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

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

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

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

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

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

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

and $\boxed{\text{no image is formed. Parallel rays leave the mirror}}$

23.8 (a) Since the object is in front of the mirror, $p > 0$. With the image behind the mirror, $q < 0$. The mirror equation gives the radius of curvature as

$$\frac{2}{R} = \frac{1}{p} + \frac{1}{q} = \frac{1}{1.00\text{ cm}} - \frac{1}{10.0\text{ cm}} = \frac{10\text{-}1}{10.0\text{ cm}}$$

or $R = 2\left(\frac{10.0\text{ cm}}{9}\right) = \boxed{+2.22\text{ cm}}$

(b) The magnification is $M = -\frac{q}{p} = -\frac{(-10.0\text{ cm})}{1.00\text{ cm}} = \boxed{+10.0}$

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 $M=-\frac{q}{p}=-\frac{(-13.3\text{ cm})}{40.0\text{ cm}}=\boxed{+1/3}$

The image is **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

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

The image is **virtual, upright, and 10.0 cm in front of the lens**

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

The image is **virtual, upright, and 6.67 cm in front of the lens**

23.44 (a) We start with the final image and work backward. From Figure P22.44, observe that $q_2 = -(50.0\text{ cm} - 31.0\text{ cm}) = -19.0\text{ cm}$. The thin lens equation

then gives $$p_2 = \frac{q_2 f_2}{q_2 - f_2} = \frac{(-19.0\text{ cm})(20.0\text{ cm})}{-19.0\text{ cm} - 20.0\text{ cm}} = +9.74\text{ cm}$$

The image formed by the first lens serves as the object for the second lens and is located 9.74 cm in front of the second lens.

Thus, $q_1 = 50.0\text{ cm} - 9.74\text{ cm} = 40.3\text{ cm}$ and the thin lens equation gives

$$p_1 = \frac{q_1 f_1}{q_1 - f_1} = \frac{(40.3\text{ cm})(10.0\text{ cm})}{40.3\text{ cm} - 10.0\text{ cm}} = +13.3\text{ cm}$$

The original object should be located $\boxed{13.3\text{ cm}}$ in front of the first lens.

(b) The overall magnification is

$$M = M_1 M_2 = \left(-\frac{q_1}{p_1}\right)\left(-\frac{q_2}{p_2}\right) = \left(-\frac{40.3\text{ cm}}{13.3\text{ cm}}\right)\left(-\frac{(-19.0\text{ cm})}{9.74\text{ cm}}\right) = \boxed{-5.90}$$

(c) Since $M < 0$, the final image is $\boxed{\text{inverted}}$;

and since $q_2 < 0$, it is $\boxed{\text{virtual}}$