Chapter 5 Solutions

5.1 All OPLs from S to P must be equal, therefore $l_0 n_1 + l_i n_2 =$ constant; drop a perpendicular from A to the optical axis, the point where it touches is B. $\overline{BP} = s_0 + s_i - x$ and the rest follows from the Pythagorean Theorem.

5.2 $l_0 + l_i 3/2 = \text{constant},\ 5 + (6)3/2 = 14.$ Therefore $2l_0 + 3l_i = 28$ when $l_0 = 6,\ l_i = 5.3,\ l_0 = 7,\ l_i = 4.66.$ Note that the arcs centered on S and P have to intercept for physically meaningful values of l_0 and l_i.

5.3 The OPD from F_1 to any point D on Σ must be constant: $(\overline{F_1 A})n_2 + (\overline{AD})n_1 = C$ and $(\overline{F_1 A}) + (\overline{AD})n_{12} = C/n_2 = C'$; if Σ corresponds to the directrix of the ellipse, $(\overline{F_2 A}) = e(\overline{AD})$ where e is the eccentricity; if $n_{12} = e$ we get $(\overline{F_1 A}) + (\overline{F_2 A}) = C'$.

5.4 A plane wave impinging on a concave elliptical surface becomes spherical. If the second spherical surface has that same curvature, the wave will have all rays normal to it and emerge unaltered.

5.5 Recall that the angles of a triangle sum to $180°$.

$$\begin{aligned}
\theta_2 + (180° - \varphi) + \beta &= 180°;\\
\theta_2 &= \varphi - \beta.\\
\sin\theta_2 &= \sin(\varphi - \beta)\\
&= \sin\varphi\cos(-\beta) + \cos\varphi\sin(-\beta)\\
&\simeq \sin\varphi - \sin\beta\\
&= h/R - h/s_i\\
(180° - \theta_1) + \varphi - \alpha &= 180°\\
\theta_1 &= \varphi + \alpha\\
\sin\theta_1 &= \sin(\varphi + \alpha)\\
&= \sin\varphi\cos\alpha\\
&\quad + \cos\varphi\sin\alpha \simeq \sin\varphi + \sin\alpha = h/R + h/s.
\end{aligned}$$

(4.4) $n_1 \sin\theta_1 = n_2 \sin\theta_2;\ n_1(h/R + h/s_o) = n_2(h/R - h/s_i),$

$n_i/s_o + n_2/s_i = (n_2 - n_1)/R.$

5.6 From Snell's Law $n_1\theta_i = n_2\theta_t$; $\tan\theta_i = y_o/s_o$ and $\tan\theta_t = -y_i/s_i$ since y_i is negative; thus $\theta_i = y_o/s_o$ and $\theta_t = -y_i/s_i$, therefore $M_T = y_i/y_o = -(n_1 s_i)/(n_2 s_0)$.

5.7 From Eq. (5.8), $1/30.0 + 1.33/s_i = (1.333 - 1.000)/5.0;$ $s_i = 40$ cm and $M_T = -1.33,$ thus the image is 3.05 cm tall.

5.8 First surface $n_1/s_o + n_2/s_i = (n_2 - n_1)/R,\ 1/1.2 + 1.5/s_i = 0.5/0.1,$ $s_i = 0.36$ m (real image 0.36 m to the right of first vertex). Second surface $s_o = 0.20 - 0.36 = -0.16$ m (virtual object distance). $1.5/(-0.16) + 1/s_i = -0.5/(-0.1),\ s_i = 0.069$ m. The final image is real $(s_i > 0),$ inverted $(M_T < 0),$ and 6.9 cm to the right of the second vertex.

5.9 At the first surface from Eq. (5.8), $1/30.0+1.33/s_i=(1.333-1.000)/5.0$ and $s_i=40$; a real image right of the vertex. For the second surface $s_o=-30$ cm and the image will be right of the second vertex, so $1.33/(-30)+1/s_i=(1.000-1.333)/(-5.000)$; and $s_i=9.01$ cm to the right of the second surface. The first surface produces a magnification of $M_T=-1.33$, thus the intermediate image is 4 cm tall. The second surface produces a magnification of

$$M_T=-(n_1 s_i)/(n_2 s_o)=-(1.333)(9.01)/(1.000)(-30)=0.4$$

and the total magnification is the product of the two, viz., –0.532. The image is real, inverted and minified.

5.10 (5.16) $1/f=(n-1)(1/R_1-1/R_2)$ where $R_2=-R_1$, so

$$\begin{aligned}1/f&=(n-1)(2/R_1)\\ R_1&=(n-1)(2)(f)=(1.5-1)(2)(+10.0\text{ cm})\\ &=10.0\text{ cm}\end{aligned}$$

(5.17) $1/s_o+1/s_i=1/f$; $s_o=1.0$ cm;
$1/s_i=1/f-1/s_o=1/10.0\text{ cm}-1/1.0\text{ cm}=-9.0/10.0; s_i=-1.1$ cm.
(5.25) $M_T=-s_i/s_o=-(-1.1\text{ cm})/(1.0\text{ cm})=+1.1$. Image is virtual, erect, and larger than the object.

5.11 (5.14) In the thin lens limit $(d\to 0)$ becomes
$n_m/s_o+n_m/s_i=(n_l-n_m)(1/R_1-1/R_2)$ so,
$1/s_o+1/s_i=1/f=(n_l-n_m/n_m)(1/R_1-1/R_2)$. For a double concave lens $R_1<0$, $R_2>0$, so that $(1/R_1-1/R_2)<0$. For air lens in water, $n_l<n_m$, so that $n_l-n_m<0$; $1/f>0$, lens is converging.

5.12 (5.15) $1/s_o+1/s_i=(n_l-1)(1/R_1-1/R_2)$ so,

$$\begin{aligned}\frac{1}{s_i}&=(0.5)\left(\frac{1}{20}-\frac{1}{10}\right)-\frac{1}{20}\\ &=\frac{1}{40}-\frac{1}{20}\\ s_i&=-40\end{aligned}$$

$$1/s_i=(n_l-1)(1/R_1-1/R_2)-1/s_o;\ 1/s_i=-13.3\text{ cm}.$$

(5.25) $M_T=-s_i/s_o=-13.3/20.0=+0.67$. Image is virtual, erect, and smaller than the object.

5.13 $1/8+1.5/s_i=0.5/(-20)$. At the first surface, $s_i=-10$ cm. Virtual image 10 cm to the left of first vertex. At second surface, object is *real* 15 cm from second vertex. $1.5/15+1/s_i=-0.5/10$, $s_i=-20/3=-6.66$ cm. Virtual, to left of second vertex.

From (5.15)

$$\frac{1}{8}+\frac{1}{s_i}=(1.5-1)\left(\frac{1}{20}-\frac{1}{10}\right)$$

$$\frac{1}{s_i}=(0.5)\left(\frac{-1}{20}\right)-\frac{1}{8}$$

$$\frac{1}{s_i}=-0.15$$

$$s_i=-6.67\text{ cm}$$

5.14 (a) (5.17) $1/s_o+1/s_i=1/f$ so,
$1/s_i=1/f-1/s_o=1/(5.00\text{ cm})-1/(1000\text{ cm})$; $s_i=5.03\text{ cm}=50.3\text{ mm}$.
(b) (5.25) $M_T=-s_i/s_o=-5.03\text{ cm}/1000\text{ cm}=-.00503$.
Image size $=|M_T|$(object size) = (.00503)(1700 mm) = 8.55 mm.

5.15 $s_o+s_i=s_os_i/f$ to minimize s_o+s_i, $(d/ds_o)(s_o+s_i)=0=1+ds_i/ds_o$ or

$$\frac{d}{ds_o}\left(\frac{s_os_i}{f}\right)=\frac{s_i}{f}+\frac{s_o}{f}\frac{ds_i}{ds_o}=0.$$

Thus $ds_i/ds_o=-1$ and $ds_i/ds_o=-s_i/s_o$, therefore $s_i=s_o$.

5.16 $1/5+1/s_i=1/10$, $s_i=-10$ cm virtual, $M_T=-s_i/s_o=10/5=2$ erect.
Image is 4 cm high. Or $-5(x_i)=100$, $x_i=-20$,
$M_T=-x_i/f=20/10=2$.

5.17 $1/s_o+1/s_i=1/f$. For $s_o=0,\ f,\infty,2f,3f,-f,-2f,f/2$, $s_i=0,\infty$, $f, 2f, f3/2, f/2, f2/3, -f$, respectively.

5.18 Draw a ray at 6.0° to the axis passing through the center of the lens. The image is virtual and on the image plane 50.0 cm in front of the lens. The image height y_i is gotten from the fact that tan 6.0° = y_i/f and so $y_i=5.3$ cm.

5.19

$$\frac{1}{S_o}+\frac{1}{S_i}=\frac{1}{f}$$

$$\frac{1}{-10}+\frac{1}{30}=\frac{1}{f}$$

$f=-15$ cm

This lens must be negative because $|S_i|>S_o$ for negative lenses and $S_o>|S_i|$ for positive lenses

5.20 $s_i<0$ because image is virtual. 1/100 + 1/(−50) = 1/f, $f=-100$ cm.
Image is 50 cm to the right as well. $M_T=-s_i/s_o=50/100=0.5$. Ant's image is half-sized and erect $(M_T>0)$.

5.21 $\dfrac{1}{S_o}+\dfrac{1}{S_i}=\dfrac{1}{f}$

If $S_o=\infty$ then $S_i=f$, thus if the object is moved $S_o=18$ cm and $s_i=3f$, then:

$$\frac{1}{18}+\frac{1}{3f}=\frac{1}{f}$$

$$\frac{1}{18}=\frac{1}{3f}-\frac{1}{f}=\frac{2}{3f}$$

$$f = 12 \text{ cm}$$

5.22 (5.16) $1/f=(n_l-1)(1/R_1-1/R_2)=(1.5-1)(1/20-1/(-40))=3/80;$
$f = 27$ cm. (5.17). $1/s_o+1/s_i=1/f$ so $1/s_i=1/f-1/s_o=1/27-1/40,$
$s_i=+83$ cm. (5.25) $M_T=-s_i/s_o=-80/40=-2.08.$ Image is real, inverted, at +80 cm and twice the size of the object.

5.23 $1/f=(n_l-1)[(1/R_1)-(1/R_2)]=0.5(1/\infty-1/10)=-0.5/10,$
$f = -20$ cm, $D = 1/f = -1/0.2 = -5$ D.

5.24 $\dfrac{1}{f}=(n_l-1)\left(\dfrac{1}{R_1}+\dfrac{1}{R_2}\right)$

For this plano-convex lens, $n_l=1.530$, $R_1=\infty$, and $f = 250$ cm.

$$\frac{1}{250\text{ cm}}=(1.530-1)\left(\frac{1}{\infty}+\frac{1}{R_2}\right)$$

$$-R_2=(250\text{ cm})(1.530-1)$$

$$R_2=-132.5\text{ cm}$$

If n was reduced to $n_l=1.500$:

$$-R_2=(250\text{ cm})(1.500-1)$$

$$R_2=-125.0\text{ cm}$$

5.25 $\dfrac{1}{S_o}+\dfrac{1}{S_i}=\dfrac{1}{f}$

At $S_o=\infty$, then $S_i=f$, if the object is then moved $S_o=90$ cm and $S_i=3f$, then:

$$\frac{1}{90}+\frac{1}{3f}=\frac{1}{f}$$

$$\frac{1}{90}=\frac{1}{f}-\frac{1}{3f}=\frac{2}{3f}$$

$$f=60\text{ cm}$$

5.26 (5.16) $1/f=(n_l-1)(1/R_1-1/R_2)=(1.5-1)(1/(5.00\text{ cm})-1/\infty)$
$=1/(10.0\text{ cm});\ f=+10.0$ cm.

In a medium where $n_m\neq 0$, (5.16) becomes

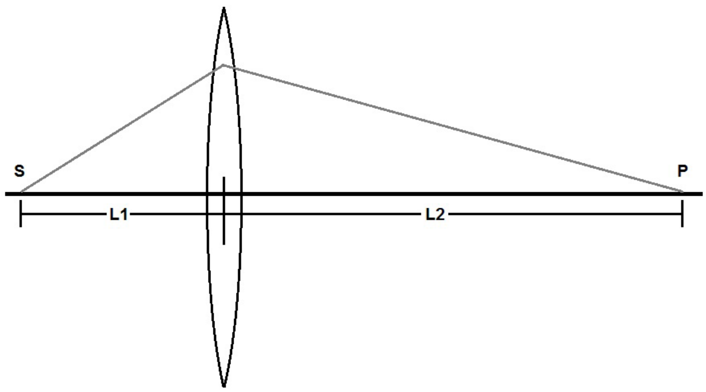
$$1/f=((n_l-n_m)/n_m)(1/R_1-1/R_2).$$

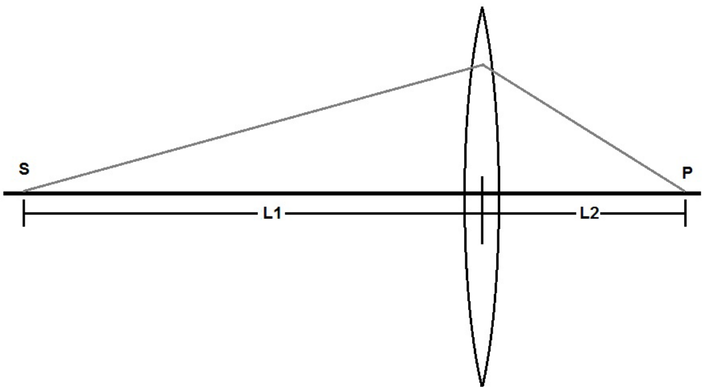
So, for water

$$(n_m=1.33),\ 1/f=((1.5-1.33)/1.33)(1/(5.00\text{ cm})-1/\infty).$$

$f = 39.1$ cm (so f increases).

5.27 Yes, it is possible to move the lens to a new location and not change the positions S and P. This is done by moving the lens such that the original object distance is now the image distance and the original image distance is now the object distance.





5.28 $\frac{1}{S_o} + \frac{1}{S_i} = \frac{1}{f}$

In this case the new positions are $S_i{}'$ and $S_o{}'$, such that:

$$\frac{1}{S_o} + \frac{1}{S_i} = \frac{1}{S_0'} + \frac{1}{S_i'}$$

Then $M_T = -\frac{s_i}{s_o} = -\frac{80 \text{ cm}}{40 \text{ cm}} = -2$, and $M_T' = -\frac{S_i'}{S_0'} = -\frac{40 \text{ cm}}{80 \text{ cm}} = -\frac{1}{2}$

5.29 $M_T = -\frac{S_i}{S_o} = -N\frac{S_i'}{S_o'}$

Since $S_i = S_o'$, and $S_o = S_i'$, then,

$$\frac{S_i}{S_o} = N\frac{S_o}{S_i}$$

$$N = \frac{S_i^2}{S_o^2} \Rightarrow \sqrt{N} = \frac{S_i}{S_o}$$

$$S_o\sqrt{N} = S_i$$

Next use,

$$S_i + S_o = d$$
$$S_i' + S_o' = d$$
$$\frac{1}{S_o} + \frac{1}{S_i} = \frac{1}{f} = \frac{1}{S_o'} + \frac{1}{S_i'}$$
$$f = \frac{S_i S_o}{S_i + S_o} = \frac{S_i S_o}{d} = \frac{S_i' S_o'}{d}$$

Plug in $S_o\sqrt{N} = S_i$:

$$f = \frac{s_o^2\sqrt{N}}{S_o + S_o\sqrt{N}} = \frac{S_o^2\sqrt{N}}{S_o(1+\sqrt{N})} = \frac{S_o\sqrt{N}}{(1+\sqrt{N})}$$

Next, take from above and plug in $S_o\sqrt{N} = S_i$

$$S_i + S_o = d$$
$$d = S_o\sqrt{N} + S_o = S_o(1+\sqrt{N})$$
$$S_o = \frac{d}{(1+\sqrt{N})}$$

Plug this into the relation for *f* above, to obtain:

$$f = \frac{\sqrt{N}}{(1+\sqrt{N})^2} d$$

5.30 (5.17) $1/f = 1/s_o + 1/s_i = 1/45 + 1/90 = 3/90;\ f = +30$ cm.

5.31 (a) From the Gaussian lens equation $1/15.0 + 1/s_i = 1/3.00$, $s_i = +3.75$ m. (b) Computing the magnification, we obtain $M_T = -s_i/s_o = -3.75/15.0 = -0.25$. Because the image distance is positive, the image is *real*. Because the magnification is negative, the image is *inverted*, and because the absolute value of the magnification is less than one, the image is *minified*. (c) From the definition of magnification, it follows that $y_i = M_T y_o = (-0.25)(2.25\text{ m}) = -0.563$ m. where the minus sign reflects the fact that the image is inverted. (d) Again from the Gaussian equation $1/17.5 + 1/s_i = 1/3.00$ and $s_i = +3.62$ m. The entire equine image is only 0.13 m long.

5.32 (5.17) $1/f = 1/s_o + 1/s_i$ so,

$$1/s_i = 1/f - 1/s_o = 1/(-30) - 1/(+10) = -4/3.$$

$s_i = -7.5$ cm. (5.25) $M_T = -s_i/s_o = -(-7.5)/30 = 1/4 = 0.25$.

(Image size) = M_T (object size) = (0.25) (6.00 cm) = 1.50 cm.

The image is virtual, 7.5 cm in front of the lens, erect, and 1.50 cm tall.

5.33 $|R_1| = |R_2|$, so (5.16) becomes

$$1/f = (n_l - 1)(1/R_1 - 1/(-R_1)) = (n_l - 1)(2/R_1) = 1/s_i + 1/s_o;$$

$s_o + s_i = 60$ cm (Image real). $|M_T| = (25 \text{ cm})/(5.0 \text{ cm}) = 5 = s_i/s_o$ so,

$$s_o = 60 \text{ cm}$$

$$|M_T| = \frac{25}{5} = 5 = \frac{s_i}{s_o} = \frac{s_i}{60}$$

$$s_o = 300 \text{ cm}$$

$$\frac{1}{f} = \frac{1}{s_o} + \frac{1}{s_i} = \frac{1}{60} + \frac{1}{300} = \frac{6}{300}$$

$$f = 50 \text{ cm}$$

$$\frac{1}{f} = \frac{1}{50} = (n_l - 1)\left(\frac{2}{R}\right)$$

$$0.02 = (0.5)\left(\frac{2}{R}\right)$$

$$R = 50 \text{ cm}$$

$s_i = 5(s_o)$; $\quad s_o + 5(s_o) = 60$ cm.

$s_o = 10$ cm; $\quad s_i = 50$ cm.

$1/f = 1/s_o + 1/s_i = 1/10 + 1/50 = 6/50$; $\quad f = 8.3$ cm.

$R_1 = (n_l - 1)(2)(f) = (1.5 - 1)(2)(8.3 \text{ cm}) = 8.3$ cm.

5.34 $\frac{1}{S_o} + \frac{1}{S_i} = \frac{1}{f}$

$$\frac{1}{127 \text{ cm}} + \frac{1}{S_i} = \frac{1}{f}$$

$$M_T = -\frac{S_i}{S_o}$$

$$-5.80 = -\frac{127 \text{ cm}}{S_o}$$

$$S_o = 21.90 \text{ cm}$$

$$\frac{1}{127 \text{ cm}} + \frac{1}{21.90 \text{ cm}} = \frac{1}{f}$$

$$f = +18.7 \text{ cm}$$

5.35 $M = -2 = -\frac{s_i}{s_o}$

$M = s_i = 2s_o$

$$\frac{1}{f} = (n-1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) = (1.5-1)\frac{1}{100\ cm}$$

$f = 200\ cm$

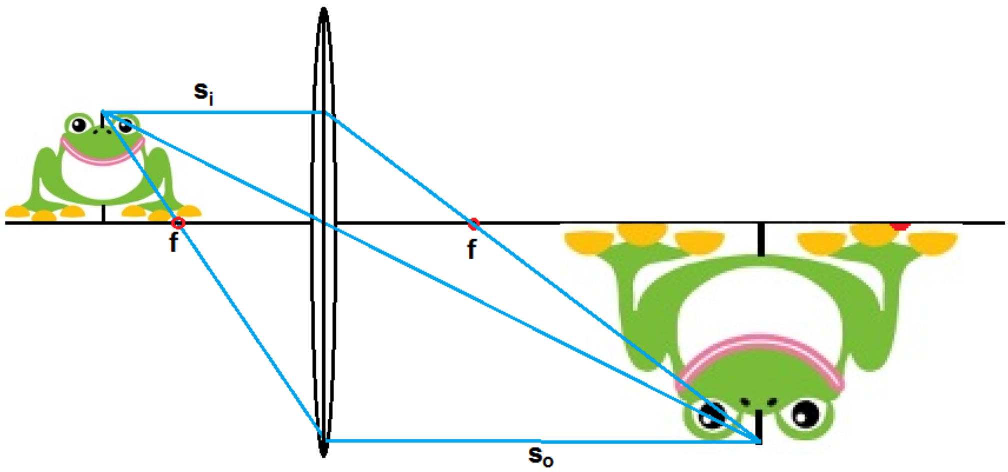
$$\frac{1}{f} = \frac{1}{s_i} + \frac{1}{s_o}$$

$$\frac{1}{200} = \frac{1}{2s_o} + \frac{1}{s_o} = \frac{3}{2s_o}$$

$s_o = 300\ cm$

$d = s_i + s_o = 3s_o = 900\ cm$

Ray Diagram:



5.36 $\frac{1}{S_o} + \frac{1}{S_i} = \frac{1}{f}$

At $S_o = \infty$, then $S_i = f$, if the object is then moved $S_o = 180$ cm and $S_i = 3f$, then:

$$\frac{1}{180} + \frac{1}{3f} = \frac{1}{f}$$

$$\frac{1}{180} = \frac{1}{3f} - \frac{1}{f} = \frac{2}{3f}$$

$$f = 120 \text{ cm}$$

$$\frac{1}{f} = (n_l - 1)\left(\frac{1}{R_1} + \frac{1}{R_2}\right)$$

Since this is an equiconvex lense, $R_1 = R_2$:

$$\frac{1}{f} = (n_l - 1)\left(\frac{1}{R} + \frac{1}{R}\right) = \frac{1}{f} = (n_l - 1)\left(\frac{2}{R}\right)$$
$$\frac{1}{120 \text{ cm}} = (1.5 - 1)\left(\frac{2}{R}\right) = \left(\frac{1}{2}\right)\left(\frac{2}{R}\right)$$
$$R = 120 \text{ cm}$$

5.37 $1/s_o + 1/s_i = 1/f$ and $M_T = -s_i/s_o = -1/2$ hence $1/s_o + 2/s_o = 1/f$ but $s_o = 60.0$ cm, hence $f = 20.0$ cm; draw a ray cone from an axial image point, it enters the edges of the lens and focuses at 30.0 cm and then spreads out beyond to create a blur on the screen; from the geometry (0.04 mm)/(10.0 mm) = (R/300 mm), R = 1.2 cm so the diameter is 2.4 cm.

5.38 The first thing to find is the focal length in water, using the lensmaker's formula. Taking the ratio

$f_w/f_a = f_w/(10\text{ cm}) = (n_g - 1)/[(n_g/n_w) - 1] = 0.56/0.17 = 3.24;$

$f_w = 32$ cm. The Gaussian lens formula gives the image distance:

$1/s_i + 1/100 = 1/32.4;\ s_i = 48$ cm.

5.39 The image will be inverted if it's to be real, so the set must be upside down or else something more will be needed to flip the image;

$M_T = -3 = -s_i/s_o;\ 1/s_o + 1/3s_o = 1/0.60;\ s_o = 0.80$ m, hence

0.80 m + 3(0.80 m) = 3.2 m.

5.40 $1/f = (n_{lm} - 1)(1/R_1 - 1/R_2),\ 1/f_w = (n_{lm} - 1)/(n_l - 1)f_a = 0.125/0.5f_a,\ f_w = 4f_a.$

5.41 $1/s_o + 1/s_i = 1/f$ hence for $\vec{A}$ and $\vec{B}$, $1/(1.1f) + 1/s_i = 1/f$ and so $s_i = 11f$, hence $M_T = -s_i/s_o = -(11f)/(1.10f) = -10$; both vectors are imaged inverted and 10 times larger than life, viz., 1 f long. $\vec{A}$ is in the $-x$-direction and $\vec{B}$ is in the $-z$-direction. As for $\vec{C}$, from (5.28)

$$M_L = -MT^2$$
$$M_L = 100$$

5.42 Image-to- object distance $= L = s_{o1} + s_{i1} = s_{o2} + s_{i2}$. Also,

$$s_{o1} - s_{o2} = d = s_{i2} - s_{i1}\ \ 1/f = 1/s_{i1} + 1/s_{o1};$$
$$1/f = 1/s_{i2} + 1/s_{o2} = 1/(s_{i1} - d) + 1/(s_{o1} + d).$$

Approach: With three is independent equations (two for 1/f and $L = s_{o1} + s_{i1}$) eliminate s_{o1} and s_{i1}, leaving $f(L, d)$.

5.43 Find s_{i1} first, and use this position for s_{o2}. (5.17) $1/f = 1/s_o + 1/s_i$, so

$1/s_{i1} = 1/f_1 - 1/s_{o1};\ 1/s_{i1} = 1/(+30) - 1/(+50) = (5-3)/150;$

$s_{i1} = 75$ cm, which puts s_{o2} at (20 – 75 cm) cm = – 55 cm.

$1/s_{i2} = 1/(+50) - 1/(-55\text{ cm}) = -0.038;\ s_{i2} = -26.2$ cm, (real image).

5.44 For the first lens $s_{i1} = (s_{o1}f_1)/(s_{o1} - f_1) = +37.5$ cm and $M_{T1} = -1.50$; for the second lens $s_{o2} = 60.0 - 37.5 = +22.5$ cm, and $s_{i2} = (s_{o2}f_2)/(s_{o2} - f_2) = +9.00$ cm and $M_{T2} = 9.00/22.5 = +0.40$; the net magnification is $M_T = M_{T1}M_{T2} = -0.60$; the image is real, minified, and inverted.

5.45 $M_{T1} = -s_{i1}/s_{o1} = -f_1/(s_{o1} - f_1)$, $M_{T2} = -s_{i2}/s_{o2} = -s_{i2}/(d - s_{i1})$,
$M_T = f_1 s_{i2}/(s_{o1} - f_1)(d - s_{il})$. From (5.30), on substituting for s_{i1},
we have $M_T = f_1 s_{i2}/[(s_{o1} - f_1)d - s_{o1} f_1]$.

5.46 (a) (5.17) $1/f = 1/s_o + 1/s_2$, so

$1/s_{i1} = 1/f_1 - 1/s_{o1} = 1/(+10.0\text{ cm}) - 1/(+15.0\text{ cm}) = (3-2)/(30.0);$

$s_{i1} = 30.0\text{ cm} = 300\text{ mm}.$

(b) Image is real, inverted, and larger than the object.
(c) (5.25) $M_{T1} = -s_{i1}/s_{o1} = -30.0/15.0 = -2.00$. (d) s_{i1} sets s_{o2} at -5.00 cm (beyond the second lens, virtual object).
$1/s_{i2} = 1/f - 1/s_{o2} = 1/(-7.50\text{ cm}) - 1/(-5.00\text{ cm}) = (-2+3)/(15.00);$
$s_{i2} = 15.0\text{ cm} = 150\text{ mm}.$
(e) $M_{T2} = -s_{i2}/s_{o2} = -(15.0)/(-5.00) = 3.00$. $M_T = (M_{T1})(M_{T2}) = (-2.00)(3.00) = -6.00$. (Image is real, inverted).

5.47 First lens $1/s_{i1} = 1/30 - 1/30 = 0$, $s_{i1} = \infty$. Second lens
$1/s_{i2} = 1/(-20) - 1/(-\infty)$, the object for the second lens is to the right at ∞, that is $s_{o2} = -\infty$. $s_{i2} = -20$ cm, virtual, 10 cm to the left of first lens. $M_T = (-\infty/30)(+20/-\infty) = 2/3$ or from (5.34)
$M_T = 30(-20)/[10(30-30) - 30(30)] = 2/3.$

5.48 (5.17) $1/f = 1/s_o + 1/s_i$ so

$1/s_{i1} = 1/f_1 - 1/s_{o1} = 1/(+15.0) - 1/(+25.0) = (5-3)/75.0;$

$s_{i1} = +37.5$ cm, which makes $s_{o2} = -12.5$ cm.

$M_{T1} = -s_{i1}/s_{o1} = -25.0/37.5 = -0.67.$
$1/s_{i2} = 1/f_2 - 1/s_{o2} = 1/(-15.0) - 1/(-12.5);\quad s_{i2} = +75.0\text{ cm}.$
$M_{T2} = -s_{i2}/s_{o2} = -(+75.0)/(-12.5) = +6.00.$
$M_T = (M_{T1})(M_{T2}) = (-0.67)(+6.00) = -4.00.$

Image is real, inverted, 75.0 cm beyond the second lens and 4 times the size of the object.

5.49 For the two positive lenses, note that incoming parallel rays result in outgoing parallel rays.

5.50 (5. 34) $M_T = \dfrac{f_1 s_{i2}}{d(s_{o1} - f_1) - s_{o1} f_1}$

But $s_{i2} = s_{o1} = s \Rightarrow \infty.$ $\qquad M_T = \dfrac{f_1 s}{d(s - f_1) - s f_1} = \dfrac{f_1}{d - (df_1/s) - f_1}.$

$$\lim_{s\to\infty} M_T = \frac{f_1}{d - f_1},$$

where $d = f_1 + f_2$, $M_T = \dfrac{f_1}{(f_1 + f_2) - f_1} = f_1/f_2;$

$f_2 = f_1 M_T = (+5.00\text{ cm})(0.80\text{ cm}/0.10\text{ cm}) = +40.0\text{ cm};$
$d = f_1 + f_2 = +45.0\text{ cm}.$

5.51 Figure 5.110

5.53 In 5.53a, the rays through h_2 should bend away from the axis (diverging lens). In 5.53b, ray 4 should be directed at F_1'; also $|F_2| \neq |F_2'|$.

5.54 $M = -\dfrac{f_o}{f_e} = \dfrac{1200 \text{ mm}}{40 \text{ mm}} = 30\times$

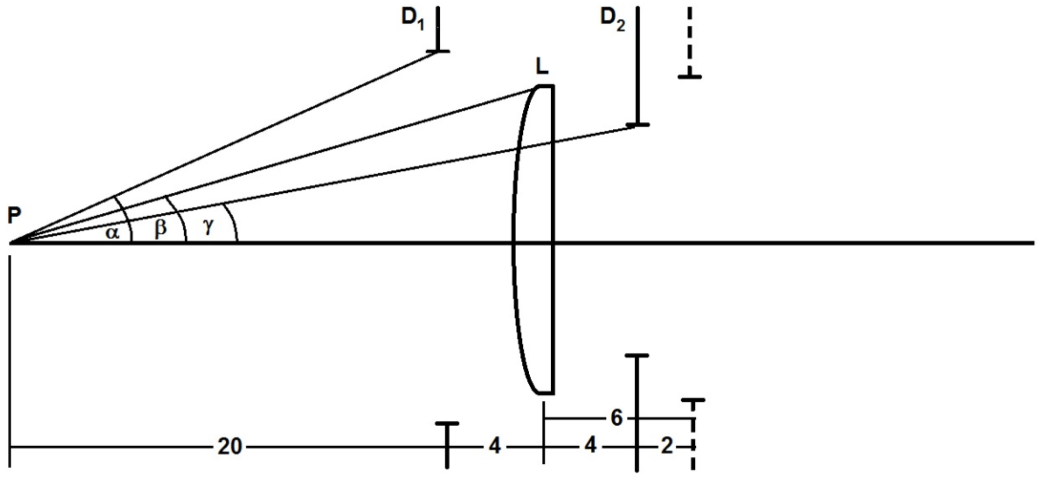
$f/\# = \dfrac{f}{D} = \dfrac{120 \text{ cm}}{3 \text{ cm}} = 40$

5.55 The angle subtended by L_1 at S is $\tan^{-1} 3/12 = 14°$. To find the image of the diaphragm in L_1 we use Eq. (5.23): $x_o x_i = f^2$, $(-6)(x_i) = 81$, $x_i = -13.5$ cm, so that the image is 4.5 cm behind L_1. The magnification is $-x_i/f = 13.5/9 = 1.5$, and thus the image (of the edge) of the hole is (0.5)(1.5) = 0.75 cm in radius. Hence the angle subtended at S is $\tan^{-1} 0.75/16.5 = 2.6°$. The image of L_2 in L_1 is obtained from $(-4)(x_i) = 81$, $x_i = -20.2$ cm, in other words, the image is 11.2 cm to the right of L_1. $M_T = 20.2/9 = 2.2$; hence the edge of L_2 is imaged 4.4 cm above the axis. Thus its subtended angle at S is $\tan^{-1} 4.4/(12+11.2)$ or 9.8°. Accordingly, the diaphragm is the A.S., and the entrance pupil (its image in L_1) has a diameter of 1.5 cm at 4.5 cm behind L_1. The image of the diaphragm in L_2 is the exit pupil. Consequently, $1/2 + 1/s_i = 1/3$ and $s_i = -6$, that is, 6 cm in front of L_2. $M_T = 6/2 = 3$, so that exit pupil diameter is 3 cm.

5.56 (a) D_1 is its own image since there is no lens to the left of it.
(b) L is its own image since there is no lens to the left of it.

(c)
$$\frac{1}{s_o} + \frac{1}{s_i} = \frac{1}{f}$$
$$\frac{1}{4\ cm} + \frac{1}{s_i} = \frac{1}{12 \text{ cm}}$$
$$\frac{1}{S_i} = \frac{1}{12 \text{ cm}} - \frac{1}{4 \text{ cm}} = -\frac{1}{6 \text{ cm}}$$
$$S_i = -6 \text{ cm}$$
$$M_T = -\frac{S_i}{S_o} = -\frac{-6 \text{ cm}}{4 \text{ cm}} = 1.5$$

(d)



γ is the smallest angle, thus D2 is the aperture stop and its image (located 6 cm behind the lens) is the entrance pupil, which is $1.5\times 8\text{ cm} = 12\text{ cm}$ in diameter.

5.57 Either the margin of L_1 or L_2 will be the A.S.; thus, since no lenses are to the left of L_1, either its periphery or P_1 corresponds to the entrance pupil. Beyond (to the left of) point A, L_1 subtends the smallest angle and is the entrance pupil; nearer in (to the right of A), P_1 marks the edge of the entrance pupil. In the former case P_2 is the exit pupil; in the latter (since there are no lenses to the right of L_2) the exit pupil is the edge of L_2 itself.

5.58 The A.S. is either the edge of L_1 or L_2. Thus the entrance pupil is either marked by P_1 or P_2. Beyond F_{o1}, P_1 subtends the smaller angle; thus Σ_1 locates the A.S. The image of the A.S. in the lens to its right, L_2, locates P_3 as the exit pupil.

5.59 $M = \dfrac{D_o}{D_e}$

$$10 = \frac{5.0\text{ cm}}{D_e}$$

$$D_e = \frac{5.0\text{ cm}}{10} = 5.0\text{ mm}$$

5.60 Draw the chief ray from the tip to L_1 such that when extended it passes through the center of the entrance pupil. From there it goes through the center of the A.S., and then it bends at L_2 so as to extend through the center of the exit pupil. A marginal ray from S extends to the edge of the entrance pupil, bends at L_1 so it just misses the edge of the A.S., and then bends at L_2 so as to pass by the edge of the exit pupil.

5.61 Figures P.5.61a and P5.61b.

5.62 No—although she might be looking at you.

5.63 The mirror is parallel to the plane of the painting, and so the girl's image should be directly behind her and not off to the side.

5.64 $1/s_o + 1/s_i = -2/R$. Let $R \to \infty$: $1/s_o + 1/s_i = 0$, $s_o = -s_i$, and $M_T = +1$. Image is virtual, same size, and erect.

5.65 For a plane mirror $|s_i| = |s_o|$, thus the tree is located next to the woman. The tree will appear as if it were viewed from 1200 cm away, but will have left-right reversal.

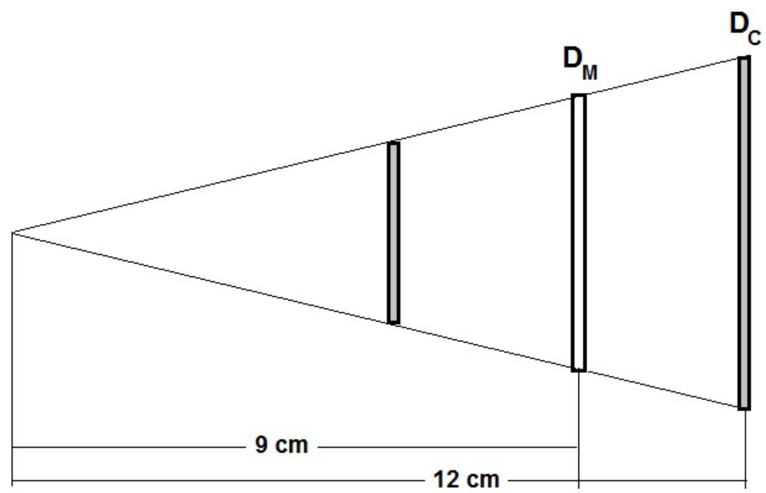
5.66 Q_2 will appear to be located above Q_1. Q_2 will appear to be located at the same point in space as Q_3.

5.67 $\overline{Q_1A} = \overline{QA}$ thus Q_1 is 16 cm from A

For $\overline{Q_2A}$, the light travels from the source to A (8 cm), from A to B (20 cm) so $\overline{Q_2B} = 28$ cm and $\overline{Q_2A} = 28 + 20 = 48$ cm.

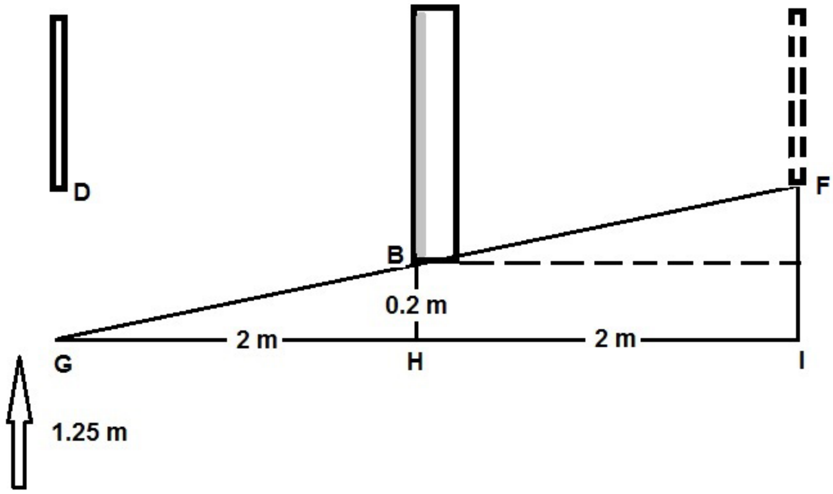
For $\overline{Q_3A}$, the light travels from the source to A (8 cm), from A to B (20 cm) and back to B (20 cm), thus $\overline{Q_3A} = 48$ cm.

5.68



$$\frac{D_M}{D_C} = \frac{9\text{ cm}}{12\text{ cm}}$$

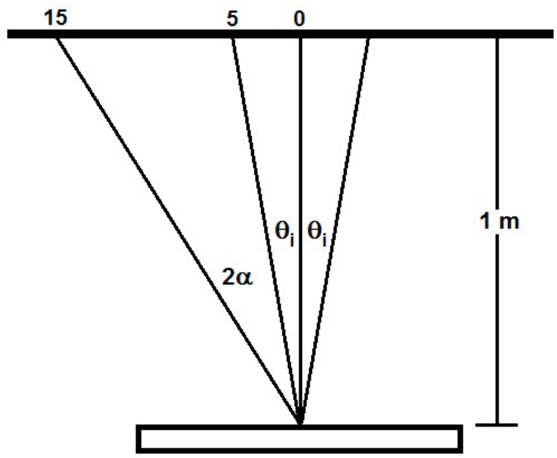
5.69



Triangles GBH ad GFI are similar. As a result $\overline{DG} = \overline{FI} = 2\overline{BH} = 2(0.20 \text{ m}) = 0.40 \text{ m}$

Point is therefore 1.25 m + 0.40 m = 1.65 m above the floor.

5.70



$$\tan(2\alpha + \theta_i) = \frac{20 \text{ cm}}{100 \text{ cm}} = 0.20$$

$$2\alpha + \theta_i = 11.31°$$

$$\tan(\theta_i) = \frac{5 \text{ cm}}{100 \text{ cm}} = 0.05$$

$$\theta_i = 2.86°$$

$$2\alpha = 8.45°,\ \alpha = 4.23°$$

5.71 From Eq. (5.50), $1/100 + 1/s_i = -2/80$, and so $s_i = -28.6$ cm. Virtual $(s_i < 0)$, erect $(M_T > 0)$, and minified. (Check with Table 5.5.)

5.72 (5.48) $1/s_o + 1/s_i = -2/R,\ R = 0.5$ ft.
$1/s_i = -2/R - 1/s_o = -2/(0.5\text{ ft}) - 1/(+5\text{ ft}), \qquad s_i = -5/21 = -0.24$ ft.
$M_T = -s_i/s_o = (-0.24)/(5) = 0.048.$

Image is virtual (seen in the mirror), erect, and 0.048 times the object size.

5.73 Ant has 3 images: from lens, from mirror, back out from lens.
(i) (5.17) $1/f = 1/s_o + 1/s_i$ so,
$1/s_i = 1/f - 1/s_o = 1/50.0 - 1/250 = 4/250,\ s_i = 62.5$ cm (between lens and mirror). (ii) (5.48) $1/s_o + 1/s_i = -2/R$ so,
$1/s_i = -2/R - 1/s_o = 1/s_o,\ (R = \infty),\ s_i = -187.5$ cm (virtual image).
(iii) $1/s_i = 1/f - 1/50 = 1/50.0 - 1/(250 + 187.5),\ s_i = +56.5$ cm. Real image, (left of lens).

5.74 Image on screen must be real, therefore s_i is positive.
$1/25 + 1/100 = -2/R,\ 5/100 = -2/R,\ R = -40$ cm.

5.75 The image is erect and minified. That implies (Table 5.5) a convex spherical mirror.

5.76
$$\frac{1}{S_o} + \frac{1}{S_i} = \frac{1}{f}$$
$$\frac{1}{35\text{ cm}} + \frac{1}{s_i} = \frac{1}{30\text{ cm}}$$
$$\frac{1}{S_i} = \frac{1}{30\text{ cm}} - \frac{1}{35\text{ cm}}$$
$$S_i = +210\text{ cm}$$
$$M_T = -\frac{210\text{ cm}}{35\text{ cm}} = -6$$

The image is magnified, inverted and real. It is 6×1 cm = 6 cm.

$$f = \frac{R}{2}$$
$$R = 2f = 60\text{ cm}$$

5.77 From Eq. (5. 8), $1/\infty + n/s_i = (n-1)/R;\ s_i = 2R;\ n/2R = (n-1)/R;\ n = 2.$

5.78 Want $|M_T| = |s_i / s_o| = y_i/y_0 = 1.0\text{ cm}/100\text{ cm} = .01.\ s_o = 1000$ cm.
$|s_i| = s_o M_T = (1000)(.01) = 10$ cm. Want real image, so $s_i > 0$, and image will be inverted. Detector is 10 cm in front of the mirror.
(5.50) $1/s_o + 1/s_i = 1/f;\ 1/f = 1/1000 + 1/10 = 101/1000;\ f = 9.9$ cm.

5.79
$$\frac{1}{S_o} + \frac{1}{S_i} = \frac{1}{f} = \frac{2}{R}$$
$$\frac{1}{30\text{ cm}} + \frac{1}{s_i} = -\frac{2}{12\text{ cm}} = -\frac{1}{6\text{ cm}}$$
$$\frac{1}{S_i} = -\frac{1}{6\text{ cm}} - \frac{1}{30\text{ cm}}$$

$S_i = -5$ cm

$$M_T = -\frac{-5\text{ cm}}{30\text{ cm}} = \frac{1}{6}$$

$y_i = 0.1$ cm

The image is virtual, minified and erect.

5.80 To be magnified and erect the mirror must be concave, and the image virtual; $M_T = 2.0 = s_i/(0.015\text{ m}), s_i = -0.03\text{ m}$, and hence $1/f = 1/0.015\text{ m} + 1/(-0.03\text{ m})$; $f = 0.03$ m and $f = -R/2$; R = − 0.06 m.

5.81 $M_T = y_i/y_o = -s_i/s_o$, using Eq. (5.51), $s_i = fs_o/(s_o - f)$, and since $f = -R/2, M_T = -f/(s_o - f) = -(-R/2)/(s_o + R/2) = R/(2s_o + R)$.

5.82 (5.49) $f = -R/2$ so $R = -2f$. (5.50) $1/s_o + 1/s_i = 1/f$. $M_T = -s_i/s_o$, so $s_i = -s_o M_T = -(10.0\text{ cm})(0.037) = -0.37$ cm (image is virtual). $1/f = 1/s_o + 1/s_i = 1/(10.0) + 1/(-0.37)$, $f = -0.38$ cm. $R = -2(-0.38) = 0.76$ cm.

5.83 (5.50) $1/f = 1/s_o + 1/s_i$; $s_o/f = 1 + s_o/s_i = (s_i + s_o)/s_i$

$$= \frac{(s_i/s_o + 1)}{(s_i/s_o)} = (-M_T + 1)/(-M_T).\ s_o = f(M_T - 1)/M_T.$$

(5.50) $1/f = 1/s_o + 1/s_i$; $s_i/f = s_i/s_o + 1 = (-M_T) + 1$; $s_i = -f(M_T - 1)$.

5.84 $M_T = -s_i/25\text{ cm} = -0.064$; $s_i = 1.6$ cm. $1/25 + 1/1.6 = -2/R$, $R = -3.0$ cm.

5.85 Image size in plane mirror equals object size, so $|M_T$ (convex mirror)$| = 0.5$; $|M_T| = |s_i / s_o|$, so $|s_i| = |s_o||M_T| = (5.0)(0.5) = 2.5$ m; $s_i = -2.5$ m (image is virtual). (5.50) $1/f = 1/s_o + 1/s_i = 1/(5.0\text{ m}) + 1/(-2.5\text{ m})$, $f = -5.0$ m.

5.86 (5.49) $f = -R/2$. Primary $f_p = -(-(200\text{ cm}))/2 = +100$ cm.
(5.50) $1/s_o + 1/s_i = 1/f_p$, $s_o = \infty$, so $1/s_i = 1/f_p$; $s = +100$ cm. Object for secondary is at $s_o = -25$ cm. $1/f_s = 1/s_o + 1/s_i$ so $1/s_i = 1/f_s - 1/s_o$.
Secondary $f_s = -R/2 = -(+60\text{ cm})/2 = -30$ cm.
$1/s_i = 1/(-30) - 1/(-25)$; $s_i = +150$ cm, or 75 cm behind the primary.
The effective focal length of the "lens" is +75 cm.

5.87 See Table 5.3. For $f < s_o < 2f$, a real inverted image is made with $\infty > s_i > 2f$. If this image is directed back at the same angles, the final image will occur at the original object. So, it should be placed at the image of the lens (at s_i).

5.88 $M_T = -s_i/s_o$, so, $s_i = -M_T s_o = -1.5 s_o$.
(5.50) $1/f = 1/s_o + 1/s_i = 1/s_o + 1/(-1.5 s_o)$; $1/10 = 1/3s_o$;
$s_o = 10/3 = 3.3$ cm.
Note in Table 5.5 $s_o < f$ for an erect, magnified image.

5.89 $f = -R/2 = 30$ cm, $1/20 + 1/s_i = 1/30$, $1/s_i = 1/30 - 1/20$. $s_i = -60$ cm, $M_T = s_i/s_o = 60/20 = 3$. Image is virtual $(s_i < 0)$, erect $(M_T > 0)$, located 60 cm behind mirror, and 9 inches tall.

5.90 The light passes through the lens twice.

$$\frac{1}{f}=\frac{1}{f_L}+\frac{1}{f_L}+\frac{1}{f_M}$$

$$\frac{1}{f}=\frac{2}{f_L}+\frac{2}{R_M}$$

5.91 Treat the first surface as a mirror with radius of curvature R.
(5.49) $f_m=-R/2$, which is where the parallel reflected rays converge.
Lens: (5.16) $1/f_l=(n_l-1)(1/R_1-1/R_2)$; $R_1=-R$, $R_2=+R$ so
$1/f_l=(2-1)(1/(-R)-1/R)=-2/R$; $f_l=-R/2=f_m$.

5.92 Image is rotated through 180°.

5.93 From Eq. (5.61),

$$NA=(2.624-2.310)^{1/2}=0.560, \qquad \theta_{\max}=\sin^{-1}0.560=34°05'.$$

Maximum acceptance angle is $2\theta_{\max}=68°10'$. A ray at 45° would quickly leak out of the fiber; in other words, it will strike the interior walls at less than Q_c and thus only be partially reflected.

5.94

$$\begin{aligned}\sin\theta_{\max}&=NA=(n_f^2-n_c^2)^{1/2}\\&=(1.481^2-1.461^2)^{1/2}\\&=0.2426\end{aligned}$$

$$\theta_{\max}=14°$$

$$2\theta_{\max}=28°$$

5.95 Considering Eq. (5.62), $\log 0.5=-0.30=-\alpha L/10$, and so $L=15$ km.

5.96

$$\text{V-number}=\frac{\pi D}{\lambda_C}(n_f^2-n_c^2)^{\frac{1}{2}}=2.405$$

$$\lambda_C=\frac{\pi D(1.457^2-1.451^2)^{\frac{1}{2}}}{2.405}$$

$$\lambda_C=\pi D(0.0549)=0.604\,\mu\text{m}$$

5.97

$$\lambda_C=\frac{\pi DNA}{2.405}=\frac{\pi(8.0\,\mu\text{m})(0.13)}{2.405}=1.358\,\mu\text{m}$$

$$\nu_C=\frac{c}{\lambda_C}=2.2\times10^{14}\,\text{Hz}$$

5.98 From Eq. (5.61), $NA=0.232$ and $N_m=9.2\times10^2$.

5.99

$$NA=(n_f^2-n_c^2)^{1/2}=(1.50^2-1.48^2)=0.2441$$

$$\begin{aligned}\text{V-number}&=\frac{\pi DNA}{\lambda_C}\\&=\frac{(100\times10^{-6}\,\text{m})\pi(0.2441)}{(1300\times10^{-9}\,\text{m})}=58.989\end{aligned}$$

$$N_m=\frac{V^2}{2}=1739$$

5.100 (5.68) $\Delta t = (Ln_f/c)(n_f/n_c - 1)$, so $\Delta t/L = (n_f/c)(n_f/n_c - 1)$.
$\Delta t/L = 1.500/(3\times10^{-4}\ \text{km/ns})(1.500/1.485 - 1) = 50.51\ \text{km/ns}$.

5.101 $M_T = -f/x_o = (-1/x_o)D$. For the human eye $D \approx 58.6$ diopters.
$x_o = 230{,}000 \times 1.61 = 371\times10^3\,\text{km}$,
$M_T = -1/3.71\times10^6(58.6) = 4.6\times10^{-11}$,
$y_i = 2160\times1.61\times10^3\times4.6\times10^{-11} = 0.16\ \text{mm}$.

5.102 Recall that the angles of a triangle sum to 180°. Recall that at both mirrors $\theta_r = \theta_i$. For the triangle made by the three rays, $(2\theta_{i1}) + (2\theta_{i2}) + (180° - \theta) = 180°$ so $\theta = 2(\theta_{i1} + \theta_{i2})$. For the triangle containing "β," $\beta + (90° - \theta_{i1}) + (90° - \theta_{i2}) = 180°$. $\beta = (\theta_{i1} + \theta_{i2})$, so, $\theta = 2\beta$.

5.103 $1/20 + 1/s_{io} = 1/4$, $s_{io} = 5$ m. $1/0.3 + 1/s_{oe} = 1/0.6$, $s_{oe} = -0.6$ m.

$$M_{To} = -5/20 = -0.25,\ M_{Te} = -\frac{0.3}{(-0.6)} = +0.5 = +1.2,\ M_{To}M_{Te} = -0.125.$$

5.104 From Table 5.3, the types, positions, and sizes of the images are OK, but the rays from one portion of an object do not consistently trace to the same portion of the image.

5.105 The pinhole allows the eye to get much closer to the object and still see it clearly and that creates a larger retinal image. The pinhole works like a magnifier.

5.106 Want same amount of light to reach the film. $f/\#$ varies as the square root of the time, so we want $f/5.5$.

5.107 See figure on page 686 of text. Ray 1 in the figure misses the eye-lens, and there is, therefore, a decrease in the energy arriving at the corresponding image point. This is vignetting.

5.108 Rays that would have missed the eye-lens in the previous problem are made to pass through it by the field-lens. Note how the field-lens bends the chief rays a bit so that they cross the optical axis slightly closer to the eye-lens, thereby moving the exit pupil and shortening the eye relief. (For more on the subject, see *Modern Optical Engineering*, by Smith.)

5.109 From Table 5.3, image is virtual, erect, and magnified. As thickness of lens approaches 0, $|s_i|$ approaches s_o, i.e., $|M_T|$ approaches 1. However, the entire bug is imaged, so that this can be used as a field-lens.

5.110 (a) $D = 1/f$. If $s_o = \infty$, $1/f = 1/s_i$. $D = 1/(0.02\ \text{m}) = 50\ \text{m}^{-1}$.
If $s_o = 0.50\ \text{m}, 1/f = 1/(0.50\ \text{m}) + 1/0.02\ \text{m}, D = 52\ \text{m}^{-1}$.
(b) Accommodation of $2\ \text{m}^{-1}$.
(c) $D = 1/f = 1/(0.25\ \text{m}) + 1/(0.02\ \text{m}) = 54\ \text{m}^{-1}$.
(d) Need to add $2\ \text{m}^{-1}$.

5.111 Unaided eye,
$D = 1/f = 1/s_o + 1/s_i$, $(s_i \simeq 2\ \text{cm})$, $D = 1/(1.25\ \text{m}) + 1/(0.02\ \text{m}) = 50.8\ \text{m}^{-1}$.
Want $D = 1/f = 1/(0.25\ \text{m}) + 1/(0.02\ \text{cm}) = 54\ \text{m}^{-1}$. Lens must have a power of $(54 - 50.8) = 3.2\ \text{m}^{-1}$.

Insert new solutions for 5.112 Missing

5.113 $D_c = -7D$

$$D_l = \frac{D_C}{1+D_C d} = \frac{-7}{1+(-7)(0.015)} = -7.82D$$

5.114 $D_C = \dfrac{D_l}{1+D_l d} = \dfrac{9}{1-(9)(0.012)} = 10.1D$

5.115 A far point of 16.67 cm means that $S_i = -16.67$ and $S_o = \infty$.

$$\frac{1}{S_o} + \frac{1}{S_i} = \frac{1}{f} \Rightarrow -\frac{1}{16.67} + \frac{1}{\infty} = \frac{1}{f}$$

$$D_l = \frac{-\frac{1}{0.1667}}{1-(1.2)\left(\frac{1}{0.1667}\right)} = 6.46D$$

5.116 An object 25 cm away should appear 100 cm away.

$$\frac{1}{S_o} + \frac{1}{S_i} = \frac{1}{f}$$

$$\frac{1}{f} = \frac{1}{25\text{ cm}} + \frac{1}{-100\text{ cm}}$$

$$f = 33\frac{1}{3}\text{ cm}$$

$$\frac{1}{S_o} + \frac{1}{S_i} = \frac{1}{f}$$

$$\frac{1}{S_o} + \frac{1}{\infty} = \frac{1}{33\frac{1}{3}\text{ cm}}$$

The new far point is therefore $33\frac{1}{3}$ cm.

5.117 $D_1 = D_c/(1+D_c d) = 3.0D/[1+(3.0D)(0.017\text{m})] = +2.85D$ or to two figures +2.9 D. $f_1 = 0.345$ m, and so the far point is $0.345 - 0.017$ m = 0.33 m behind the eye lens. For the contact lens $f_c = 1/3.0 = 3.3$ m. Hence the far point at 3.3 m is the same for both, as it indeed must be.

5.118 (a) (5. 77) $MP = d_o \cdot D + 1 = (0.25\text{ m})(1/.0254\text{ m}) + 1 = 10.8$.

(b) Size = (MP) (object size) = 10.8 (5.0 mm) = 54 mm diameter.

(c) $\tan\alpha_u = y_o/d_o = (0.0254\text{ m})/(0.25\text{ m})$, $\alpha_u = 5.80° = 0.101$ rad.

(d) $\tan\alpha_\alpha = y_i/L \simeq y_i/d_o = (0.054\text{ m})/(0.25\text{ m})$, $\alpha_a = 12.19° = 0.213$ rad.

5.119 (a) The intermediate image-distance is obtained from the lens formula applied to the objective; $1/27 + 1/s_i = 1/25$ and $s_i = 3.38 \times 10^2$ mm. This is the distance from the objective to the intermediate image, to which must be added the focal length of the eyepiece to get the lens separation; $3.38 \times 10^2 + 25 = 3.6 \times 10^2$ mm.

(b) $M_{To} = -s_i / s_o = -3.38 \times 10^2 / 27 = -12.5\times$, while the eyepiece has a magnification of $d_o D = 254/25 = 10.2\times$. Thus the total magnification is $MP = (-12.5)(10.2) = -1.3 \times 10^2$; the minus just means the image is inverted.

5.120 The x-ray "lens" is a mirrored surface that forms a portion of a non-spherical mirror. The reflected rays converge to the focus (F_1).

5.121 (a) These are a parabola and a hyperbola of two sheets. The parabola and left-hand hyperbola share a common focus, F_1. Rays reflected from the parabola head for that focus. Rays directed at the first focus of a hyperbola reflect toward the second focus. (b) Parallel rays coming off the parabola seem to be leaving its first focus. Because this is also the focus of the ellipse the rays reflect toward its second focus.

5.122 The limit of resolution is $1.22\lambda/D$; at 0.50μm, $1.22(0.50 \times 10^{-6})/2.4 = 2.54 \times 10^{-7}$ radians; $1.0 \times 10^{-2} = R2.54 \times 10^{-7}$ and $R = 39$ km.