23.7 The radius of curvature of a concave mirror is positive, so \( R = +20.0 \text{ cm} \). The mirror equation then gives

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

(a) If \( p = 40.0 \text{ cm} \), \( q = +13.3 \text{ cm} \) and \( M = -\frac{q}{p} = \frac{-13.3 \text{ cm}}{40.0 \text{ cm}} = -0.333 \)

The image is \( 13.3 \text{ cm} \) in front of the mirror, real, and inverted

(b) When \( p = 20.0 \text{ cm} \), \( q = +20.0 \text{ cm} \) and \( M = -\frac{q}{p} = \frac{-20.0 \text{ cm}}{20.0 \text{ cm}} = -1.00 \)

The image is \( 20.0 \text{ cm} \) in front of the mirror, real, and inverted

(c) If \( p = 10.0 \text{ cm} \), \( q = \frac{(10.0 \text{ cm})(10.0 \text{ cm})}{10.0 \text{ cm} - 10.0 \text{ cm}} \rightarrow \infty \)

and no image is formed. Parallel rays leave the mirror

23.29 From the thin lens equation, \( \frac{1}{p} + \frac{1}{q} = \frac{1}{f} \), the image distance is found to be

\[
q = \frac{fp}{p - f} = \frac{(20.0 \text{ cm})p}{p - 20.0 \text{ cm}}
\]

(a) If \( p = 40.0 \text{ cm} \), then \( q = 40.0 \text{ cm} \) and \( M = -\frac{q}{p} = \frac{-40.0 \text{ cm}}{40.0 \text{ cm}} = -1.00 \)

The image is real, inverted, and 40.0 cm beyond the lens

(b) If \( p = 20.0 \text{ cm} \), \( q \rightarrow \infty \) No image formed. Parallel rays leave the lens.

(c) When \( p = 10.0 \text{ cm} \), \( q = -20.0 \text{ cm} \) and

\[
M = -\frac{q}{p} = \frac{-20.0 \text{ cm}}{10.0 \text{ cm}} = +2.00
\]

The image is virtual, upright, and 20.0 cm in front of the lens
23.31 From the thin lens equation, \( \frac{1}{p} + \frac{1}{q} = \frac{1}{f} \), the image distance is found to be

\[ q = \frac{fp}{p-f} = \frac{(-20.0 \text{ cm})p}{p-(-20.0 \text{ cm})} = \frac{(20.0 \text{ cm})p}{p+20.0 \text{ cm}} \]

(a) If \( p = 40.0 \text{ cm} \), then \( q = -13.3 \text{ cm} \) and \( M = -\frac{q}{p} = -\frac{(-13.3 \text{ cm})}{40.0 \text{ cm}} = +1/3 \)

The image is \textit{virtual, upright, and 13.3 cm in front of the lens}

(b) If \( p = 20.0 \text{ cm} \), then \( q = -10.0 \text{ cm} \) and

\[ M = -\frac{q}{p} = -\frac{(-10.0 \text{ cm})}{20.0 \text{ cm}} = +1/2 \]

The image is \textit{virtual, upright, and 10.0 cm in front of the lens}

(c) When \( p = 10.0 \text{ cm} \), \( q = -6.67 \text{ cm} \) and \( M = -\frac{q}{p} = -\frac{(-6.67 \text{ cm})}{10.0 \text{ cm}} = +2/3 \)

The image is \textit{virtual, upright, and 6.67 cm in front of the lens}
23.40 With \( p_1 = 20.0 \text{ cm} \) and \( f = 25.0 \text{ cm} \), the thin lens equation gives the position of the image formed by the first lens as

\[
q_1 = \frac{p_1 f}{p_1 - f} = \frac{(20.0 \text{ cm})(25.0 \text{ cm})}{20.0 \text{ cm} - 25.0 \text{ cm}} = -100 \text{ cm}
\]

and the magnification by this lens is \( M_1 = -\frac{q_1}{p_1} = -\frac{-100 \text{ cm}}{20.0 \text{ cm}} = +5.00 \)

This virtual image serves as the object for the second lens, so the object distance is \( p_2 = 25.0 \text{ cm} + |q_1| = 125 \text{ cm} \). Then, the thin lens equation gives the final image position as

\[
q_2 = \frac{p_2 f}{p_2 - f} = \frac{(125 \text{ cm})(-10.0 \text{ cm})}{125 \text{ cm} - (-10.0 \text{ cm})} = -9.26 \text{ cm}
\]

with a magnification by the second lens of

\[
M_2 = -\frac{q_2}{p_2} = -\frac{-9.26 \text{ cm}}{125 \text{ cm}} = +0.0741
\]

Thus, the final image is located \( 9.26 \text{ cm in front of the second lens} \) and the overall magnification is \( M = M_1 M_2 = (+5.00)(+0.0741) = +0.370 \)

23.42 (a) With \( p_1 = +15.0 \text{ cm} \), the thin lens equation gives the position of the image formed by the first lens as

\[
q_1 = \frac{p_1 f}{p_1 - f} = \frac{(15.0 \text{ cm})(10.0 \text{ cm})}{15.0 \text{ cm} - 10.0 \text{ cm}} = +30.0 \text{ cm}
\]

This image serves as the object for the second lens, with an object distance of \( p_2 = 10.0 \text{ cm} - q_1 = 10.0 \text{ cm} - 30.0 \text{ cm} = -20.0 \text{ cm} \) (a virtual object). If the image formed by this lens is at the position of \( o_1 \), the image distance is

\[
q_1 = -(10.0 \text{ cm} + p_1) = -(10.0 \text{ cm} + 15.0 \text{ cm}) = -25.0 \text{ cm}
\]

The thin lens equation then gives the focal length of the second lens as

\[
f_2 = \frac{p_2 q_1}{p_2 + q_1} = \frac{(-20.0 \text{ cm})(-25.0 \text{ cm})}{-20.0 \text{ cm} - 25.0 \text{ cm}} = +11.1 \text{ cm}
\]
23.45 Since the final image is to be real and in the film plane, \( q = + d \)

Then, the thin lens equation gives

\[
P_2 = -\frac{q f_2}{q - f_2} = \frac{d (13.0 \text{ cm})}{d - 13.0 \text{ cm}}
\]

Note from Figure P23.45 that \( d < 12.0 \text{ cm} \). The above result then shows that \( p_2 < 0 \), so the object for the second lens will be a virtual object.

The object of the second lens \( (L_2) \) is the image formed by the first lens \( (L_1) \), so

\[
q = (12.0 \text{ cm} - d) - p_2 = 12.0 \text{ cm} - d \left(1 + \frac{13.0 \text{ cm}}{d - 13.0 \text{ cm}}\right) = 12.0 \text{ cm} - \frac{d^2}{d - 13.0 \text{ cm}}
\]

If \( d = 5.00 \text{ cm} \), then \( q = +15.1 \text{ cm} \); and when \( d = 10.0 \text{ cm} \), \( q = +45.3 \text{ cm} \)

From the thin lens equation, \( p_1 = \frac{q_1 f_1}{q_1 - f_1} = \frac{q (15.0 \text{ cm})}{q - 15.0 \text{ cm}} \)

When \( q = +15.1 \text{ cm} \) (\( d = 5.00 \text{ cm} \)), then \( p_1 = 1.82 \times 10^3 \text{ cm} = 18.2 \text{ m} \)

When \( q = +45.3 \text{ cm} \) (\( d = 10.0 \text{ cm} \)), then \( p_1 = 22.4 \text{ cm} = 0.224 \text{ m} \)

Thus, the range of focal distances for this camera is \( 0.224 \text{ m} \) to \( 18.2 \text{ m} \)