Summary

A **camera** lens forms an image on film, or on an electronic sensor (CCD or CMOS) in a digital camera. Light is allowed in briefly through a shutter. The image is focused by moving the lens relative to the film or sensor, and the ***f*-stop** (or lens opening) must be adjusted for the brightness of the scene and the chosen shutter speed. The *f*-stop is defined as the ratio of the focal length to the diameter of the lens opening.

The human **eye** also adjusts for the available light—by opening and closing the iris. It focuses not by moving the lens, but by adjusting the shape of the lens to vary its focal length. The image is formed on the retina, which contains an array of receptors known as rods and cones.

Diverging eyeglass or contact lenses are used to correct the defect of a nearsighted eye, which cannot focus well on distant objects. Converging lenses are used to correct for defects in which the eye cannot focus on close objects.

A **simple magnifier** is a converging lens that forms a virtual image of an object placed at (or within) the focal point. The **angular magnification**, when viewed by a relaxed normal eye, is

$$M = \frac{N}{f}, \qquad \textbf{(25–2a)}$$

where f is the focal length of the lens and N is the near point of the eye (25 cm for a "normal" eye).

An **astronomical telescope** consists of an **objective lens** or mirror, and an **eyepiece** that magnifies the real image formed by the objective. The **magnification** is equal to the ratio of the objective and eyepiece focal lengths, and the image is inverted:

$$M = -\frac{f_o}{f_e}. \qquad \textbf{(25–3)}$$

A compound **microscope** also uses objective and eyepiece lenses, and the final image is inverted. The total magnification is the product of the magnifications of the two lenses and is approximately

$$M \approx \frac{N\ell}{f_e f_o}, \qquad \textbf{(25–6b)}$$

where ℓ is the distance between the lenses, N is the near point of the eye, and f_o and f_e are the focal lengths of objective and eyepiece, respectively.

Microscopes, telescopes, and other optical instruments are limited in the formation of sharp images by **lens aberrations**. These include **spherical aberration**, in which rays passing through the edge of a lens are not focused at the same point as those that pass near the center; and **chromatic aberration**, in which different colors are focused at different points. Compound lenses, consisting of several elements, can largely correct for aberrations.

The wave nature of light also limits the sharpness, or **resolution**, of images. Because of diffraction, it is *not possible to discern details smaller than the wavelength* of the radiation being used. The useful magnification of a light microscope is limited by diffraction to about 500×.

[*__X-rays__ are a form of electromagnetic radiation of very short wavelength. They are produced when high-speed electrons, accelerated by high voltage in an evacuated tube, strike a glass or metal target.]

[*__Computed tomography__ (CT or CAT scan) uses many narrow X-ray beams through a section of the body to construct an image of that section.]

Questions

1. Why must a camera lens be moved farther from the sensor or film to focus on a closer object?
2. Why is the depth of field greater, and the image sharper, when a camera lens is "stopped down" to a larger *f*-number? Ignore diffraction.
3. Describe how diffraction affects the statement of Question 2. [*Hint*: See Eq. 24–3 or 25–7.]
4. Why are bifocals needed mainly by older persons and not generally by younger people?
5. Will a nearsighted person who wears corrective lenses in her glasses be able to see clearly underwater when wearing those glasses? Use a diagram to show why or why not.
6. You can tell whether people are nearsighted or farsighted by looking at the width of their face through their glasses. If a person's face appears narrower through the glasses (Fig. 25–47), is the person farsighted or nearsighted? Try to explain, but also check experimentally with friends who wear glasses.

FIGURE 25–47
Question 6.

7. In attempting to discern distant details, people will sometimes squint. Why does this help?
8. Is the image formed on the retina of the human eye upright or inverted? Discuss the implications of this for our perception of objects.
9. The human eye is much like a camera—yet, when a camera shutter is left open and the camera is moved, the image will be blurred. But when you move your head with your eyes open, you still see clearly. Explain.
10. Reading glasses use converging lenses. A simple magnifier is also a converging lens. Are reading glasses therefore magnifiers? Discuss the similarities and differences between converging lenses as used for these two different purposes.
11. Nearsighted people often look over (or under) their glasses when they want to see something small up close, like a cell phone screen. Why?
12. Spherical aberration in a thin lens is minimized if rays are bent equally by the two surfaces. If a planoconvex lens is used to form a real image of an object at infinity, which surface should face the object? Use ray diagrams to show why.
13. Explain why chromatic aberration occurs for thin lenses but not for mirrors.
14. Inexpensive microscopes for children's use usually produce images that are colored at the edges. Why?