Optical Instruments
Answers to Conceptual Questions

4. For a lens to operate as a simple magnifier, the object should be located just inside the focal point of the lens. If the power of the lens is +20.0 diopters, it focal length is

$$f = (1.00 \text{ m})/P = (1.00 \text{ m})/+20.0 = 0.050\ 0 \text{ m} = 5.00 \text{ cm}$$

   The object should be placed slightly less than 5.00 cm in front of the lens.

8. You want a real image formed at the location of the paper. To form such an image, the object distance must be greater than the focal length of the lens.

12. The angular magnification produced by a simple magnifier is $m = (25 \text{ cm})/f$. Note that this is proportional to the optical power of a lens, $P = 1/f$, where the focal length f is expressed in meters. Thus, if the power of the lens is doubled, the angular magnification will also double.

Problem Solutions

25.3 The thin lens equation, $\dfrac{1}{p} + \dfrac{1}{q} = \dfrac{1}{f}$, gives the image distance as

$$q = \frac{pf}{p-f} = \frac{(100 \text{ m})(52.0 \text{ m m})}{100 \text{ m} - 52.0 \times 10^{-3} \text{ m}} = 52.0 \text{ m m}$$

   From the magnitude of the lateral magnification, $|M| = h'/h = |-q/p|$, where the height of the image is $h' = 0.092\ 0 \text{ m} = 92.0 \text{ m m}$, the height of the object (the building) must be

$$h = h'\left|-\frac{p}{q}\right| = (92.0 \text{ m m})\left|-\frac{100 \text{ m}}{52.0 \text{ m m}}\right| = \boxed{177 \text{ m}}$$

25.9 This patient needs a lens that will form an upright, virtual image at her near point (60.0 cm) when the object distance is $p = 24.0 \text{ cm}$. From the thin lens equation, the needed focal length is

$$f = \frac{pq}{p+q} = \frac{(24.0 \text{ cm})(-60.0 \text{ cm})}{24.0 \text{ cm} - 60.0 \text{ cm}} = \boxed{+40.0 \text{ cm}}$$

25.13 (a) The lens should form an upright, virtual image at the far point $\left(q=-50.0 \text{ cm}\right)$ for very distant objects $\left(p \approx \infty\right)$. Therefore, $f=q=-50.0 \text{ cm}$, and the required power is

$$P = \frac{1}{f} = \frac{1}{-0.500 \text{ m}} = \boxed{-2.00 \text{ diopters}}$$

(b) If this lens is to form an upright, virtual image at the near point of the unaided eye $\left(q=-13.0 \text{ cm}\right)$, the object distance should be

$$p = \frac{qf}{q-f} = \frac{\left(-13.0 \text{ cm}\right)\left(-50.0 \text{ cm}\right)}{-13.0 \text{ cm} - \left(-50.0 \text{ cm}\right)} = \boxed{17.6 \text{ cm}}$$

25.16 (a) The upper portion of the lens should form an upright, virtual image of very distant objects $\left(p \approx \infty\right)$ at the far point of the eye $\left(q=-1.5 \text{ m}\right)$. The thin lens equation then gives $f=q=-1.5 \text{ m}$, so the needed power is

$$P = \frac{1}{f} = \frac{1}{-1.5 \text{ m}} = \boxed{-0.67 \text{ diopters}}$$

(b) The lower part of the lens should form an upright, virtual image at the near point of the eye $\left(q=-30 \text{ cm}\right)$ when the object distance is $p=25 \text{ cm}$. From the thin lens equation,

$$f = \frac{pq}{p+q} = \frac{\left(25 \text{ cm}\right)\left(-30 \text{ cm}\right)}{25 \text{ cm} - 30 \text{ cm}} = +1.5 \times 10^2 \text{ cm} = +1.5 \text{ m}$$

Therefore, the power is $P = \dfrac{1}{f} = \dfrac{1}{+1.5 \text{ m}} = \boxed{+0.67 \text{ diopters}}$

25.17 (a) The simple magnifier (a converging lens) is to form an upright, virtual image located 25 cm in front of the lens $\left(q=-25 \text{ cm}\right)$. The thin lens equation then gives

$$p = \frac{qf}{q-f} = \frac{\left(-25 \text{ cm}\right)\left(7.5 \text{ cm}\right)}{-25 \text{ cm} - 7.5 \text{ cm}} = +5.8 \text{ cm}$$

so the stamp should be placed $\boxed{5.8 \text{ cm in front of the lens}}$

(b) When the image is at the near point of the eye, the angular magnification produced by the simple magnifier is

$$m = m_{max} = 1 + \frac{25 \text{ cm}}{f} = 1 + \frac{25 \text{ cm}}{7.5 \text{ cm}} = \boxed{4.3}$$

25.19 (a) From the thin lens equation,

$$f = \frac{pq}{p+q} = \frac{(3.50 \text{ cm})(-25.0 \text{ cm})}{3.50 \text{ cm} - 25.0 \text{ cm}} = \boxed{+4.07 \text{ cm}}$$

(b) With the image at the normal near point, the angular magnification is

$$m = m_{max} = 1 + \frac{25.0 \text{ cm}}{f} = 1 + \frac{25.0 \text{ cm}}{4.07 \text{ cm}} = \boxed{+7.14}$$

25.23 The overall magnification is $m = M_1 m_e = M_1 \left(\dfrac{25 \text{ cm}}{f_e} \right)$

where M_1 is the magnification produced by the objective lens. Therefore, the required focal length for the eye piece is

$$f_e = \frac{M_1(25 \text{ cm})}{m} = \frac{(-12)(25 \text{ cm})}{-140} = \boxed{2.1 \text{ cm}}$$

25.25 Some of the approximations made in the textbook while deriving the overall magnification of a compound microscope are not valid in this case. Therefore, we start with the eyepiece and work backwards to determine the overall magnification.

If the eye is relaxed, the eyepiece image is at infinity $(q_e \to -\infty)$, so the object distance is $p_e = f_e = 2.50 \text{ cm}$, and the angular magnification by the eyepiece is

$$m_e = \frac{25.0 \text{ cm}}{f_e} = \frac{25.0 \text{ cm}}{2.50 \text{ cm}} = 10.0$$

The image distance for the objective lens is then,

$$q_1 = L - p_e = 15.0 \text{ cm} - 2.50 \text{ cm} = 12.5 \text{ cm}$$

and the object distance is $p_1 = \dfrac{q_1 f_o}{q_1 - f_o} = \dfrac{(12.5 \text{ cm})(1.00 \text{ cm})}{12.5 \text{ cm} - 1.00 \text{ cm}} = 1.09 \text{ cm}$

The magnification by the objective lens is $M_1 = -\dfrac{q_1}{p_1} = -\dfrac{(12.5\ cm)}{1.09\ cm} = -11.5$, and the

overall magnification of the microscope is

$$m = M_1 m_e = (-11.5)(10.0) = \boxed{-115}$$

25.28   Use the larger focal length (lowest power) lens as the objective element and the shorter focal length (largest power) lens for the eye piece. The focal lengths are

$$f_o = \frac{1}{+1.20\ diopters} = +0.833\ m\ ,\ and\ \ f_e = \frac{1}{+9.00\ diopters} = +0.111\ m$$

(a)   The angular magnification (or magnifying power) of the telescope is then

$$m = \frac{f_o}{f_e} = \frac{+0.833\ m}{+0.111\ m} = \boxed{7.50}$$

(b)   The length of the telescope is

$$L = f_o + f_e = 0.833\ m + 0.111\ m = \boxed{0.944\ m}$$ **25.29**   (a)   From the thin lens

equation, $q = \dfrac{pf}{p-f}$, so the lateral magnification by the objective lens is

$M = h'/h = -q/p = -f/(p-f)$. Therefore, the image size will be

$$h' = M\ h = -\frac{fh}{p-f} = \boxed{\frac{fh}{f-p}}$$

(b)   If $p \gg f$, then $f - p \approx -p$ and $h' \approx \boxed{-\dfrac{fh}{p}}$

(c)   Suppose the telescope observes the space station at the zenith.

$$\text{Then,}\qquad h' \approx -\frac{fh}{p} = -\frac{(4.00\ m)(108.6\ m)}{407 \times 10^3\ m} = -1.07 \times 10^{-3}\ m = \boxed{-1.07\ mm}$$