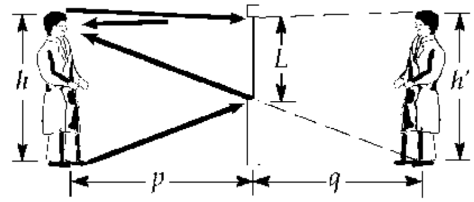
26.3 The flatness of the mirror is described



by $R = \infty, f = \infty$

and $1/f = 0$

By our general mirror equation,

$$\frac{1}{p} + \frac{1}{q} = \frac{1}{f} = 0$$

or $q = -p$

Thus, the image is as far behind the mirror as the person is in front. The magnification is then

$$M = \frac{-q}{p} = 1 = \frac{h'}{h}$$

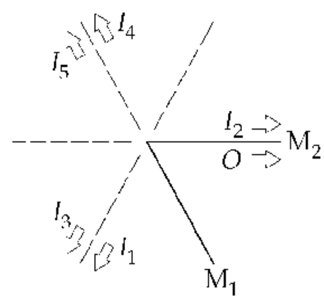
so $h' = h = 70.0$ inches

The required height of the mirror is defined by the triangle from the person's eyes to the top and bottom of his image, as shown. From the geometry of the triangle, we see that the mirror height must be:

$$h'\left(\frac{p}{p-q}\right) = h'\left(\frac{p}{2p}\right) = \frac{h'}{2}$$

Thus, the mirror must be **at least 35.0 inches high**.

26.5 A graphical construction produces 5 images, with images I_1 and I_2 directly into the mirrors from the object O,



and (O, I_3, I_4)

and (I_2, I_1, I_5)

forming the vertices of equilateral triangles.

26.6 (1) The first image in the left mirror is 5.00 ft behind the mirror, or **10.0 ft** from the position of the person.

(2) The first image in the right mirror is located 10.0 ft behind the right mirror, but this location is 25.0 ft from the left mirror. Thus, the second image in the left mirror is 25.0 ft behind the mirror, or **30.0 ft** from the person.

(3) The first image in the left mirror forms an image in the right mirror. This first image is 20.0 ft from the right mirror, and, thus, an image 20.0 ft behind the right mirror is formed. This image in the right mirror also forms an image in the left mirror. The distance from this image in the right mirror to the left mirror is 35.0 ft. The third image in the left mirror is, thus, 35.0 ft behind the mirror, or **40.0 ft** from the person.

26.8 For a concave mirror, both R and f are positive.

We also know that $$f = \frac{R}{2} = 10.0 \text{ cm}$$

(a) $$\frac{1}{q} = \frac{1}{f} - \frac{1}{p} = \frac{1}{10.0 \text{ cm}} - \frac{1}{40.0 \text{ cm}} = \frac{3}{40.0 \text{ cm}}$$

and $$\boxed{q = 13.3 \text{ cm}}$$

$$M = \frac{q}{p} = -\frac{13.3 \text{ cm}}{40.0 \text{ cm}} = \boxed{-0.333}$$

The image is 13.3 cm in front of the mirror, is **real, and inverted**

(b) $$\frac{1}{q} = \frac{1}{f} - \frac{1}{p} = \frac{1}{10.0 \text{ cm}} - \frac{1}{20.0 \text{ cm}} = \frac{1}{20.0 \text{ cm}}$$

and $$\boxed{q = 20.0 \text{ cm}}$$

$$M = \frac{q}{p} = -\frac{20.0 \text{ cm}}{20.0 \text{ cm}} = \boxed{-1.00}$$

The image is 20.0 cm in front of the mirror, is **real, and inverted**

(c) $$\frac{1}{q} = \frac{1}{f} - \frac{1}{p} = \frac{1}{10.0 \text{ cm}} - \frac{1}{10.0 \text{ cm}} = 0$$

Thus, q = infinity.

No image is formed. The rays are reflected parallel to each other.

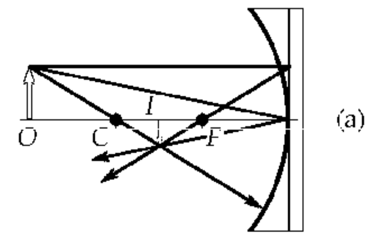
***26.9** (a) $\frac{1}{p}+\frac{1}{q}=\frac{2}{R}$ becomes $\frac{1}{q}=\frac{2}{60.0\text{ cm}}-\frac{1}{90.0\text{ cm}}$

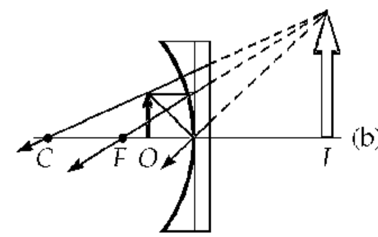
$q=\boxed{45.0\text{ cm}}$ and $M=\frac{-q}{p}=-\frac{45.0\text{ cm}}{90.0\text{ cm}}=\boxed{-0.500}$

(b) $\frac{1}{p}+\frac{1}{q}=\frac{2}{R}$ becomes $\frac{1}{q}=\frac{2}{60.0\text{ cm}}-\frac{1}{20.0\text{ cm}}$

$q=\boxed{-60.0\text{ cm}}$ and $M=\frac{-q}{p}=-\frac{(-60.0\text{ cm})}{(20.0\text{ cm})}=\boxed{3.00}$

(c) The image (a) is real, inverted and diminished. That of (b) is virtual, upright, and enlarged. The ray diagrams are similar to Figure 26.12(a) and 26.12(b), respectively.



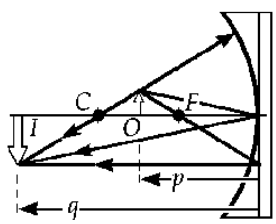


***26.12** (a) $M=-\frac{q}{p}.$ For a real image, $q>0$ so in this case $M=-4.00$

$q=-pM=120\text{ cm}$

and from $\frac{1}{p}+\frac{1}{q}=\frac{2}{R}$ $R=\frac{2pq}{p+q}=\frac{2(30.0\text{ cm})(120\text{ cm})}{(150\text{ cm})}=\boxed{48.0\text{ cm}}$

(b)



***26.14** $M=-\frac{q}{p}$

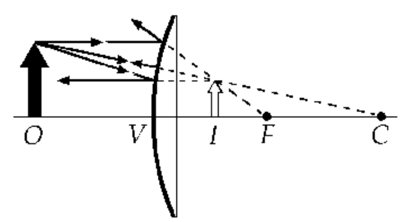
$q=-Mp=-0.013(30\text{ cm})=-0.39\text{ cm}$

$\frac{1}{p}+\frac{1}{q}=\frac{1}{f}=\frac{2}{R}$

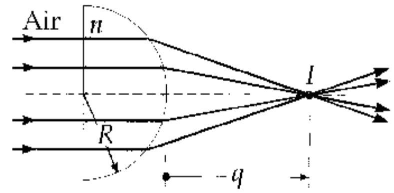
$\frac{1}{30\text{ cm}}+\frac{1}{-0.39\text{ cm}}=\frac{2}{R}$

$R=\frac{2}{-2.53\text{ m}^{-1}}=-0.790\text{ cm}$

The cornea is convex, with radius of curvature $\boxed{0.790\text{ cm}}$



26.49 A hemisphere is too thick to be described as a thin lens. The light is undeviated on entry into the flat face. We next consider the light's exit from the second surface, for which $R = -6.00$ cm



The incident rays are parallel, so $p = \infty$

Then, $$\frac{n_1}{p} + \frac{n_2}{q} = \frac{n_2 - n_1}{R}$$

becomes $$0 + \frac{1}{q} = \frac{1.00 - 1.56}{-6.00\text{ cm}}$$

and $$\boxed{q = 10.7\text{ cm}}$$

26.51 For the mirror, $f = R/2 = +1.50$ m. In addition, because the distance to the Sun is so much larger than any other distances, we can take $p = \infty$.

The mirror equation, $\frac{1}{p} + \frac{1}{q} = \frac{1}{f}$, then gives $q = f = \boxed{1.50\text{ m}}$

Now, in $$M = -\frac{q}{p} = \frac{h'}{h}$$

the magnification is nearly zero, but we can be more precise: h/p is the angular diameter of the object. Thus, the image diameter is

$$h' = -\frac{hq}{p} = (-0.533°)\left(\frac{\pi\text{ rad}}{180°}\right)(1.50\text{ m}) = -0.140\text{ m} = \boxed{-1.40\text{ cm}}$$

26.24 Let R_1 = outer radius and R_2 = inner radius

$$\frac{1}{f} = (n-1)\left[\frac{1}{R_1} - \frac{1}{R_2}\right] = (1.50 - 1)\left[\frac{1}{2.00\text{ m}} - \frac{1}{2.50\text{ cm}}\right] = 0.0500\text{ cm}^{-1}$$

so $f = \boxed{20.0\text{ cm}}$

26.25 For a converging lens, f is positive. We use $\frac{1}{p}+\frac{1}{q}=\frac{1}{f}$

(a) $\frac{1}{q}=\frac{1}{f}-\frac{1}{p}=\frac{1}{20.0\text{ cm}}-\frac{1}{40.0\text{ cm}}=\frac{1}{40.0\text{ cm}}$ $\boxed{q=40.0\text{ cm}}$

$M=-\frac{q}{p}=-\frac{40.0}{40.0}=\boxed{-1.00}$

The image is $\boxed{\text{real, inverted}}$, and located 40.0 cm past the lens.

(b) $\frac{1}{q}=\frac{1}{f}-\frac{1}{p}=\frac{1}{20.0\text{ cm}}-\frac{1}{20.0\text{ cm}}=0$ $\boxed{q=\text{infinity}}$

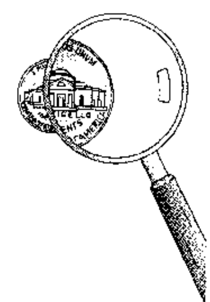
$\boxed{\text{No image}}$ is formed. The rays emerging from the lens are parallel to each other.

(c) $\frac{1}{q}=\frac{1}{f}-\frac{1}{p}=\frac{1}{20.0\text{ cm}}-\frac{1}{10.0\text{ cm}}=-\frac{1}{20.0\text{ cm}}$ $\boxed{q=-20.0\text{ cm}}$

$M=-\frac{q}{p}=-\frac{(-20.0)}{10.0}=\boxed{2.00}$

The image is $\boxed{\text{upright, virtual}}$ and 20.0 cm in front of the lens.

26.27 We are looking at an enlarged, upright, virtual image:



$M=\frac{h'}{h}=2=-\frac{q}{p}$ so $p=-\frac{q}{2}=-\frac{(-2.84\text{ cm})}{2}=+1.42\text{ cm}$

$\frac{1}{p}+\frac{1}{q}=\frac{1}{f}$ gives $\frac{1}{1.42\text{ cm}}+\frac{1}{(-2.84\text{ cm})}=\frac{1}{f}$

$\boxed{f=2.84\text{ cm}}$

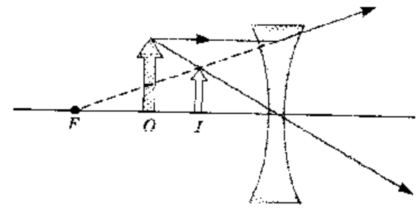
26.28 (a) $\frac{1}{p}+\frac{1}{q}=\frac{1}{f}$: $\frac{1}{32.0\text{ cm}}+\frac{1}{8.00\text{ cm}}=\frac{1}{f}$

so $\boxed{f=6.40\text{ cm}}$

(b) $M=-\frac{q}{p}=-\frac{8.00\text{ cm}}{32.0\text{ cm}}=\boxed{-0.250}$

(c) Since $f>0$, the lens is $\boxed{\text{converging}}$

***26.33** (a) $\frac{1}{p}+\frac{1}{q}=\frac{1}{f}$ $\qquad$ $\frac{1}{20.0 \text{ cm}}+\frac{1}{q}=\frac{1}{(-32.0 \text{ cm})}$



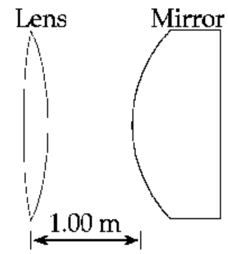
so $\qquad q=-\left(\frac{1}{20.0}+\frac{1}{32.0}\right)^{-1}=\boxed{-12.3 \text{ cm}}$

The image is 12.3 cm to the left of the lens.

(b) $M=-\frac{q}{p}=-\frac{(-12.3 \text{ cm})}{20.0 \text{ cm}}=\boxed{0.615}$

(c) See the ray diagram to the right.

26.43 Start with the first pass through the lens.



$\frac{1}{q_1}=\frac{1}{f_1}-\frac{1}{p_1}=\frac{1}{80.0 \text{ cm}}-\frac{1}{100 \text{ cm}}$ $\qquad$ $q_1=400$ cm to right of lens

For the mirror, $\qquad$ $p_2=-300$ cm

$\frac{1}{q_2}=\frac{1}{f_2}-\frac{1}{p_2}=\frac{1}{(-50.0 \text{ cm})}-\frac{1}{(-300 \text{ cm})}$ $\qquad$ $q_2=-60.0$ cm

For the second pass through the lens, $\qquad$ $p_3=160$ cm

$\frac{1}{q_3}=\frac{1}{f_1}-\frac{1}{p_3}=\frac{1}{80.0 \text{ cm}}-\frac{1}{160 \text{ cm}}$ $\qquad$ $q_3=\boxed{160 \text{ cm to the left of lens}}$

$M_1=-\frac{q_1}{p_1}=-\frac{400 \text{ cm}}{100 \text{ cm}}=-4.00$ $\qquad$ $M_2=-\frac{q_2}{p_2}=-\frac{(-60.0 \text{ cm})}{(-300 \text{ cm})}=-\frac{1}{5}$

$M_3=-\frac{q_3}{p_3}=-\frac{160 \text{ cm}}{160 \text{ cm}}=-1$ $\qquad$ $M=M_1M_2M_3=\boxed{-0.800}$

Since $M<0$ the final image is $\boxed{\text{inverted}}$.

26.46 $$\frac{1}{q_1} = \frac{1}{f_1} - \frac{1}{p_1} = \frac{1}{10.0\text{ cm}} - \frac{1}{12.5\text{ cm}}$$

so $q_1 = 50.0\text{ cm}$ (to left of mirror)

This serves as an object for the lens (a virtual object), so

$$\frac{1}{q_2} = \frac{1}{f_2} - \frac{1}{p_2} = \frac{1}{(-16.7\text{ cm})} - \frac{1}{(-25.0\text{ cm})}$$

$q_2 = -50.3\text{ cm}$ (to right of lens)

Thus, the final image is located $\boxed{\text{25.3 cm to right of mirror}}$.

$$M_1 = -\frac{q_1}{p_1} = -\frac{50.0\text{ cm}}{12.5\text{ cm}} = -4.00$$

$$M_2 = -\frac{q_2}{p_2} = -\frac{(-50.3\text{ cm})}{(-25.0\text{ cm})} = -2.01$$

$$M = M_1 M_2 = \boxed{8.05}$$

Thus, the final image is $\boxed{\text{virtual, upright}}$, 8.05 times the size of object, and 25.3 cm to right of the mirror.

***26.48** (a) $$I = \frac{\mathcal{P}}{4\pi r^2} = \frac{4.50\text{ W}}{4\pi\left(1.60\times10^{-2}\text{ m}\right)^2} = \boxed{1.40\text{ kW/m}^2}$$

(b) $$I = \frac{\mathcal{P}}{4\pi r^2} = \frac{4.50\text{ W}}{4\pi(7.20\text{ m})^2} = \boxed{6.91\text{ mW/m}^2}$$

(c) $\frac{1}{p} + \frac{1}{q} = \frac{1}{f}$: $$\frac{1}{7.20\text{ m}} + \frac{1}{q} = \frac{1}{0.350\text{ m}}$$

so $q = 0.368\text{ m}$

and $$M = \frac{h'}{3.20\text{ cm}} = -\frac{q}{p} = -\frac{0.368\text{ m}}{7.20\text{ m}}$$

$$h' = \boxed{0.164\text{ cm}}$$

(d) The lens intercepts power given by $$\mathcal{P} = IA = \left(6.91\times10^{-3}\text{ W/m}^2\right)\left[\frac{\pi}{4}(0.150\text{ m})^2\right]$$

and puts it all onto the image where $$I = \frac{\mathcal{P}}{A} = \frac{\left(6.91\times10^{-3}\text{ W/m}^2\right)\left[\pi(15.0\text{ cm})^2/4\right]}{\pi(0.164\text{ cm})^2/4}$$

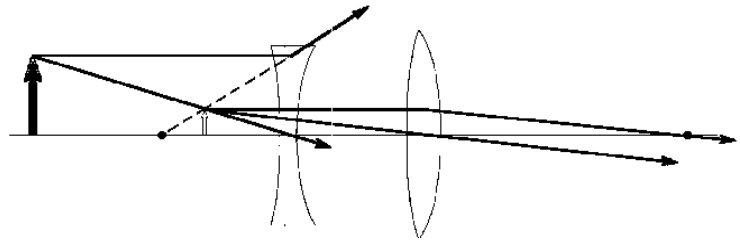
$$I = \boxed{58.1\text{ W/m}^2}$$

26.53 From the thin lens equation, $q_1 = \frac{f_1 p_1}{p_1 - f_1} = \frac{(-6.00\text{ cm})(12.0\text{ cm})}{12.0\text{ cm} - (-6.00\text{ cm})} = -4.00\text{ cm}$

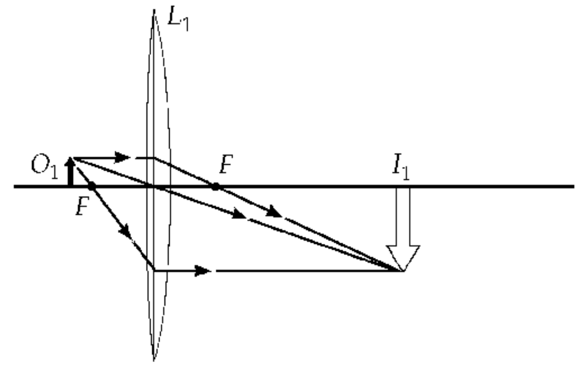
When we require that $q_2 \to \infty$, the thin lens equation becomes $p_2 = f_2$.

In this case, $p_2 = d - (-4.00\text{ cm})$

Therefore, $d + 4.00\text{ cm} = f_2 = 12.0\text{ cm}$ and $d = \boxed{8.00\text{ cm}}$



26.57 (a) For lens one, as shown in the first figure,

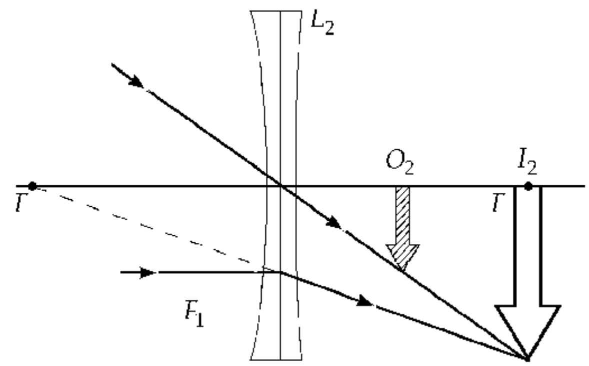


$$\frac{1}{40.0\text{ cm}}+\frac{1}{q_1}=\frac{1}{30.0\text{ cm}}$$

$$q_1 = 120\text{ cm}$$

$$M_1 = -\frac{q_1}{p_1} = -\frac{120\text{ cm}}{40.0\text{ cm}} = -3.00$$

This real image $I_1 = O_2$ is a virtual object for the second lens. That is, it is *behind* the lens, as shown in the second figure. The object distance is



$$p_2 = 110\text{ cm} - 120\text{ cm} = -10.0\text{ cm}$$

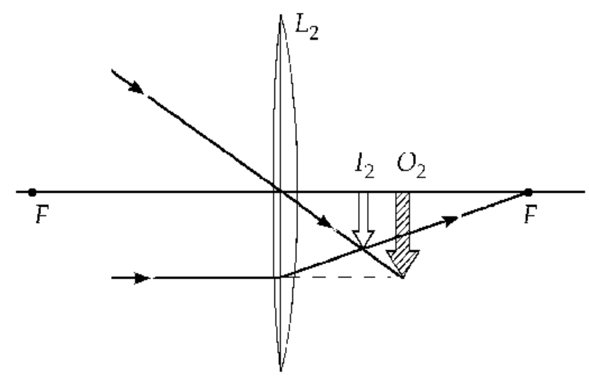
$$\frac{1}{-10.0\text{ cm}}+\frac{1}{q_2}=\frac{1}{-20.0\text{ cm}}:$$

$$q_2 = \boxed{20.0\text{ cm}}$$

$$M_2 = -\frac{q_2}{p_2} = -\frac{20.0\text{ cm}}{(-10.0\text{ cm})} = +2.00$$

$$M_{\text{overall}} = M_1M_2 = \boxed{-6.00}$$

(b) $M_{\text{overall}} < 0$, so final image is $\boxed{\text{inverted}}$.



(c) If lens two is a converging lens (third figure):

$$\frac{1}{-10.0\text{ cm}}+\frac{1}{q_2}=\frac{1}{20.0\text{ cm}}$$

$$q_2 = \boxed{6.67\text{ cm}}$$

$$M_2 = -\frac{6.67\text{ cm}}{(-10.0\text{ cm})} = +0.667$$

$$M_{\text{overall}} = M_1M_2 = \boxed{-2.00}$$

Again, $M_{\text{overall}} < 0$ and the final image is $\boxed{\text{inverted}}$