* 23–9 Combinations of Lenses

Multiple lenses: image formed by first lens is object for second lens

We now consider how to deal with lenses used in combination. When light passes through more than one lens, we find the image formed by the first lens as if it were alone. This image becomes the *object* for the second lens, and we find the image then formed by this second lens, which is the final image if there are only two lenses. The total magnification will be the product of the separate magnifications of each lens, as we shall see. Even if the second lens intercepts the light from the first lens before it forms an image, this technique still works.

EXAMPLE 23–12 **A two-lens system.** Two converging lenses, A and B, with focal lengths $f_A = 20.0\,\text{cm}$ and $f_B = 25.0\,\text{cm}$, are placed 80.0 cm apart, as shown in Fig. 23–41a. An object is placed 60.0 cm in front of the first lens as shown in Fig. 23–41b. Determine (*a*) the position, and (*b*) the magnification, of the final image formed by the combination of the two lenses.

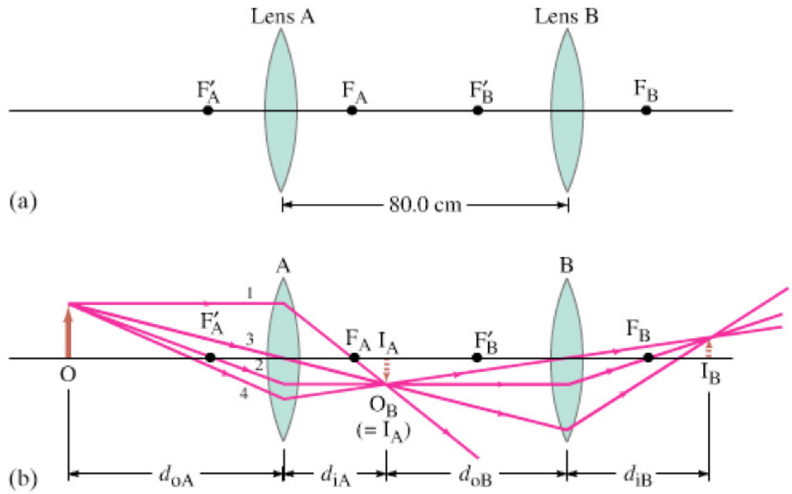

FIGURE 23–41 Two lenses, A and B, used in combination, Example 23–12. The small numbers refer to the easily drawn rays.

APPROACH Starting at the tip of our object O, we draw rays 1, 2, and 3 for the first lens, A, and also a ray 4 which, after passing through lens A, acts as "ray 3" (through the center) for the second lens, B. Ray 2 for lens A exits parallel, and so is ray 1 for lens B. To determine the position of the image I_A formed by lens A, we use Eq. 23–8 with $f_A = 20.0\,\text{cm}$ and $d_{oA} = 60.0\,\text{cm}$. The distance of I_A from lens B is the object distance d_{oB} for lens B. The final image is found using the thin lens equation, this time with all distances relative to lens B. For (*b*) the magnifications are found from Eq. 23–9 for each lens in turn.

SOLUTION (*a*) The object is a distance $d_{oA} = +60.0\,\text{cm}$ from the first lens, A, and this lens forms an image whose position can be calculated using the thin lens equation:

$$\frac{1}{d_{iA}} = \frac{1}{f_A} - \frac{1}{d_{oA}} = \frac{1}{20.0\,\text{cm}} - \frac{1}{60.0\,\text{cm}} = \frac{3-1}{60.0\,\text{cm}} = \frac{1}{30.0\,\text{cm}}.$$

CAUTION *Note that object distance for second lens is* **not** *equal to the image distance for first lens*

So the first image I_A is at $d_{iA} = 30.0\,\text{cm}$ behind the first lens. This image becomes the object for the second lens, B. It is a distance $d_{oB} = 80.0\,\text{cm} - 30.0\,\text{cm} = 50.0\,\text{cm}$ in front of lens B, as shown in Fig. 23–41b. The image formed by lens B, again using the thin lens equation, is at a distance d_{iB} from the lens B:

$$\frac{1}{d_{iB}} = \frac{1}{f_B} - \frac{1}{d_{oB}} = \frac{1}{25.0\,\text{cm}} - \frac{1}{50.0\,\text{cm}} = \frac{2-1}{50.0\,\text{cm}} = \frac{1}{50.0\,\text{cm}}.$$

Hence $d_{iB} = 50.0\,\text{cm}$ behind lens B. This is the final image—see Fig. 23–41b.