Optical Instruments

Quick Quizzes

1. (c). The corrective lens for a farsighted eye is a converging lens, while that for a nearsighted eye is a diverging lens. Since a converging lens is required to form a real image of the Sun on the paper to start a fire, the campers should use the glasses of the farsighted person.

2. (a). We would like to reduce the minimum angular separation for two objects below the angle subtended by the two stars in the binary system. We can do that by reducing the wavelength of the light—this in essence makes the aperture larger, relative to the light wavelength, increasing the resolving power. Thus, we would choose a blue filter.

Answers to Conceptual Questions

2.   The objective lens of the microscope must form a real image just inside the focal point of the eyepiece lens. In order for this to occur, the object must be located just outside the focal point of the objective lens. Since the focal length of the objective lens is typically quite short $(\sim 1 \text{ cm})$, this means that the microscope can focus properly only on objects close to the end of the barrel and will be unable to focus on objects across the room.

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
$$f = (1.00 \text{ m})/\mathcal{P} = (1.00 \text{ m})/+20.0 = 0.050\,0 \text{ m} = 5.00 \text{ cm}$$
The object should be placed slightly less than 5.00 cm in front of the lens.

6.   The aperture of a camera is a close approximation to the iris of the eye. The retina of the eye corresponds to the film of the camera, and a close approximation to the cornea of the eye is the lens of the camera.

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.

10. Under low ambient light conditions, a photoflash unit is used to insure that light entering the camera lens will deliver sufficient energy for a proper exposure to each area of the film. Thus, the most important criterion is the additional energy per unit area (product of intensity and the duration of the flash, assuming this duration is less than the shutter speed) provided by the flash unit.

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, $\mathcal{P} = 1/f$, where the focal length f is expressed in meters. Thus, if the power of the lens is doubled, the angular magnification will also double.

Answers to Even Numbered Problems

2.　31 mm

4.　1.09 mm

6.　**(b)**　$\approx 1/100$ s

8.　2.2 mm farther from the film

10.　For the right eye, $\mathcal{P} = -1.18$ diopters ; for the left eye, $\mathcal{P} = -0.820$ diopters .

12.　**(a)**　33.3 cm　　　　　　　　**(b)**　+3.00 diopters

14.　**(a)**　+50.8 diopters to +60.0 diopters
　　　(b)　−0.800 diopters; diverging

16.　**(a)**　-0.67 diopters　　　　　**(b)**　+0.67 diopters

18.　**(a)**　$m = +2.0$　　　　　　　**(b)**　$m = +1.0$

20.　**(a)**　4.17 cm in front of the lens　　　**(b)**　$m = +6.00$

22.　**(a)**　0.400 cm　　　　**(b)**　1.25cm　　　　**(c)**　$M = -1\,000$

24.　0.806 μm

26.　1.6×10^2 mi

28.　**(a)**　$m = 7.50$　　　　　　　**(b)**　0.944 m

30.　**(a)**　virtual image　　　　**(b)**　$q_2 \to \infty$　　　　**(c)**　$f_o = 15.0$ cm, $f_e = -5.00$ cm

32.　0.77 m ($\approx$30 inches)

34.　1.00 mrad

36.　**(a)**　2.29×10^{-4} rad　　　　**(b)**　43.6 m

38.　38 cm

40.　**(a)**　3.6×10^3 lines　　　　**(b)**　1.8×10^3 lines

42.　1.31×10^3 fringe shifts

44.　39.6 μm

46.   1.000 5

48.   **(a)**   -4.3 diopters   **(b)**   -4.0 diopters, 44 cm

50.   **(a)**   1.96 cm   **(b)**   3.27   **(c)**   9.80

52. $\theta_m \leq 2.0 \times 10^{-3}$ rad

54.   **(a)**   0.060 1 cm   **(b)** -2.00 cm   **(c)**   6.02 cm   **(d)** $m = 4.00$

56.   5.07 mm

Problem Solutions

25.1   Using the thin lens equation, the image distance is

$$q = \frac{pf}{p-f} = \frac{(150 \text{ cm})(25.0 \text{ cm})}{150 \text{ cm} - 25.0 \text{ cm}} = 30.0 \text{ cm}$$

so the image is located $\boxed{30.0 \text{ cm beyond the lens}}$. The lateral magnification is

$$M = -\frac{q}{p} = -\frac{30.0 \text{ cm}}{150 \text{ cm}} = \boxed{-\frac{1}{5}}$$

25.2   The *f*-number of a camera lens is defined as $f\text{-number} = \text{focal length/diameter}$.

Therefore, the diameter is $D = \dfrac{f}{f\text{-number}} = \dfrac{55 \text{ mm}}{1.8} = \boxed{31 \text{ mm}}$

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

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

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

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

25.4   The image distance is $q \approx f$ since the object is so far away. Therefore, the lateral magnification is $M = h'/h = -q/p \approx -f/p$, and the diameter of the Moon's image is

$$h' = |M|h = \left(\frac{f}{p}\right)(2R_{moon}) = \left(\frac{120 \text{ mm}}{3.84 \times 10^8 \text{ m}}\right)\left[2(1.74 \times 10^6 \text{ m})\right] = \boxed{1.09 \text{ mm}}$$

25.5 The exposure time is being reduced by a factor of $\dfrac{t_2}{t_1} = \dfrac{1/256 \text{ s}}{1/32 \text{ s}} = \dfrac{1}{8}$

Thus, to maintain correct exposure, the intensity of the light reaching the film should be increased by a factor of 8. This is done by increasing the area of the aperture by a factor of 8, so in terms of the diameter, $\pi D_2^2/4 = 8\left(\pi D_1^2/4\right)$ or $D_2 = \sqrt{8}\, D_1$.

The new f-number will be

$$\left(f\text{-number}\right)_2 = \frac{f}{D_2} = \frac{f}{\sqrt{8}\, D_1} = \frac{\left(f\text{-number}\right)_1}{\sqrt{8}} = \frac{4.0}{\sqrt{8}} = 1.4 \text{ or } \boxed{f/1.4}$$

25.6 (a) The intensity is a measure of the rate at which energy is received by the film *per unit area of the image*, or $I \propto 1/A_{image}$. Consider an object with horizontal and vertical dimensions h_x and h_y as shown at the right. If the vertical dimension intercepts angle θ, the vertical dimension of the image is $h_y' = q\theta$, or $h_y' \propto q$.
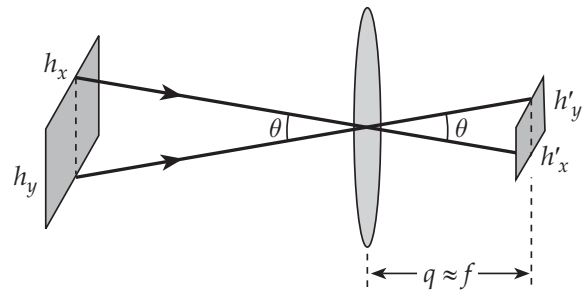
Similarly for the horizontal dimension, $h_x' \propto q$, and the area of the image is $A_{image} = h_x' h_y' \propto q^2$. Assuming a very distant object, $q \approx f$, so $A_{image} \propto f^2$ and we conclude that $I \propto 1/f^2$.

The intensity of the light reaching the film is also proportional to the area of the lens and hence, to the square of the diameter of that lens, or $I \propto D^2$. Combining this with our earlier conclusion gives

$$I \propto \frac{D^2}{f^2} = \frac{1}{\left(f/D\right)^2} \text{ or } \boxed{I \propto \frac{1}{\left(f\text{-number}\right)^2}}$$

(b) The total light energy hitting the film is proportional to the product of intensity and exposure time, It. Thus, to maintain correct exposure, this product must be kept constant, or $I_2 t_2 = I_1 t_1$ giving

$$t_2 = \left(\frac{I_1}{I_2}\right) t_1 = \left[\frac{\left(f_2\text{-number}\right)^2}{\left(f_1\text{-number}\right)^2}\right] t_1 = \left(\frac{4.0}{1.8}\right)^2 \left(\frac{1}{500} \text{ s}\right) \approx \boxed{1/100 \text{ s}}$$

25.7 Since the exposure time is unchanged, the intensity of the light reaching the film should be doubled so the energy delivered will be doubled. Using the result of Problem 6 (part a), we obtain

$$\left(f_2\text{-number}\right)^2 = \left(\frac{I_1}{I_2}\right)\left(f_1\text{-number}\right)^2 = \left(\frac{1}{2}\right)(11)^2 = 61 \text{, or } f_2\text{-number} = \sqrt{61} = 7.8$$

Thus, you should use the $\boxed{f/8.0}$ setting on the camera.

25.8 To focus on a very distant object, the original distance from the lens to the film was $q_1 = f = 65.0$ mm . To focus on an object 2.00 m away, the thin lens equation gives

$$q_2 = \frac{p_2 f}{p_2 - f} = \frac{\left(2.00 \times 10^3 \text{ mm}\right)(65.0 \text{ mm})}{2.00 \times 10^3 \text{ mm} - 65.0 \text{ mm}} = 67.2 \text{ mm}$$

Thus, the lens should be moved

$$\Delta q = q_2 - q_1 = \boxed{2.2 \text{ mm farther from the film}}$$

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 $p = 24.0$ cm . From the thin lens equation, the needed focal length is

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

25.10 For the right eye, the lens should form a virtual image of the most distant object at a position 84.4 cm in front of the eye (that is, $q = -84.4$ cm when $p \to \infty$). Thus, $f_{right} = q = -84.4$ cm , and the power is

$$\mathcal{P}_{right} = \frac{1}{f_{right}} = \frac{1}{-0.844 \text{ m}} = \boxed{-1.18 \text{ diopters}}$$

Similarly, for the left eye $f_{left} = -122$ cm and

$$\mathcal{P}_{left} = \frac{1}{f_{left}} = \frac{1}{-1.22 \text{ m}} = \boxed{-0.820 \text{ diopters}}$$

25.11   His lens must form an upright, virtual image of a very distant object ($p \approx \infty$) at his far point, 80.0 cm in front of the eye. Therefore, the focal length is $f = q = -80.0$ cm .

If this lens is to form a virtual image at his near point ($q = -18.0$ cm), the object distance must be

$$p = \frac{qf}{q - f} = \frac{(-18.0 \text{ cm})(-80.0 \text{ cm})}{-18.0 \text{ cm} - (-80.0 \text{ cm})} = \boxed{23.2 \text{ cm}}$$

25.12   (a)   The lens should form an upright, virtual image at the near point $\left(q = -100 \text{ cm} \right)$ when the object distance is $p = 25.0$ cm . Therefore,

$$f = \frac{pq}{p + q} = \frac{(25.0 \text{ cm})(-100 \text{ cm})}{25.0 \text{ cm} - 100 \text{ cm}} = \boxed{33.3 \text{ cm}}$$

(b)   The power is $\mathcal{P} = \dfrac{1}{f} = \dfrac{1}{+0.333 \text{ m}} = \boxed{+3.00 \text{ diopters}}$

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, $f = q = -50.0$ cm , and the required power is

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

(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

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

25.14 (a) When the child clearly sees objects at her far point $\left(p_{max} = 125 \text{ cm}\right)$ the lens-cornea combination has assumed a focal length suitable of forming the image on the retina $\left(q = 2.00 \text{ cm}\right)$. The thin lens equation gives the optical power under these conditions as

$$\mathcal{P}_{far} = \frac{1}{f_{in \; meters}} = \frac{1}{p} + \frac{1}{q} = \frac{1}{1.25 \text{ m}} + \frac{1}{0.020 \, 0 \text{ m}} = \boxed{+50.8 \text{ diopters}}$$

When the eye is focused $\left(q = 2.00 \text{ cm}\right)$ on objects at her near point $\left(p_{min} = 10.0 \text{ cm}\right)$ the optical power of the lens-cornea combination is

$$\mathcal{P}_{near} = \frac{1}{f_{in \; meters}} = \frac{1}{p} + \frac{1}{q} = \frac{1}{0.100 \text{ m}} + \frac{1}{0.020 \, 0 \text{ m}} = \boxed{+60.0 \text{ diopters}}$$

(b) If the child is to see very distant objects $\left(p \rightarrow \infty\right)$ clearly, her eyeglass lens must form an erect virtual image at the far point of her eye $\left(q = -125 \text{ cm}\right)$. The optical power of the required lens is

$$\mathcal{P} = \frac{1}{f_{in \; meters}} = \frac{1}{p} + \frac{1}{q} = 0 + \frac{1}{-1.25 \text{ m}} = \boxed{-0.800 \text{ diopters}}$$

Since the power, and hence the focal length, of this lens is negative, it is $\boxed{\text{diverging}}$

25.15 Considering the image formed by the cornea as a virtual object for the implanted lens, we have $p = -\left(2.80 \text{ cm} + 2.53 \text{ cm}\right) = -5.33 \text{ cm}$ and $q = +2.80 \text{ cm}$. The thin lens equation then gives the focal length of the implanted lens as

$$f = \frac{pq}{p+q} = \frac{\left(-5.33 \text{ cm}\right)\left(2.80 \text{ cm}\right)}{-5.33 \text{ cm} + 2.80 \text{ cm}} = +5.90 \text{ cm}$$

so the power is $\qquad \mathcal{P} = \frac{1}{f} = \frac{1}{+0.059 \, 0 \text{ m}} = \boxed{+17.0 \text{ diopters}}$

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

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

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

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

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

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

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

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

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

25.18 (a) With the image at the normal near point $(q = -25 \text{ cm})$, the angular magnification is

$$m = 1 + \frac{25 \text{ cm}}{f} = 1 + \frac{25 \text{ cm}}{25 \text{ cm}} = \boxed{+2.0}$$

(b) When the eye is relaxed, parallel rays enter the eye and

$$m = \frac{25 \text{ cm}}{f} = \frac{25 \text{ cm}}{25 \text{ cm}} = \boxed{+1.0}$$

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

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

25.20 (a) For maximum magnification, the image should be at the normal near point $(q = -25.0 \text{ cm})$ of the eye. Then, from the thin lens equation,

$$p = \frac{qf}{q-f} = \frac{(-25.0 \text{ cm})(5.00 \text{ cm})}{-25.0 \text{ cm} - 5.00 \text{ cm}} = \boxed{+4.17 \text{ cm}}$$

(b) The magnification is $m = 1 + \dfrac{25.0 \text{ cm}}{f} = 1 + \dfrac{25.0 \text{ cm}}{5.00 \text{ cm}} = \boxed{+6.00}$

25.21 (a) From the thin lens equation, a real inverted image is formed at an image distance of

$$q = \frac{pf}{p-f} = \frac{(71.0 \text{ cm})(39.0 \text{ cm})}{71.0 \text{ cm} - 39.0 \text{ cm}} = +86.5 \text{ cm}$$

so the lateral magnification produced by the lens is

$$M = \frac{h'}{h} = -\frac{q}{p} = -\frac{86.5 \text{ cm}}{71.0 \text{ cm}} = -1.22 \qquad \text{and the magnitude is} \qquad |M| = \boxed{1.22}$$

(b) If $|h|$ is the actual length of the leaf, the small angle approximation gives the angular width of the leaf when viewed by the unaided eye from a distance of $d = 126 \text{ cm} + 71.0 \text{ cm} = 197 \text{ cm}$ as

$$\theta_0 \approx \frac{|h|}{d} = \frac{|h|}{197 \text{ cm}}$$

The length of the image formed by the lens is $|h'| = |Mh| = 1.22|h|$, and its angular width when viewed from a distance of $d' = 126 \text{ cm} - q = 39.5 \text{ cm}$ is

$$\theta \approx \frac{|h'|}{d'} = \frac{1.22|h|}{39.5 \text{ cm}}$$

The angular magnification achieved by viewing the image instead of viewing the leaf directly is

$$\frac{\theta}{\theta_0} \approx \frac{1.22|h|/39.5 \text{ cm}}{|h|/197 \text{ cm}} = \frac{1.22(197 \text{ cm})}{39.5 \text{ cm}} = \boxed{6.08}$$

25.22 (a) The lateral magnification produced by the objective lens of a good compound microscope is closely approximated by $M_1 \approx -L/f_O$, where L is the length of the microscope tube and f_O is the focal length of this lens. Thus, if $L = 20.0 \text{ cm}$ and $M_1 = -50.0$ (inverted image), the focal length of the objective lens is

$$f_O \approx -\frac{L}{M_1} = -\frac{20.0 \text{ cm}}{-50.0} = \boxed{+0.400 \text{ cm}}$$

(b) When the compound microscope is adjusted for most comfortable viewing (with parallel rays entering the relaxed eye), the angular magnification produced by the eyepiece lens is $m_e = 25 \text{ cm}/f_e$. If $m_e = 20.0$, the focal length of the eyepiece is

$$f_e = \frac{25.0 \text{ cm}}{m_e} = \frac{25.0 \text{ cm}}{20.0} = \boxed{+1.25 \text{ cm}}$$

(c) The overall magnification is $m = M_1 m_e = (-50.0)(20.0) = \boxed{-1\,000}$

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

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

25.24 **Note**: Here, we need to determine the overall lateral magnification of the microscope, $M = h'_e/h_1$ where h'_e is the size of the image formed by the eyepiece, and h_1 is the size of the object for the objective lens. The lateral magnification of the objective lens is $M_1 = h'_1/h_1 = -q_1/p_1$ and that of the eyepiece is $M_e = h'_e/h_e = -q_e/p_e$. Since the object of the eyepiece is the image formed by the objective lens, $h_e = h'_1$, and the overall lateral magnification is $M = M_1 M_e$.

Using the thin lens equation, the object distance for the eyepiece is found to be

$$p_e = \frac{q_e f_e}{q_e - f_e} = \frac{(-29.0 \text{ cm})(0.950 \text{ cm})}{-29.0 \text{ cm} - 0.950 \text{ cm}} = 0.920 \text{ cm}$$

and the magnification produced by the eyepiece is

$$M_e = -\frac{q_e}{p_e} = -\frac{(-29.0 \text{ cm})}{0.920 \text{ cm}} = +31.5$$

The image distance for the objective lens is then

$$q_1 = L - p_e = 29.0 \text{ cm} - 0.920 \text{ cm} = 28.1 \text{ cm}$$

and the object distance for this lens is

$$p_1 = \frac{q_1 f_o}{q_1 - f_o} = \frac{(28.1 \text{ cm})(1.622 \text{ cm})}{28.1 \text{ cm} - 1.622 \text{ cm}} = 1.72 \text{ cm}$$

The magnification by the objective lens is given by

$$M_1 = -\frac{q_1}{p_1} = -\frac{(28.1 \text{ cm})}{1.72 \text{ cm}} = -16.3$$

and the overall lateral magnification is $M = M_1 M_e = (-16.3)(+31.5) = -514$

The lateral size of the final image is

$$h_e' = |q_e| \cdot \theta = (29.0 \text{ cm})(1.43 \times 10^{-3} \text{ rad}) = 4.15 \times 10^{-2} \text{ cm}$$

and the size of the red blood cell serving as the original object is

$$h_1 = \frac{h_e'}{|M|} = \frac{4.15 \times 10^{-4} \text{ m}}{514} = 8.06 \times 10^{-7} \text{ m} = \boxed{0.806 \ \mu\text{m}}$$

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 $M_1 = -\dfrac{q_1}{p_1} = -\dfrac{(12.5 \text{ cm})}{1.09 \text{ cm}} = -11.5$, and the overall magnification of the microscope is

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

25.26 The moon may be considered an infinitely distant object $(p \to \infty)$ when viewed with this lens, so the image distance will be $q = f_o = 1\,500$ cm.

Considering the rays that pass undeviated through the center of this lens as shown in the sketch, observe that the angular widths of the image and the object are equal. Thus, if w is the linear width of an object forming a 1.00 cm wide image, then

$$\theta = \frac{w}{3.8 \times 10^8 \text{ m}} = \frac{1.0 \text{ cm}}{f_o} = \frac{1.0 \text{ cm}}{1\,500 \text{ cm}}$$

or $\quad w = (3.8 \times 10^8 \text{ m}) \left(\dfrac{1.0 \text{ cm}}{1\,500 \text{ cm}} \right) \left(\dfrac{1 \text{ mi}}{1\,609 \text{ m}} \right) = \boxed{1.6 \times 10^2 \text{ mi}}$
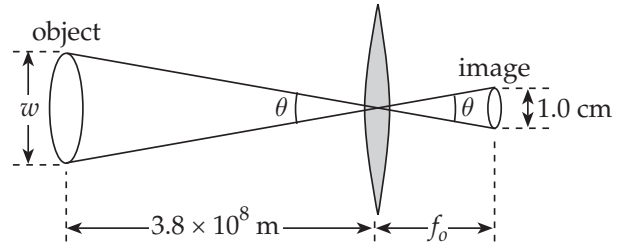
25.27 The length of the telescope is $\qquad L = f_o + f_e = 92$ cm

and the angular magnification is $\qquad m = \dfrac{f_o}{f_e} = 45$

Therefore, $f_o = 45 f_e$ and $L = f_o + f_e = 45 f_e + f_e = 46 f_e = 92$ cm, giving

$$\boxed{f_e = 2.0 \text{ cm}} \quad \text{and} \quad f_o = 92 \text{ cm} - f_e \qquad \text{or} \qquad \boxed{f_o = 90 \text{ cm}}$$

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

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

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

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

(b) The length of the telescope is

$$L = f_o + f_e = 0.833 \text{ m} + 0.111 \text{ m} = \boxed{0.944 \text{ m}}$$

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

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

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

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

Then, $h' \approx -\dfrac{fh}{p} = -\dfrac{(4.00 \text{ m})(108.6 \text{ m})}{407 \times 10^3 \text{ m}} = -1.07 \times 10^{-3} \text{ m} = \boxed{-1.07 \text{ mm}}$
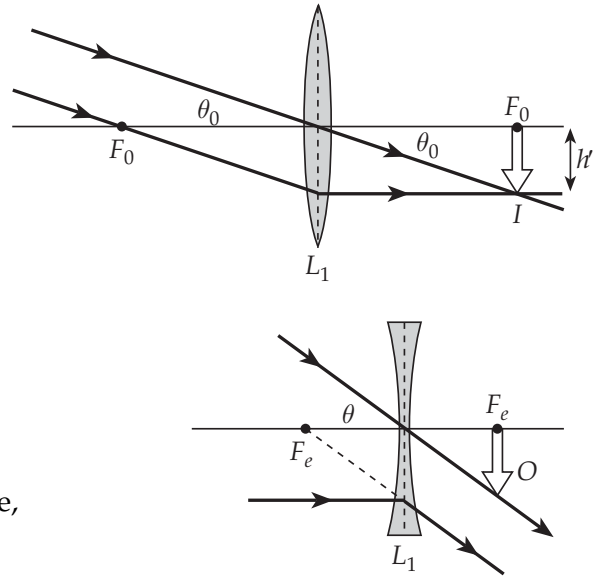
25.30 (b) The objective forms a real, diminished, inverted image of a very distant object at $q_1 = f_o$. This image is a virtual object for the eyepiece at $p_e = -|f_e|$, giving

$$\frac{1}{q_e} = \frac{1}{p_e} - \frac{1}{f_e} = \frac{1}{-|f_e|} + \frac{1}{|f_e|} = 0$$

and $\boxed{q_e \to \infty}$

(a) Parallel rays emerge from the eyepiece, so the eye observes a $\boxed{\text{virtual image}}$

(c)   The angular magnification is $m = \dfrac{f_o}{|f_e|} = 3.00$, giving

$f_o = 3.00|f_e|$. Also, the length of the telescope is $L = f_o + f_e = 3.00|f_e| - |f_e| = 10.0$ cm , giving

$$f_e = -|f_e| = -\frac{10.0 \text{ cm}}{2.00} = \boxed{-5.00 \text{ cm}} \text{ and } f_o = 3.00|f_e| = \boxed{15.0 \text{ cm}}$$

25.31   The lens for the left eye forms an upright, virtual image at $q_L = -50.0$ cm when the object distance is $p_L = 25.0$ cm , so the thin lens equation gives its focal length as

$$f_L = \frac{p_L q_L}{p_L + q_L} = \frac{(25.0 \text{ cm})(-50.0 \text{ cm})}{25.0 \text{ cm} - 50.0 \text{ cm}} = 50.0 \text{ cm}$$

Similarly for the other lens, $q_R = -100$ cm when $p_R = 25.0$ cm , and $f_R = 33.3$ cm .

(a)   Using the lens for the left eye as the objective,

$$m = \frac{f_o}{f_e} = \frac{f_L}{f_R} = \frac{50.0 \text{ cm}}{33.3 \text{ cm}} = \boxed{1.50}$$

(b)   Using the lens for the right eye as the eyepiece and, for maximum magnification, requiring that the final image be formed at the normal near point $(q_e = -25.0 \text{ cm})$ gives

$$p_e = \frac{q_e f_e}{q_e - f_e} = \frac{(-25.0 \text{ cm})(33.3 \text{ cm})}{-25.0 \text{ cm} - 33.3 \text{ cm}} = +14.3 \text{ cm}$$

The maximum magnification by the eyepiece is then

$$m_e = 1 + \frac{25.0 \text{ cm}}{f_e} = 1 + \frac{25.0 \text{ cm}}{33.3 \text{ cm}} = +1.75$$

and the image distance for the objective is

$$q_1 = L - p_e = 10.0 \text{ cm} - 14.3 \text{ cm} = -4.30 \text{ cm}$$

The thin lens equation then gives the object distance for the objective as

$$p_1 = \frac{q_1 f_1}{q_1 - f_1} = \frac{(-4.30 \text{ cm})(50.0 \text{ cm})}{-4.30 \text{ cm} - 50.0 \text{ cm}} = +3.94 \text{ cm}$$

The magnification by the objective is then

$$M_1 = -\frac{q_1}{p_1} = -\frac{(-4.30 \text{ cm})}{3.94 \text{ cm}} = +1.09$$

and the overall magnification is $m = M_1 m_e = (+1.09)(+1.75) = \boxed{1.90}$

25.32   The angular resolution needed is

$$\theta_{\text{min}} = \frac{s}{r} = \frac{300 \text{ m}}{3.8 \times 10^8 \text{ m}} = 7.9 \times 10^{-7} \text{ rad}$$

For a circular aperture $\theta_{\text{min}} = 1.22 \frac{\lambda}{D}$

so $D = 1.22 \frac{\lambda}{\theta_{\text{min}}} = 1.22 \left(\frac{500 \times 10^{-9} \text{ m}}{7.9 \times 10^{-7} \text{ rad}} \right) = \boxed{0.77 \text{ m}}$ (about 30 inches)

25.33   If just resolved, the angular separation is

$$\theta = \theta_{\text{min}} = 1.22 \frac{\lambda}{D} = 1.22 \left(\frac{500 \times 10^{-9} \text{ m}}{0.300 \text{ m}} \right) = 2.03 \times 10^{-6} \text{ rad}$$

Thus, the altitude is $h = \frac{d}{\theta} = \frac{1.00 \text{ m}}{2.03 \times 10^{-6} \text{ rad}} = 4.92 \times 10^5 \text{ m} = \boxed{492 \text{ km}}$

25.34   For a narrow slit, Rayleigh's criterion gives

$$\theta_{\text{min}} = \frac{\lambda}{a} = \frac{500 \times 10^{-9} \text{ m}}{0.500 \times 10^{-3} \text{ m}} = 1.00 \times 10^{-3} = \boxed{1.00 \text{ mrad}}$$

25.35   The limit of resolution in air is $\theta_{min}\big|_{air} = 1.22\dfrac{\lambda}{D} = 0.60 \ \mu\text{rad}$

In oil, the limiting angle of resolution will be

$$\theta_{min}\big|_{oil} = 1.22\frac{\lambda_{oil}}{D} = 1.22\frac{\left(\lambda/n_{oil}\right)}{D} = \left(1.22\frac{\lambda}{D}\right)\frac{1}{n_{oil}}$$

or $\theta_{min}\big|_{oil} = \dfrac{\theta_{min}\big|_{air}}{n_{oil}} = \dfrac{0.60 \ \mu\text{rad}}{1.5} = \boxed{0.40 \ \mu\text{rad}}$

25.36   (a)   The wavelength of the light within the eye is $\lambda_n = \lambda/n$. Thus, the limiting angle of resolution for light passing through the pupil (a circular aperture with diameter $D = 2.00$ mm), is

$$\theta_{min} = 1.22\frac{\lambda_n}{D} = 1.22\frac{\lambda}{nD} = 1.22\frac{\left(500 \times 10^{-9} \text{ m}\right)}{(1.33)\left(2.00 \times 10^{-3} \text{ m}\right)} = \boxed{2.29 \times 10^{-4} \text{ rad}}$$

(b)   From $s = r\theta$, the distance from the eye that two points separated by a distance $s = 1.00$ cm will intercept this minimum angle of resolution is

$$r = \frac{s}{\theta_{min}} = \frac{1.00 \text{ cm}}{2.29 \times 10^{-4} \text{ rad}} = 4.36 \times 10^{3} \text{ cm} = \boxed{43.6 \text{ m}}$$

25.37   The minimum angle of resolution when light of 500 nm wavelength passes through a 20-inch diameter circular aperture is

$$\theta_{min} = 1.22\frac{\lambda}{D} = 1.22\frac{\left(500 \times 10^{-9} \text{ m}\right)}{20 \text{ inches}}\left(\frac{39.37 \text{ inches}}{1 \text{ m}}\right) = 1.2 \times 10^{-6} \text{ rad}$$

If two stars, 8.0 lightyears away, are just resolved by a telescope of 20-in diameter, their separation from each other is

$$s = r\theta_{min} = \left[8.0 \text{ ly}\left(\frac{9.461 \times 10^{15} \text{ m}}{1 \text{ ly}}\right)\right]\left(1.2 \times 10^{-6} \text{ rad}\right) = 9.1 \times 10^{10} \text{ m} = \boxed{9.1 \times 10^{7} \text{ km}}$$

25.38   If just resolved, the angular separation of the objects is $\theta = \theta_{min} = 1.22\dfrac{\lambda}{D}$

and $s = r\theta = \left(200 \times 10^{3} \text{ m}\right)\left[1.22\left(\dfrac{550 \times 10^{-9} \text{ m}}{0.35 \text{ m}}\right)\right] = 0.38 \text{ m} = \boxed{38 \text{ cm}}$

25.39 If just resolved, the angular separation of the objects is $\theta = \theta_{min} = 1.22 \dfrac{\lambda}{D}$

and $s = r\theta = (8.0 \times 10^7 \ \text{km}) \left[1.22 \left(\dfrac{500 \times 10^{-9} \ \text{m}}{5.00 \ \text{m}} \right) \right] = \boxed{9.8 \ \text{km}}$

25.40 The resolving power of a diffraction grating is $\qquad R = \dfrac{\lambda}{\Delta\lambda} = Nm$

(a) The number of lines the grating must have to resolve the H_α line in the first order is

$$N = \dfrac{R}{m} = \dfrac{\lambda/\Delta\lambda}{(1)} = \dfrac{656.2 \ \text{nm}}{0.18 \ \text{nm}} = \boxed{3.6 \times 10^3 \ \text{lines}}$$

(b) In the second order $(m = 2)$, $N = \dfrac{R}{2} = \dfrac{656.2 \ \text{nm}}{2(0.18 \ \text{nm})} = \boxed{1.8 \times 10^3 \ \text{lines}}$

25.41 The grating spacing is $d = \dfrac{1 \ \text{cm}}{6\ 000} = 1.67 \times 10^{-4} \ \text{cm} = 1.67 \times 10^{-6} \ \text{m}$, and the highest order of 600 nm light that can be observed is

$$m_{max} = \dfrac{d \sin 90°}{\lambda} = \dfrac{(1.67 \times 10^{-6} \ \text{m})(1)}{600 \times 10^{-9} \ \text{m}} = 2.78 \ \rightarrow \ 2 \ \text{orders}$$

The total number of slits is $N = (15.0 \ \text{cm})(6\ 000 \ \text{slits/cm}) = 9.00 \times 10^4$, and the resolving power of the grating in the second order is

$$R_{available} = Nm = (9.00 \times 10^4)2 = \boxed{1.80 \times 10^5}$$

The resolving power required to separate the given spectral lines is

$$R_{needed} = \dfrac{\lambda}{\Delta\lambda} = \dfrac{600.000 \ \text{nm}}{0.003 \ \text{nm}} = \boxed{2.0 \times 10^5}$$

These lines $\boxed{\text{cannot be separated}}$ with this grating.

25.42 A fringe shift occurs when the mirror moves distance $\lambda/4$. Thus, if the mirror moves distance $\Delta L = 0.180 \ \text{mm}$, the number of fringe shifts observed is

$$N_{shifts} = \dfrac{\Delta L}{\lambda/4} = \dfrac{4(\Delta L)}{\lambda} = \dfrac{4(0.180 \times 10^{-3} \ \text{m})}{550 \times 10^{-9} \ \text{m}} = \boxed{1.31 \times 10^3 \ \text{fringe shifts}}$$

25.43 A fringe shift occurs when the mirror moves distance $\lambda/4$. Thus, the distance moved (length of the bacterium) as 310 shifts occur is

$$\Delta L = N_{shifts}\left(\frac{\lambda}{4}\right) = 310\left(\frac{650\times10^{-9}\text{ m}}{4}\right) = 5.04\times10^{-5}\text{ m} = \boxed{50.4\ \mu\text{m}}$$

25.44 A fringe shift occurs when the mirror moves distance $\lambda/4$. Thus, the distance the mirror moves as 250 fringe shifts are counted is

$$\Delta L = N_{shifts}\left(\frac{\lambda}{4}\right) = 250\left(\frac{632.8\times10^{-9}\text{ m}}{4}\right) = 3.96\times10^{-5}\text{ m} = \boxed{39.6\ \mu\text{m}}$$

25.45 When the optical path length that light must travel as it goes down one arm of a Michelson's interferometer changes by one wavelength, four fringe shifts will occur (one shift for every quarter-wavelength change in path length).

The number of wavelengths (in a vacuum) that fit in a distance equal to a thickness t is $N_{vac} = t/\lambda$. The number of wavelengths that fit in this thickness while traveling through the transparent material is $N_n = t/\lambda_n = t/(\lambda/n) = nt/\lambda$. Thus, the change number of wavelengths that fit in the path down this arm of the interferometer is

$$\Delta N = N_n - N_{vac} = (n-1)\frac{t}{\lambda}$$

and the number of fringe shifts that will occur as the sheet is inserted will be

$$\#\text{ fringe shifts} = 4(\Delta N) = 4(n-1)\frac{t}{\lambda} = 4(1.40-1)\left(\frac{15.0\times10^{-6}\text{ m}}{600\times10^{-9}\text{ m}}\right) = \boxed{40}$$

25.46 A fringe shift will occur each time the effective length of the tube changes by a quarter of a wavelength (that is, for each additional wavelength fitted into the length of the tube, 4 fringe shifts occur). If L is the length of the tube, the number of fringe shifts observed as the tube is filled with gas is

$$N_{shifts} = 4\left[\frac{L}{\lambda_n} - \frac{L}{\lambda}\right] = 4\left[\frac{L}{\lambda/n_{gas}} - \frac{L}{\lambda}\right] = \frac{4L}{\lambda}\left(n_{gas}-1\right)$$

Hence, $n_{gas} = 1 + \left(\frac{\lambda}{4L}\right)N_{shifts} = 1 + \left[\frac{600\times10^{-9}\text{ m}}{4(5.00\times10^{-2}\text{ m})}\right](160) = \boxed{1.000\ 5}$

25.47 Removing air from the cell alters the wavelength of the light passing through the cell. Four fringe shifts will occur for each additional wavelength fitted into the length of the cell. Therefore, the number of fringe shifts that occur as the cell is evacuated will be

$$N_{shifts} = 4\left[\frac{L}{\lambda_n} - \frac{L}{\lambda}\right] = 4\left[\frac{L}{\lambda/n_{air}} - \frac{L}{\lambda}\right] = \frac{4L}{\lambda}(n_{air} - 1)$$

or $\quad N_{shifts} = \dfrac{4(5.00 \times 10^{-2} \text{ m})}{590 \times 10^{-9} \text{ m}}(1.000\,29 - 1) = 98.3 \quad \boxed{98 \text{ complete shifts}}$

25.48 (a) Since this eye can already focus on objects located at the near point of a normal eye (25 cm), no correction is needed for near objects. To correct the distant vision, a corrective lens (located 2.0 cm from the eye) should form virtual images of very distant objects at 23 cm in front of the lens (or at the far point of the eye). Thus, we must require that $q = -23$ cm when $p \to \infty$. This gives

$$P = \frac{1}{f} = \frac{1}{p} + \frac{1}{q} = 0 + \frac{1}{-0.23 \text{ m}} = \boxed{-4.3 \text{ diopters}}$$

(b) A corrective lens in contact with the cornea should form virtual images of very distant objects at the far point of the eye. Therefore, we require that that $q = -25$ cm when $p \to \infty$, giving

$$\mathscr{P} = \frac{1}{f} = \frac{1}{p} + \frac{1}{q} = 0 + \frac{1}{-0.25 \text{ m}} = \boxed{-4.0 \text{ diopters}}$$

When the contact lens $\left(f = \dfrac{1}{\mathscr{P}} = -25 \text{ cm}\right)$ is in place, the object distance which yields a virtual image at the near point of the eye (that is, $q = -16$ cm) is given by

$$p = \frac{qf}{q-f} = \frac{(-16 \text{ cm})(-25 \text{ cm})}{-16 \text{ cm} - (-25 \text{ cm})} = \boxed{44 \text{ cm}}$$

25.49 (a) The lens should form an upright, virtual image at the near point of the eye $q = -75.0$ cm when the object distance is $p = 25.0$ cm. The thin lens equation then gives

$$f = \frac{pq}{p+q} = \frac{(25.0 \text{ cm})(-75.0 \text{ cm})}{25.0 \text{ cm} - 75.0 \text{ cm}} = 37.5 \text{ cm} = 0.375 \text{ m}$$

so the needed power is $\mathscr{P} = \dfrac{1}{f} = \dfrac{1}{0.375 \text{ m}} = \boxed{+2.67 \text{ diopters}}$

(b) If the object distance must be $p = 26.0$ cm to position the image at $q = -75.0$ cm, the actual focal length is

$$f = \frac{pq}{p+q} = \frac{(26.0 \text{ cm})(-75.0 \text{ cm})}{26.0 \text{ cm} - 75.0 \text{ cm}} = 0.398 \text{ m}$$

and $\mathcal{P} = \dfrac{1}{f} = \dfrac{1}{0.398 \text{ m}} = +2.51$ diopters

The error in the power is

$$\Delta\mathcal{P} = (2.67 - 2.51) \text{ diopters} = \boxed{0.16 \text{ diopters too low}}$$

25.50 (a) If $q = 2.00$ cm when $p = 1.00$ m $= 100$ cm, the thin lens equation gives the focal length as

$$f = \frac{pq}{p+q} = \frac{(100 \text{ cm})(2.00 \text{ cm})}{100 \text{ cm} + 2.00 \text{ cm}} = \boxed{1.96 \text{ cm}}$$

(b) The *f*-number of a lens aperture is the focal length of the lens divided by the diameter of the aperture. Thus, the smallest *f*-number occurs with the largest diameter of the aperture. For the typical eyeball focused on objects 1.00 m away, this is

$$(f\text{-number})_{min} = \frac{f}{D_{max}} = \frac{1.96 \text{ cm}}{0.600 \text{ cm}} = \boxed{3.27}$$

(c) The largest *f*-number of the typical eyeball focused on a 1.00-m-distance object is

$$(f\text{-number})_{max} = \frac{f}{D_{min}} = \frac{1.96 \text{ cm}}{0.200 \text{ cm}} = \boxed{9.80}$$

25.51 (a) The implanted lens should give an image distance of $q = 22.4$ mm for distant $(p \to \infty)$ objects. The thin lens equation then gives the focal length as $f = q = 22.4$ mm, so the power of the implanted lens should be

$$\mathcal{P}_{implant} = \frac{1}{f} = \frac{1}{22.4 \times 10^{-3} \text{ m}} = \boxed{+44.6 \text{ diopters}}$$

(b) When the object distance is $p = 33.0$ cm , the corrective lens should produce parallel rays $(q \rightarrow \infty)$. Then the implanted lens will focus the final image on the retina. From the thin lens equation, the required focal length is $f = p = 33.0$ cm , and the power of this lens should be

$$\mathcal{P}_{corrective} = \frac{1}{f} = \frac{1}{0.330 \text{ m}} = \boxed{+3.03 \text{ diopters}}$$

25.52 When viewed from a distance of 50 meters, the angular length of a mouse (assumed to have an actual length of ≈ 10 cm) is

$$\theta = \frac{s}{r} = \frac{0.10 \text{ m}}{50 \text{ m}} = 2.0 \times 10^{-3} \text{ radians}$$

Thus, the limiting angle of resolution of the eye of the hawk must be

$$\theta_{min} \leq \theta = \boxed{2.0 \times 10^{-3} \text{ rad}}$$

25.53 The resolving power of the grating is $R = \lambda / \Delta\lambda = Nm$. Thus, the total number of lines needed on the grating to resolve the wavelengths in order m is

$$N = \frac{R}{m} = \frac{\lambda}{m(\Delta\lambda)}$$

(a) For the sodium doublet in the first order,

$$N = \frac{589.30 \text{ nm}}{(1)(0.59 \text{ nm})} = \boxed{1.0 \times 10^3}$$

(b) In the third order, we need $N = \frac{589.30 \text{ nm}}{(3)(0.59 \text{ nm})} = \boxed{3.3 \times 10^2}$

25.54 (a) The image distance for the objective lens is

$$q_1 = \frac{p_1 f_1}{p_1 - f_1} = \frac{(40.0\text{ m})(8.00\times10^{-2}\text{ m})}{40.0\text{ m} - 8.00\times10^{-2}\text{m}} = 8.02\times10^{-2}\text{ m} = 8.02\text{ cm}$$

The magnification by the objective is $M_1 = h'/h = -q_1/p_1$, so the size of the image formed by this lens is

$$h' = h|M_1| = h\left(\frac{q_1}{p_1}\right) = (30.0\text{ cm})\left(\frac{8.02\times10^{-2}\text{ m}}{40.0\text{ m}}\right) = \boxed{0.060\,1\text{ cm}}$$

(b) To have parallel rays emerge from the eyepiece, its virtual object must be at its focal point, or $p_e = f_e = \boxed{-2.00\text{ cm}}$

(c) The distance between the lenses is $L = q_1 + p_e = 8.02\text{ cm} - 2.00\text{ cm} = \boxed{6.02\text{ cm}}$

(d) The overall angular magnification is $m = \left|\dfrac{f_1}{f_e}\right| = \left|\dfrac{8.00\text{ cm}}{-2.00\text{ cm}}\right| = \boxed{4.00}$

25.55 The angular magnification is $m = \theta/\theta_o$, where θ is the angle subtended by the final image, and θ_o is the angle subtended by the object as shown in the figure. When the telescope is adjusted for minimum eyestrain, the rays entering the eye are parallel. Thus, the objective lens must form its image at the focal point of the eyepiece.
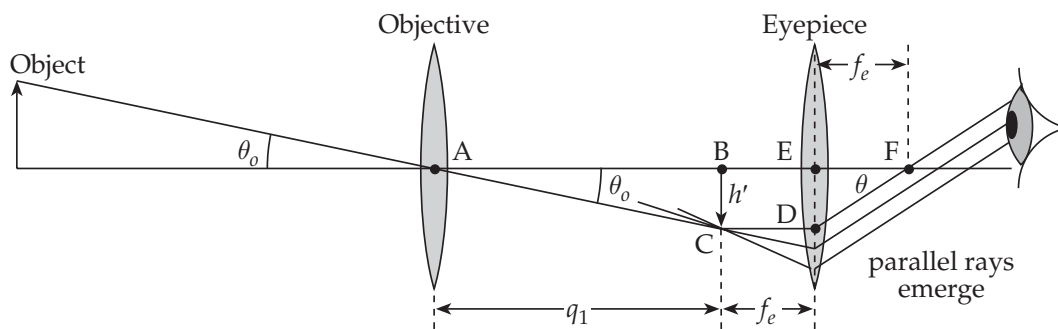
From triangle ABC, $\theta_o \approx \tan\theta_o = h'/q_1$ and from triangle DEF, $\theta \approx \tan\theta = h'/f_e$. The angular magnification is then $m = \dfrac{\theta}{\theta_o} = \dfrac{h'/f_e}{h'/q_1} = \dfrac{q_1}{f_e}$

From the thin lens equation, the image distance of the objective lens in this case is

$$q_1 = \frac{p_1 f_1}{p_1 - f_1} = \frac{(300 \text{ cm})(20.0 \text{ cm})}{300 \text{ cm} - 20.0 \text{ cm}} = 21.4 \text{ cm}$$

With an eyepiece of focal length $f_e = 2.00 \text{ cm}$, the angular magnification for this telescope is

$$m = \frac{q_1}{f_e} = \frac{21.4 \text{ cm}}{2.00 \text{ cm}} = \boxed{10.7}$$

25.56 We use $\dfrac{n_1}{p} + \dfrac{n_2}{q} = \dfrac{n_2 - n_1}{R}$, with $p \to \infty$ and q equal to the cornea to retina distance. Then,

$$R = q\left(\frac{n_2 - n_1}{n_2}\right) = (2.00 \text{ cm})\left(\frac{1.34 - 1.00}{1.34}\right) = 0.507 \text{ cm} = \boxed{5.07 \text{ mm}}$$

25.57 When a converging lens forms a real image of a very distant object, the image distance equals the focal length of the lens. Thus, if the scout started a fire by focusing sunlight on kindling 5.00 cm from the lens, $f = q = 5.00 \text{ cm}$.

(a) When the lens is used as a simple magnifier, maximum magnification is produced when the upright, virtual image is formed at the near point of the eye ($q = -15 \text{ cm}$ in this case). The object distance required to form an image at this location is

$$p = \frac{qf}{q - f} = \frac{(-15 \text{ cm})(5.0 \text{ cm})}{-15 \text{ cm} - 5.0 \text{ cm}} = \frac{15 \text{ cm}}{4.0}$$

and the lateral magnification produced is $\qquad M = -\dfrac{q}{p} = -\dfrac{-15 \text{ cm}}{15 \text{ cm}/4.0} = \boxed{+4.0}$

(b) When the object is viewed directly while positioned at the near point of the eye, its angular size is $\theta_0 = h/15 \text{ cm}$. When the object is viewed by the relaxed eye while using the lens as a simple magnifier (with the object at the focal point so parallel rays enter the eye), the angular size of the upright, virtual image is $\theta = h/f$. Thus, the angular magnification gained by using the lens is

$$m = \frac{\theta}{\theta_0} = \frac{h/f}{h/15 \text{ cm}} = \frac{15 \text{ cm}}{f} = \frac{15 \text{ cm}}{5.0 \text{ cm}} = \boxed{3.0}$$