The overall magnification of a microscope is the product of the magnifications produced by the two lenses. The image I_1 formed by the objective lens is a factor m_o greater than the object itself. From Fig. 25–23a and Eq. 23–9 for the magnification of a simple lens, we have

$$m_o = \frac{h_i}{h_o} = \frac{d_i}{d_o} = \frac{l - f_e}{d_o}, \tag{25–4}$$

where d_o and d_i are the object and image distances for the objective lens, l is the distance between the lenses (equal to the length of the barrel), and we ignored the minus sign in Eq. 23–9 which only tells us that the image is inverted. We set $d_i = l - f_e$, which is true only if the eye is relaxed, so that the image I_1 is at the eyepiece focal point F_e. The eyepiece acts like a simple magnifier. If we assume that the eye is relaxed, the eyepiece angular magnification M_e is (from Eq. 25–2a)

$$M_e = \frac{N}{f_e}, \tag{25–5}$$

where the near point $N = 25\text{ cm}$ for the normal eye. Since the eyepiece enlarges the image formed by the objective, the overall angular magnification M is the product of the lateral magnification of the objective lens, m_o, times the angular magnification, M_e, of the eyepiece lens (Eqs. 25–4 and 25–5):

Magnification of microscope

$$M = M_e m_o = \left(\frac{N}{f_e}\right)\left(\frac{l - f_e}{d_o}\right) \tag{25–6a}$$

$$\approx \frac{Nl}{f_e f_o}. \qquad [f_o \text{ and } f_e \ll l] \tag{25–6b}$$

The approximation, Eq. 25–6b, is accurate when f_e and f_o are small compared to l, so $l - f_e \approx l$ and $d_o \approx f_o$ (Fig. 25–23a). This is a good approximation for large magnifications, which are obtained when f_o and f_e are very small (they are in the denominator of Eq. 25–6b). To make lenses of very short focal length, which can be done best for the objective, compound lenses involving several elements must be used to avoid serious aberrations, as discussed in the next Section.

EXAMPLE 25–9 **Microscope.** A compound microscope consists of a 10× eyepiece and a 50× 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 $N = 25\text{ cm}$.

APPROACH The overall magnification is the product of the eyepiece magnification and the objective magnification. The focal length of the eyepiece is found from Eq. 25–2a or 25–5 for the magnification of a simple magnifier. For the objective lens, it is easier to next find d_o (part *c*) using Eq. 25–4 before we find f_o.

SOLUTION (*a*) The overall magnification is $(10\times)(50\times) = 500\times$.
(*b*) The eyepiece focal length is (Eq. 25–5) $f_e = N/M_e = 25\text{ cm}/10 = 2.5\text{ cm}$. Next we solve Eq. 25–4 for d_o, and find

$$d_o = \frac{l - f_e}{m_o} = \frac{(17.0\text{ cm} - 2.5\text{ cm})}{50} = 0.29\text{ cm}.$$

Then, from the thin lens equation for the objective with $d_i = l - f_e = 14.5\text{ cm}$ (see Fig. 25–23a),

$$\frac{1}{f_o} = \frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{0.29\text{ cm}} + \frac{1}{14.5\text{ cm}} = 3.52\text{ cm}^{-1};$$

so $f_o = 1/(3.52\text{ cm}^{-1}) = 0.28\text{ cm}$.
(*c*) We just calculated $d_o = 0.29\text{ cm}$, which is very close to f_o.