Phys102 Lecture 23/24

Lenses and Optical Instruments

Key Points

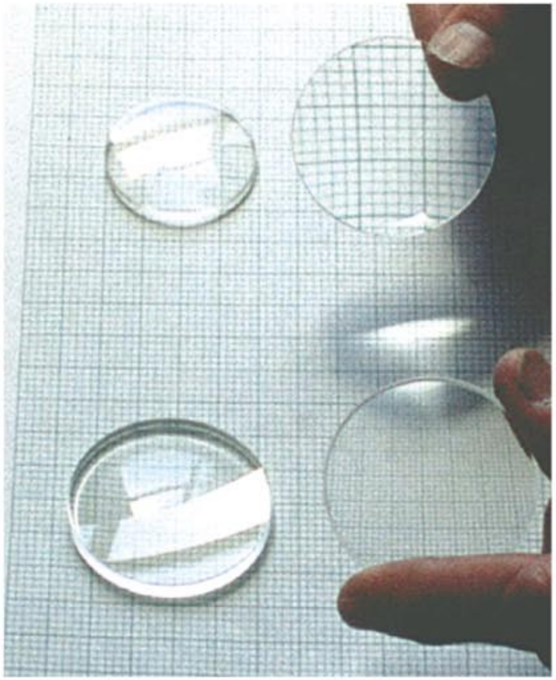
- Thin Lenses; Ray Tracing
- Combinations of Lenses
- The Human Eye; Corrective Lenses
- Compound Microscope

References

23-7,8,9; 25-2,3,4,5.

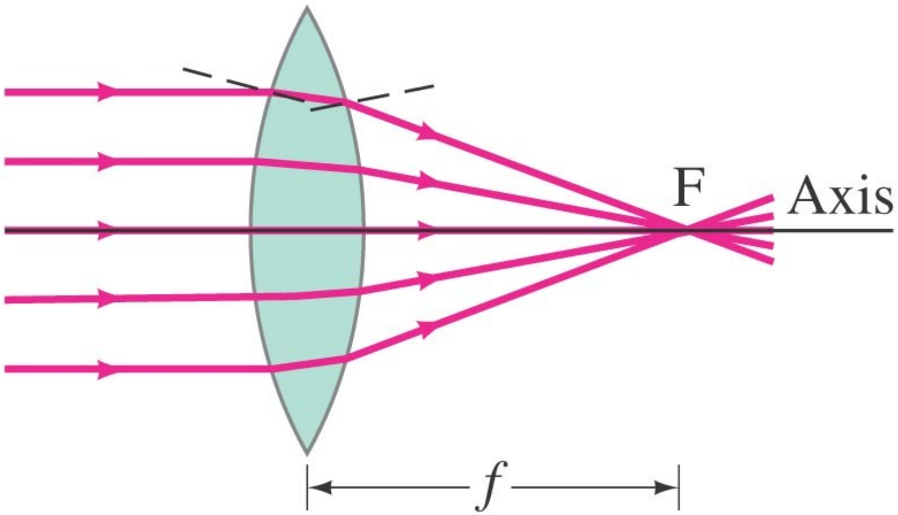
Thin Lenses

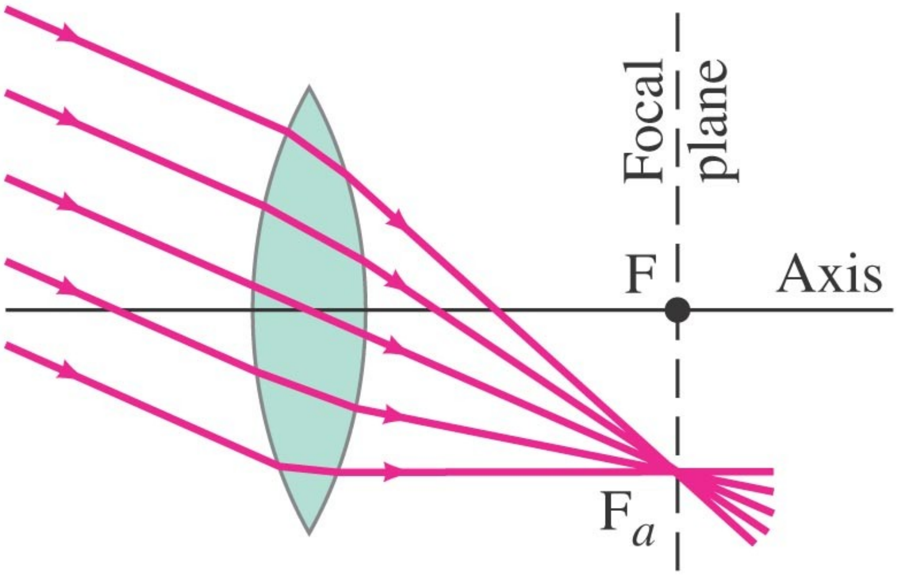
Thin lenses are those whose thickness is small compared to their radius of curvature. They may be either converging (a) or diverging (b).



Ray Tracing

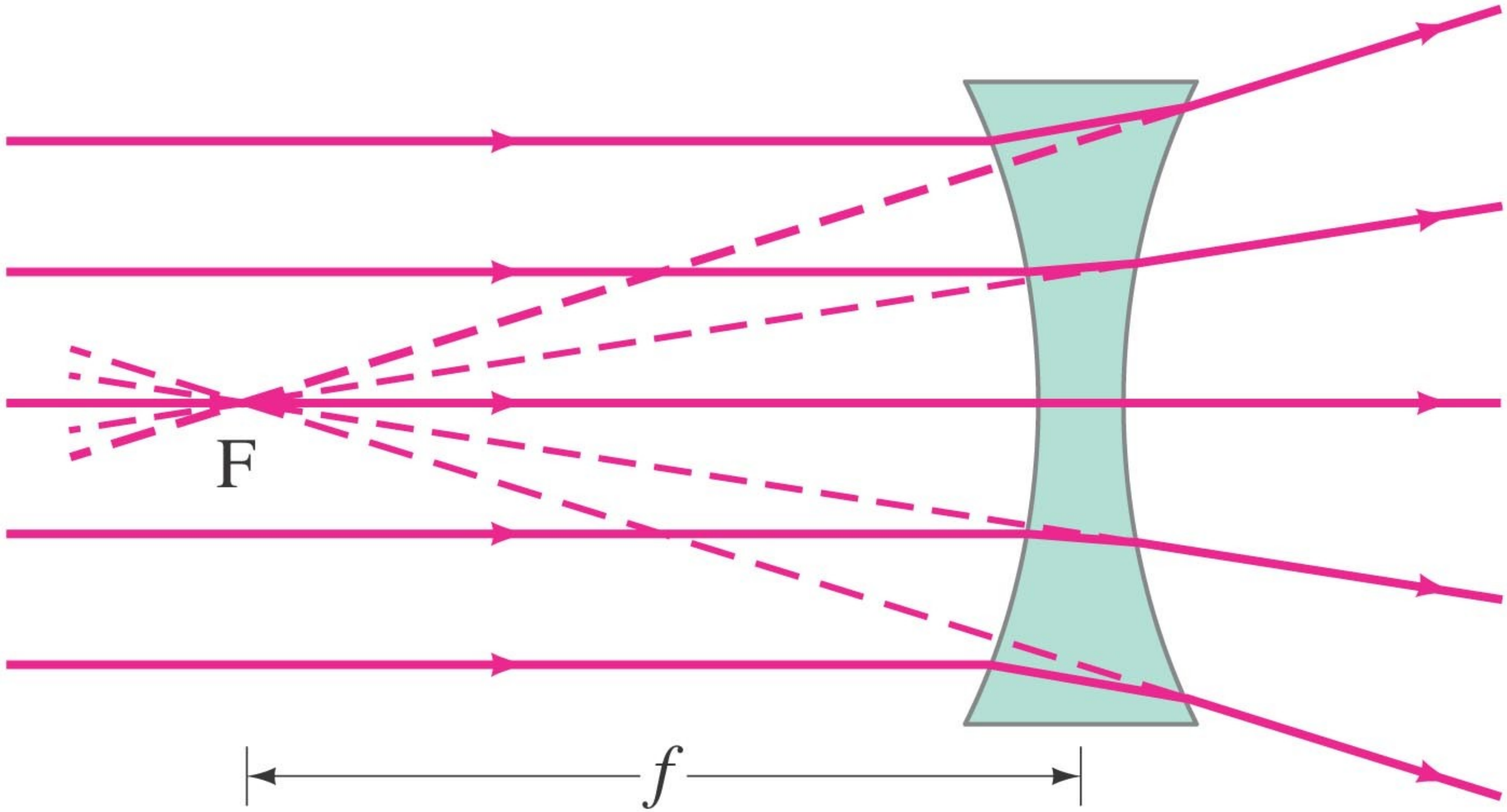
Parallel rays are brought to a focus by a converging lens (one that is thicker in the center than it is at the edge).





Ray Tracing

A diverging lens (thicker at the edge than in the center) makes parallel light diverge; the focal point is that point where the diverging rays would converge if projected back.



The Power of a Lens

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

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

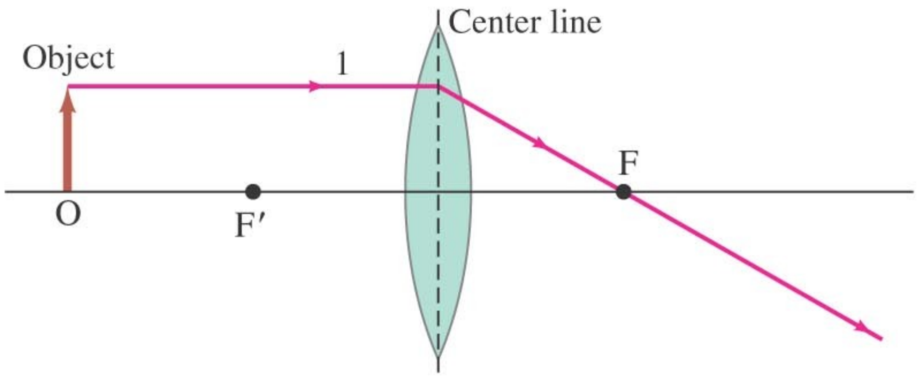
Lens power is measured in diopters, D:

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

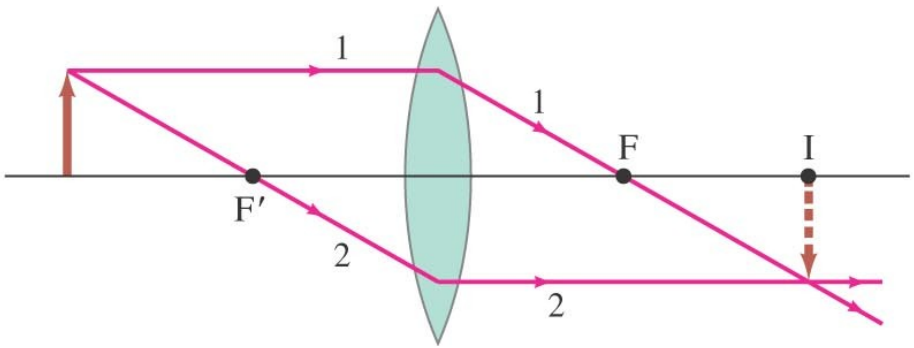
Thin Lenses; Ray Tracing

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

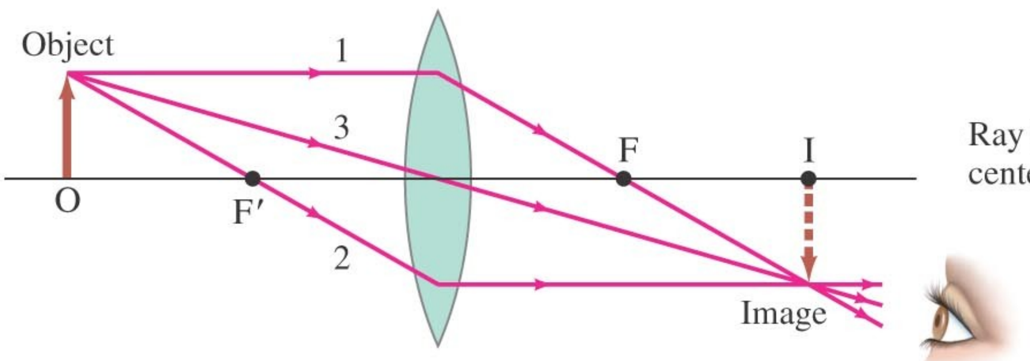
1. This ray comes in parallel to the axis and exits through the focal point.
2. This ray comes in through the focal point and exits parallel to the axis.
3. This ray goes through the center of the lens and is undeflected.



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

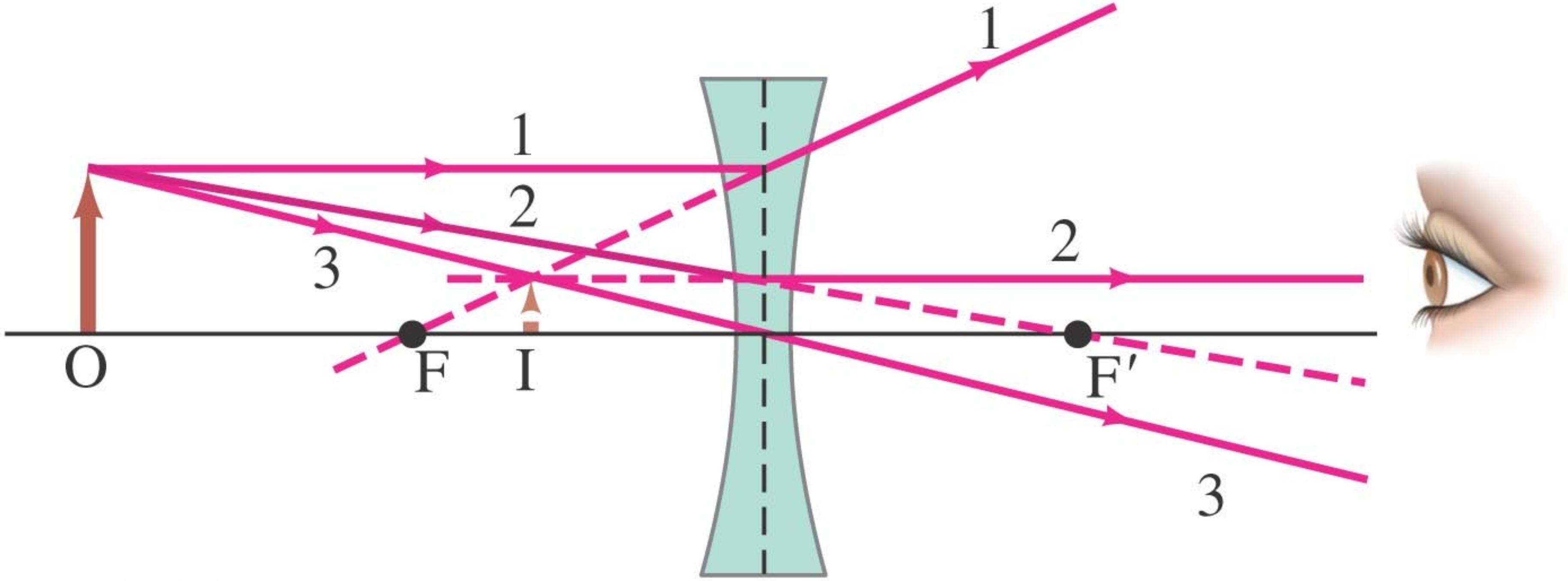


Ray 2 passes through F′ in front of the lens; therefore it is parallel to the axis behind the lens.



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

For a diverging lens, we can use the same three rays.



Ray 1 is drawn parallel to the axis, but does not pass through the focal point F’ behind the lens. Instead it seems to come from the focal point F in front of the lens.

Conceptual Example: Half-blocked lens.

What happens to the image of an object if the top half of a lens is covered by a piece of cardboard?

A) Half of the image is blocked, so we can only see half of the image.

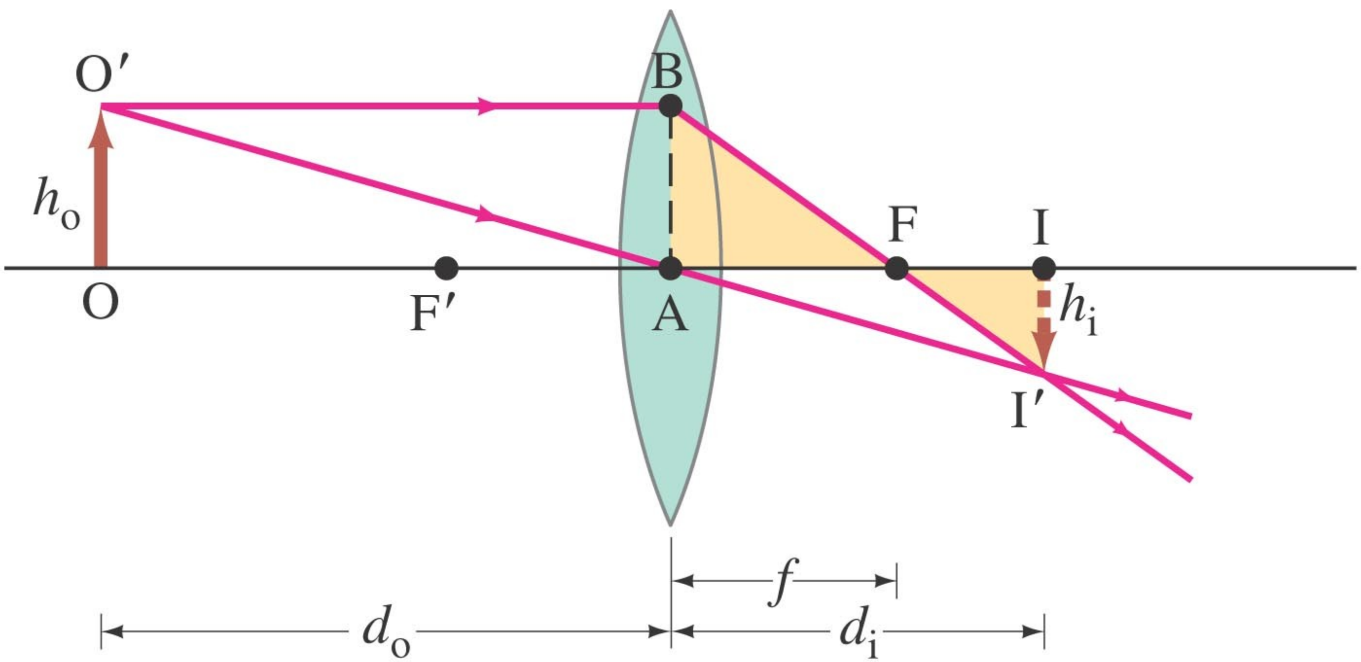
B) We can still see the whole image, but not as bright.

C) The image is not affected at all.

The Thin Lens Equation

The thin lens equation is similar to the mirror equation:

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



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.

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

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

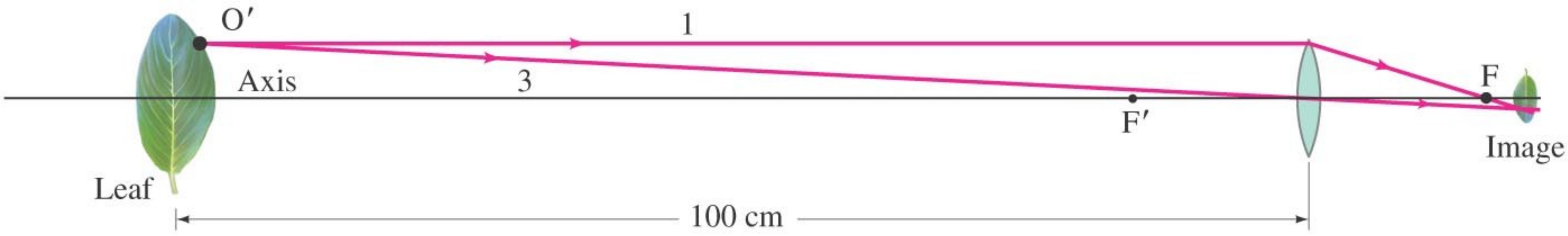
The power of a lens (p=1/f) is positive if it is converging and negative if it is diverging.

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.

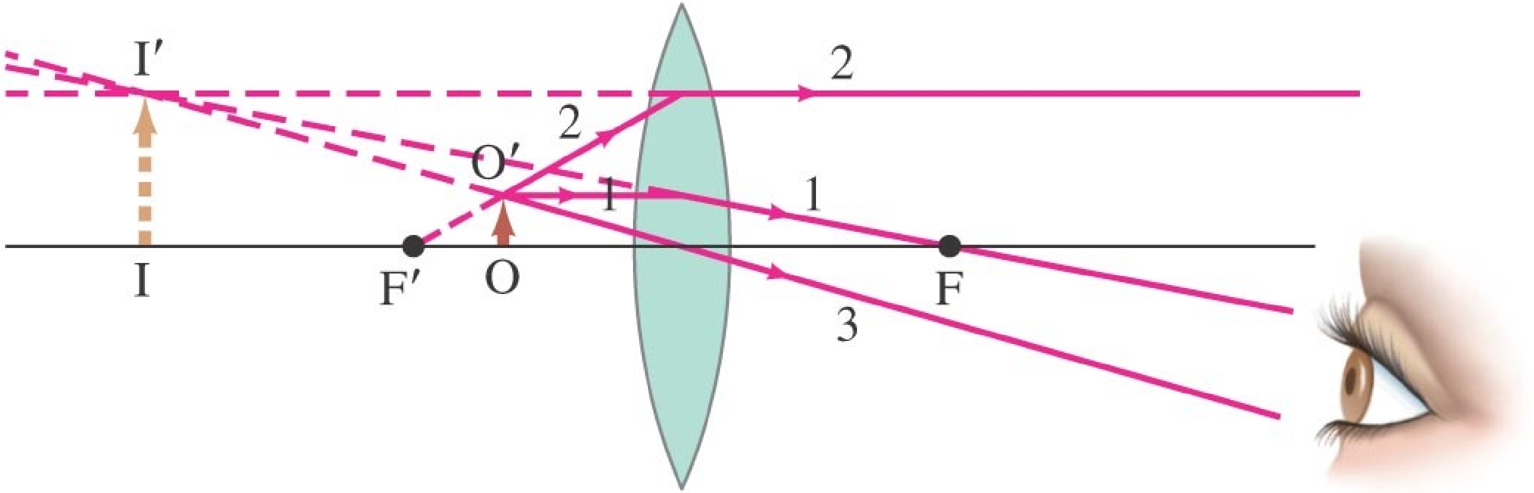
Example: Image formed by converging lens.

What are (a) the position, and (b) the size, of the image of a 7.6-cm-high leaf placed 1.00 m from a +50.0-mm-focal-length camera lens?



Example: Object close to converging lens.

An object is placed 10 cm from a 15-cm-focal-length converging lens. Determine the image position and size (a) analytically, and (b) using a ray diagram.



Example: Diverging lens.

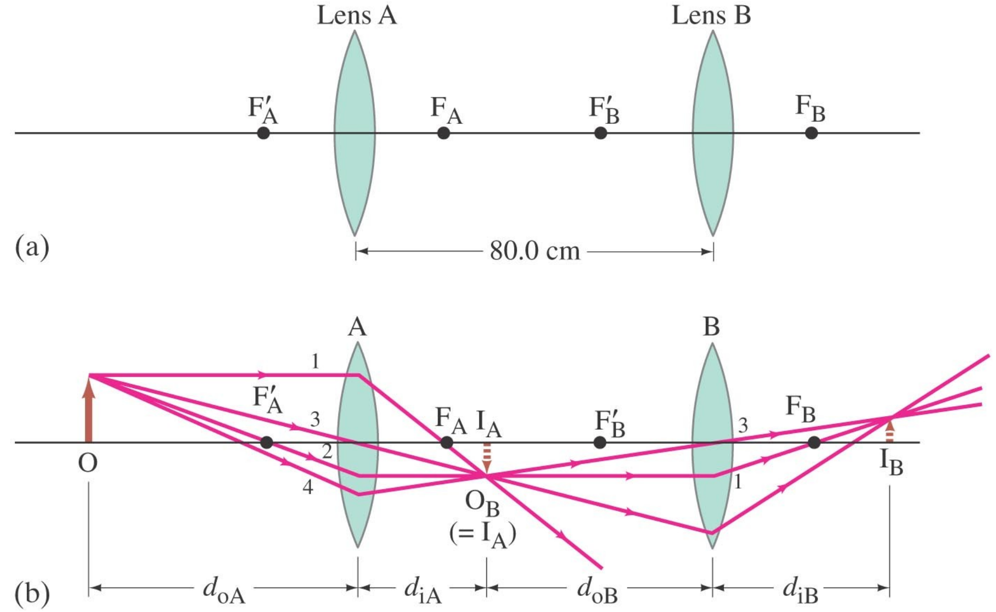
Where must a small insect be placed if a 25-cm-focal-length diverging lens is to form a virtual image 20 cm from the lens, on the same side as the object?

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.

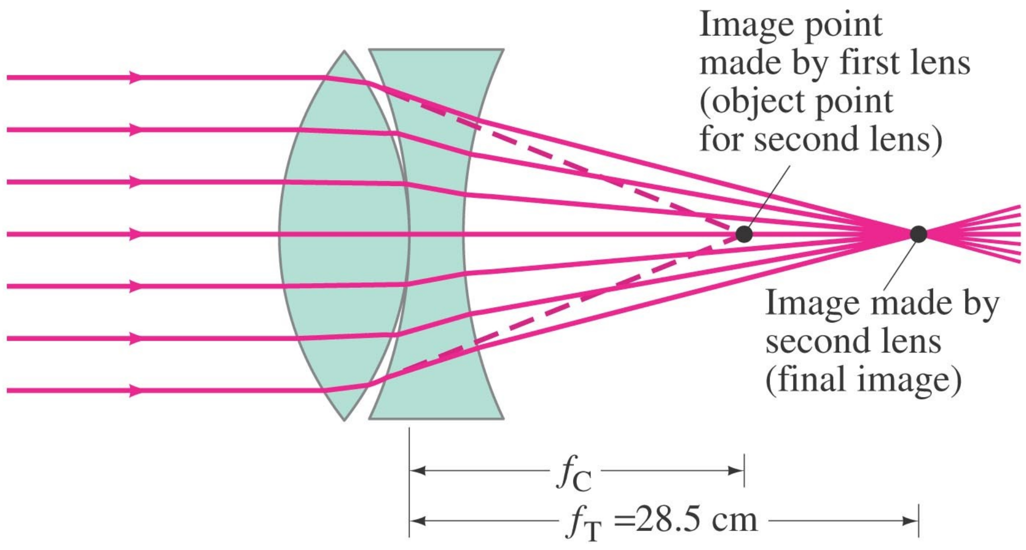
Example: A two-lens system.

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.



Example: Measuring f for a diverging lens.

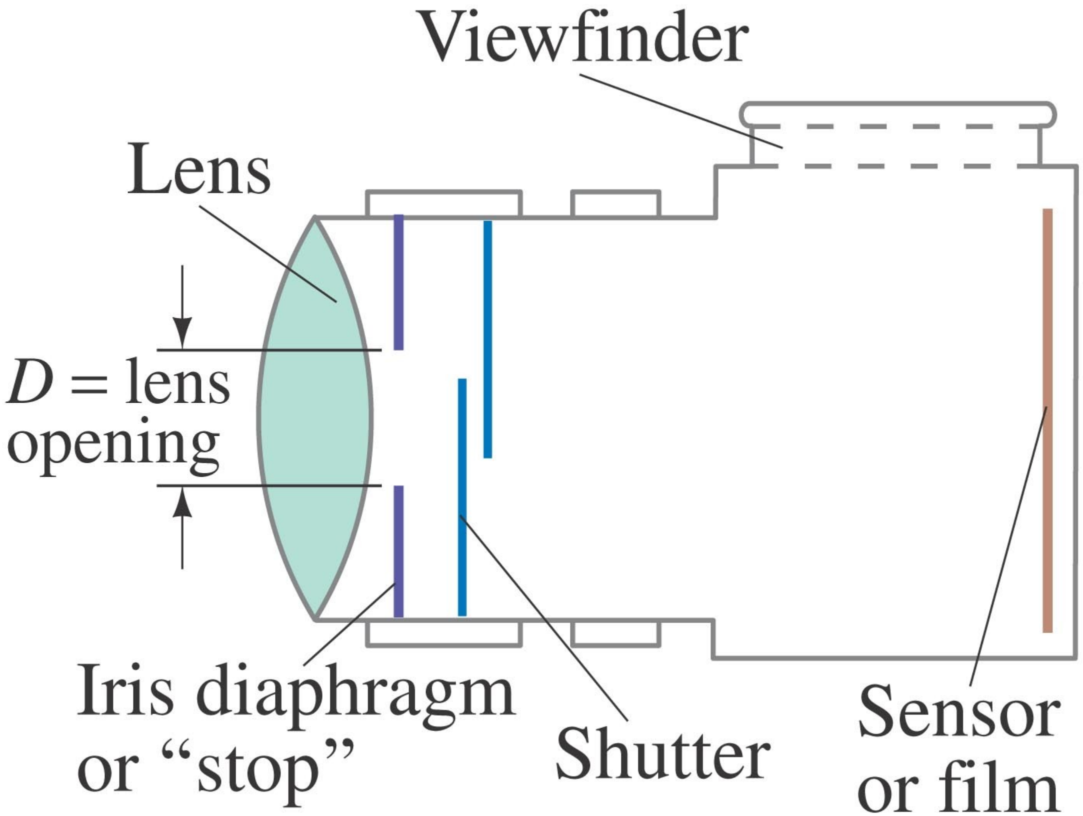
To measure the focal length of a diverging lens, a converging lens is placed in contact with it. The Sun's rays are focused by this combination at a point 28.5 cm behind the lenses as shown. If the converging lens has a focal length f_C of 16.0 cm, what is the focal length f_D of the diverging lens? Assume both lenses are thin and the space between them is negligible.



Cameras

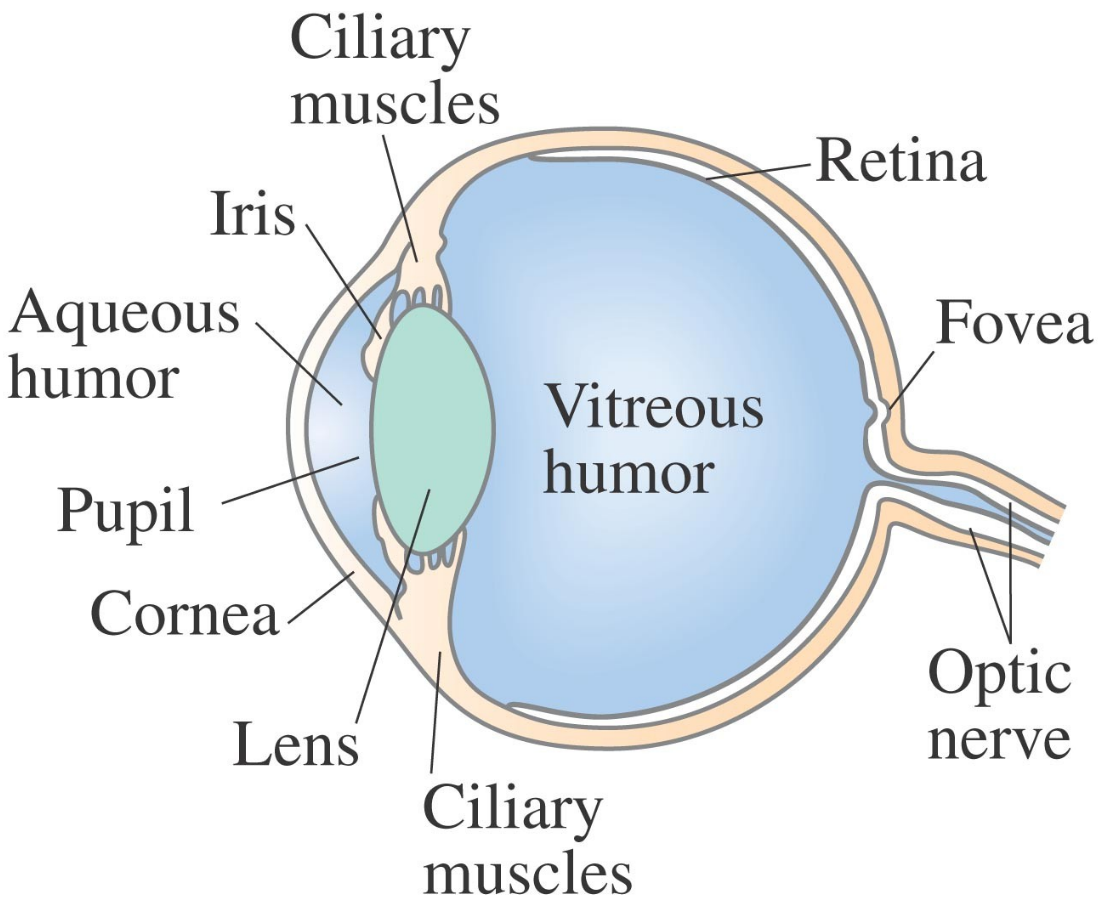
Basic parts of a camera:

- **Lens**
- **Light-tight box**
- **Shutter**
- **Film or electronic sensor**



The Human Eye

The human eye resembles a camera in its basic functioning, with an adjustable lens, the iris, and the retina.



The Human Eye

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

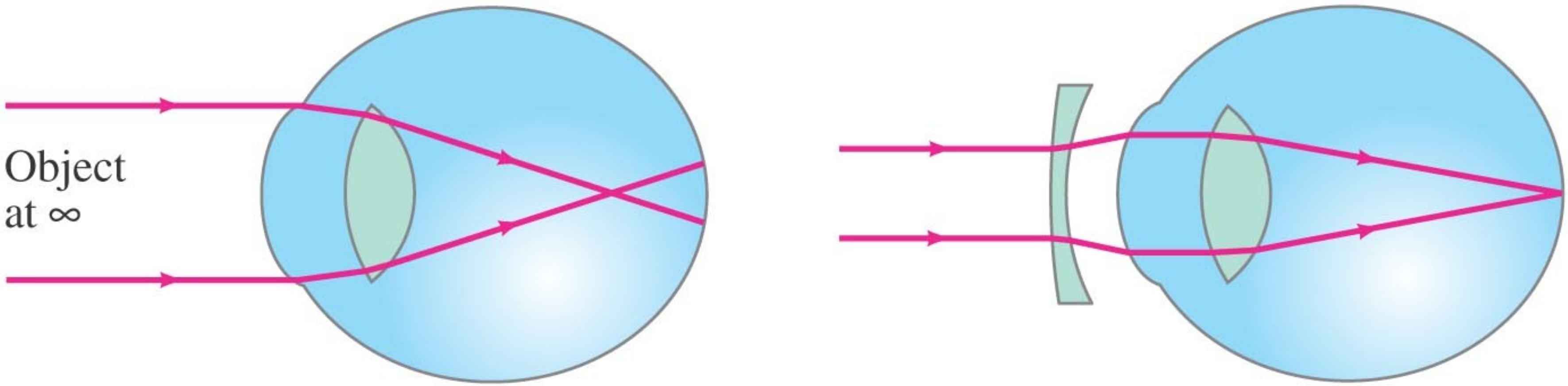
Far point: farthest distance at which object can be seen clearly. Normal is at infinity.

Nearsightedness: far point is too close.

Farsightedness: near point is too far away.

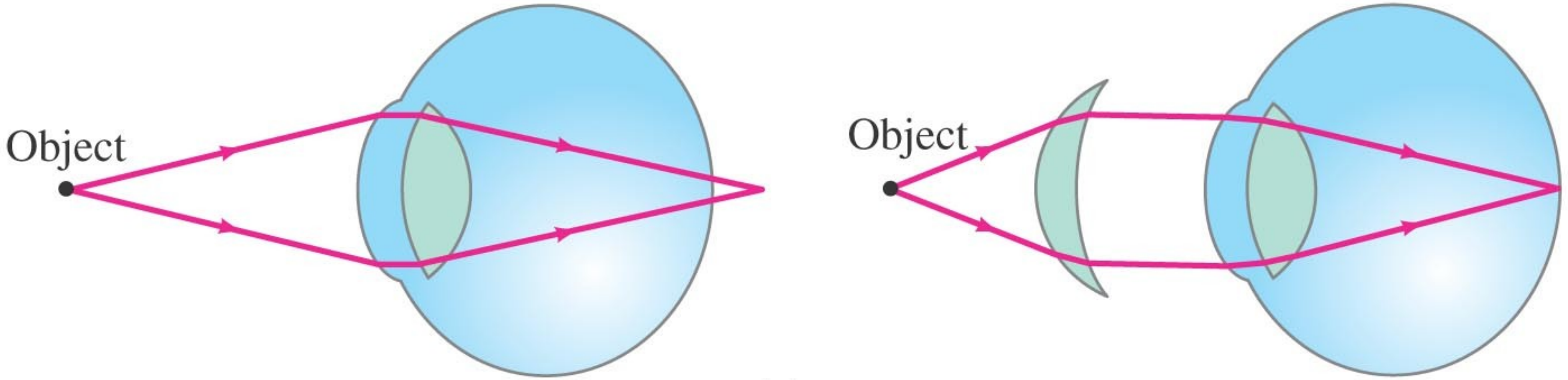
Corrective Lenses

Nearsightedness can be corrected with a diverging lens.



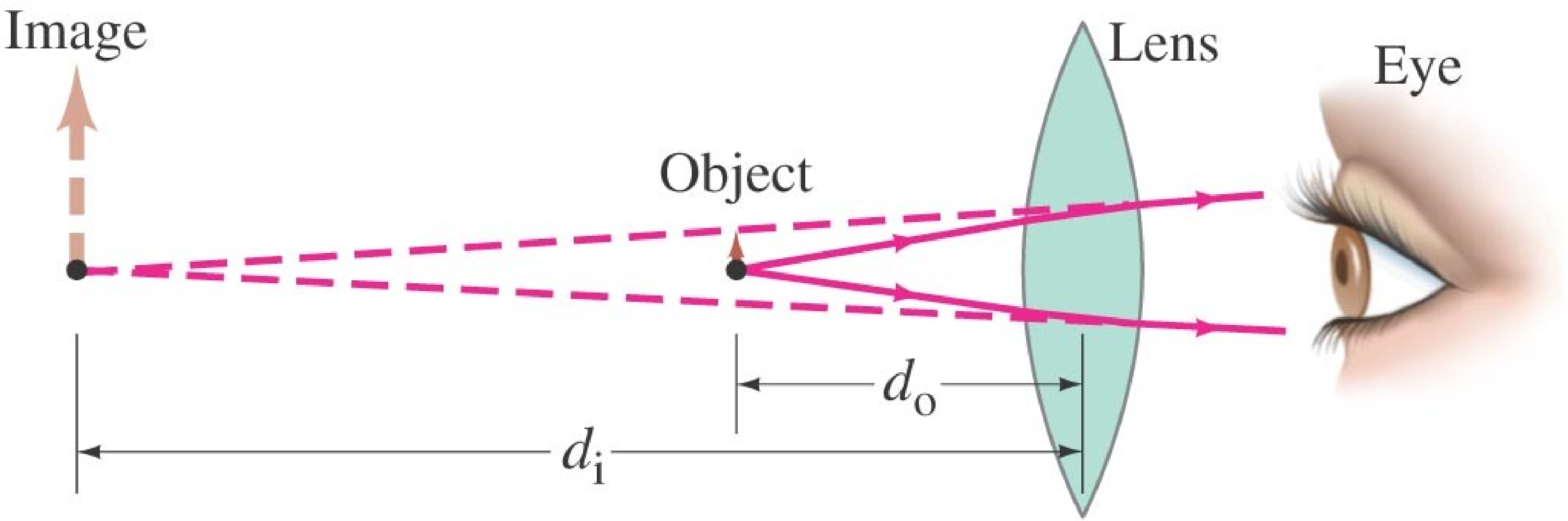
Corrective Lenses

And farsightedness with a converging lens.



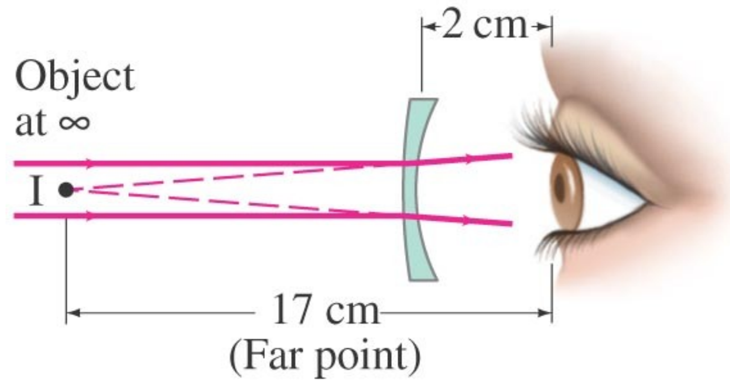
Example: Farsighted eye.

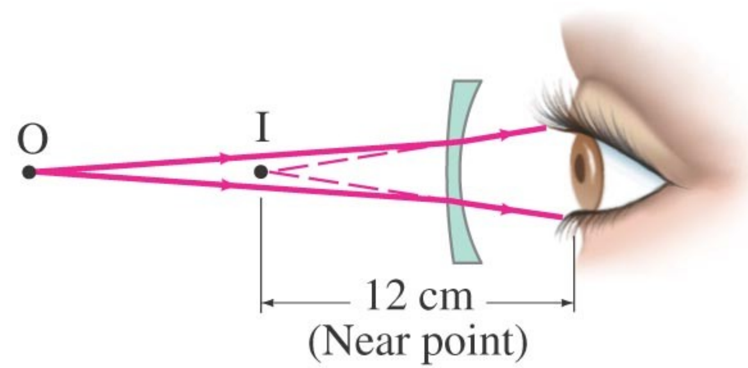
Sue is farsighted with a near point of 100 cm. Reading glasses must have what lens power so that she can read a newspaper at a distance of 25 cm? Assume the lens is very close to the eye.



Example: Nearsighted eye.

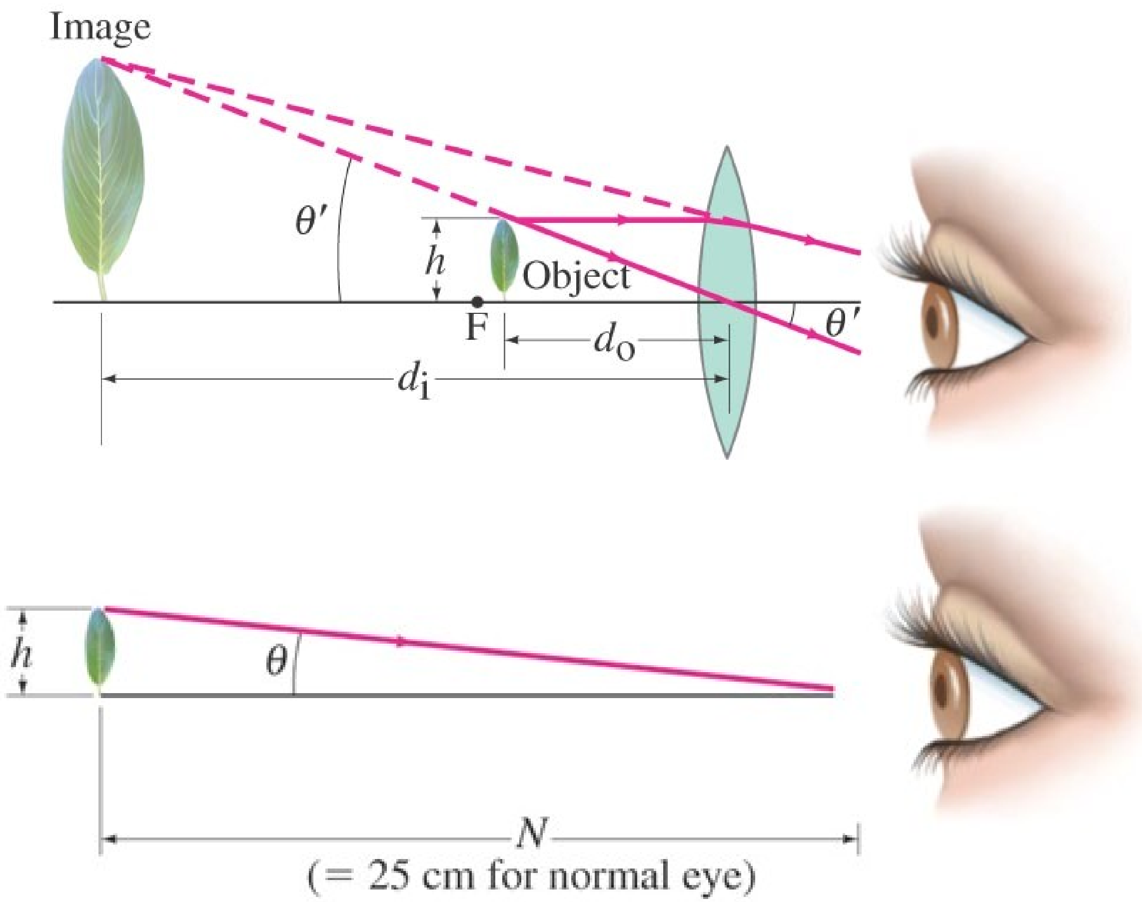
A nearsighted eye has near and far points of 12 cm and 17 cm, respectively. (a) What lens power is needed for this person to see distant objects clearly, and (b) what then will be the near point? Assume that the lens is 2.0 cm from the eye (typical for eyeglasses).





Magnifying Glass

A magnifying glass (simple magnifier) is a converging lens. It allows us to focus on objects closer than the near point, so that they make a larger, and therefore clearer, image on the retina.



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):

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

If the eye is focused at the near point:

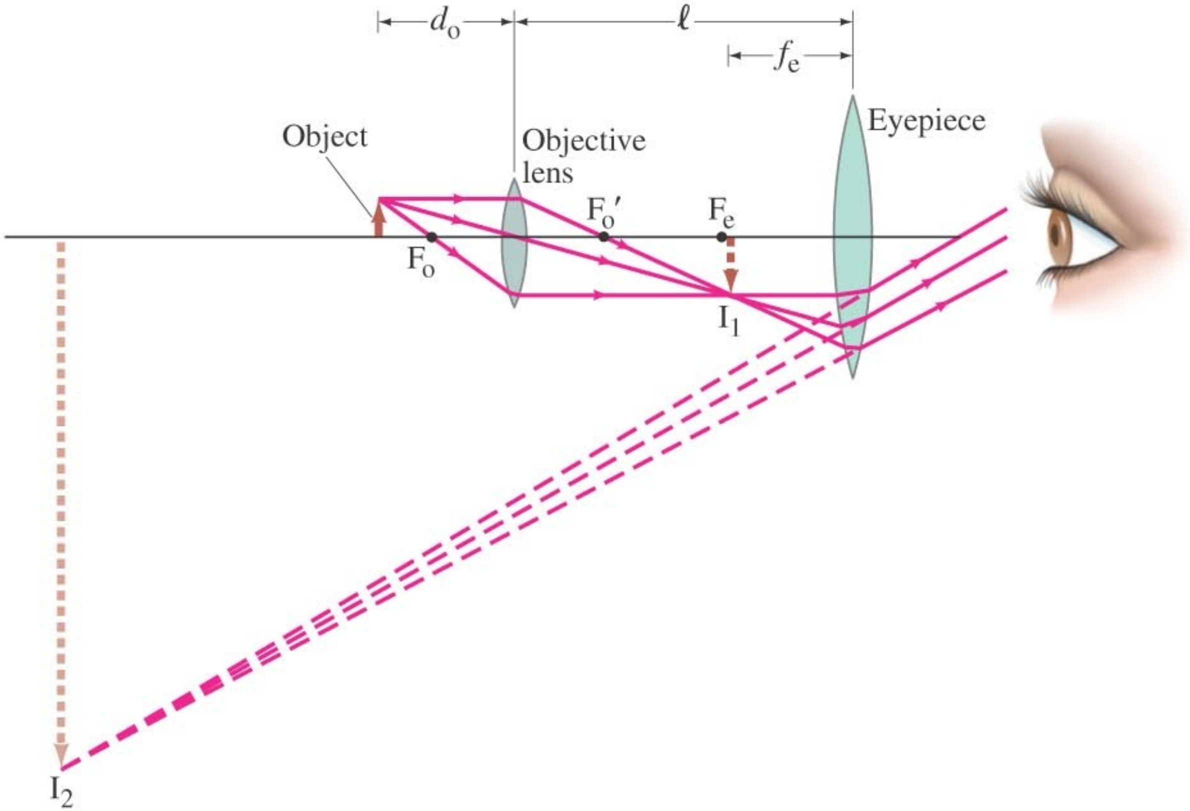
$$M = \frac{N}{f} + 1. \quad \left[\begin{array}{c}\text{eye focused at near point, } N; \\ N = 25 \text{ cm for normal eye}\end{array}\right]$$

Example: A jeweler's "loupe."

An 8-cm-focal-length converging lens is used as a "jeweler's loupe," which is a magnifying glass. Estimate (a) the magnification when the eye is relaxed, and (b) the magnification if the eye is focused at its near point N = 25 cm.

Compound Microscope

A compound microscope also has an objective and an eyepiece; it is different from a telescope in that the object is placed very close to the eyepiece.



Compound Microscope

The magnification is given by

$$M = M_e m_o = \left(\frac{N}{f_e}\right)\left(\frac{\ell - f_e}{d_o}\right) \qquad \text{[microscope]}$$

$$\approx \frac{N\ell}{f_e f_o}. \qquad [f_o \text{ and } f_e \ll \ell]$$

Example: Microscope.

A compound microscope consists of a 10X eyepiece and a 50X objective 17.0 cm apart. Determine (a) the overall magnification, (b) the focal length of each lens, and (c) the position of the object when the final image is in focus with the eye relaxed. Assume a normal eye, so N = 25 cm.