Chapter 23

ANSWERS TO MULTIPLE CHOICE QUESTIONS

1. The image formed by a flat mirror of a real object is always an upright, virtual image that is the same size as the object and located as far behind the mirror as the object is in front of the mirror. Thus, statements (b), (c), and (e) are all true, while statements (a) and (d) are false.

2. Since the size of the image is 1.50 times the size of the object, the magnitude of the magnification is $|M| = 1.50$. Because the image is upright, $M > 0$. Thus, $M = -q/p = +1.50$, which gives $q = -1.50p$. Then from the mirror equation, we have

$$f = \frac{R}{2} = \frac{qp}{p+q} = \frac{(-1.50p)p}{p-1.50p} = +3.00p = +3.00(+30.0 \text{ cm}) = +90.0 \text{ cm}$$

and the correct choice is (d).

3. For a convergent lens, $f > 0$, and because the image is real, $q > 0$. The thin-lens equation, $1/p + 1/q = 1/f$, then gives

$$p = \frac{qf}{q-f} = \frac{(12.0 \text{ cm})(8.00 \text{ cm})}{12.0 \text{ cm} - 8.00 \text{ cm}} = +24.0 \text{ cm}$$

Since $p > 0$, the object is in front (in this case, to the left) of the lens, and the correct choice is (c).

4. For a converging lens, the focal length is positive, or $f > 0$. Since the object is virtual, we know that the object distance is negative, or $p < 0$ and $p = -|p|$. Thus, the thin-lens equation gives the image distance as

$$q = \frac{pf}{p-f} = \frac{-|p|f}{-|p|-f} = +\left(\frac{|p|}{|p|+f}\right)f$$

Since $|p|$ and f are positive quantities, we see that $q > 0$ and the image is real. Also, since $|p|/(|p|+f) < 1$, we see that $q < f$. Thus, we have shown that choices (a) and (d) are false statements, while choices (b), (c), and (e) are all true.

5. From the mirror equation, $1/p + 1/q = 2/R = 1/f$, with $f < 0$ since the mirror is convex, the image distance is found to be

$$q = \frac{pf}{p-f} = \frac{(16.0 \text{ cm})(-6.00 \text{ cm})}{16.0 \text{ cm} - (-6.00 \text{ cm})} = -4.36 \text{ cm}$$

Since $q < 0$, the image is virtual and located 4.36 cm behind the mirror. Choice (d) is the correct answer.

7. A concave mirror forms inverted, real images of real objects located outside the focal point ($p > f$), and upright, magnified, virtual images of real objects located inside the focal point ($p < f$). Virtual images, located behind the mirror, have negative image distances by the sign convention of Table 23.1. Choices (d) and (e) are true statements, and all other choices are false.

8. A convergent lens forms inverted, real images of real objects located outside the focal point ($p > f$). When $p > 2f$, the real image is diminished in size, and the image is enlarged if $2f > p > f$. For real objects located inside the focal point ($p < f$) of the convergent lens, the image is upright, virtual, and enlarged. In the given case, $p > 2f$, so the image is real, inverted, and diminished in size. Choice (c) is the correct answer.

9. With a real object in front of a convex mirror, the image is always upright, virtual, diminished in size, and located between the mirror and the focal point. Thus, of the available choices, only choice (c) is a true statement.

10. For a real object ($p > 0$) and a diverging lens ($f < 0$), the image distance given by the thin-lens equation is

$$q = \frac{pf}{p-f} = \frac{|p|(-|f|)}{|p|-(-|f|)} = -\frac{|p||f|}{|p|+|f|} < 0$$

and the magnification is

$$M = -\frac{q}{p} = -\frac{-|q|}{|p|} > 0$$

Thus, the image is always virtual and upright, meaning that choice (b) is a true statement while all other choices are false.

PROBLEM SOLUTIONS

23.1 (a) Due to the finite value of the speed of light, the light arriving at your eye must have reflected from your face at a slightly earlier time. Thus, the image viewed in the mirror $\boxed{\text{shows you younger than your actual age}}$.

(b) If you stand 40 cm in front of the mirror, the time required for light scattered from your face to travel to the mirror and back to your eye is

$$\Delta t = \frac{2d}{c} = \frac{2(0.40 \text{ m})}{3.0 \times 10^8 \text{ m/s}} = 2.7 \times 10^{-9} \text{ s} \qquad \text{or} \qquad \boxed{\sim 10^{-9} \text{ s}}$$

23.6 (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

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

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

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

23.7 (a) The center of curvature of a convex mirror is behind the mirror. Therefore, the radius of curvature, and hence the focal length $f = R/2$, is negative. With the image behind the mirror, the image is virtual and $q = -10.0$ cm. The mirror equation then gives

$$p = \frac{q\,f}{q-f} = \frac{(-10.0\text{ cm})(-15.0\text{ cm})}{-10.0\text{ cm} - (-15.0\text{ cm})} = +30.0\text{ cm}$$

The object should be placed $\boxed{\text{30.0 cm in front of the mirror}}$.

(b) The magnification of the mirror is

$$M = -\frac{q}{p} = -\frac{(-10.0\text{ cm})}{+30.0\text{ cm}} = \boxed{+0.333}$$

Therefore, the image is upright and one-third the size of the object.

23.9 (a) The center of curvature of a concave mirror is in front of the mirror. Therefore, both the radius of curvature and the focal length, $f = R/2$, are positive. Since the image is virtual, the image distance is negative and $q = -20.0$ cm. With $R = +40.0$ cm and $f = +20.0$ cm, the mirror equation gives

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

Thus, the object should be placed $\boxed{\text{10.0 cm in front of the mirror}}$.

(b) The magnification of the mirror is

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

Therefore, the image is upright and twice the size of the object.

23.21 From $\frac{n_1}{p} + \frac{n_2}{q} = \frac{n_2 - n_1}{R}$, with $R \to \infty$, the image position is found to be

$$q = -\frac{n_2}{n_1}p = -\left(\frac{1.00}{1.309}\right)(50.0\text{ cm}) = -38.2\text{ cm}$$

or the virtual image is $\boxed{\text{38.2 cm below the upper surface of the ice}}$.

23.31 The focal length of a converging lens is positive, so $f = +10.0$ cm. The thin-lens equation then yields an image distance of $q = \dfrac{pf}{p-f} = \dfrac{p(10.0\text{ cm})}{p-10.0\text{ cm}}$.

(a) When $p = +20.0$ cm, $q = \dfrac{(20.0\text{ cm})(10.0\text{ cm})}{20.0\text{ cm}-10.0\text{ cm}} = +20.0$ cm, and $M = -\dfrac{q}{p} = -1.00$, so the image is located $\boxed{\text{20.0 cm beyond the lens}}$, is $\boxed{\text{real } (q>0)}$, is $\boxed{\text{inverted } (M<0)}$, and is $\boxed{\text{the same size as the object } (|M| = 1.00)}$.

(b) When $p = f = +10.0$ cm, the object is at the focal point and $\boxed{\text{no image is formed}}$. Instead, $\boxed{\text{parallel rays emerge from the lens}}$.

(c) When $p = 5.00$ cm, $q = \dfrac{(5.00\text{ cm})(10.0\text{ cm})}{5.00\text{ cm}-10.0\text{ cm}} = -10.0$ cm, and $M = -\dfrac{q}{p} = +2.00$, so the image is located $\boxed{\text{10.0 cm in front of the lens}}$, is $\boxed{\text{virtual } (q<0)}$, is $\boxed{\text{upright } (M>0)}$, and is $\boxed{\text{twice the size of the object } (|M| = 2.00)}$.

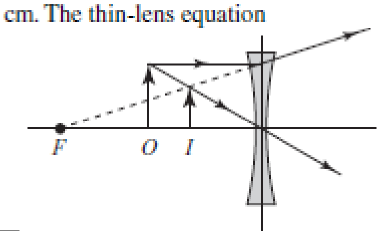
23.36 We must first realize that we are looking at an upright, enlarged, virtual image. Thus, we have a real object located between a converging lens and its front-side focal point, so $q < 0$, $p > 0$, and $f > 0$.

The magnification is $M = -\dfrac{q}{p} = +2$, giving $q = -2p$. Then, from the thin-lens equation, $\dfrac{1}{p} - \dfrac{1}{2p} = +\dfrac{1}{2p} = \dfrac{1}{f}$, or $f = 2p = 2(2.84\text{ cm}) = \boxed{5.68\text{ cm}}$.

23.38 (a) This is a real object, so the object distance is $p = +20.0$ cm. The thin-lens equation gives the image distance as

$$q = \frac{pf}{p-f} = \frac{(20.0\text{ cm})(-32.0\text{ cm})}{20.0\text{ cm}-(-32.0\text{ cm})} = -12.3\text{ cm}$$

so the image is $\boxed{\text{12.3 cm to the left of the lens}}$.



(b) The magnification is $M = -\dfrac{q}{p} = -\dfrac{(-12.3\text{ cm})}{+20.0\text{ cm}} = \boxed{+0.615}$.

(c) The ray diagram for this arrangement is shown above.