36.3 The flatness of the mirror is described by $R = \infty$, $f = \infty$, and $1/f = 0$. By our general mirror equation,

$$\frac{1}{p} + \frac{1}{q} = \frac{1}{f}, \quad \text{or} \quad q = -p$$

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

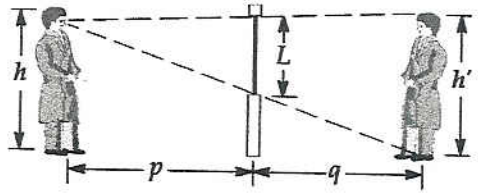


Figure for Goal Solution

$$M = \frac{-q}{p} = 1 = \frac{h'}{h} \quad \text{so} \quad h' = h = 70.0''$$

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" high**.

***36.5** (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.

36.15 Assume that the object distance is the same in both cases (i.e., her face is the same distance from the hubcap regardless of which way it is turned). Also realize that the near image ($q = -10.0$ cm) occurs when using the convex side of the hubcap. Applying the mirror equation to both cases gives:

(concave side: $R = |R|$, $q = -30.0$ cm) $\quad \frac{1}{p} - \frac{1}{30.0} = \frac{2}{|R|}$, or $\frac{2}{|R|} = \frac{30.0\text{ cm} - p}{(30.0\text{ cm})p}$ [1]

(convex side: $R = -|R|$, $q = -10.0$ cm) $\quad \frac{1}{p} - \frac{1}{10.0} = -\frac{2}{|R|}$, or $\frac{2}{|R|} = \frac{p - 10.0\text{ cm}}{(10.0\text{ cm})p}$ [2]

(a) Equating Equations (1) and (2) gives: $\quad \frac{30.0\text{ cm} - p}{3.00} = p - 10.0\text{ cm} \quad$ or $\quad p = 15.0$ cm

Thus, her face is **15.0 cm** from the hubcap.

(b) Using the above result ($p = 15.0$ cm) in Equation [1] gives:

$$\frac{2}{|R|} = \frac{30.0\text{ cm} - 15.0\text{ cm}}{(30.0\text{ cm})(15.0\text{ cm})} \quad \text{or} \quad \frac{2}{|R|} = \frac{1}{30.0\text{ cm}}, \quad \text{and} \quad |R| = 60.0\text{ cm}$$

The radius of the hubcap is **60.0 cm**.

36.25 n_1 n_2 $n_2 - n_1$

***36.28** 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.

***36.35** $\frac{1}{p}+\frac{1}{q}=\frac{1}{f}$: $p^{-1}+q^{-1}=\text{constant}$

We may differentiate through with respect to p: $-1p^{-2}-1q^{-2}\frac{dq}{dp}=0$

$$\frac{dq}{dp}=-\frac{q^2}{p^2}=-M^2$$

36.36 The image is inverted: $M=\frac{h'}{h}=\frac{-1.80\text{ m}}{0.0240\text{ m}}=-75.0=\frac{-q}{p}$ $q=75.0p$

(b) $q+p=3.00\text{ m}=75.0p+p$, $p=\boxed{39.5\text{ mm}}$

(a) $q=2.96\text{ m}$ $\frac{1}{f}=\frac{1}{p}+\frac{1}{q}=\frac{1}{0.0395\text{ m}}+\frac{1}{2.96\text{ m}}$

$f=\boxed{39.0\text{ mm}}$

***36.41** To properly focus the image of a distant object, the lens must be at a distance equal to the focal length from the film ($q_1=65.0$ mm). For the closer object:

$\frac{1}{p_2}+\frac{1}{q_2}=\frac{1}{f}$ becomes $\frac{1}{2000\text{ mm}}+\frac{1}{q_2}=\frac{1}{65.0\text{ mm}}$ and $q_2=(65.0\text{ mm})\left(\frac{2000}{2000-65.0}\right)$

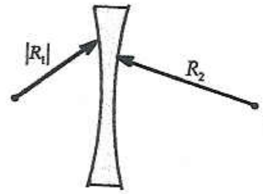
The lens must be moved $\boxed{\text{away from the film}}$ by a distance

$$D=q_2-q_1=(65.0\text{ mm})\left(\frac{2000}{2000-65.0}\right)-65.0\text{ mm}=\boxed{2.18\text{ mm}}$$

*36.42 (a) The focal length of the lens is given by

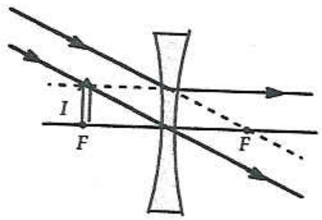
$$\frac{1}{f}=(n-1)\left(\frac{1}{R_1}-\frac{1}{R_2}\right)=(1.53-1.00)\left(\frac{1}{-32.5\text{ cm}}-\frac{1}{42.5\text{ cm}}\right)$$

$f=-34.7$ cm



Note that R_1 is negative because the center of curvature of the first surface is on the virtual image side.

When $p=\infty$, the thin lens equation gives $q=f$. Thus, the violet image of a very distant object is formed at $\boxed{q=-34.7\text{ cm}}$. The image is $\boxed{\text{virtual, upright, and diminished}}$.



(b) The same ray diagram and image characteristics apply for red light. Again, $q=f$, and now

$$\frac{1}{f}=(1.51-1.00)\left(\frac{1}{-32.5\text{ cm}}-\frac{1}{42.5\text{ cm}}\right)\text{ giving } f=\boxed{-36.1\text{ cm}}.$$