea* is a small region in the center of our field of view where we have the most distinct vision.
- The *blind spot* is the spot in the retina where the nerves carrying all the information leave the eye in a narrow bundle.
- Adjustments in focusing of the image on the retina are made by changing the thickness and shape of the lens to regulate its focal length.

30.7 Some Defects in Vision

Three common vision problems are farsightedness, nearsightedness, and astigmatism.

- A **farsighted person** has trouble focusing on nearby objects because the eyeball is too short and images form behind the retina. The remedy for farsightedness is to increase the converging effect of the eye by wearing eyeglasses or contact lenses with converging lenses.
- A **nearsighted person** can see nearby objects clearly, but does not see distant objects clearly because they are focused too near the lens, in front of the retina. A remedy for nearsightedness is to wear corrective lenses that diverge the rays from distant objects so that they focus on the retina instead of in front of it.
- **Astigmatism** of the eye is a defect that results when the cornea is curved more in one direction than the other, somewhat like the side of a barrel. The remedy for astigmatism is cylindrical corrective lenses that have more curvature in one direction than in another.

30.8 Some Defects of Lenses

Two types of aberration are spherical aberration and chromatic aberration.

- The distortions in an image are called **aberrations.**
- *Spherical aberration* results when light passes through the edges of a lens and focuses at a slightly different place from light passing through the center of the lens.
- *Chromatic aberration* is the result of the different speeds of light of various colors and hence the different refractions they undergo.
- In the eye, vision is sharpest when the pupil is smallest because light then passes through only the center of the eye's lens, where spherical and chromatic aberrations are minimal.