

Chapter 33

Lenses and Optical Instruments

subtends a small angle θ . As shown in Fig. 33-33a, the object is placed at the focal point of a magnifying glass, a converging lens, which produces a virtual image, which the eye is to focus on it. If the eye is relaxed, the object is exactly at the focal point. If you "focus" on the object, the object subtends at the eye is much larger. In part (b), in which the eye, relaxed, views the image, the angular magnification or magnifying power, M , is the ratio of the angle subtended by an object when using the lens to the angle subtended using the unaided eye, with the object at the near point ($N = 25\text{ cm}$ for a normal eye):

$$M = \frac{\theta'}{\theta}, \quad (33-5)$$

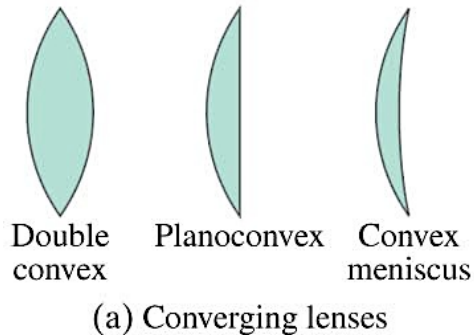
where θ and θ' are shown in Fig. 33-33. We can write M in terms of the focal length by noting that $\theta = h/N$ (Fig. 33-33a), where h is the height of the object and we assume the angles are small so θ and θ' equal their sines and tangents. If the eye is relaxed, the image will be at infinity and the object will be at the focal point; see Fig. 33-34. If the eye is strained, the image will be at the near point; see Fig. 33-35. In either case, $d_o = f$ and $\theta' = h/f$. Then

Units of Chapter 33

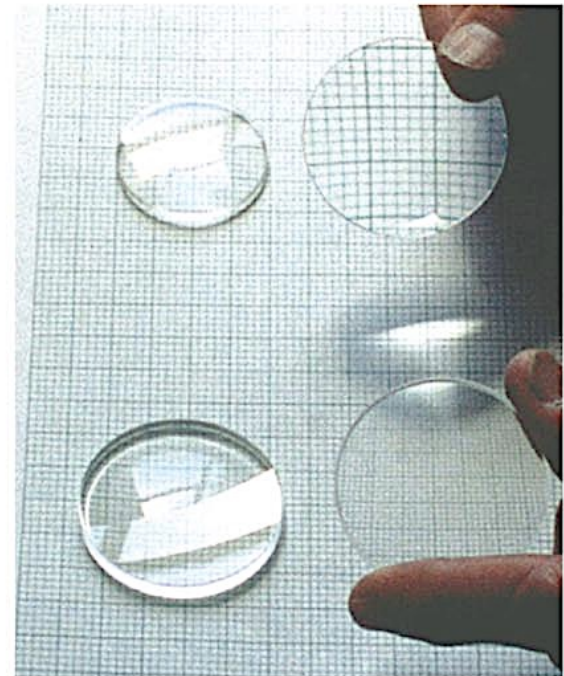
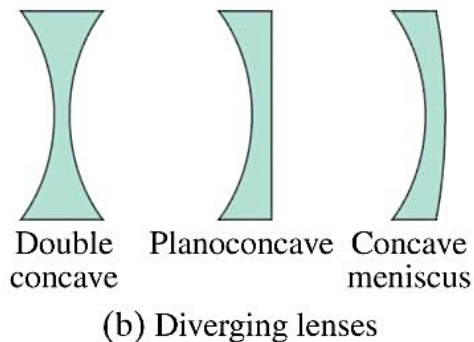
- **Thin Lenses; Ray Tracing**
- **The Thin Lens Equation; Magnification**
- **Combinations of Lenses**
- **Lensmaker's Equation**
- **The Human Eye; Corrective Lenses**
- **Magnifying Glass**

33-1 Thin Lenses; Ray Tracing

Thin lenses are those whose thickness is small compared to their radius of curvature. They may be either converging (a) or diverging (b).



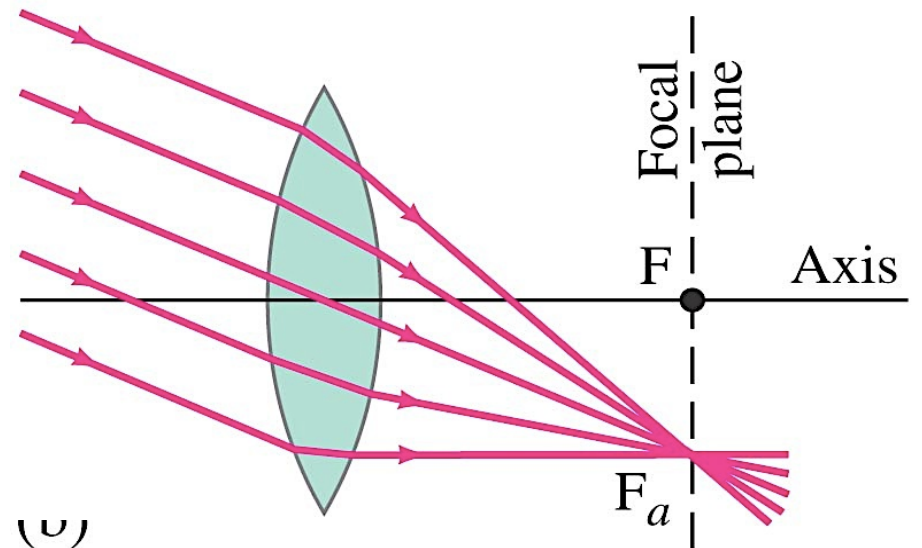
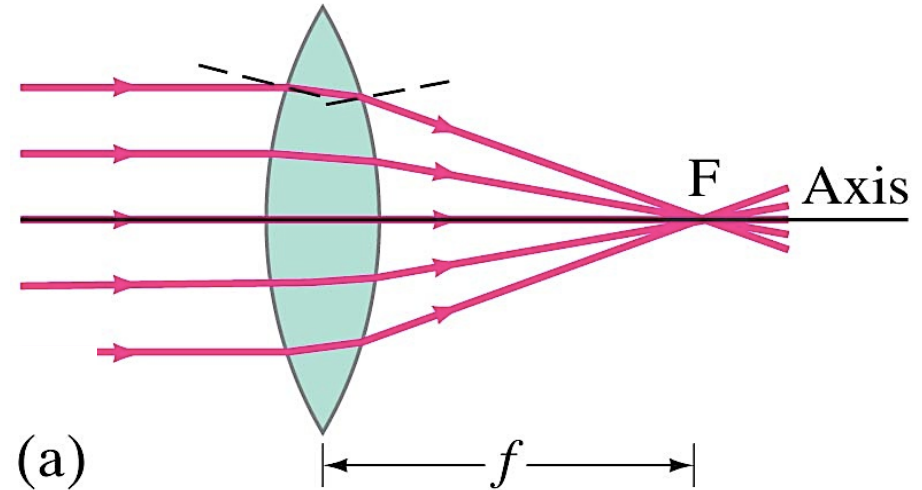
(c)



(d)

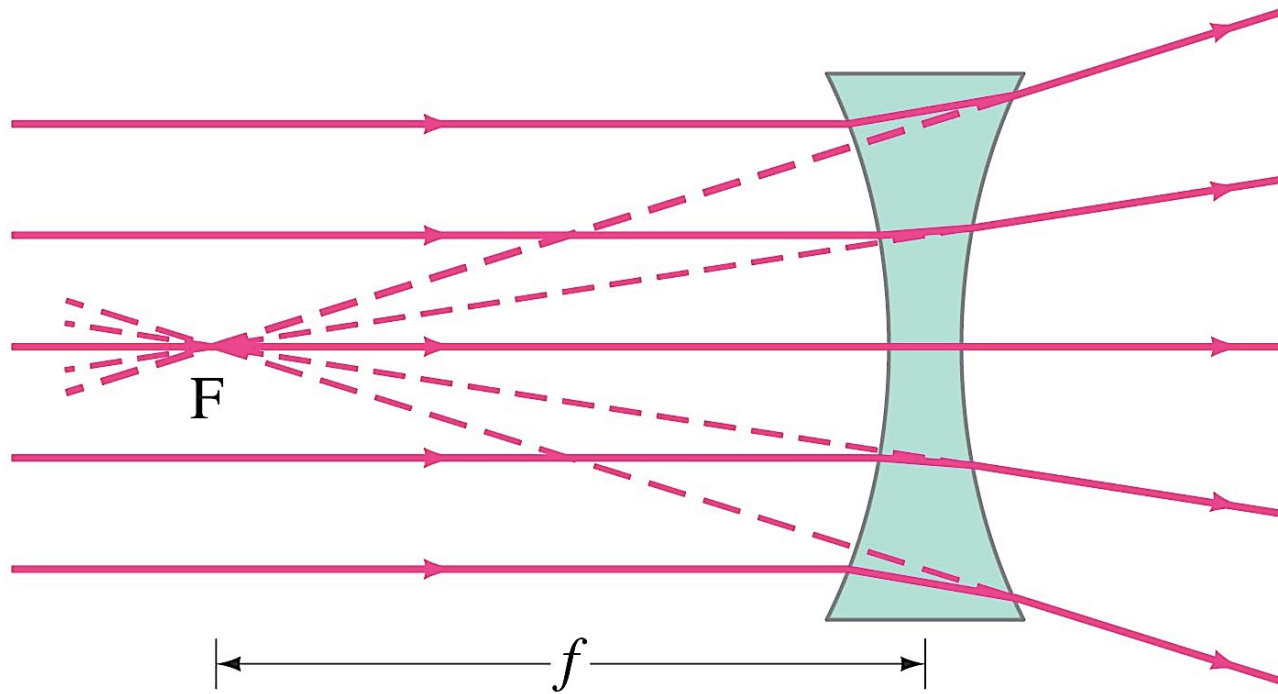
33-1 Thin Lenses; Ray Tracing

Parallel rays are brought to a focus by a converging lens.



33-1 Thin Lenses; Ray Tracing

A diverging lens makes parallel light diverge; the focal point is that point where the diverging rays would converge if projected back.



33-1 Thin Lenses; Ray Tracing

The power of a lens is the inverse of its focal length:

$$P = \frac{1}{f}$$

Lens power is measured in diopters, D:

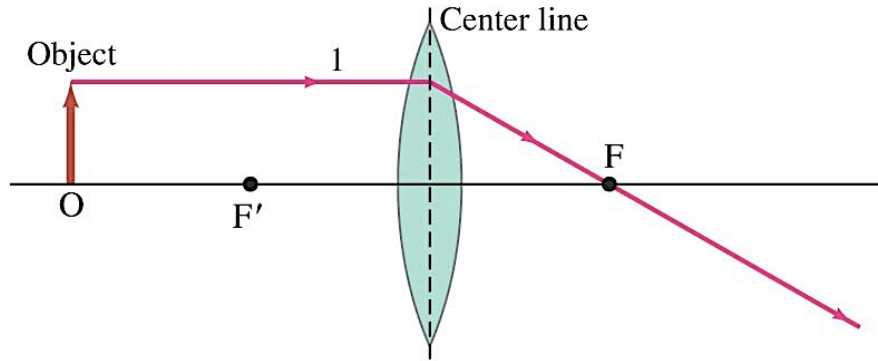
$$1 \text{ D} = 1 \text{ m}^{-1}.$$

33-1 Thin Lenses; Ray Tracing

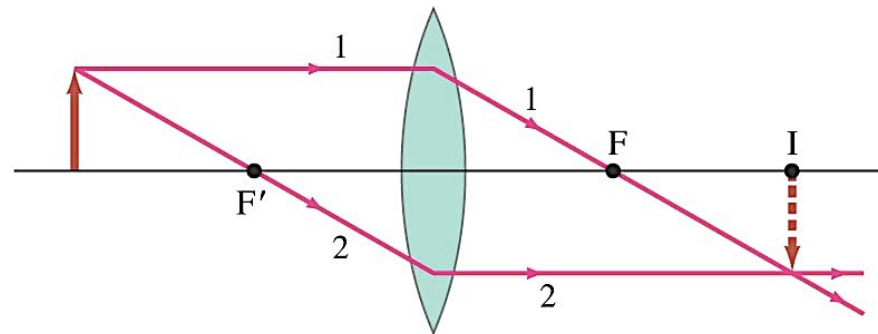
Ray tracing for thin lenses is similar to that for mirrors. We have three key rays:

1. This ray comes in parallel to the axis and exits through the focal point.
2. This ray comes in through the focal point and exits parallel to the axis.
3. This ray goes through the center of the lens and is undeflected.

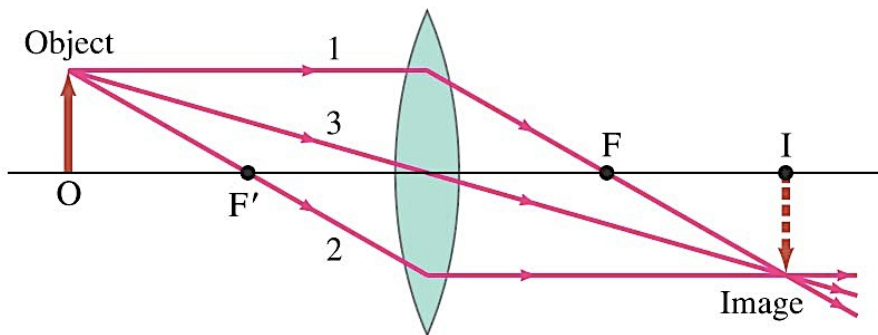
33-1 Thin Lenses; Ray Tracing



(a) Ray 1 leaves one point on object going parallel to the axis, then refracts through focal point behind the lens.



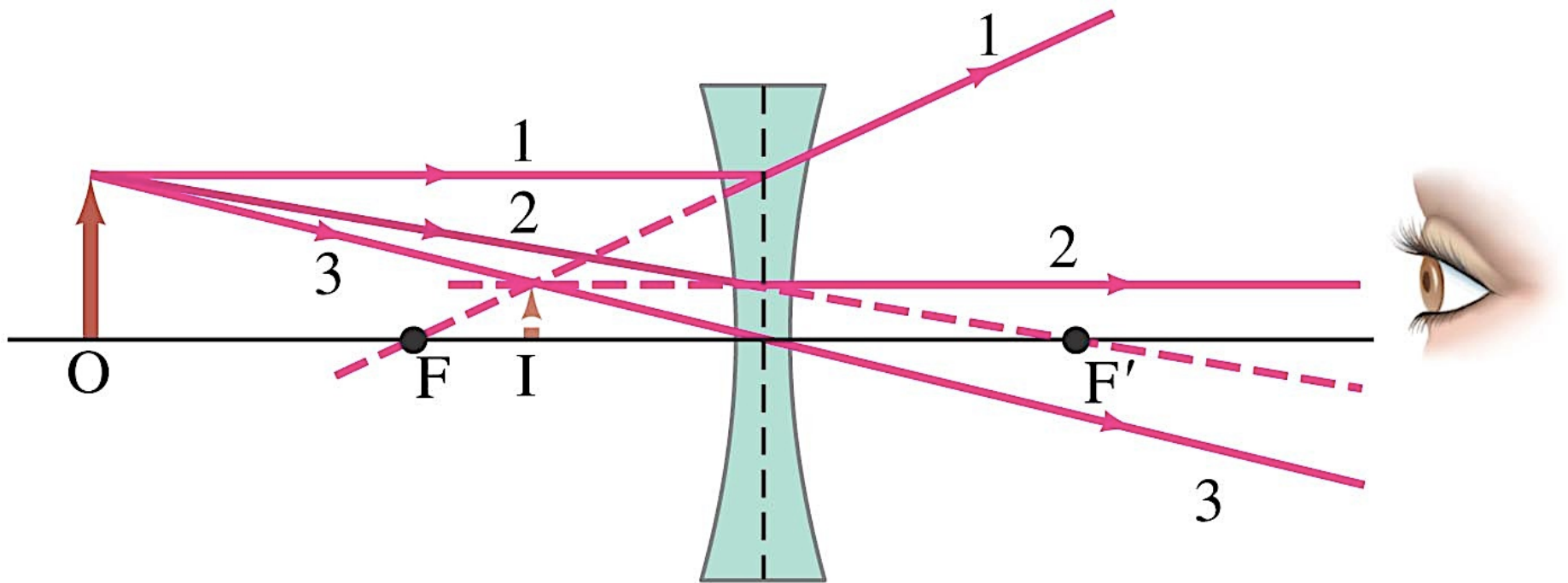
(b) Ray 2 passes through F' in front of the lens; therefore it is parallel to the axis behind the lens.



(c) Ray 3 passes straight through the center of the lens (assumed very thin).

33-1 Thin Lenses; Ray Tracing

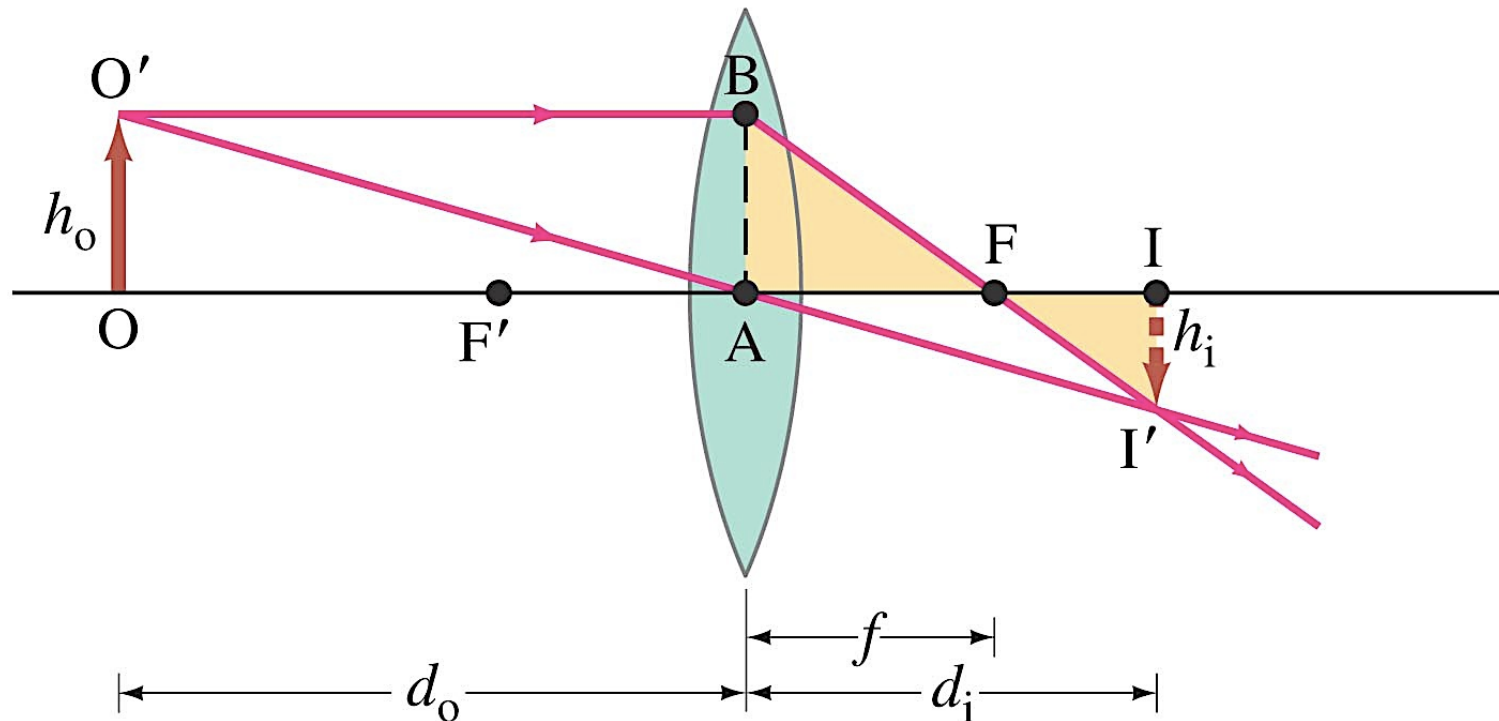
For a diverging lens, we can use the same three rays; the image is upright and virtual.



33-2 The Thin Lens Equation; Magnification

The thin lens equation
is similar to the mirror
equation:

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



33-2 The Thin Lens Equation; Magnification

The sign conventions are slightly different:

- 1. The focal length is positive for converging lenses and negative for diverging.**
- 2. The object distance is positive when the object is on the same side as the light entering the lens (not an issue except in compound systems); otherwise it is negative.**
- 3. The image distance is positive if the image is on the opposite side from the light entering the lens; otherwise it is negative.**
- 4. The height of the image is positive if the image is upright and negative otherwise.**

33-2 The Thin Lens Equation; Magnification

The magnification formula is also the same as that for a mirror:

$$m = \frac{h_i}{h_o} = -\frac{d_i}{d_o}$$

The power of a lens is positive if it is converging and negative if it is diverging.

33-2 The Thin Lens Equation; Magnification

Problem Solving: Thin Lenses

- 1. Draw a ray diagram. The image is located where the key rays intersect.**
- 2. Solve for unknowns.**
- 3. Follow the sign conventions.**
- 4. Check that your answers are consistent with the ray diagram.**

33-3 Combinations of Lenses

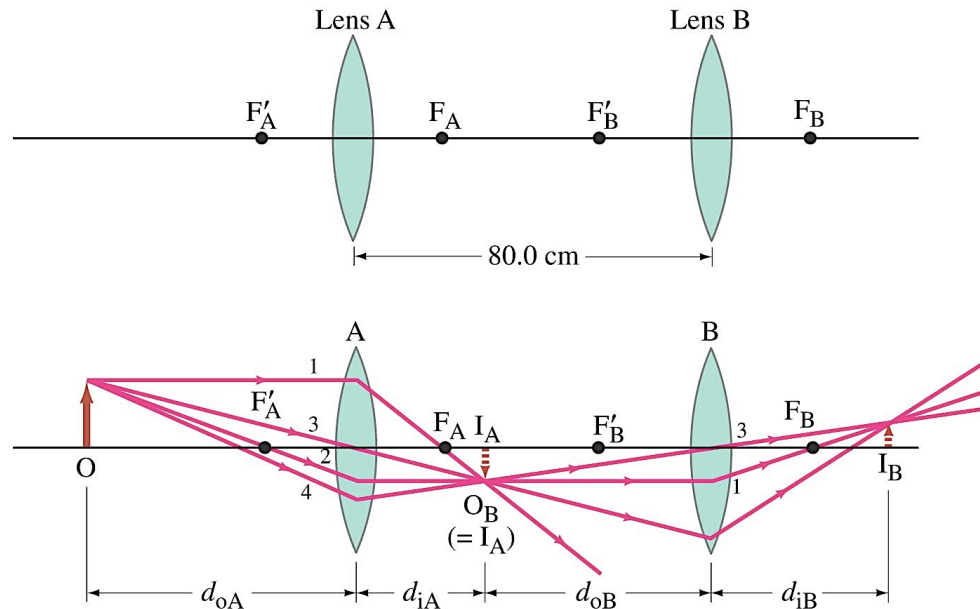
In lens combinations, the image formed by the first lens becomes the object for the second lens (this is where object distances may be negative).

The total magnification is the product of the magnification of each lens.

33-3 Combinations of Lenses

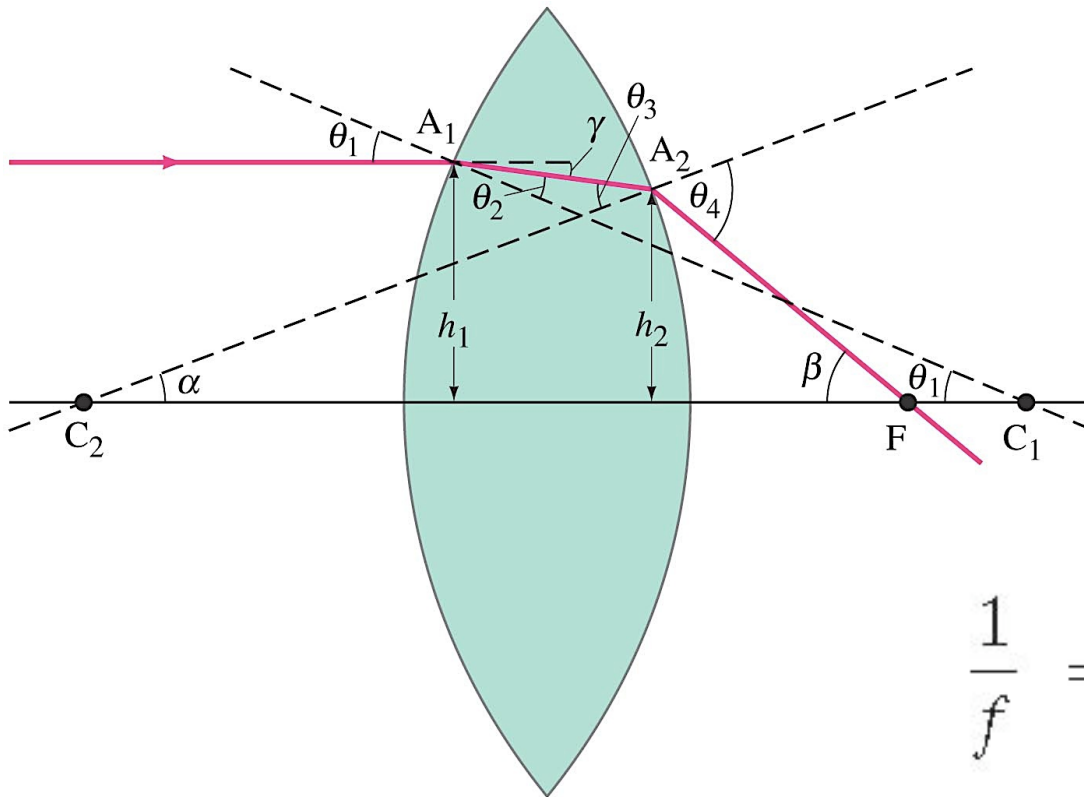
Example 33-5: A two-lens system.

Two converging lenses, A and B, with focal lengths $f_A = 20.0$ cm and $f_B = 25.0$ cm, are placed 80.0 cm apart. An object is placed 60.0 cm in front of the first lens. Determine (a) the position, and (b) the magnification, of the final image formed by the combination of the two lenses.



33-4 Lensmaker's Equation

This useful equation relates the radii of curvature of the two lens surfaces, and the index of refraction, to the focal length:



$$\frac{1}{f} = (n - 1) \left(\frac{1}{R_1} + \frac{1}{R_2} \right).$$

33-6 The Human Eye; Corrective Lenses

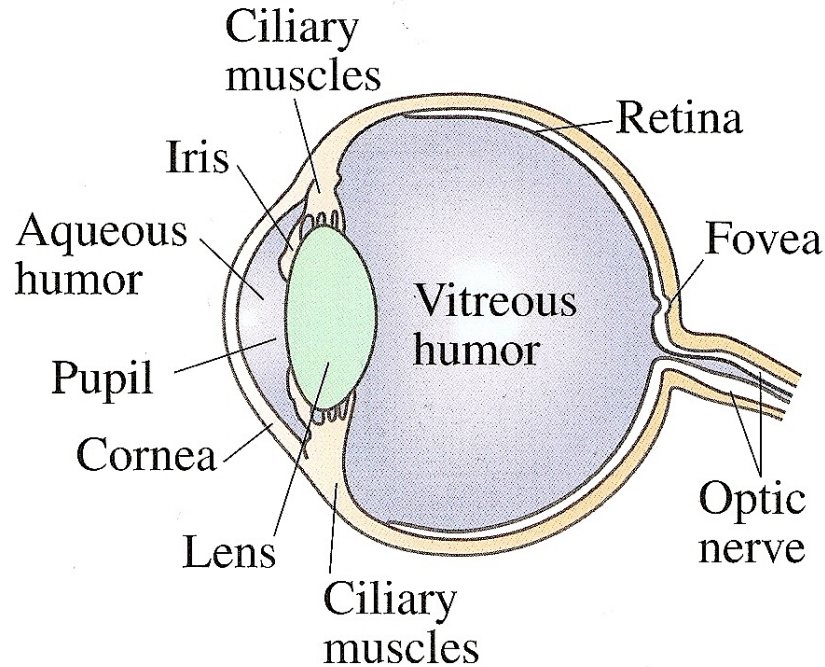
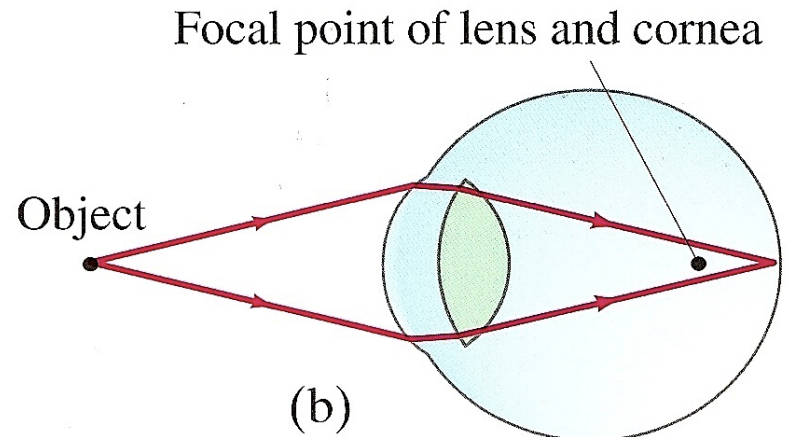
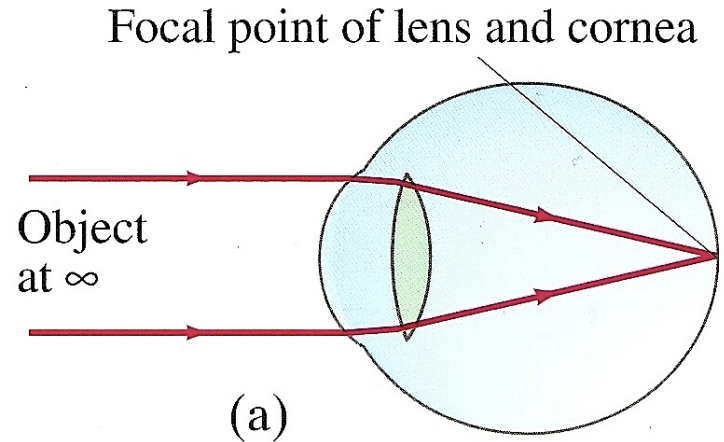


Figure 33.25



Most of the refraction is done at the front surface of the cornea. The **lens** act as a fine adjustment for focusing at different distances, so-called **accommodation**.

33-6 The Human Eye; Corrective Lenses

Near point: closest distance at which eye can focus clearly. Normal is about 25 cm.

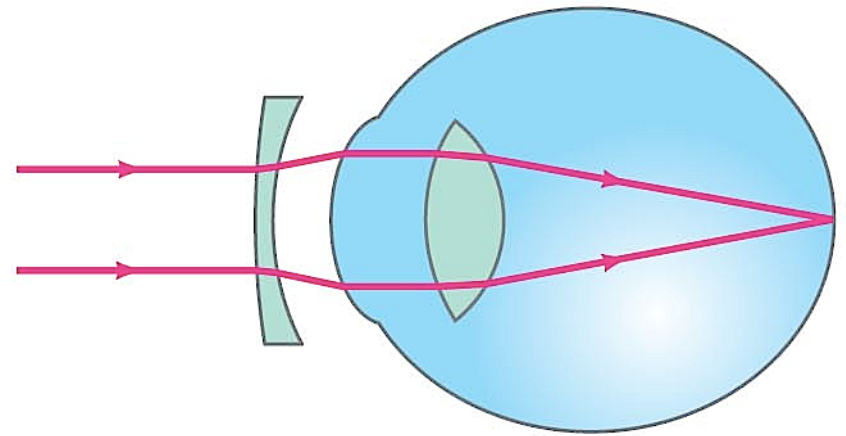
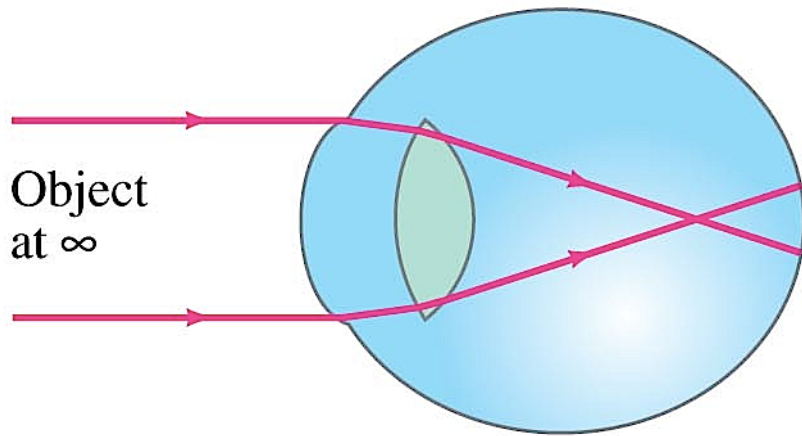
Far point: farthest distance at which object can be seen clearly. Normal is at infinity.

Nearsightedness: far point is too close.

Farsightedness: near point is too far away.

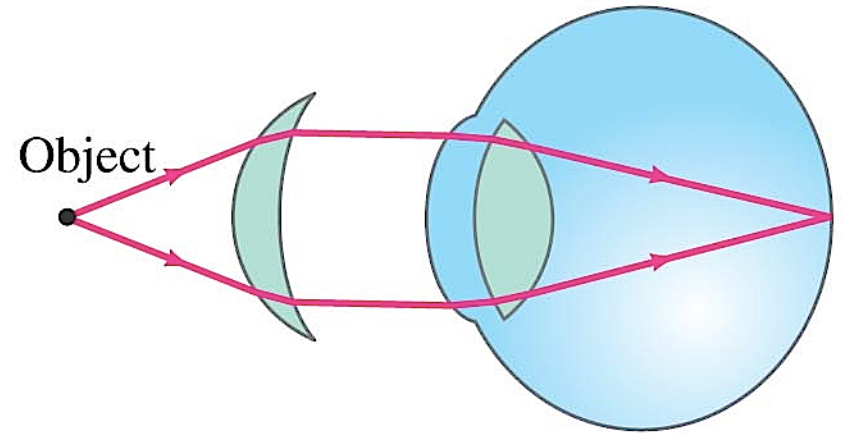
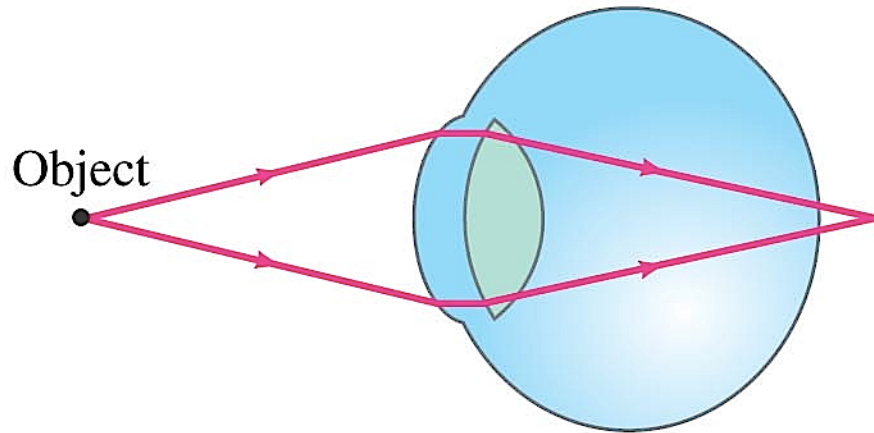
33-6 The Human Eye; Corrective Lenses

Nearsightedness (or myopia) can be corrected with a diverging lens.



33-6 The Human Eye; Corrective Lenses

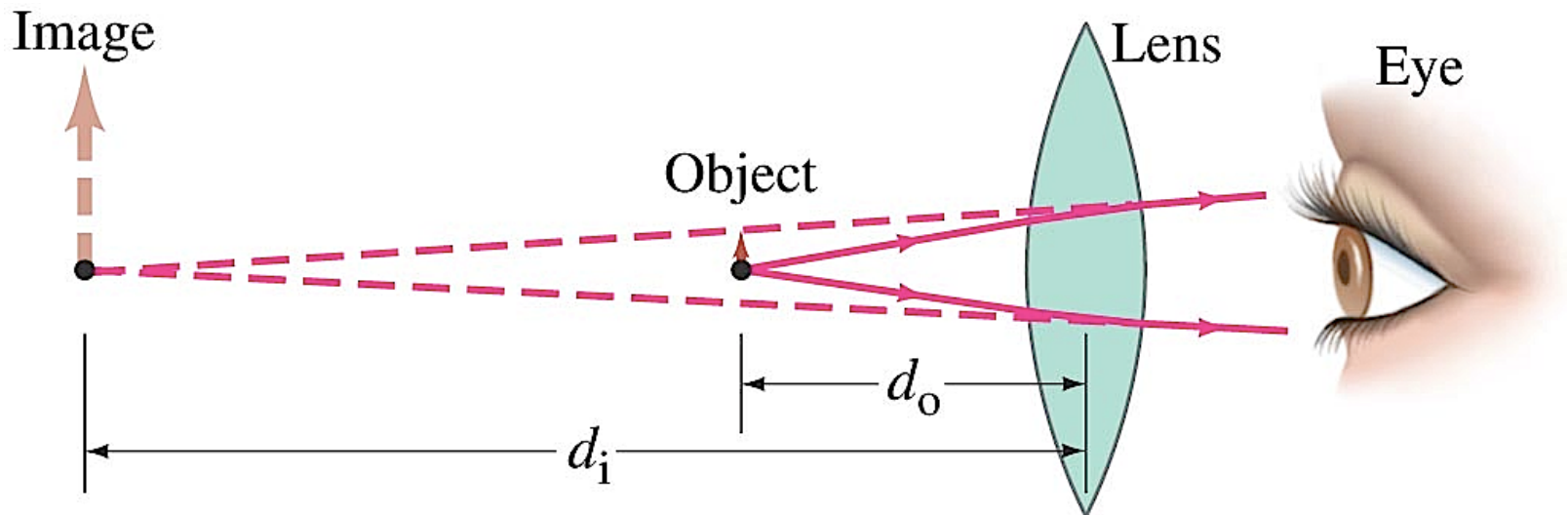
And farsightedness (hyperopia) with a diverging lens.



33-6 The Human Eye; Corrective Lenses

Example 33-12: Farsighted eye.

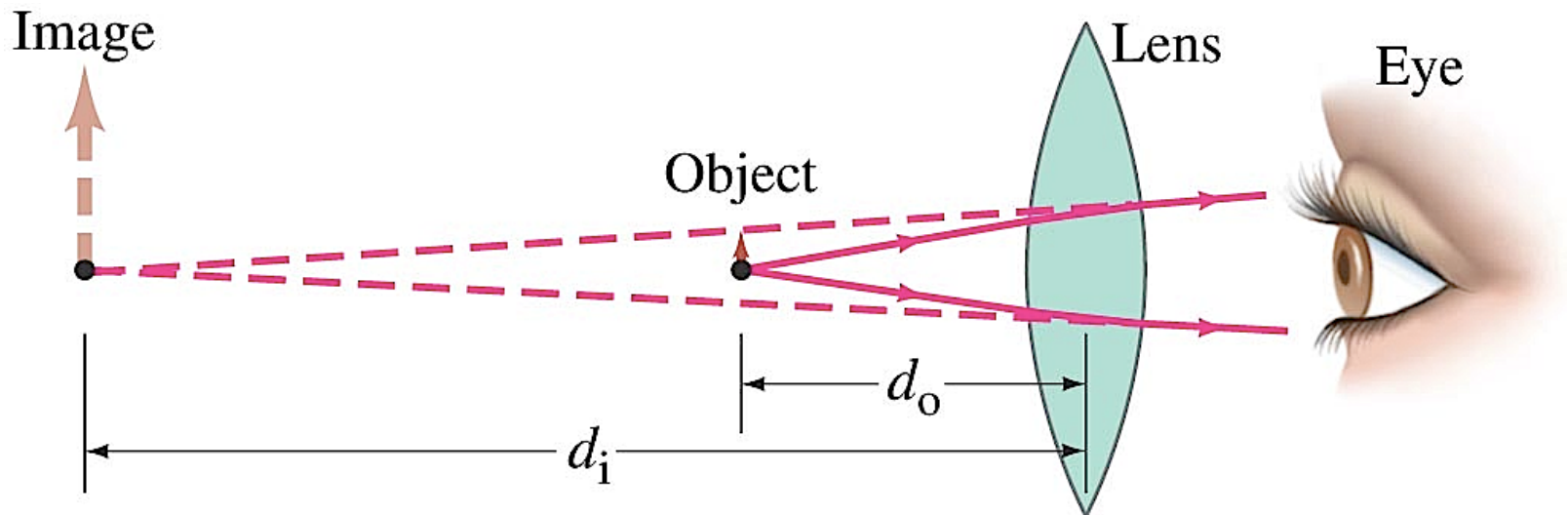
Sue is farsighted with a near point of 100 cm. Reading glasses must have what lens power so that she can read a newspaper at a distance of 25 cm? Assume the lens is very close to the eye.



33-6 The Human Eye; Corrective Lenses

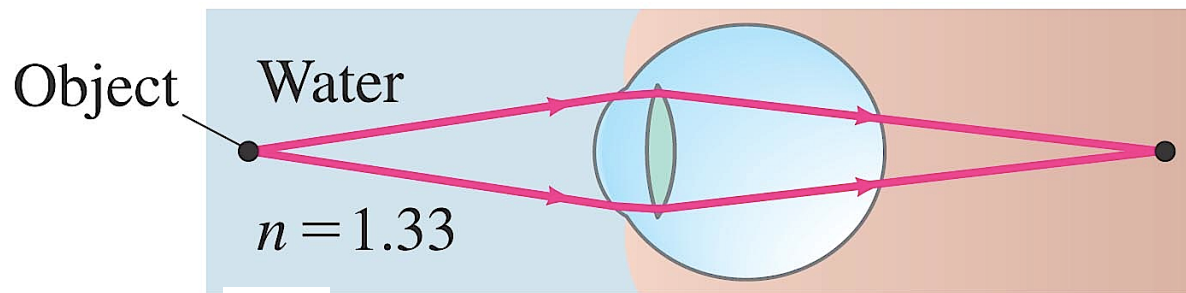
Solution:

Using $d_o = 25$ cm and $d_i = -100$ cm gives $f = 0.33$ m. The lens power is $+3.0$ D.

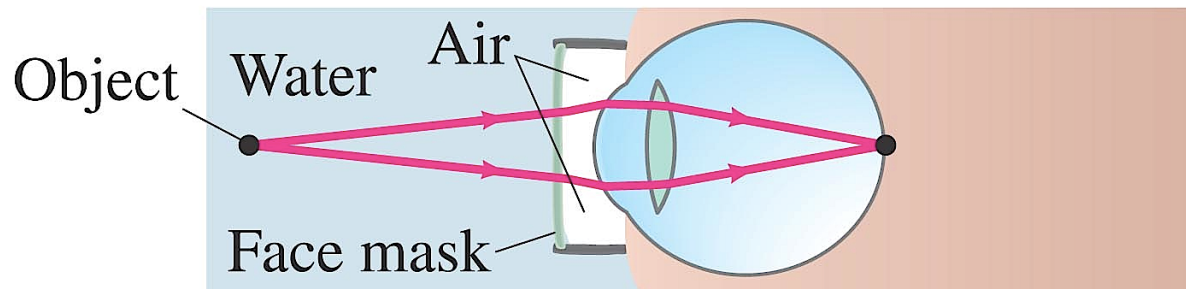


33-6 The Human Eye; Corrective Lenses

Vision is blurry under water because light rays are bent much less than they would be if entering the eye from air. This can be avoided by wearing goggles.



(a)

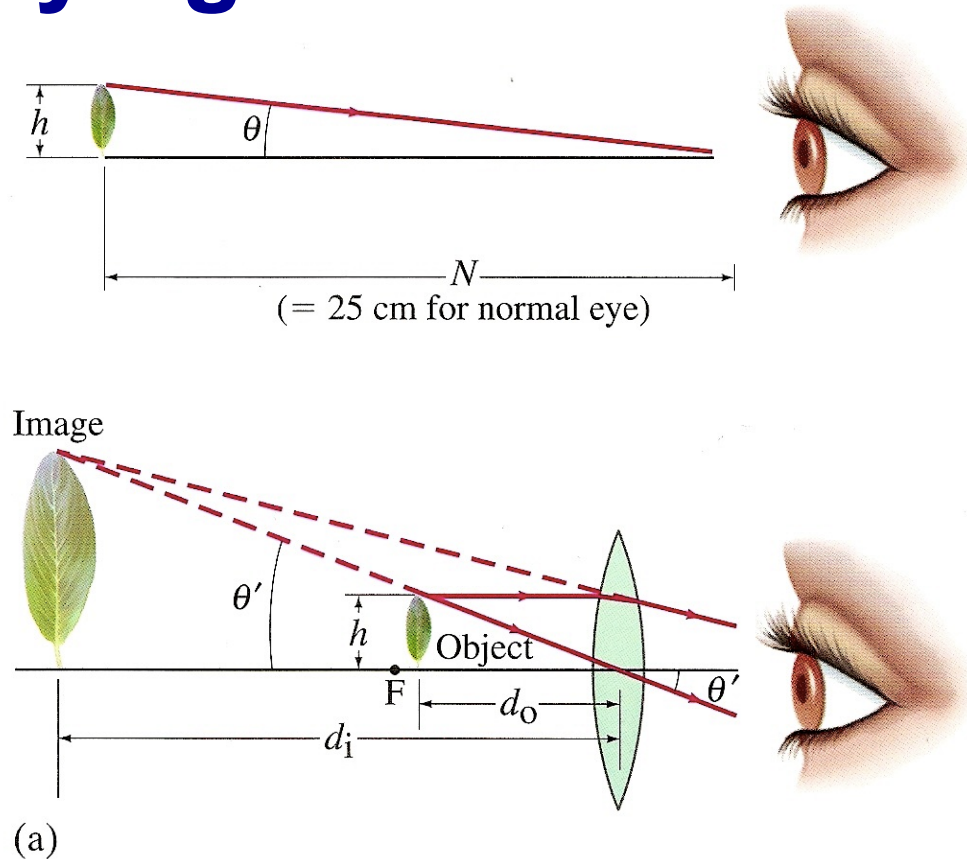


33-7 Magnifying Glass

The closest distance at which a normal eye can focus clearly is called the near point of the eye (which is in average 25 cm).

If instead the lens is held such that the image is at the near point of the eye (25 cm), a larger angular magnification can be obtained.

If the lens is held such that its front focal point is on the object being viewed, the relaxed eye can view the image with angular magnification



Angular magnification or magnifying power

$$M = \frac{\tan \theta'}{\tan \theta} \cong \frac{\theta'}{\theta} = \frac{h/f}{h/N} = \frac{N}{f}$$

33-7 Magnifying Glass

The power of a magnifying glass is described by its angular magnification:

$$M = \frac{\theta'}{\theta}.$$

If the eye is relaxed (N is the near point distance and f the focal length):

$$M = \frac{\theta'}{\theta} = \frac{h/f}{h/N} = \frac{N}{f}. \quad \left[\begin{array}{l} \text{eye focused at } \infty; \\ N = 25 \text{ cm for normal eye} \end{array} \right]$$

If the eye is focused at the near point:

$$M = \frac{N}{f} + 1. \quad \left[\begin{array}{l} \text{eye focused at near point, } N; \\ N = 25 \text{ cm for normal eye} \end{array} \right]$$