Chapter 27

Optical Instruments

Answers to Even-numbered Conceptual Questions

2. No. The lens will still show a complete image, though you may have to move your head more from side to side to see it all.

4. The reason things look blurry underwater is that there is much less refraction of light when it passes from water to your cornea than when it passes from air to your cornea. Therefore, your eyes simply aren't converging light enough when they are in water. Since farsightedness is caused when your eyes don't converge light as much as they should (see Figure 27-11), this can be considered as an extreme case of farsightedness.

6. A concave lens always forms an image smaller than the object, as can be seen in Figure 26-34. A convex lens, on the other hand, produces an enlarged image when the object is closer than the focal point, as shown in Figure 26-35 (b). Therefore, the person is wearing glasses that converge, like a convex lens. Such lenses are used to correct farsightedness (see Figure 27-11), and hence we conclude that the person is farsighted.

8. The answer is (b). If a person is nearsighted, the eye converges (bends) light too much to bring it to a proper focus on distant objects (see Figure 27-6). To reduce the amount of convergence, the intracorneal ring should decrease the cornea's curvature – that is, it should make the cornea flatter.

10. Yes, it matters. A simple magnifier is nothing more than a convex lens. As we can see from Figure 26-35, a convex lens forms an enlarged (magnified) image only when the object is closer to the lens than its focal length.

12. As we can see in Figure 27-15 and Example 27-5, the lens with the shorter focal length is the one that is used as the objective. Therefore, we should pick the 0.45 cm lens to be the objective.

14. The instrument is a telescope. In general, the length of a telescope is roughly equal to the sum of the focal lengths of its objective and eyepiece, as we see in Figure 27-16.

16. The image you view when looking into a telescope is virtual. First, the objective forms a real image of a distant object, as shown in Figure 27-16. Next, the eyepiece forms an upright and enlarged image of the objective's image. The situation with the eyepiece is essentially same as that shown in Figure 26-35 (b). Therefore, it is clear that the final image is virtual in this case. On the other hand, when a telescope is used to make a photograph, it can project a real image onto the photographic film.

18. As an object moves closer to the front of an octopus eye, the image it forms moves farther behind the eye. The situation is similar to that in Active Example 27-1 and Figure 26-35 (a). To keep the image on the retina, therefore, it is necessary to move the lens itself farther from the retina.

20. No. Chromatic aberration occurs in lenses because light of different frequency refracts by different amounts. In the case of a mirror, however, all light – regardless of its frequency – obeys the same simple law of reflection; namely, that the angle of reflection is equal to the angle of incidence. Since light of all colors is bent in the same way by a mirror, there is no chromatic aberration.

Solutions to Problems

1. (a) $h_\text{i} = mh_\text{o} = -\frac{d_\text{i}h_\text{o}}{d_\text{o}} = \frac{(0.017\text{ m})(1.6\text{ m})}{3.0\text{ m}} = \boxed{9.1\text{ mm}}$

(b) $h_\text{i} = \frac{(0.017\text{ m})(1.6\text{ m})}{4.0\text{ m}} = \boxed{6.8\text{ mm}}$

2. The image height is proportional to h_o/d_o.

tree: $\frac{h_\text{o}}{d_\text{o}} = \frac{43\text{ ft}}{210\text{ ft}} = 0.20$

flower: $\frac{h_\text{o}}{d_\text{o}} = \frac{12\text{ in.}}{(2.0\text{ ft})\left(\frac{12\text{ in.}}{1\text{ ft}}\right)} = 0.50$

Since 0.50 > 0.20, the $\boxed{\text{flower}}$ forms the larger image.

3. $\frac{1}{f} = \frac{1}{d_\text{i}} + \frac{1}{d_\text{o}} = \frac{1}{d_\text{i}} + \frac{1}{N}$

$N = \left(\frac{1}{f} - \frac{1}{d_\text{i}}\right)^{-1} = \left(\frac{1}{2.20\text{ cm}} - \frac{1}{2.60\text{ cm}}\right)^{-1} = \boxed{14\text{ cm}}$

4. (a) $\frac{1}{f} = \frac{1}{d_\text{i}} + \frac{1}{d_\text{o}}$

$f = \left(\frac{1}{d_\text{i}} + \frac{1}{d_\text{o}}\right)^{-1} = \left(\frac{1}{2.60\text{ cm}} + \frac{1}{120\text{ cm}}\right)^{-1} = \boxed{2.54\text{ cm}}$

(b) $f = \left(\frac{1}{2.60\text{ cm}} + \frac{1}{12\text{ cm}}\right)^{-1} = \boxed{2.14\text{ cm}}$

5. $D = \frac{f}{f\text{-number}}$

Lens	Focal Length (mm)	*f*-number	Diameter (mm)	Rank
A	150	$f/1.2$	130	1
B	150	$f/5.6$	27	3
C	35	$f/1.2$	29	2
D	35	$f/5.6$	6.3	4

Ranking from largest to smallest: $\boxed{\text{A, C, B, D}}$

6. (a) $f\text{-number} = \dfrac{f}{D} = \dfrac{17\text{ mm}}{2.0\text{ mm}} = \boxed{8.5}$

(b) $f\text{-number} = \dfrac{17\text{ mm}}{7.0\text{ mm}} = \boxed{2.4}$

7. (a) $D = \dfrac{f}{f\text{-number}}$

Since the diameter is inversely proportional to the *f*-number, the smallest *f*-number gives the largest diameter. So, $\boxed{2.8}$ gives the largest diameter.

(b)

Focal Length (mm)	*f*-number	Diameter (mm)
55	2.8	20
55	4	14
55	8	6.9
55	11	5.0
55	16	3.4

8. Find d_i in terms of d_o.

$$m = \frac{h_\text{i}}{h_\text{o}} = -\frac{d_\text{i}}{d_\text{o}}$$

$$d_\text{i} = -\frac{h_\text{i}}{h_\text{o}} d_\text{o}$$

Substitute into the thin lens equation.

$$\frac{1}{f} = \frac{1}{d_\text{i}} + \frac{1}{d_\text{o}}$$

$$= \frac{1}{-\frac{h_\text{i}}{h_\text{o}} d_\text{o}} + \frac{1}{d_\text{o}}$$

$$= \frac{1}{d_\text{o}}\left(1 - \frac{h_\text{o}}{h_\text{i}}\right)$$

$$d_\text{o} = f\left(1 - \frac{h_\text{o}}{h_\text{i}}\right)$$

$$= (0.055\text{ m})\left(1 - \frac{1.7\text{ m}}{-0.036\text{ m}}\right) = \boxed{2.7\text{ m}}$$

9. Find d_{i} in terms of d_{o}.

$$m=\frac{h_{\text{i}}}{h_{\text{o}}}=-\frac{d_{\text{i}}}{d_{\text{o}}}$$

$$d_{\text{i}}=-\frac{h_{\text{i}}}{h_{\text{o}}}d_{\text{o}}$$

Substitute into the thin lens equation.

$$\frac{1}{f}=\frac{1}{d_{\text{i}}}+\frac{1}{d_{\text{o}}}$$

$$=\frac{1}{-\frac{h_{\text{i}}}{h_{\text{o}}}d_{\text{o}}}+\frac{1}{d_{\text{o}}}$$

$$=\frac{1}{d_{\text{o}}}\left(1-\frac{h_{\text{o}}}{h_{\text{i}}}\right)$$

$$d_{\text{o}}=f\left(1-\frac{h_{\text{o}}}{h_{\text{i}}}\right)$$

$$=(0.150\text{ m})\left(1-\frac{2.0\text{ m}}{-0.036\text{ m}}\right)=\boxed{8.5\text{ m}}$$

10. Find d_{i} in terms of d_{o} and f.

$$\frac{1}{f}=\frac{1}{d_{\text{i}}}+\frac{1}{d_{\text{o}}}$$

$$\frac{1}{d_{\text{i}}}=\frac{1}{f}-\frac{1}{d_{\text{o}}}$$

$$=\frac{d_{\text{o}}-f}{fd_{\text{o}}}$$

$$d_{\text{i}}=\frac{fd_{\text{o}}}{d_{\text{o}}-f}$$

Substitute into the magnification equation.

$$m=\frac{h_{\text{i}}}{h_{\text{o}}}=-\frac{1}{d_{\text{o}}}\left(\frac{fd_{\text{o}}}{d_{\text{o}}-f}\right)=\frac{f}{f-d_{\text{o}}}$$

$$\frac{h_{\text{i}}}{h_{\text{o}}}=\frac{f}{f-d_{\text{o}}}$$

$$f-d_{\text{o}}=\frac{h_{\text{o}}f}{h_{\text{i}}}$$

$$f\left(1-\frac{h_{\text{o}}}{h_{\text{i}}}\right)=d_{\text{o}}$$

$$f=\frac{d_{\text{o}}}{1-\frac{h_{\text{o}}}{h_{\text{i}}}}$$

$$=\frac{3.0\text{ m}}{1-\frac{1.2\text{ m}}{-0.036\text{ m}}}$$

$$=\boxed{87\text{ mm}}$$

11. Determine the ratio of the aperture areas.

$$\frac{A_{2.4}}{A_8}=\frac{\frac{1}{4}\pi D_{2.4}{}^2}{\frac{1}{4}\pi D_8{}^2}=\frac{\left(\frac{f}{2.4}\right)^2}{\left(\frac{f}{8}\right)^2}=\left(\frac{8}{2.4}\right)^2>1$$

Since the diameter has increased, the shutter speed must be decreased.

$$\frac{\frac{1}{125}}{\left(\frac{8}{2.4}\right)^2}=\frac{1}{125}\cdot\frac{9}{100}=\frac{9}{12,500}\approx\frac{10}{10,000}=\boxed{\frac{1}{1000}}$$

12. (a) Since it is one quarter as bright, the exposure time must be quadrupled. $4\left(\frac{1}{100}\text{ s}\right)=\boxed{\frac{1}{25}\text{ s}}$

(b) In this case, the aperture area must be quadrupled.

$$\frac{A_\text{f}}{A_\text{i}}=\frac{\frac{1}{4}\pi D_\text{f}{}^2}{\frac{1}{4}\pi D_\text{i}{}^2}=\frac{\left(\frac{f}{f\text{-number}}\right)^2}{\left(\frac{f}{11}\right)^2}=\frac{11^2}{f\text{-number}^2}=4$$

$$f\text{-number}=\sqrt{\frac{11^2}{4}}=5.5\approx\boxed{5.6}$$

13. (a) Since using a shorter exposure time decreases the amount of light entering the camera, the area of the aperture must be increased to compensate. Since $D\propto\frac{1}{f\text{-number}}$, the smallest *f*-number gives the largest aperture diameter, and thus, the largest aperture area. So, the *f*-stop should be set to $\boxed{2}$.

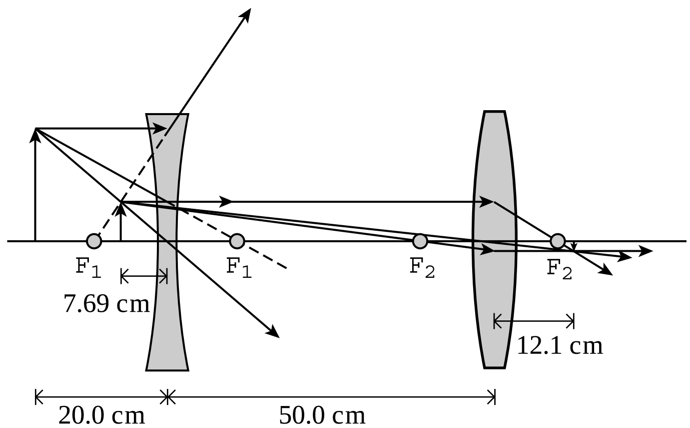
(b) $t=\left(\frac{1}{125}\text{ s}\right)\left(\frac{2}{5.6}\right)^2\approx\boxed{\frac{1}{1000}\text{ s}}$

14. (a) $\frac{f}{D}=\frac{16.9\text{ m}}{5.08\text{ m}}=\boxed{3.33}$

(b) $\frac{f_\text{eff}}{D}=\frac{155.4\text{ m}}{5.08\text{ m}}=\boxed{30.6}$

(c) $\boxed{\text{Neither}}$, since the aperture diameter is unchanged, both images receive the same amount of light, however, the light is more spread out with the larger *f*-number.

15.



16. $f = \dfrac{1}{\text{refractive power}} = \dfrac{1}{+43.0 \text{ diopters}} = \boxed{2.33 \text{ cm}}$

17. Since the student is using a plane mirror, the image distance is twice the distance from the mirror to the student's eyes. So, the greatest distance the student can stand from the mirror is $\dfrac{1.8 \text{ m}}{2} = \boxed{90 \text{ cm}}$.

18. $f = \dfrac{1}{\text{refractive power}} = \dfrac{1}{+2.3 \text{ diopters}} = \boxed{43 \text{ cm}}$

19. Find d_{i1} in terms of d_{o2}.

$$m_1 m_2 = \left(-\frac{d_{i1}}{d_{o1}}\right)\left(-\frac{d_{i2}}{d_{o2}}\right) = m = -\frac{d_{i2}}{d_{o1}}$$

$$\frac{d_{i1}d_{i2}}{d_{o1}d_{o2}} = -\frac{d_{i2}}{d_{o1}}$$

$$\frac{d_{i1}}{d_{o2}} = -1$$

$$d_{i1} = -d_{o2}$$

Find f_{eff} in terms of f_1 and f_2.

$$\frac{1}{f_{\text{eff}}} = \frac{1}{d_{o1}} + \frac{1}{d_{i2}}$$

$$= \frac{1}{d_{o1}} + \left(\frac{1}{d_{i1}} - \frac{1}{d_{i1}}\right) + \left(\frac{1}{d_{o2}} - \frac{1}{d_{o2}}\right) + \frac{1}{d_{i2}}$$

$$= \left(\frac{1}{d_{o1}} + \frac{1}{d_{i1}}\right) - \frac{1}{d_{i1}} - \frac{1}{d_{o2}} + \left(\frac{1}{d_{o2}} + \frac{1}{d_{i2}}\right)$$

$$= \frac{1}{f_1} - \frac{1}{-d_{o2}} - \frac{1}{d_{o2}} + \frac{1}{f_2}$$

$$= \frac{1}{f_1} + \frac{1}{f_2}$$

$$= \frac{1}{25.0 \text{ cm}} + \frac{1}{-40.0 \text{ cm}}$$

$$f_{\text{eff}} = \boxed{66.7 \text{ cm}}$$

20. Find d_{i1} in terms of d_{o2}.

$$m_1 m_2 = \left(-\frac{d_{i1}}{d_{o1}}\right)\left(-\frac{d_{i2}}{d_{o2}}\right) = m = -\frac{d_{i2}}{d_{o1}}$$

$$\frac{d_{i1}d_{i2}}{d_{o1}d_{o2}} = -\frac{d_{i2}}{d_{o1}}$$

$$\frac{d_{i1}}{d_{o2}} = -1$$

$$d_{i1} = -d_{o2}$$

Find f_{eff} in terms of f_1 and f_2.

$$\frac{1}{f_{eff}} = \frac{1}{d_{o1}} + \frac{1}{d_{i2}}$$

$$= \frac{1}{d_{o1}} + \left(\frac{1}{d_{i1}} - \frac{1}{d_{i1}}\right) + \left(\frac{1}{d_{o2}} - \frac{1}{d_{o2}}\right) + \frac{1}{d_{i2}}$$

$$= \left(\frac{1}{d_{o1}} + \frac{1}{d_{i1}}\right) - \frac{1}{d_{i1}} - \frac{1}{d_{o2}} + \left(\frac{1}{d_{o2}} + \frac{1}{d_{i2}}\right)$$

$$= \frac{1}{f_1} - \frac{1}{-d_{o2}} - \frac{1}{d_{o2}} + \frac{1}{f_2}$$

$$= \frac{1}{f_1} + \frac{1}{f_2}$$

So, $\text{r.p.}_{eff} = \text{r.p.}_1 + \text{r.p.}_2 = 4.00 \text{ diopters} + (-2.50 \text{ diopters}) = \boxed{1.50 \text{ diopters}}$

21. (a) Let the object be located 24 cm to the left of the left lens (1).

$$\frac{1}{d_{1i}} = \frac{1}{f} - \frac{1}{d_{1o}}$$

$$d_{1i} = \left(\frac{1}{f} - \frac{1}{d_{1o}}\right)^{-1} = \left(\frac{1}{-12 \text{ cm}} - \frac{1}{24 \text{ cm}}\right)^{-1} = -8.00 \text{ cm}$$

The image due to lens 1 is located 8.00 cm to the left of lens 1. So, the object distance for the right lens (2) is 8.00 cm + 6.0 cm = 14.0 cm to the left of lens 2.

$$d_{2i} = \left(\frac{1}{f} - \frac{1}{d_{2o}}\right)^{-1} = \left(\frac{1}{-12 \text{ cm}} - \frac{1}{14.0 \text{ cm}}\right)^{-1} = -6.46 \text{ cm}$$

$$6.46 \text{ cm} - 6.0 \text{ cm} = 0.5 \text{ cm}$$

$\boxed{\text{The final image is located 5 mm in front of the lens closest to the object.}}$

(b) $m = m_1 m_2 = \left(-\frac{d_{1i}}{d_{1o}}\right)\left(-\frac{d_{2i}}{d_{2o}}\right) = \left(-\frac{-8.00}{24}\right)\left(-\frac{-6.46}{14.0}\right) = \boxed{0.15}$

22. (a) The light rays must bend more sharply in traveling from the object to the retina, so the eye's refractive power $\boxed{\text{increases}}$.

(b) $f_{close} = \dfrac{1}{\text{refractive power}} = \dfrac{1}{\frac{1}{0.017 \text{ m}} + 16 \text{ diopters}} = \boxed{1.3 \text{ cm}}$

23. **(a)** Lens refraction is lessened because n_{water} is closer to n_{lens} than n_{air} is. The compensating change in the lens's refractive power must be an $\boxed{\text{increase}}$.

(b) $f_{\text{after}} = \dfrac{1}{\text{refractive power}} = \dfrac{1}{\frac{1}{0.0012\text{ m}} + 45\text{ diopters}} = \boxed{1.1\text{ mm}}$

24. **(a)** $\dfrac{1}{f_1} = \dfrac{1}{d_{o1}} + \dfrac{1}{d_{i1}}$

$$d_{i1} = \left(\frac{1}{f_1} - \frac{1}{d_{o1}}\right)^{-1} = \left(\frac{1}{8.000\text{ cm}} - \frac{1}{12.0\text{ cm}}\right)^{-1} = 24.0\text{ cm}$$

$d_{o2} = 20.0\text{ cm} - 24.0\text{ cm} = -4.0\text{ cm}$

$\dfrac{1}{f_2} = \dfrac{1}{d_{o2}} + \dfrac{1}{d_{i2}}$

$$d_{i2} = \left(\frac{1}{f_2} - \frac{1}{d_{o2}}\right)^{-1} = \left(\frac{1}{-6.00\text{ cm}} - \frac{1}{-4.0\text{ cm}}\right)^{-1} = 12\text{ cm}$$

The final image is located $\boxed{\text{12 cm to the right of the diverging lens}}$.

(b) $m = m_1 m_2 = \left(-\dfrac{d_{i1}}{d_{o1}}\right)\left(-\dfrac{d_{i2}}{d_{o2}}\right) = \dfrac{d_{i1}d_{i2}}{d_{o1}d_{o2}} = \dfrac{(24.0\text{ cm})(12\text{ cm})}{(12.0\text{ cm})(-4.0\text{ cm})} = \boxed{-6.0}$

25. **(a)** $\dfrac{1}{f_1} = \dfrac{1}{d_{o1}} + \dfrac{1}{d_{i1}}$

$$d_{i1} = \left(\frac{1}{f_1} - \frac{1}{d_{o1}}\right)^{-1} = \left(\frac{1}{-6.00\text{ cm}} - \frac{1}{18.0\text{ cm}}\right)^{-1} = -4.50\text{ cm}$$

$d_{o2} = 20.0\text{ cm} + 4.50\text{ cm} = 24.5\text{ cm}$ to the right of the converging lens.

$\dfrac{1}{f_2} = \dfrac{1}{d_{o2}} + \dfrac{1}{d_{i2}}$

$$d_{i2} = \left(\frac{1}{f_2} - \frac{1}{d_{o2}}\right)^{-1} = \left(\frac{1}{8.00\text{ cm}} - \frac{1}{24.5\text{ cm}}\right)^{-1} = 12\text{ cm}$$

The final image is located $\boxed{\text{12 cm to the left of the converging lens}}$.

(b) $m = m_1 m_2 = \left(-\dfrac{d_{i1}}{d_{o1}}\right)\left(-\dfrac{d_{i2}}{d_{o2}}\right) = \dfrac{d_{i1}d_{i2}}{d_{o1}d_{o2}} = \dfrac{(-4.50\text{ cm})(12\text{ cm})}{(18.0\text{ cm})(24.5\text{ cm})} = \boxed{-0.12}$

26. $\dfrac{1}{f} = \dfrac{1}{d_o} + \dfrac{1}{d_i}$

$$f = \left(\frac{1}{d_o} + \frac{1}{d_i}\right)^{-1} = \left(\frac{1}{10.5\text{ cm}} - \frac{1}{172\text{ cm}}\right)^{-1} = \boxed{11.2\text{ cm}}$$

27. $\dfrac{1}{f} = \dfrac{1}{d_o} + \dfrac{1}{d_i} \approx \dfrac{1}{d_i}$ since $d_o >> d_i$.

$f \approx d_i = \boxed{-130\text{ cm}}$

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

$$f=\left(\frac{1}{d_o}+\frac{1}{d_i}\right)^{-1}=\left(\frac{1}{25\text{ cm}}-\frac{1}{56\text{ cm}}\right)^{-1}=\boxed{45\text{ cm}}$$

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

$$d_i=\left(\frac{1}{f}-\frac{1}{d_o}\right)^{-1}=\left(\frac{1}{-0.085\text{ m}}-\frac{1}{8.5\text{ m}}\right)^{-1}=-8.4\text{ cm}$$

Her uncorrected far-point distance is $\boxed{8.4\text{ cm}}$.

30. $\frac{1}{f}=\frac{1}{d_o}+\frac{1}{d_i}\approx\frac{1}{d_i}$ since $d_o >> d_i$.

$$f\approx d_i=-(4.5\text{ m}-0.021\text{ m})=\boxed{-4.5\text{ m}}$$

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

$$f=\left(\frac{1}{d_o}+\frac{1}{d_i}\right)^{-1}=\left[\frac{1}{25\text{ cm}-2.0\text{ cm}}+\frac{1}{-(39\text{ cm}-2.0\text{ cm})}\right]^{-1}=\boxed{61\text{ cm}}$$

$$\text{refractive power}=\frac{1}{f}=\frac{1}{0.23\text{ m}}+\frac{1}{-0.37\text{ m}}=\boxed{1.6\text{ diopters}}$$

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

$$f=\left(\frac{1}{d_o}+\frac{1}{d_i}\right)^{-1}$$

(a) $f=\left[\frac{1}{25.0\text{ m}-0.0200\text{ m}}+\frac{1}{-(2.50\text{ m}-0.0200\text{ m})}\right]^{-1}=\boxed{-2.75\text{ m}}$

(b) $f=\left[\frac{1}{25.0\text{ m}-0.0100\text{ m}}+\frac{1}{-(2.50\text{ m}-0.0100\text{ m})}\right]^{-1}=\boxed{-2.77\text{ m}}$

33. (a) Since your Aunt can only focus on objects near her eyes, she is $\boxed{\text{nearsighted}}$.

(b) Since a diverging lens can produce an image of a distant object at your Aunt's far point, your aunt should wear glasses with $\boxed{\text{diverging}}$ lenses.

(c) $\text{refractive power}=\frac{1}{f}=\frac{1}{d_o}+\frac{1}{d_i}=\frac{1}{0.250\text{ m}-0.0200\text{ m}}+\frac{1}{-(0.120\text{ m}-0.0200\text{ m})}=\boxed{-5.7\text{ diopters}}$

34. (a) When a normal eye relaxes, it is focused on distant objects, and its refractive power is at a minimum:

$$\frac{1}{f_{\text{rel}}} = \frac{1}{d_{\text{o-max}}} + \frac{1}{d_{\text{i}}} = \frac{1}{\infty} + \frac{1}{0.0240\text{ m}} = 41.7\text{ diopters}$$

A person whose eyes refract more strongly than this in a relaxed state cannot see distant objects clearly ($1/d_{\text{o-max}} > 0$). The patient is $\boxed{\text{nearsighted}}$.

(b) $$d_{\text{o-max}} = \left(\frac{1}{f_{\text{rel}}} - \frac{1}{d_{\text{i}}}\right)^{-1} = \left(48.5\text{ m}^{-1} - \frac{1}{0.0240\text{ m}}\right)^{-1} = \boxed{15\text{ cm}}$$

35. (a) $$\frac{1}{f} = \frac{1}{d_0} + \frac{1}{d_{\text{i}}} = \frac{1}{0.28\text{ m}} + \frac{1}{0.0240\text{ m}} = \boxed{45.2\text{ diopters}}$$

(b) As d_0 increases, the refractive power $\frac{1}{f} = \frac{1}{d_0} + \frac{1}{d_{\text{i}}}$ $\boxed{\text{decreases}}$.

36. (a) $$\text{refractive power} = \frac{1}{f} = \frac{1}{d_{\text{o}}} + \frac{1}{d_{\text{i}}} \approx \frac{1}{d_{\text{i}}} = \frac{1}{-(1.5\text{ m} - 0.020\text{ m})} = \boxed{-0.68\text{ diopters}}$$

(b) $$\frac{1}{f} = \frac{1}{d_{\text{o}}} + \frac{1}{d_{\text{i}}}$$

$$d_{\text{o}} = \left(\frac{1}{f} - \frac{1}{d_{\text{i}}}\right)^{-1} = \left[\frac{1}{-(1.5\text{ m} - 0.020\text{ m})} - \frac{1}{-(0.25\text{ m} - 0.020\text{ m})}\right]^{-1} = \boxed{27\text{ cm}}$$

37. $$\frac{1}{f_1} = \frac{1}{d_{\text{o1}}} + \frac{1}{d_{\text{i1}}}$$

$$d_{\text{i1}} = \left(\frac{1}{f_1} - \frac{1}{d_{\text{o1}}}\right)^{-1} = \left(\frac{1}{20.5\text{ cm}} - \frac{1}{30.0\text{ cm}}\right)^{-1} = 64.7\text{ cm}$$

$$d_{\text{o2}} = -64.7\text{ cm} + 30.0\text{ cm} = -34.7\text{ cm}$$

$$d_{\text{i2}} = \left(\frac{1}{f_2} - \frac{1}{d_{\text{o2}}}\right)^{-1} = \left(\frac{1}{-42.5\text{ cm}} - \frac{1}{-34.7\text{ cm}}\right)^{-1} = 190\text{ cm}$$

$$h_{\text{i}} = mh_{\text{o}} = m_1 m_2 h_{\text{o}} = \left(-\frac{d_{\text{i1}}}{d_{\text{o1}}}\right)\left(-\frac{d_{\text{i2}}}{d_{\text{o2}}}\right)h_{\text{o}} = \frac{d_{\text{i1}} d_{\text{i2}} h_{\text{o}}}{d_{\text{o1}} d_{\text{o2}}} = \frac{(64.7\text{ cm})(190\text{ cm})(2.05\text{ cm})}{(30.0\text{ cm})(-34.7\text{ cm})} = -24.2\text{ cm}$$

The final image is inverted and $\boxed{24.2\text{ cm}}$ tall.

38. **(a)** $\frac{1}{f_1} = \frac{1}{d_{o1}} + \frac{1}{d_{i1}}$

$$d_{i1} = \left(\frac{1}{f_1} - \frac{1}{d_{o1}}\right)^{-1} = \left(\frac{1}{39.0\text{ cm}} - \frac{1}{400\text{ cm}}\right)^{-1} = 43.2\text{ cm}$$

$$d_o = 36.0\text{ cm} - 43.2\text{ cm} = -7.2\text{ cm}$$

$$d_{i2} = \left(\frac{1}{f_2} - \frac{1}{d_{o2}}\right)^{-1} = \left(\frac{1}{-10.0\text{ cm}} - \frac{1}{-7.2\text{ cm}}\right)^{-1} = 30\text{ cm}$$

The film should be placed $\boxed{30\text{ cm}}$ behind the concave lens.

(b) $m = m_1 m_2 = \left(-\frac{d_{i1}}{d_{o1}}\right)\left(-\frac{d_{i2}}{d_{o2}}\right) = \frac{d_{i1}d_{i2}}{d_{o1}d_{o2}} = \frac{(43.2\text{ cm})(25.7\text{ cm})}{(400\text{ cm})(-7.2\text{ cm})} = \boxed{-0.4}$

39. **(a)** A $\boxed{\text{diverging}}$ lens will produce an image of a distant object within the librarian's far point.

(b) A $\boxed{\text{converging}}$ lens will produce an image beyond the librarian's near point of an object that is within the near point.

(c) diverging (distant objects):

$$\text{refractive} = \frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i} \approx \frac{1}{d_i} = \frac{1}{-(5.0\text{ m} - 0.020\text{ m})} = \boxed{-0.20\text{ diopters}}$$

converging (near objects):

$$\text{refractive power} = \frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{0.25\text{ m} - 0.020\text{ m}} + \frac{1}{-(0.50\text{ m} - 0.020\text{ m})} = \boxed{+2.3\text{ diopters}}$$

40. **(a)** A $\boxed{\text{diverging}}$ lens will produce an image of a distant object within the physician's far point.

(b) A $\boxed{\text{converging}}$ lens will produce an image beyond the physician's near point of an object that is within the near point.

(c) diverging (distant objects):

$$\text{refractive power} = \frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i} \approx \frac{1}{d_i} = \frac{1}{-5.0\text{ m}} = \boxed{-0.20\text{ diopters}}$$

converging (near objects):

$$\text{refractive power} = \frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{0.25\text{ m}} + \frac{1}{-0.50\text{ m}} = \boxed{+2.0\text{ diopters}}$$

41. $\frac{1}{f}=\frac{1}{d_\text{o}}+\frac{1}{d_\text{i}+0.0200\text{ m}}\approx\frac{1}{d_\text{i}+0.0200\text{ m}}$ for distant objects.

$$d_\text{i}+0.0200\text{ m}\approx f=\frac{1}{\text{refractive power}}=\frac{1}{-0.425\text{ diopter}}=-2.35\text{ m}$$

The far point is $\boxed{2.37\text{ m}}$.

$$\begin{aligned}d_\text{i}&=\left(\frac{1}{f}-\frac{1}{d_\text{o}}\right)^{-1}-2.00\text{ cm}\\&=\left(\text{refractive power}-\frac{1}{d_\text{o}}\right)^{-1}-2.00\text{ cm}\\&=\left(1.55\text{ diopters}-\frac{1}{0.250\text{ m}}\right)^{-1}-2.00\text{ cm}\\&=-42.8\text{ cm}\end{aligned}$$

The near point is $\boxed{42.8\text{ cm}}$.

42. $\frac{1}{f}=\frac{1}{d_\text{o}}+\frac{1}{d_\text{i}+2.00\text{ cm}}\approx\frac{1}{d_\text{i}+2.00\text{ cm}}$ for distant objects.

$$d_\text{i}\approx f-2.00\text{ cm}=\frac{1}{\text{refractive power}}-2.00\text{ cm}=\frac{1}{-0.0625\text{ diopter}}-0.0200\text{ m}=-16.0\text{ m}$$

The far point is $\boxed{16.0\text{ m}}$.

$$\begin{aligned}d_\text{i}&=\left(\frac{1}{f}-\frac{1}{d_\text{o}}\right)^{-1}-2.00\text{ cm}=\left(\text{refractive power}-\frac{1}{d_\text{o}}\right)^{-1}-2.00\text{ cm}=\left(1.05\text{ diopters}-\frac{1}{0.230\text{ m}}\right)^{-1}-0.0200\text{ m}\\&=-32.3\text{ cm}\end{aligned}$$

The near point is $\boxed{32.3\text{ cm}}$.

43. $\frac{1}{f_1}=\frac{1}{d_{\text{o}1}}+\frac{1}{d_{\text{i}1}}$

$$d_{\text{i}1}=\left(\frac{1}{f_1}-\frac{1}{d_{\text{o}1}}\right)^{-1}=\left(\frac{1}{20.0\text{ cm}}-\frac{1}{50.0\text{ cm}}\right)^{-1}=33.3\text{ cm}$$

(a) $d_{\text{o}2}=115\text{ cm}-33.3\text{ cm}=82\text{ cm}$ to the left of lens 2.

$$d_{\text{i}2}=\left(\frac{1}{f_2}-\frac{1}{d_{\text{o}2}}\right)^{-1}=\left(\frac{1}{30.0\text{ cm}}-\frac{1}{82\text{ cm}}\right)^{-1}=47\text{ cm}$$

The final image is located $\boxed{\text{47 cm to the right of lens 2}}$.

$$m=m_1m_2=\frac{d_{\text{i}1}d_{\text{i}2}}{d_{\text{o}1}d_{\text{o}2}}=\frac{(33.3\text{ cm})(47\text{ cm})}{(50.0\text{ cm})(82\text{ cm})}=\boxed{0.38}$$

(b) $d_{\text{o}2}=33.3\text{ cm}-30.0\text{ cm}=3.3\text{ cm}$ to the right of lens 2.

$$d_{\text{i}2}=\left(\frac{1}{30.0\text{ cm}}-\frac{1}{-3.3\text{ cm}}\right)^{-1}=3.0\text{ cm}$$

The final image is located $\boxed{\text{3.0 cm to the right of lens 2}}$.

$$m=\frac{(33.3\text{ cm})(3.0\text{ cm})}{(50.0\text{ cm})(-3.3\text{ cm})}=\boxed{-0.61}$$

(c) $d_{o2} = 33.3\text{ cm} - 0\text{ cm} = 33.3\text{ cm}$ to the right of lens 2.

$$d_{i2} = \left(\frac{1}{30.0\text{ cm}} - \frac{1}{-33.3\text{ cm}}\right)^{-1} = 15.8\text{ cm}$$

The final image is located $\boxed{15.8\text{ cm to the right of lens 2}}$.

$$m = \frac{(33.3\text{ cm})(15.8\text{ cm})}{(50.0\text{ cm})(33.3\text{ cm})} = \boxed{0.316}$$

(d) $$f_{\text{eff}} = \left(\frac{1}{f_1} + \frac{1}{f_2}\right)^{-1} = \left(\frac{1}{20.0\text{ cm}} + \frac{1}{30.0\text{ cm}}\right)^{-1} = 12.0\text{ cm}$$

$d_o = 50.0\text{ cm}$ and $d_i = 15.8\text{ cm}$.

$$f_{\text{eff}} = \left(\frac{1}{d_o} + \frac{1}{d_i}\right)^{-1} = \left(\frac{1}{50.0\text{ cm}} + \frac{1}{15.8\text{ cm}}\right)^{-1} = 12.0\text{ cm}$$

44. Find d_{i1}.

$$\frac{1}{f} = \frac{1}{d_{o1}} + \frac{1}{d_{i1}}$$

$$d_{i1} = \left(\frac{1}{f} - \frac{1}{d_{o1}}\right)^{-1} = \left(\frac{1}{4.0\text{ cm}} - \frac{1}{12\text{ cm}}\right)^{-1} = 6.0\text{ cm}$$

$d_{o2} = x - 6.0\text{ cm}$

Find d_{i2} in terms of d_{o2}.

$$1 = m = \frac{d_{i1}d_{i2}}{d_{o1}d_{o2}}$$

$$d_{i2} = \frac{d_{o1}d_{o2}}{d_{i1}} = \left(\frac{1}{4.0\text{ cm}} - \frac{1}{12\text{ cm}}\right)(12\text{ cm})d_{o2} = 2.0d_{o2}$$

Find x.

$$\frac{1}{f} = \frac{1}{d_{o2}} + \frac{1}{d_{i2}} = \frac{1}{d_{o2}} + \frac{1}{2.0d_{o2}} = \frac{1}{d_{o2}}\left(1 + \frac{1}{2.0}\right) = \frac{1.50}{d_{o2}} = \frac{1.50}{x - 6.0\text{ cm}}$$

$$x = 1.50f + 6.0\text{ cm} = 1.50(4.0\text{ cm}) + 6.0\text{ cm} = 12.0\text{ cm}$$

The lenses are separated by a distance of $\boxed{12.0\text{ cm}}$.

45. (a) $$\theta = \tan^{-1}\frac{y}{x} = \tan^{-1}\frac{3476\text{ km}}{384,400\text{ km}} = \boxed{9.042 \times 10^{-3}\text{ rad}}$$

(b) $$x = \frac{d}{\tan\theta} = (0.019\text{ m})\frac{384,400\text{ km}}{3476\text{ km}} = \boxed{2.1\text{ m}}$$

46. (a) $M = \frac{N}{f} = \frac{25 \text{ cm}}{12.0 \text{ cm}} = \boxed{2.1}$

(b) $M = 1 + \frac{N}{f} = 1 + \frac{25 \text{ cm}}{12.0 \text{ cm}} = \boxed{3.1}$

$M = 1 + \frac{N}{f} = \frac{N}{d_\text{o}}$

$d_\text{o} = \left(\frac{1}{N} + \frac{1}{f}\right)^{-1} = \left(\frac{1}{25 \text{ cm}} + \frac{1}{12.0 \text{ cm}}\right)^{-1} = \boxed{8.11 \text{ cm}}$

47. (a) Since a smaller focal length results in a larger magnification, the lens with focal length $\boxed{f_1}$ can produce the greater magnification.

(b) $M_1 = 1 + \frac{N}{f} = 1 + \frac{25 \text{ cm}}{5.0 \text{ cm}} = \boxed{6.0}$

$M_2 = 1 + \frac{25 \text{ cm}}{13 \text{ cm}} = \boxed{2.9}$

48. Since the eye is relaxed, the image is at infinity.

$M = \frac{N}{f}$

$\text{apparent length} = (\text{length})\frac{N}{f} = (4.43 \text{ mm})\frac{25 \text{ cm}}{11.4 \text{ cm}} = \boxed{9.7 \text{ mm}}$

49. (a) $M = 1 + \frac{N}{f} = \frac{N}{d_\text{o}}$

$d_\text{o} = \left(\frac{1}{N} + \frac{1}{f}\right)^{-1} = \left(\frac{1}{25.2 \text{ cm}} + \frac{1}{8.75 \text{ cm}}\right)^{-1} = \boxed{6.49 \text{ cm}}$

(b) $M = 1 + \frac{N}{f} = 1 + \frac{25.2 \text{ cm}}{8.75 \text{ cm}} = \boxed{3.88}$

50. $M = \frac{N}{f} = \frac{20.8 \text{ cm}}{7.50 \text{ cm}} = \boxed{2.77}$

51. $M = \frac{N}{d_\text{o}} = \frac{20.8 \text{ cm}}{5.59 \text{ cm}} = \boxed{3.72}$

52. $M_{\text{near point}} = 1 + \dfrac{N}{f}$

$M_{\infty} = \dfrac{N}{f}$

Set $M_{\text{near point}} = 1.5M_{\infty}$.

$$1 + \frac{N}{f} = \frac{1.5N}{f}$$
$$1 = \frac{0.5N}{f}$$
$$f = 0.5N = 0.5(25\text{ cm}) = \boxed{13\text{ cm}}$$

53. $M_{\text{total}} = -\dfrac{d_{\text{i}}N}{f_{\text{obj}}f_{\text{e}}} = -\dfrac{(12\text{ cm})(25\text{ cm})}{(2.0\text{ cm})(5.0\text{ cm})} = \boxed{-30}$

54. $\dfrac{1}{d_{\text{i}}} = \dfrac{1}{f_{\text{obj}}} - \dfrac{1}{d_{\text{o}}} = \dfrac{1}{f_{\text{obj}}} - \dfrac{1}{N}$

$$d_{\text{i}} = \left(\frac{1}{f_{\text{obj}}} - \frac{1}{N}\right)^{-1}$$

$$\theta' = |M_{\text{total}}|\theta = \frac{d_{\text{i}}N\theta}{f_{\text{obj}}f_{\text{e}}} = \left(\frac{1}{0.49\text{ cm}} - \frac{1}{25\text{ cm}}\right)^{-1} \frac{(25\text{ cm})(1.9\times10^{-5}\text{ rad})}{(0.49\text{ cm})(2.7\text{ cm})} = \boxed{1.8\times10^{-4}\text{ rad}}$$

55. (a) $\dfrac{1}{d_{\text{o}}} = \dfrac{1}{f_{\text{obj}}} - \dfrac{1}{d_{\text{i}}} = \dfrac{1}{f_{\text{obj}}} + \dfrac{1}{mf_{\text{obj}}}$

$$d_{\text{o}} = f_{\text{obj}}\left(1 + \frac{1}{m}\right)^{-1} = (4.00\text{ mm})\left(1 + \frac{1}{-40.0}\right)^{-1} = \boxed{4.10\text{ mm}}$$

(b) $M_{\text{total}} = m_{\text{o}}M_{\text{e}} = m_{\text{o}}\dfrac{N}{f_{\text{e}}}$

$$f_{\text{e}} = \frac{m_{\text{o}}N}{M_{\text{total}}} = \frac{(-40.0)(25\text{ cm})}{125} = \boxed{-8.0\text{ cm}}$$

56. $M_{\text{total}} = -\dfrac{d_{\text{i}}N}{f_{\text{obj}}f_{\text{e}}}$

$$f_{\text{obj}} = -\frac{d_{\text{i}}N}{M_{\text{total}}f_{\text{e}}} = \frac{(2.62\text{ cm} - 18.0\text{ cm})(0.250\text{ cm})}{(-4525)(2.62\text{ cm})} = \boxed{0.324\text{ mm}}$$

57. $\dfrac{1}{d_{\text{o}}} = \dfrac{1}{f_{\text{obj}}} - \dfrac{1}{d_{\text{i}}} = \dfrac{1}{f_{\text{obj}}} - \dfrac{1}{18.0\text{ cm} - f_{\text{e}}} = -\dfrac{M_{\text{total}}f_{\text{e}}}{(18.0\text{ cm} - f_{\text{e}})N} - \dfrac{1}{18.0\text{ cm} - f_{\text{e}}}$

$$d_{\text{o}} = \frac{(f_{\text{e}} - 18.0\text{ cm})N}{M_{\text{total}}f_{\text{e}} + N} = \frac{(2.62\text{ cm} - 18.0\text{ cm})(0.250\text{ m})}{(-4525)(2.62\text{ cm}) + 25.0\text{ cm}} = \boxed{0.325\text{ mm}}$$

58. $\dfrac{1}{f_{\text{obj}}}=\dfrac{1}{d_{\text{i}}}+\dfrac{1}{d_{\text{o}}}=\dfrac{1}{15\text{ cm}-f_{\text{e}}}+\dfrac{1}{d_{\text{o}}}$

$$f_{\text{o}}=\left(\frac{1}{15\text{ cm}-f_{\text{e}}}+\frac{1}{d_{\text{o}}}\right)^{-1}=\left(\frac{1}{15\text{ cm}-5.0\text{ cm}}+\frac{1}{1.0\text{ cm}}\right)^{-1}=\boxed{9.1\text{ mm}}$$

59. (a) Find d_{i}.

$$\frac{1}{f_{\text{obj}}}=\frac{1}{d_{\text{o}}}+\frac{1}{d_{\text{i}}}$$

$$d_{\text{i}}=\left(\frac{1}{f_{\text{obj}}}-\frac{1}{d_{\text{o}}}\right)^{-1}=\left(\frac{1}{75\text{ mm}}-\frac{1}{122\text{ mm}}\right)^{-1}=0.2\text{ m}$$

barrel length $=0.2\text{ m}+0.020\text{ m}=\boxed{0.2\text{ m}}$

(b) $M_{\text{total}}=-\dfrac{d_{\text{i}}N}{f_{\text{obj}}f_{\text{e}}}=-\dfrac{\left(\frac{1}{75\text{ mm}}-\frac{1}{122\text{ mm}}\right)^{-1}(250\text{ mm})}{(75\text{ mm})(20\text{ mm})}=\boxed{-30}$

60. (a) $L=d_{\text{i}}-f_{\text{obj}}$

$d_{\text{i}}=L+f_{\text{obj}}$

$$\frac{1}{f_{\text{obj}}}=\frac{1}{d_{\text{o}}}+\frac{1}{d_{\text{i}}}$$

$$\begin{aligned}d_{\text{o}}&=\left(\frac{1}{f_{\text{obj}}}-\frac{1}{d_{\text{i}}}\right)^{-1}\\&=\left(\frac{1}{f_{\text{obj}}}-\frac{1}{L+f_{\text{obj}}}\right)^{-1}\\&=\left(\frac{1}{0.00750\text{ m}}-\frac{1}{0.16\text{ m}+0.00750\text{ m}}\right)^{-1}\\&=\boxed{7.85\text{ mm}}\end{aligned}$$

(b) $M_{\text{total}}=-\dfrac{d_{\text{i}}N}{f_{\text{obj}}f_{\text{e}}}$

$$\begin{aligned}f_{\text{e}}&=-\frac{d_{\text{i}}N}{f_{\text{obj}}M_{\text{total}}}\\&=\frac{-(L+f_{\text{obj}})N}{f_{\text{obj}}M_{\text{total}}}\\&=\frac{-(0.16\text{ m}+0.00750\text{ m})(0.25\text{ m})}{(0.00750\text{ m})(-55)}\\&=\boxed{10\text{ cm}}\end{aligned}$$

(c) $f_{\text{e}}=\dfrac{-(0.16\text{ m}+0.00750\text{ m})(0.25\text{ m})}{(0.00750\text{ m})(-110)}=\boxed{5.1\text{ cm}}$

61. $f_{\text{obj}}=M_{\text{total}}f_{\text{e}}=35(5.0\text{ cm})=\boxed{1.8\text{ m}}$

62. $M_{\text{total}} = \dfrac{f_{\text{obj}}}{f_{\text{e}}} = \dfrac{L - f_{\text{e}}}{f_{\text{e}}}$

$L = M_{\text{total}} f_{\text{e}} + f_{\text{e}} = (5.0\text{ cm})(1 + 42) = \boxed{2.2\text{ m}}$

63. (a) $M = \dfrac{f_{\text{obj}}}{f_{\text{e}}}$ is greatest when f_{obj} is as large and f_{e} is as small as possible.

$M = \dfrac{30.0\text{ cm}}{5.00\text{ cm}} = \boxed{6.00}$

(b) $L = f_{\text{obj}} + f_{\text{e}} = 30.0\text{ cm} + 5.00\text{ cm} = \boxed{35.0\text{ cm}}$

64. $f_{\text{obj}} = M_{\text{total}} f_{\text{e}} = 28(14\text{ mm}) = \boxed{39\text{ cm}}$

65. (a) $d = f_1 + f_2 = 30.0\text{ cm} + 5.0\text{ cm} = \boxed{35.0\text{ cm}}$

(b) $\dfrac{1}{d_{\text{i}}} = \dfrac{1}{f_1} - \dfrac{1}{d_{\text{o}}}$

$d = f_2 + d_i = f_2 + \left(\dfrac{1}{f_1} - \dfrac{1}{d_{\text{o}}}\right)^{-1} = 5.0\text{ cm} + \left(\dfrac{1}{30.0\text{ cm}} - \dfrac{1}{500\text{ cm}}\right)^{-1} = \boxed{36.9\text{ cm}}$

66. $M_{\text{"wrong" end}} = \dfrac{1}{M_{\text{total}}} = \dfrac{1}{25} = \boxed{0.040}$

67. (a) Since the angular magnification is $M_{\text{total}} = \dfrac{f_{\text{obj}}}{f_{\text{e}}}$, the lens with the larger focal length, or lower refractive power, should be used as the objective. He should use his $\boxed{\text{right lens}}$.

(b) $M_{\text{total}} = \dfrac{f_{\text{obj}}}{f_{\text{e}}} = \dfrac{\text{r. p. eyepiece}}{\text{r. p. objective}} = \dfrac{5.0\text{ diopters}}{2.0\text{ diopters}} = \boxed{2.5}$

68. (a) $M_{\text{total}} = -\dfrac{f_{\text{obj}}}{f_{\text{e}}}$

$$\begin{aligned} f_{\text{e}} &= -\frac{f_{\text{obj}}}{M_{\text{total}}} \\ &= -\frac{1.7\text{ m}}{3.0} \\ &= \boxed{-57\text{ cm}} \end{aligned}$$

(b) $L = f_{\text{obj}} + f_{\text{e}} = 1.7\text{ m} - 0.57\text{ m} = \boxed{1.1\text{ m}}$

69. $M_{\text{total}} = \dfrac{\theta'}{\theta} = \dfrac{f_{\text{obj}}}{f_{\text{e}}}$

$\theta' = \dfrac{f_{\text{obj}}}{f_{\text{e}}}\theta = \dfrac{53\text{ cm}}{2.5\text{ cm}}(0.50°) = \boxed{11°}$

70. $M_{\text{total}} = \frac{\theta'}{\theta} = \frac{f_{\text{obj}}}{f_{\text{e}}}$

$$f_{\text{e}} = \frac{\theta}{\theta'} f_{\text{obj}} = \frac{0.50°}{15°}(53 \text{ cm}) = \boxed{1.8 \text{ cm}}$$

71. (a) $L = f_{\text{e}} + f_{\text{obj}}$

$$\begin{aligned} f_{\text{e}} &= L - f_{\text{obj}} \\ &= 275 \text{ mm} - 257 \text{ mm} \\ &= \boxed{18 \text{ mm}} \end{aligned}$$

(b) $M_{\text{total}} = \frac{f_{\text{obj}}}{f_{\text{e}}} = \frac{257 \text{ mm}}{18 \text{ mm}} = \boxed{14}$

72. (a) When an eye is focused on the near point of a normal, healthy eye, at 25 cm, its refractive power is at a maximum:

$$\begin{aligned} \frac{1}{f_{\text{near}}} &= \frac{1}{N_{\text{normal}}} + \frac{1}{d_{\text{i}}} \\ &= \frac{1}{0.25 \text{ m}} + \frac{1}{0.0240 \text{ m}} \\ &= 45.7 \text{ diopters} \end{aligned}$$

A person whose eyes cannot refract this strongly cannot see objects as close as 25 cm clearly. The patient is $\boxed{\text{farsighted}}$.

(b) $N = \left(\frac{1}{f_{\text{near}}} - \frac{1}{d_{\text{i}}}\right)^{-1}$

$$\begin{aligned} &= \left(43.1 \text{ m}^{-1} - \frac{1}{0.0240 \text{ m}}\right)^{-1} \\ &= \boxed{70 \text{ cm}} \end{aligned}$$

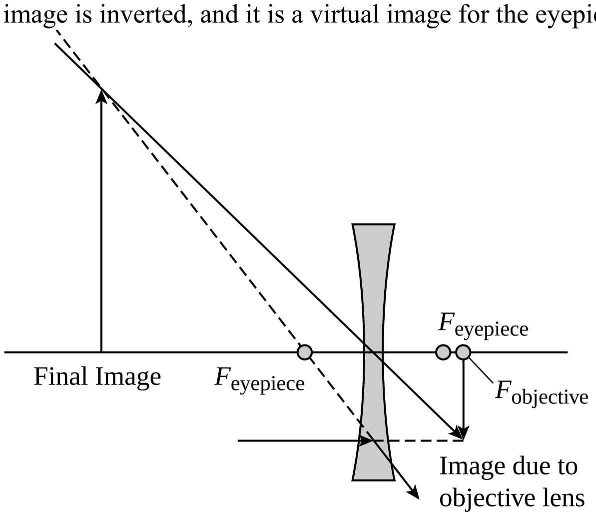
73. (a) $\frac{1}{f} = \frac{1}{d_0} + \frac{1}{d_{\text{i}}} \approx \frac{1}{\infty} + \frac{1}{0.0240 \text{ m}} = \boxed{41.7 \text{ diopters}}$

(b) As d_0 decreases, the refractive power $\frac{1}{f} = \frac{1}{d_0} + \frac{1}{d_{\text{i}}}$ $\boxed{\text{increases}}$.

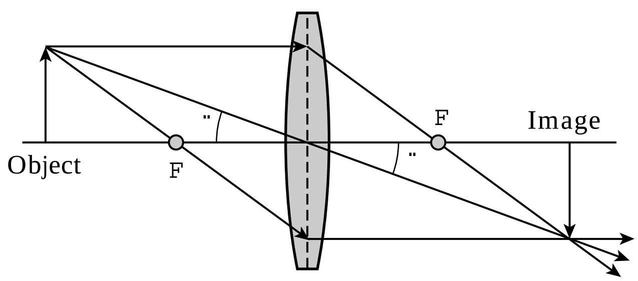
74. $\frac{1}{f}=\frac{1}{d_o}+\frac{1}{d_i}\approx\frac{1}{d_i}$ for distant objects.

So, $d_{i1}\approx f$.

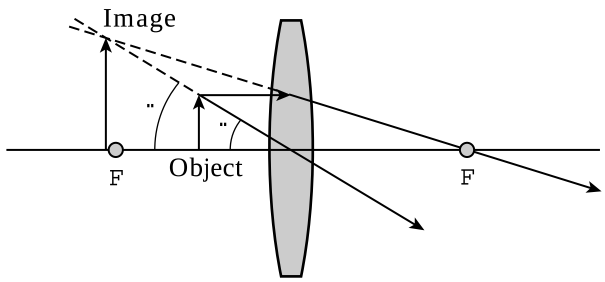
The objective lens forms an image at its focal point just beyond the right-hand focal point of the eyepiece. This image is inverted, and it is a virtual image for the eyepiece.



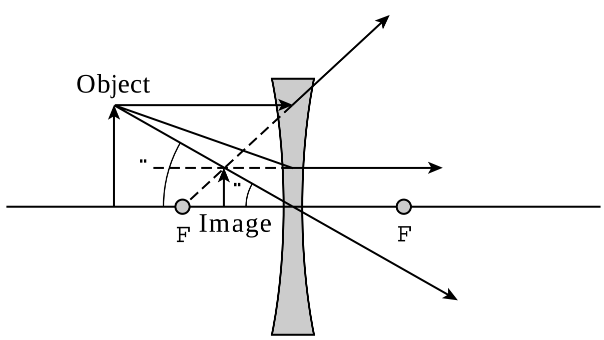
75. (a)



(b)



(c)



(d) A simple magnifier works by allowing an object to be viewed from a reduced distance, thus making it appear larger.

76. (a) Since $M_{\text{total}} = \dfrac{f_{\text{obj}}}{f_{\text{e}}}$ and $f_2 > f_1$, arrange the lenses as a telescope with $f_{\text{obj}} = f_2$ and $f_{\text{e}} = f_1$

(b) $M_{\text{total}} = \dfrac{f_{\text{obj}}}{f_{\text{e}}} = \dfrac{f_2}{f_1} = \dfrac{20.4\text{ cm}}{2.60\text{ cm}} = \boxed{7.85}$

(c) Arrange the lenses as a microscope with $f_{\text{obj}} = f_1$ and $f_{\text{e}} = f_2$.

(d) Find d_{i}.

$$\frac{1}{f_{\text{obj}}} = \frac{1}{d_{\text{o}}} + \frac{1}{d_{\text{i}}}$$

$$d_{\text{i}} = \left(\frac{1}{f_{\text{obj}}} - \frac{1}{d_{\text{o}}}\right)^{-1} = \left(\frac{1}{2.60\text{ cm}} - \frac{1}{2.35\text{ cm}}\right)^{-1} = -24\text{ cm}$$

$$M_{\text{total}} = -\frac{d_{\text{i}}N}{f_{\text{obj}}f_{\text{e}}} = -\frac{\left(\frac{1}{2.60\text{ cm}} - \frac{1}{2.35\text{ cm}}\right)^{-1}(25\text{ cm})}{(2.60\text{ cm})(20.4\text{ cm})} = \boxed{12}$$

77. (a) $f_{\text{eff}} = \dfrac{1}{\text{refractive power}} = \dfrac{1}{58.6\text{ diopters}} = \boxed{1.71\text{ cm}}$

(b) $2.5\text{ cm} - 1.71\text{ cm} = \boxed{8\text{ mm}}$

78. Find d_{i} in terms of d_{o}.

$$m = 0.035 = -\frac{d_{\text{i}}}{d_{\text{o}}}$$

$$d_{\text{i}} = -0.035 d_{\text{o}}$$

Find R.

$$-\frac{2}{R} = \frac{1}{f} = \frac{1}{d_{\text{o}}} + \frac{1}{d_{\text{i}}} = \frac{1}{d_{\text{o}}} + \frac{1}{-0.035 d_{\text{o}}} = \frac{1}{d_{\text{o}}}\left(1 - \frac{1}{0.035}\right)$$

$$R = 2d_{\text{o}}\left(\frac{1}{0.035} - 1\right)^{-1} = 2(10.0\text{ cm})\left(\frac{1}{0.035} - 1\right)^{-1} = \boxed{7.3\text{ mm}}$$

79. $\text{refractive power} = \dfrac{1}{f} = \dfrac{1}{d_{\text{o}}} + \dfrac{1}{d_{\text{i}}}$

$$d_{\text{i}} = \left(\text{refractive power} - \frac{1}{d_{\text{o}}}\right)^{-1} = \left(3.2\text{ diopters} - \frac{1}{0.25\text{ m} - 0.025\text{ m}}\right)^{-1} = -0.804\text{ m}$$

The person's near point is $0.804\text{ m} + 0.025\text{ m} = \boxed{83\text{ cm}}$.

80. (a) A lens with a refractive power of –1.25 diopters is a diverging lens. Since diverging lenses are used to focus distant objects, the person is $\boxed{\text{nearsighted}}$.

(b) $\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i} \approx \frac{1}{d_i}$ since $d_o >> d_i$ for distant objects.

$$d_i \approx f = \frac{1}{\text{refractive power}} = \frac{1}{-1.25 \text{ diopters}} = -80.0 \text{ cm}$$

The person's far point is $\boxed{80.0 \text{ cm}}$.

81. (a) Farsightedness is corrected using a convex, converging lens, with $\boxed{\text{positive}}$ refractive power.

(b)
$$\begin{aligned}\frac{1}{f} &= \frac{1}{d_0} + \frac{1}{d_i} \\ &= \frac{1}{0.23 \text{ m}} + \frac{1}{\infty} \\ &= \boxed{4.3 \text{ diopters}}\end{aligned}$$

82. (a) $D = \frac{1}{3}(26.4 \text{ cm}) = f/1.1$

$$f = 1.1\left(\frac{1}{3}\right)(26.4 \text{ cm}) = \boxed{9.7 \text{ cm}}$$

(b) $f\text{ - number} = \frac{f}{D}$

As D gets smaller, the f - number $\boxed{\text{increases}}$.

83. (a) $\text{distance} = 75.6 \text{ cm} - 1.80 \text{ cm} = \boxed{73.8 \text{ cm}}$

(b) $M_{\text{total}} = \frac{f_{\text{obj}}}{f_e} = \frac{75.6 \text{ cm}}{1.80 \text{ cm}} = \boxed{42.0}$

84. (a) $\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$

$$d_i = \left(\frac{1}{f} - \frac{1}{d_o}\right)^{-1} = \left(\text{refractive power} - \frac{1}{d_o}\right)^{-1} = \left(3.50 \text{ diopter} - \frac{1}{-0.14 \text{ m}}\right)^{-1} = 9.40 \text{ cm}$$

$\boxed{\text{The image is located 9.40 cm from the lens on the same side as the virtual object.}}$

(b) The image is $\boxed{\text{real}}$ because light passes through the image.

85. For a given length of exposure, the amount of light that falls on the film is proportional to the area of the aperture, and thus, the diameter squared.

$$\text{amount of light} \propto D^2 = \left(\frac{f}{f\text{-number}}\right)^2 = \frac{f^2}{f\text{-number}^2}$$

86. Primary mirror

$$\frac{1}{f_1}=\frac{1}{d_{o1}}+\frac{1}{d_{i1}}\approx\frac{1}{d_{i1}} \text{ since } d_{o1}>>d_{i1} \text{ for distant objects.}$$

$d_{i1}\approx f_1 = 50.0\text{ cm}$

Secondary mirror

$$-\frac{2}{R}=\frac{1}{f_2}=\frac{1}{d_{o2}}+\frac{1}{d_{i2}}$$

$$R=-2\left(\frac{1}{d_{o2}}+\frac{1}{d_{i2}}\right)^{-1}=-2\left(\frac{1}{43.0\text{ cm}-50.0\text{ cm}}+\frac{1}{43.0\text{ cm}+8.00\text{ cm}}\right)^{-1}=\boxed{16\text{ cm}}$$

87. **(a)** $\frac{1}{f}=\frac{1}{d_o}+\frac{1}{d_i}$

$$d_i=\left(\frac{1}{f}-\frac{1}{d_o}\right)^{-1}$$

$$=\left(\frac{1}{20.0\text{ cm}}-\frac{1}{25.0\text{ cm}}\right)^{-1}$$

$$=100\text{ cm}$$

The lens forms an image 100 cm – 10.0 cm = 90 cm behind the mirror. This image is reflected from the mirror so that it appears 90 cm in front of the mirror and 90 cm – 10.0 cm = 80 cm in front of the lens.

The final image is located at $d_i=\left(\frac{1}{20.0\text{ cm}}-\frac{1}{-80.0\text{ cm}}\right)^{-1}=\boxed{16\text{ cm in front of the lens}}$

(b) Since light passes through the image, it is $\boxed{\text{real}}$.

(c) $m=m_1m_2=\frac{d_{i1}d_{i2}}{d_{o1}d_{o2}}=\frac{(100\text{ cm})(16\text{ cm})}{(25.0\text{ cm})(-80\text{ cm})}=\boxed{-0.80}$

(d) Since $-0.80<0$, the image is $\boxed{\text{inverted}}$.

88. **(a)** $\frac{1}{f}=\frac{1}{d_0}+\frac{1}{d_i}$

$$d_i=\left(\frac{1}{f}-\frac{1}{d_0}\right)^{-1}$$

$$=\left(\frac{1}{-20.0\text{ cm}}-\frac{1}{25.0\text{ cm}}\right)^{-1}$$

$$=-11.11\text{ cm}$$

The lens forms an image 11.11 cm + 10.0 cm = 21.11 cm in front of the mirror. This image is reflected from the mirror so that it appears 21.11 cm behind the mirror and 21.11 cm + 10.0 cm = 31.11 cm behind the lens. The final image is located at

$$d_i=\left(\frac{1}{-20.0\text{ cm}}-\frac{1}{31.11\text{ cm}}\right)^{-1}=-12.2\text{ cm}$$

or $\boxed{\text{12.2 cm behind the lens}}$, i.e., 2.2 cm behind the mirror.

(b) Since light does not pass through the image, it is $\boxed{\text{virtual}}$.

(c) $m = m_1 m_2 = \dfrac{d_{i1} d_{i2}}{d_{o1} d_{o2}} = \dfrac{(-11.11\text{ cm})(-12.17\text{ cm})}{(25.0\text{ cm})(31.11\text{ cm})} = \boxed{0.174}$

(d) Since $m > 0$, the image is $\boxed{\text{upright}}$.

89. $\dfrac{1}{f_1} = \dfrac{1}{d_{o1}} + \dfrac{1}{d_{i1}}$

$$d_{i1} = \left(\frac{1}{f_1} - \frac{1}{d_{o1}}\right)^{-1} = \left(\frac{1}{-20.0\text{ cm}} - \frac{1}{50.0\text{ cm}}\right)^{-1} = -14.286\text{ cm}$$

(a) $d_{o2} = 115\text{ cm} - (-14.286\text{ cm}) = 129.3\text{ cm}$ to the left of lens 2.

$$d_{i2} = \left(\frac{1}{f_o} - \frac{1}{d_{o2}}\right)^{-1} = \left(\frac{1}{30.0\text{ cm}} - \frac{1}{129.3\text{ cm}}\right)^{-1} = 39.06\text{ cm}$$

The final image is located $\boxed{\text{39.1 cm to the right of lens 2}}$.

$$m = m_1 m_2 = \frac{d_{i1} d_{i2}}{d_{o1} d_{o2}} = \frac{(-14.286\text{ cm})(39.06\text{ cm})}{(50.0\text{ cm})(129.3\text{ cm})} = \boxed{-0.0863}$$

(b) $d_{o2} = 30.0\text{ cm} - (-14.286\text{ cm}) = 44.29\text{ cm}$ to the left of lens 2.

$$d_{i2} = \left(\frac{1}{f_2} - \frac{1}{d_{o2}}\right)^{-1} = \left(\frac{1}{30.0\text{ cm}} - \frac{1}{44.29\text{ cm}}\right)^{-1} = 93.0\text{ cm}$$

The final image is located $\boxed{\text{93.0 cm to the right of lens 2}}$.

$$m = \frac{(-14.286\text{ cm})(93.0\text{ cm})}{(50.0\text{ cm})(44.29\text{ cm})} = \boxed{-0.600}$$

(c) $d_{o2} = 0\text{ cm} - (-14.286\text{ cm}) = 14.286\text{ cm}$ to the left of lens 2.

$$d_{i2} = \left(\frac{1}{f_2} - \frac{1}{d_{o2}}\right)^{-1} = \left(\frac{1}{30.0\text{ cm}} - \frac{1}{14.286\text{ cm}}\right)^{-1} = -27.27\text{ cm}$$

The final image is located $\boxed{\text{27.3 cm to the left of lens 2}}$.

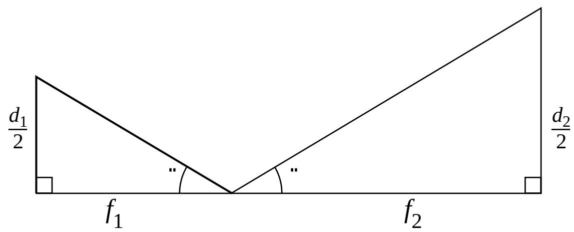
$$m = \frac{(-14.286\text{ cm})(-27.27\text{ cm})}{(50.0\text{ cm})(14.286\text{ cm})} = \boxed{0.545}$$

(d) $f_{eff} = \left(\dfrac{1}{f_1} + \dfrac{1}{f_2}\right)^{-1} = \left(\dfrac{1}{-20.0\text{ cm}} + \dfrac{1}{30.0\text{ cm}}\right)^{-1} = -60\text{ cm}$

$d_o = 50.0\text{ cm}$ and $d_i = -27.3\text{ cm}$.

$$f_{eff} = \left(\frac{1}{d_0} + \frac{1}{d_i}\right) = \left(\frac{1}{50.0\text{ cm}} + \frac{1}{-27.3\text{ cm}}\right)^{-1} = -60\text{ cm}$$

90.



The figure shows two similar right triangles formed by the rays of the laser beam. The beam enters and exits the lenses parallel to the axis of the lenses. So, $d_{i1} = f_1$ and $d_{o1} = f_2$. Find $\frac{d_1}{d_2}$.

$$\frac{\frac{d_1}{2}}{f_1} = \tan\theta = \frac{\frac{d_2}{2}}{f_2}$$
$$\frac{d_1}{2f_1} = \frac{d_2}{2f_2}$$
$$\frac{d_1}{d_2} = \boxed{\frac{f_1}{f_2}}$$

91. (a) $$\frac{1}{f_1} = \frac{1}{d_{o1}} + \frac{1}{d_{i1}}$$
$$d_{i1} = \left(\frac{1}{f_1} - \frac{1}{d_{o1}}\right)^{-1} = \left(\frac{1}{25 \text{ cm}} - \frac{1}{120 \text{ cm}}\right)^{-1} = 32 \text{ cm}$$
$$d_{o2} = 0.40 \text{ m} - 0.32 \text{ m} = 0.08 \text{ m}$$
$$d_{i2} = \left(\frac{1}{f_2} - \frac{1}{d_{o2}}\right)^{-1} = \left(\frac{1}{-15 \text{ cm}} - \frac{1}{8.42 \text{ cm}}\right)^{-1} = -5 \text{ cm}$$
$$d_{o3} = 0.50 \text{ m} - 0.40 \text{ m} + 0.05 \text{ m} = 0.15 \text{ m}$$
$$d_{i3} = \left(\frac{1}{f_3} - \frac{1}{d_{o3}}\right)^{-1} = \left(\frac{1}{11 \text{ cm}} - \frac{1}{15.39 \text{ cm}}\right)^{-1} = 39 \text{ cm}$$
$$\text{final location} = 0.50 \text{ m} + 0.39 \text{ m} = 0.89 \text{ m}$$
$$\boxed{x = 0.89 \text{ m}}$$

(b) $$m = m_1 m_2 m_3 = \left(-\frac{d_{i1}}{d_{o1}}\right)\left(-\frac{d_{i2}}{d_{o2}}\right)\left(-\frac{d_{i3}}{d_{o3}}\right) = -\frac{d_{i1}d_{i2}d_{i3}}{d_{o1}d_{o2}d_{o3}} = -\frac{(32 \text{ cm})(-5 \text{ cm})(39 \text{ cm})}{(120 \text{ cm})(8 \text{ cm})(15 \text{ cm})} = \boxed{0.4}$$

The image is $\boxed{\text{upright}}$.

92. <u>convex lens</u>

$$\frac{1}{f_1} = \frac{1}{d_{o1}} + \frac{1}{d_{i1}}$$
$$f_1 = \left(\frac{1}{d_{o1}} + \frac{1}{d_{i1}}\right)^{-1} = \left(\frac{1}{42.0 \text{ cm}} + \frac{1}{37.5 \text{ cm}}\right)^{-1} = \boxed{19.8 \text{ cm}}$$

<u>concave lens</u>

$$f_2 = \left(\frac{1}{d_{o2}} + \frac{1}{d_{i2}}\right)^{-1} = \left(\frac{1}{15.0 \text{ cm} - 37.5 \text{ cm}} + \frac{1}{35.0 \text{ cm}}\right)^{-1} = \boxed{-63.0 \text{ cm}}$$

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

$\frac{1}{d_o}=\frac{1}{f}-\frac{1}{d_i}$

$\frac{N}{d_o}=\frac{N}{f}-\frac{N}{d_i}$

$M=\frac{N}{f}-\frac{N}{d_i}$ $\left(M=\frac{N}{d_o}\right)$

The closer an image is to the eye, the greater the magnification. Since the closest an image can be to the eye and still be in focus is the near point, $d_i=-N$.

Therefore, $M=\frac{N}{f}-\frac{N}{-N}=\frac{N}{f}+1$.