Chapter 34

7. (a) Parallel rays are bent by positive-f lenses to their focal points F_1, and rays that come from the focal point positions F_2 in front of positive-f lenses are made to emerge parallel. The key, then, to this type of beam expander is to have the rear focal point F_1 of the first lens coincide with the front focal point F_2 of the second lens. Since the triangles that meet at the coincident focal point are similar (they share the same angle; they are vertex angles), then $W_f/f_2 = W_i/f_1$ follows immediately. Substituting the values given, we have

$$W_f = \frac{f_2}{f_1} W_i = \frac{30.0 \text{ cm}}{12.5 \text{ cm}} (2.5 \text{ mm}) = 6.0 \text{ mm}.$$

(b) The area is proportional to W^2. Since intensity is defined as power P divided by area, we have

$$\frac{I_f}{I_i} = \frac{P/W_f^2}{P/W_i^2} = \frac{W_i^2}{W_f^2} = \frac{f_1^2}{f_2^2} \quad \Rightarrow \quad I_f = \left(\frac{f_1}{f_2}\right)^2 I_i = 1.6 \text{ kW/m}^2.$$

(c) The previous argument can be adapted to the first lens in the expanding pair being of the diverging type, by ensuring that the front focal point of the first lens coincides with the front focal point of the second lens. The distance between the lenses in this case is

$$f_2 - |f_1| = 30.0 \text{ cm} - 26.0 \text{ cm} = 4.0 \text{ cm}.$$

8. The water is medium 1, so $n_1 = n_w$, which we simply write as n. The air is medium 2, for which $n_2 \approx 1$. We refer to points where the light rays strike the water surface as A (on the left side of Fig. 34-56) and B (on the right side of the picture). The point midway between A and B (the center point in the picture) is C. The penny P is directly below C, and the location of the "apparent" or virtual penny is V. We note that the angle $\angle CVB$ (the same as $\angle CVA$) is equal to θ_2, and the angle $\angle CPB$ (the same as $\angle CPA$) is equal to θ_1. The triangles CVB and CPB share a common side, the horizontal distance from C to B (which we refer to as x). Therefore,

$$\tan\theta_2 = \frac{x}{d_\mathrm{a}} \quad \text{and} \quad \tan\theta_1 = \frac{x}{d}.$$

Using the small angle approximation (so a ratio of tangents is nearly equal to a ratio of sines) and the law of refraction, we obtain

$$\frac{\tan\theta_2}{\tan\theta_1} \approx \frac{\sin\theta_2}{\sin\theta_1} \quad \Rightarrow \quad \frac{\frac{x}{d_a}}{\frac{x}{d}} \approx \frac{n_1}{n_2} \quad \Rightarrow \quad \frac{d}{d_\mathrm{a}} \approx n$$

which yields the desired relation: $d_\mathrm{a} = d/n$.

11-15. A concave mirror has a positive value of focal length.

(a) Then (with f = +36 cm and p = +24 cm), the radius of curvature is $r = 2f$ = + 72 cm.

(b) Equation 34-9 yields $i = pf/(p - f)$ = –72 cm.

(c) Then, by Eq. 34-7, $m = -i/p$ = +3.0.

(d) Since the image distance is negative, the image is virtual (V).

(e) The magnification computation produced a positive value, so it is upright [not inverted] (NI).

(f) A virtual image is formed on the <u>opposite</u> side of the mirror from the object.

12. **THINK** A concave mirror has a positive value of focal length.

EXPRESS For spherical mirrors, the focal length f is related to the radius of curvature r by $f = r/2$.

The object distance p, the image distance i, and the focal length f are related by Eq. 34-4:

$$\frac{1}{p} + \frac{1}{i} = \frac{1}{f}.$$

The value of i is positive for real images and negative for virtual images.

The corresponding lateral magnification is $m = -i/p$. The value of m is positive for upright (not inverted) images, and is negative for inverted images. Real images are formed on the same side as the object, while virtual images are formed on the opposite side of the mirror.

ANALYZE With f = +18 cm and p = +12 cm, the radius of curvature is $r = 2f$ = + 36 cm.

(b) Equation 34-9 yields $i = pf/(p - f)$ = –36 cm.

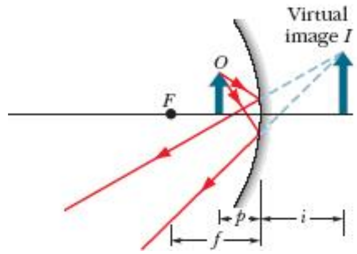
(c) Then, by Eq. 34-7, $m = -i/p$ = +3.0.

(d) Since the image distance is negative, the image is virtual (V).

(e) The magnification computation produced a positive value, so it is upright [not inverted] (NI).

(f) A virtual image is formed on the <u>opposite</u> side of the mirror from the object.

LEARN The situation in this problem is similar to that illustrated in Fig. 34-11(a). The mirror is concave, and its image is virtual, enlarged, and upright.



13. **THINK** A concave mirror has a positive value of focal length.

EXPRESS For spherical mirrors, the focal length *f* is related to the radius of curvature *r* by $f = r/2$. The object distance *p*, the image distance *i*, and the focal length *f* are related by Eq. 34-4:

$$\frac{1}{p}+\frac{1}{i}=\frac{1}{f}.$$

The value of *i* is positive for a real images, and negative for virtual images.

The corresponding lateral magnification is $m = -i/p$. The value of *m* is positive for upright (not inverted) images, and negative for inverted images. Real images are formed on the same side as the object, while virtual images are formed on the opposite side of the mirror.

ANALYZE (a) With f = +12 cm and p = +18 cm, the radius of curvature is $r = 2f = 2(12\text{ cm}) = +24$ cm.

(b) The image distance is $i = \dfrac{pf}{p-f} = \dfrac{(18\text{ cm})(12\text{ cm})}{18\text{ cm} - 12\text{ cm}} = 36\text{ cm}.$

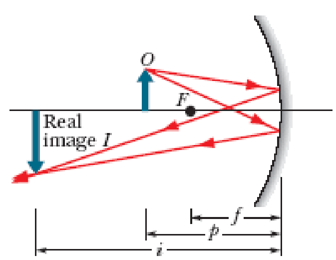
(c) The lateral magnification is $m = -i/p = -(36\text{ cm})/(18\text{ cm}) = -2.0$.

(d) Since the image distance *i* is positive, the image is real (R).

(e) Since the magnification *m* is negative, the image is inverted (I).

(f) A real image is formed on the <u>same</u> side as the object.

LEARN The situation in this problem is similar to that illustrated in Fig. 34-10(c). The object is outside the focal point, and its image is real and inverted.



14. A concave mirror has a positive value of focal length.

(a) Then (with f = +10 cm and p = +15 cm), the radius of curvature is $r = 2f = +20$ cm.

(b) Equation 34-9 yields $i = pf/(p - f)$ = +30 cm.

(c)Then, by Eq. 34-7, $m = -i/p = -2.0$.

(d) Since the image distance computation produced a positive value, the image is real (R).

(e) The magnification computation produced a negative value, so it is inverted (I).

(f) A real image is formed on the same side as the object.

15. **THINK** A convex mirror has a negative value of focal length.

EXPRESS For spherical mirrors, the focal length f is related to the radius of curvature r by $f = r/2$. The object distance p, the image distance i, and the focal length f are related by Eq. 34-4:

$$\frac{1}{p} + \frac{1}{i} = \frac{1}{f}.$$

The value of i is positive for a real images, and negative for virtual images.

The corresponding lateral magnification is

$$m = -\frac{i}{p}.$$

The value of m is positive for upright (not inverted) images, and negative for inverted images. Real images are formed on the same side as the object, while virtual images are formed on the opposite side of the mirror.

ANALYZE (a) With f = –10 cm and p = +8 cm, the radius of curvature is $r = 2f$ = –20 cm.

(b) The image distance is $i = \dfrac{pf}{p-f} = \dfrac{(8\text{ cm})(-10\text{ cm})}{8\text{ cm} - (-10)\text{ cm}} = -4.44$ cm.

(c) The lateral magnification is $m = -i/p = -(-4.44\text{ cm})/(8.0\text{ cm}) = +0.56$.

(d) Since the image distance is negative, the image is virtual (V).

(e) The magnification m is positive, so the image is upright [not inverted] (NI).

(f) A virtual image is formed on the opposite side of the mirror from the object.

16. We recall that for a diverging (D) lens, the focal length value should be negative (f = –6 cm).

(a) Equation 34-9 gives $i = pf/(p - f) = -3.8$ cm.

(b) Equation 34-7 gives $m = -i/p = +0.38$.

(c) The fact that the image distance is a negative value means the image is virtual (V).

(d) A positive value of magnification means the image is not inverted (NI).

(e) The image is on the same side as the object (see Fig. 34-16(c)).

17. **THINK** For a diverging (D) lens, the focal length value is negative.

EXPRESS The object distance p, the image distance i, and the focal length f are related by Eq. 34-9:

$$\frac{1}{f} = \frac{1}{p} + \frac{1}{i}.$$

The value of i is positive for a real images, and negative for virtual images. The corresponding lateral magnification is $m = -i/p$. The value of m is positive for upright (not inverted) images, and is negative for inverted images.

ANALYZE For this lens, we have f = –12 cm and p = +8.0 cm.

(a) The image distance is $i = \dfrac{pf}{p-f} = \dfrac{(8.0\text{ cm})(-12\text{ cm})}{8.0\text{ cm} - (-12)\text{ cm}} = -4.8\text{ cm}.$

(b) The magnification is $m = -i/p = -(-4.8\text{ cm})/(8.0\text{ cm}) = +0.60$.

(c) The fact that the image distance is a negative value means the image is virtual (V).

(d) A positive value of magnification means the image is not inverted (NI).

(e) The image is on the same side as the object.

18. We recall that for a converging (C) lens, the focal length value should be positive (f = +4 cm).

(a) Equation 34-9 gives $i = pf/(p - f) = +5.3$ cm.

(b) Equation 34-7 gives $m = -i / p = -0.33$.

(c) The fact that the image distance i is a positive value means the image is real (R).

(d) The fact that the magnification is a negative value means the image is inverted (I).

(e) The image is on the opposite side of the object (see Fig. 34-16(a)).

19. We recall that for a converging (C) lens, the focal length value should be positive ($f = +16$ cm).

(a) Equation 34-9 gives $i = pf/(p - f) = -48$ cm.

(b) Equation 34-7 gives $m = -i / p = +4.0$.

(c) The fact that the image distance is a negative value means the image is virtual (V).

(d) A positive value of magnification means the image is not inverted (NI).

(e) The image is on the same side as the object (see Fig. 34-16(b)).

20. We recall that for a converging (C) lens, the focal length value should be positive ($f = +35$ cm).

(a) Equation 34-9 gives $i = pf/(p - f) = -88$ cm.

(b) Equation 34-7 give $m = -i / p = +3.5$.

(c) The fact that the image distance is a negative value means the image is virtual (V).

(d) A positive value of magnification means the image is not inverted (NI).

(e) The image is on the same side as the object (see Fig. 34-16(b)).

82. (a) First, the lens forms a real image of the object located at a distance

$$i_1 = \left(\frac{1}{f_1} - \frac{1}{p_1}\right)^{-1} = \left(\frac{1}{f_1} - \frac{1}{2f_1}\right)^{-1} = 2f_1$$

to the right of the lens, or at

$$p_2 = 2(f_1 + f_2) - 2f_1 = 2f_2$$

in front of the mirror. The subsequent image formed by the mirror is located at a distance

$$i_2 = \left(\frac{1}{f_2} - \frac{1}{p_2}\right)^{-1} = \left(\frac{1}{f_2} - \frac{1}{2f_2}\right)^{-1} = 2f_2$$

to the left of the mirror, or at

$$p'_1 = 2(f_1 + f_2) - 2f_2 = 2f_1$$

to the right of the lens. The final image formed by the lens is at a distance i'_1 to the left of the lens, where

$$i'_1 = \left(\frac{1}{f_1} - \frac{1}{p'_1}\right)^{-1} = \left(\frac{1}{f_1} - \frac{1}{2f_1}\right)^{-1} = 2f_1.$$

This turns out to be the same as the location of the original object.

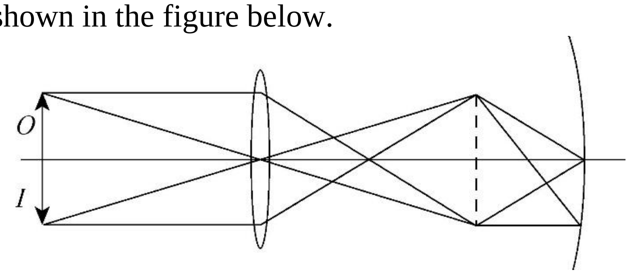
(b) The lateral magnification is

$$m = \left(-\frac{i_1}{p_1}\right)\left(-\frac{i_2}{p_2}\right)\left(-\frac{i'_1}{p'_1}\right) = \left(-\frac{2f_1}{2f_1}\right)\left(-\frac{2f_2}{2f_2}\right)\left(-\frac{2f_1}{2f_1}\right) = -1.0.$$

(c) The final image is real (R).

(d) It is at a distance i'_1 to the left of the lens,

(e) and inverted (I), as shown in the figure below.



88. By Eq. 34-9, $1/i + 1/p$ is equal to constant $(1/f)$. Thus,

$$1/(-10) + 1/(15) = 1/i_{\text{new}} + 1/(70).$$

This leads to $i_{\text{new}} = -21$ cm.