CHAPTER

17 Reflection and Mirrors

Practice Problems

17.1 Reflection from Plane Mirrors pages 457–463

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1. Explain why the reflection of light off ground glass changes from diffuse to specular if you spill water on it.

Water fills in the rough areas and makes the surface smoother.

2. If the angle of incidence of a ray of light is 42°, what is each of the following?

a. the angle of reflection

$\theta_r = \theta_i = 42°$

b. the angle the incident ray makes with the mirror

$\theta_{i,\ mirror} = 90° - \theta_i = 90° - 42° = 48°$

c. the angle between the incident ray and the reflected ray

$\theta_i + \theta_r = 2\theta_i = 84°$

3. If a light ray reflects off a plane mirror at an angle of 35° to the normal, what was the angle of incidence of the ray?

$\theta_i = \theta_r = 35°$

4. Light from a laser strikes a plane mirror at an angle of 38° to the normal. If the laser is moved so that the angle of incidence increases by 13°, what is the new angle of reflection?

$\theta_i = \theta_{i,\ initial} + 13°$
$= 38° + 13° = 51°$

$\theta_r = \theta_i = 51°$

5. Two plane mirrors are positioned at right angles to one another. A ray of light strikes one mirror at an angle of 30° to the normal. It then reflects toward the second mirror. What is the angle of reflection of the light ray off the second mirror?

$\theta_{r1} = \theta_{i1} = 30°$
$\theta_{i2} = 90° - \theta_{r1}$
$= 90° - 30° = 60°$

Section Review

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6. Reflection A light ray strikes a flat, smooth, reflecting surface at an angle of 80° to the normal. What is the angle that the reflected ray makes with the surface of the mirror?

$\theta_r = \theta_i$
$= 80°$

$\theta_{r,\ mirror} = 90° - \theta_r$
$= 90° - 80°$
$= 10°$

7. Law of Reflection Explain how the law of reflection applies to diffuse reflection.

The law of reflection applies to individual rays of light. Rough surfaces make the light rays reflect in many different directions.

8. Reflecting Surfaces Categorize each of the following as a specular or a diffuse reflecting surface: paper, polished metal, window glass, rough metal, plastic milk jug, smooth water surface, and ground glass.

Specular: window glass, smooth water, polished metal. Diffuse: paper, rough metal, ground glass, plastic milk jug.

9. Image Properties A 50-cm-tall dog stands 3 m from a plane mirror and looks at its image. What is the image position, height, and type?

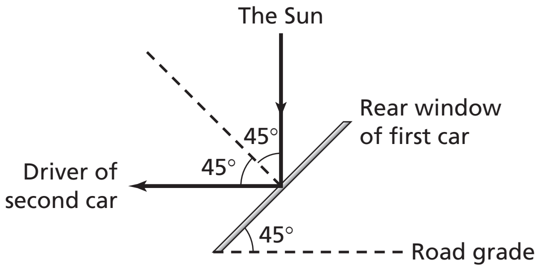
$d_i = d_o$
$= 3$ m

$h_i = h_o$

$= 50\text{ cm}$

The image is virtual.

10. Image Diagram A car is following another car down a straight road. The first car has a rear window tilted 45°. Draw a ray diagram showing the position of the Sun that would cause sunlight to reflect into the eyes of the driver of the second car.



The Sun's position directly overhead would likely reflect light into the driver's eyes, according to the law of reflection.

11. Critical Thinking Explain how diffuse reflection of light off an object enables you to see an object from any angle.

The incoming light reflects off the surface of the object in all directions. This enables you to view the object from any location.

Practice Problems

17.2 Curved Mirrors pages 464–473

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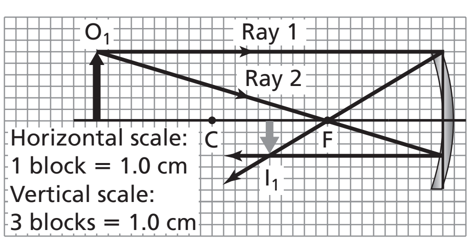
12. Use a ray diagram, drawn to scale, to solve Example Problem 2.



13. An object is 36.0 cm in front of a concave mirror with a 16.0-cm focal length. Determine the image position.

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

$$d_i = \frac{d_o f}{d_o - f}$$

$$= \frac{(36.0\text{ cm})(16.0\text{ cm})}{36.0\text{ cm} - 16.0\text{ cm}}$$

$$= 28.8\text{ cm}$$

14. A 3.0-cm-tall object is 20.0 cm from a 16.0-cm-radius concave mirror. Determine the image position and image height.

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

$$d_i = \frac{d_o f}{d_o - f}$$

$$= \frac{(20.0\text{ cm})\left(\frac{16.0\text{ cm}}{2}\right)}{20.0\text{ cm} - \left(\frac{16.0\text{ cm}}{2}\right)} = 13.3\text{ cm}$$

$$m \equiv \frac{h_i}{h_o} = \frac{-d_i}{d_o}$$

$$h_i = \frac{-d_i h_o}{d_o} = \frac{-(13.3\text{ cm})(3.0\text{ cm})}{20.0\text{ cm}}$$

$$= -2.0\text{ cm}$$

15. A concave mirror has a 7.0-cm focal length. A 2.4-cm-tall object is 16.0 cm from the mirror. Determine the image height.

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

$$d_i = \frac{d_o f}{d_o - f}$$

$$= \frac{(16.0\text{ cm})(7.0\text{ cm})}{16.0\text{ cm} - 7.0\text{ cm}}$$

$$= 12.4\text{ cm}$$

$$m \equiv \frac{h_i}{h_o} = \frac{-d_i}{d_o}$$

$$h_i = \frac{-d_i h_o}{d_o}$$

$$= \frac{-(12.4\text{ cm})(2.4\text{ cm})}{16.0\text{ cm}}$$

$$= -1.9\text{ cm}$$

16. An object is near a concave mirror of 10.0-cm focal length. The image is 3.0 cm tall, inverted, and 16.0 cm from the mirror. What are the object position and object height?

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

$$d_o = \frac{d_i f}{d_i - f}$$

$$= \frac{(16.0\text{ cm})(10.0\text{ cm})}{16.0\text{ cm} - 10.0\text{ cm}}$$

$$= 26.7\text{ cm}$$

$$m \equiv \frac{h_i}{h_o} = \frac{-d_i}{d_o}$$

$$h_o = \frac{-d_o h_i}{d_i}$$

$$= \frac{-(26.7\text{ cm})(-3.0\text{ cm})}{16.0\text{ cm}}$$

$$= 5.0\text{ cm}$$

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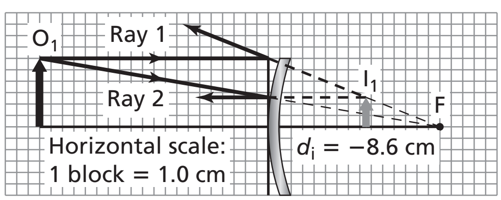
17. An object is located 20.0 cm in front of a convex mirror with a −15.0-cm focal length. Find the image position using both a scale diagram and the mirror equation.



$$\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f}$$

$$\text{so } d_i = \frac{d_o f}{d_o - f}$$

$$= \frac{(20.0\text{ cm})(-15.0\text{ cm})}{20.0\text{ cm} - (-15.0\text{ cm})}$$

$$= -8.57\text{ cm}$$

18. A convex mirror has a focal length of −13.0 cm. A lightbulb with a diameter of 6.0 cm is placed 60.0 cm from the mirror. What is the lightbulb's image position and diameter?

$$\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f}$$

$$d_i = \frac{d_o f}{d_o - f}$$

$$= \frac{(60.0\text{ cm})(-13.0\text{ cm})}{60.0\text{ cm} - (-13.0\text{ cm})}$$

$$= -10.7\text{ cm}$$

$$m \equiv \frac{h_i}{h_o} = \frac{-d_i}{d_o}$$

$$m = \frac{-(-10.7\text{ cm})}{60.0\text{ cm}}$$

$$= +0.178$$

$$h_i = mh_o = (0.178)(6.0\text{ cm})$$

$$= 1.1\text{ cm}$$

19. A convex mirror is needed to produce an image that is three-fourths the size of an object and located 24 cm behind the mirror. What focal length should be specified?

$$\frac{1}{f} = \frac{1}{d_i} + \frac{1}{d_o}$$

$$f = \frac{d_o d_i}{d_o + d_i} \text{ and } m = \frac{-d_i}{d_o}$$

$$\text{so } d_o = \frac{-d_i}{m}$$

$d_i = -24$ cm and $m = 0.75$, so

$$d_o = \frac{-(-24\text{ cm})}{0.75}$$

$$= 32\text{ cm}$$

$$f = \frac{(32\text{ cm})(-24\text{ cm})}{32\text{ cm} + (-24\text{ cm})}$$

$$= -96\text{ cm}$$

20. A 7.6-cm-diameter ball is located 22.0 cm from a convex mirror with a radius of curvature of 60.0 cm. What are the ball's image position and diameter?

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

$$d_i = \frac{d_o f}{d_o - f}$$

$$= \frac{(22.0\text{ cm})(-30.0\text{ cm})}{22.0\text{ cm} - (-30.0\text{ cm})}$$

$$= -12.7\text{ cm}$$

$$m \equiv \frac{h_i}{h_o} = \frac{-d_i}{d_o}$$

$$h_i = \frac{-d_i h_o}{d_o}$$

$$= \frac{-(-12.7\text{ cm})(7.6\text{ cm})}{22.0\text{ cm}}$$

$$= 4.4\text{ cm}$$

21. A 1.8-m-tall girl stands 2.4 m from a store's security mirror. Her image appears to be 0.36 m tall. What is the focal length of the mirror?

$$m = \frac{h_i}{h_o} = \frac{-d_i}{d_o}$$

$$d_i = \frac{-d_o h_i}{h_o}$$

$$= \frac{-(2.4\text{ m})(0.36\text{ m})}{1.8\text{ m}}$$

$$= -0.48\text{ m}$$

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

$$f = \frac{d_i d_o}{d_i + d_o}$$

$$= \frac{(-0.48\text{ m})(2.4\text{ m})}{-0.48\text{ m} + 2.4\text{ m}}$$

$$= -0.60\text{ m}$$

Section Review

17.2 Curved Mirrors pages 464–473

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22. Image Properties If you know the focal length of a concave mirror, where should you place an object so that its image is upright and larger compared to the object? Will this produce a real or virtual image?

You should place the object between the mirror and the focal point. The image will be virtual.

23. Magnification An object is placed 20.0 cm in front of a concave mirror with a focal length of 9.0 cm. What is the magnification of the image?

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

$$d_i = \frac{d_o f}{d_o - f}$$

$$= \frac{(20.0\text{ cm})(9.0\text{ cm})}{20.0\text{ cm} - 9.0\text{ cm}}$$

$$= 16.4\text{ cm}$$

$$m = \frac{-d_i}{d_o}$$

$$= \frac{-16.4\text{ cm}}{20.0\text{ cm}}$$

$$= -0.82$$

24. Object Position The placement of an object in front of a concave mirror with a focal length of 12.0 cm forms a real image that is 22.3 cm from the mirror. What is the object position?

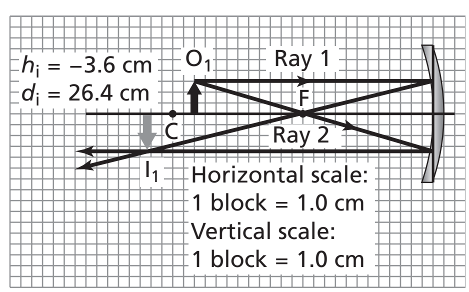
$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

$$d_o = \frac{d_i f}{d_i - f}$$

$$= \frac{(22.3\text{ cm})(12.0\text{ cm})}{22.3\text{ cm} - 12.0\text{ cm}}$$

$$= 26.0\text{ cm}$$

25. Image Position and Height A 3.0-cm-tall object is placed 22.0 cm in front of a concave mirror having a focal length of 12.0 cm. Find the image position and height by drawing a ray diagram to scale. Verify your answer using the mirror and magnification equations.



$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

$$d_i = \frac{d_o f}{d_o - f}$$

$$= \frac{(22.0\text{ cm})(12.0\text{ cm})}{22.0\text{ cm} - 12.0\text{ cm}}$$

$$= 26.4\text{ cm}$$

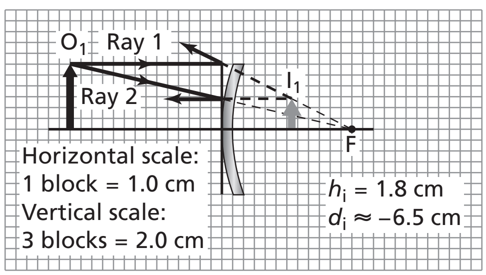
$$m \equiv \frac{h_i}{h_o} = \frac{-d_i}{d_o}$$

$$h_i = \frac{-d_i h_o}{d_o}$$

$$= \frac{-(26.4\text{ cm})(3.0\text{ cm})}{22.0\text{ cm}}$$

$$= -3.6\text{ cm}$$

26. Ray Diagram A 4.0-cm-tall object is located 14.0 cm from a convex mirror with a focal length of −12.0 cm. Draw a scale ray diagram showing the image position and height. Verify your answer using the mirror and magnification equations.



$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

$$d_i = \frac{d_o f}{d_o - f}$$

$$= \frac{(14.0\text{ cm})(-12.0\text{ cm})}{14.0\text{ cm} - (-12.0\text{ cm})}$$

$$= -6.46\text{ cm}$$

$$m \equiv \frac{h_i}{h_o} = \frac{-d_i}{d_o}$$

$$h_i = \frac{-d_i h_o}{d_o}$$

$$= \frac{-(-6.46\text{ cm})(4.0\text{ cm})}{14.0\text{ cm}}$$

$$= 1.8\text{ cm}$$

27. Radius of Curvature A 6.0-cm-tall object is placed 16.4 cm from a convex mirror. If the image of the object is 2.8 cm tall, what is the radius of curvature of the mirror?

$$m \equiv \frac{h_i}{h_o} = \frac{-d_i}{d_o}$$

$$d_i = \frac{-d_o h_i}{h_o}$$

$$= \frac{-(16.4\text{ cm})(2.8\text{ cm})}{6.0\text{ cm}}$$

$$= -7.7\text{ cm}$$

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

$$f = \frac{d_o d_i}{d_o + d_i}$$

$$= \frac{(-7.7\text{ cm})(16.4\text{ cm})}{-7.7\text{ cm} + 16.4\text{ cm}}$$

$$= -14.5\text{ cm}$$

$$r = 2|f|$$

$$= (2)(|-14.5\text{ cm}|)$$

$$= 29\text{ cm}$$

28. Focal Length A convex mirror is used to produce an image that is two-thirds the size of an object and located 12 cm behind the mirror. What is the focal length of the mirror?

$$m = \frac{h_i}{h_o} = \frac{-d_i}{d_o}$$

$$d_o = \frac{-d_i}{m}$$

$$= \frac{-(-12\text{ cm})}{\left(\frac{2}{3}\right)}$$

$$= 18\text{ cm}$$

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

$$f = \frac{d_o d_i}{d_o + d_i}$$

$$= \frac{(-12\text{ cm})(18\text{ cm})}{-12\text{ cm} + 18\text{ cm}}$$

$$= -36\text{ cm}$$

29. Critical Thinking Would spherical aberration be less for a mirror whose height, compared to its radius of curvature, is small or large? Explain.

It would be less for a mirror whose height is relatively small compared to

its radius of curvature; diverging light rays from an object that strike the mirror are more paraxial so they converge more closely to create an image that is not blurred.

Chapter Assessment

Concept Mapping

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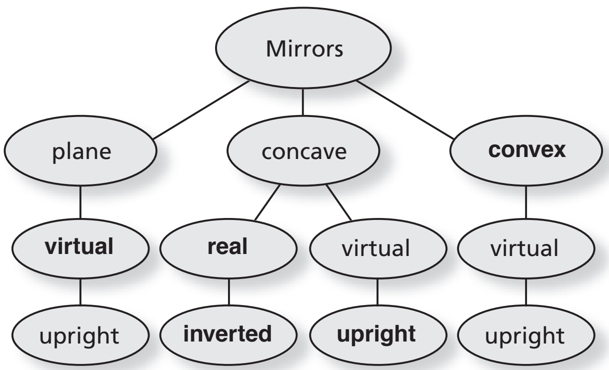
30. Complete the following concept map using the following terms: *convex, upright, inverted, real, virtual.*



Mastering Concepts

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31. How does specular reflection differ from diffuse reflection? (17.1)

When parallel light is reflected from a smooth surface, the rays are reflected parallel to each other. The result is an image of the origin of the rays. When light is reflected from a rough surface, it is reflected in many different directions. The rays are diffused or scattered. No image of the source results.

32. What is meant by the phrase "normal to the surface"? (17.1)

any line that is perpendicular to the surface at any point

33. Where is the image produced by a plane mirror located? (17.1)

The image is on a line that is perpendicular to the mirror and the same distance behind the mirror as the object is in front of the mirror.

34. Describe the properties of a plane mirror. (17.1)

A plane mirror is a flat, smooth surface from which light is reflected by specular reflection. The images created by plane mirrors are virtual, upright, and as far behind the mirror as the object is in front of it.

35. A student believes that very sensitive photographic film can detect a virtual image. The student puts photographic film at the location of a virtual image. Does this attempt succeed? Explain. (17.1)

No, the rays do not converge at a virtual image. No image forms and the student would not get a picture. Some virtual images are behind the mirror.

36. How can you prove to someone that an image is a real image? (17.1)

Place a sheet of plain paper or photographic film at the image location and you should be able to find the image.

37. An object produces a virtual image in a concave mirror. Where is the object located? (17.2)

Object must be located between F and the mirror.

38. What is the defect that all concave spherical mirrors have and what causes it? (17.2)

Rays parallel to the axis that strike the edges of a concave spherical mirror are not reflected through the focal point. This effect is called spherical aberration.

39. What is the equation relating the focal point, object position, and image position? (17.2)

$$\frac{1}{f} = \frac{1}{d_i} + \frac{1}{d_o}$$

40. What is the relationship between the center of curvature and the focal length of a concave mirror? (17.2)

$C = 2f$

41. If you know the image position and object position relative to a curved mirror, how can you determine the mirror's magnification? (17.2)

The magnification is equal to the negative of the image distance divided by the object distance.

42. Why are convex mirrors used as rearview mirrors? (17.2)

Convex mirrors are used as rearview mirrors because they allow for a wide range of view, allowing the driver to see a much larger area than is afforded by ordinary mirrors.

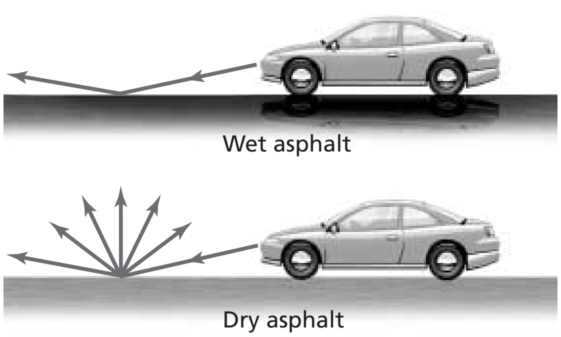
43. Why is it impossible for a convex mirror to form a real image? (17.2)

The light rays always diverge.

Applying Concepts

pages 478–479

44. Wet Road A dry road is more of a diffuse reflector than a wet road. Based on **Figure 17-16,** explain why a wet road appears blacker to a driver than a dry road does.



■ **Figure 17-16**

Less light is reflected back to the car from a wet road.

45. Book Pages Why is it desirable that the pages of a book be rough rather than smooth and glossy?

The smoother and glossier the pages are, the lesser the diffuse reflection of light and the greater the glare from the pages.

46. Locate and describe the physical properties of the image produced by a concave mirror when the object is located at the center of curvature.

The image will be at *C,* the center of curvature, inverted, real, and the same size as the object.

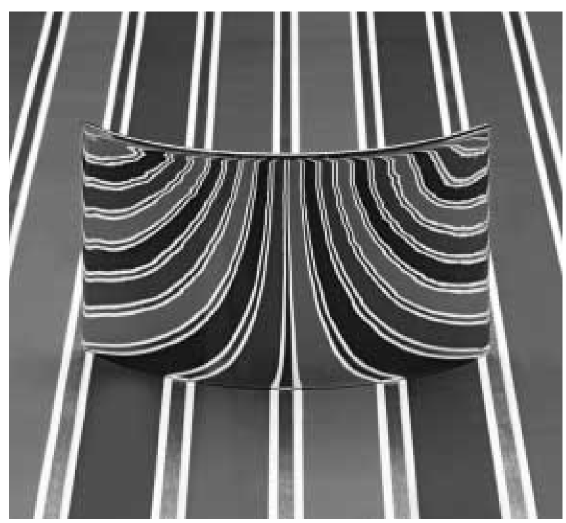
47. An object is located beyond the center of curvature of a spherical concave mirror. Locate and describe the physical properties of the image.

The image will be between *C* and *F,* and will be inverted, real, and smaller than the object.

48. Telescope You have to order a large concave mirror for a telescope that produces high-quality images. Should you order a spherical mirror or a parabolic mirror? Explain.

You should order a parabolic mirror to eliminate spherical aberrations.

49. Describe the properties of the image seen in the single convex mirror in **Figure 17-17.**



■ **Figure 17-17**

The image in a single convex mirror is always virtual, erect, smaller than the object, and located closer to the mirror than the object.

50. List all the possible arrangements in which you could use a spherical mirror, either concave or convex, to form a real image.

You can use only a concave mirror with the object beyond the focal point. A convex mirror will not form a real image.

51. List all possible arrangements in which you could use a spherical mirror, either concave or convex, to form an image that is smaller compared to the object.

You may use a concave mirror with the object beyond the center of curvature or a convex mirror with the object anywhere.

52. **Rearview Mirrors** The outside rearview mirrors of cars often carry the warning "Objects in the mirror are closer than they appear." What kind of mirrors are these and what advantage do they have?

Convex mirror; it provides a wider field of view.

Mastering Problems

17.1 Reflection from Plane Mirrors

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Level 1

53. A ray of light strikes a mirror at an angle of 38° to the normal. What is the angle that the reflected angle makes with the normal?

$\theta_r = \theta_i$

$= 38°$

54. A ray of light strikes a mirror at an angle of 53° to the normal.

a. What is the angle of reflection?

$\theta_r = \theta_i$

$= 53°$

b. What is the angle between the incident ray and the reflected ray?

$\theta = \theta_i + \theta_r$

$= 53° + 53°$

$= 106°$

55. A ray of light incident upon a mirror makes an angle of 36° with the mirror. What is the angle between the incident ray and the reflected ray?

$\theta_i = 90° - 36°$

$= 54°$

$\theta_r = \theta_i$

$= 54°$

$\theta = \theta_i + \theta_r$

$= 54° + 54°$

$= 108°$

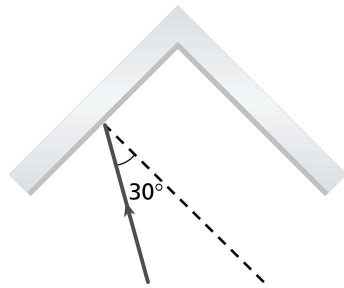
Level 2

56. **Picture in a Mirror** Penny wishes to take a picture of her image in a plane mirror, as shown in **Figure 17-18.** If the camera is 1.2 m in front of the mirror, at what distance should the camera lens be focused?

■ **Figure 17-18**

The image is 1.2 m behind the mirror, so the camera lens should be set to 2.4 m.

57. Two adjacent plane mirrors form a right angle, as shown in **Figure 17-19.** A light ray is incident upon one of the mirrors at an angle of 30° to the normal.



■ **Figure 17-19**

a. What is the angle at which the light ray is reflected from the other mirror?

Reflection from the first mirror:

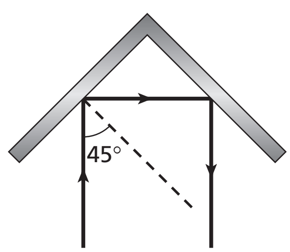
$\theta_{r1} = \theta_{i1} = 30°$

Reflection from the second mirror:

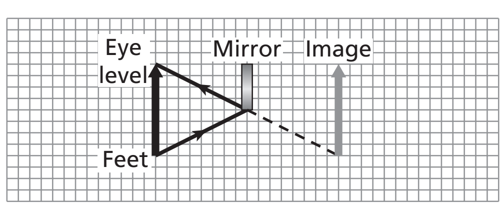
$$\theta_{i2} = 90° - \theta_{r1} = 90° - 30° = 60°$$

$$\theta_{r2} = \theta_{i2} = 60°$$

b. A retroreflector is a device that reflects incoming light rays back in a direction opposite to that of the incident rays. Draw a diagram showing the angle of incidence on the first mirror for which the mirror system acts as a retroreflector.



58. Draw a ray diagram of a plane mirror to show that if you want to see yourself from your feet to the top of your head, the mirror must be at least half your height.



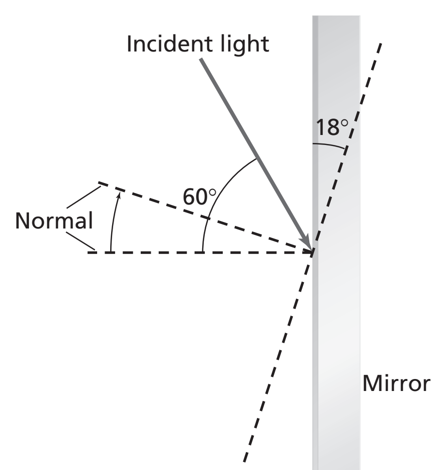
The ray from the top of the head hits the mirror halfway between the eyes and the top of the head. The ray from the feet hits the mirror halfway between the eyes and the feet. The distance between the point the two rays hit the mirror is half the total height.

Level 3

59. Two plane mirrors are connected at their sides so that they form a 45° angle between them. A light ray strikes one mirror at an angle of 30° to the normal and then reflects off the second mirror. Calculate the angle of reflection of the light ray off the second mirror.

Reflection from the first mirror is $\theta_{r,1} = \theta_{i,1} = 30°$. The angle the ray forms with the mirror is thus 90° − 30° = 60°. Because the two mirrors form a 45° angle, the angle the ray reflecting off the first mirror forms with the second mirror is 180° − 60° − 45° = 75°. The angle the ray forms with the second mirror is thus $\theta_{i,2}$ = 90° − 75° = 15°. The angle of reflection from the second mirror is $\theta_{r,2} = \theta_{i,2}$ = 15°.

60. A ray of light strikes a mirror at an angle of 60° to the normal. The mirror is then rotated 18° clockwise, as shown in **Figure 17-20.** What is the angle that the reflected ray makes with the mirror?



■ **Figure 17-20**

$$\theta_i = \theta_{i,old} - 18° = 60° - 18° = 42°$$

$$\theta_r = \theta_i$$
$$= 42°$$

$$\theta_{r,\ mirror} = 90° - \theta_r$$
$$= 90° - 42°$$
$$= 48°$$

17.2 Curved Mirrors

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Level 1

61. A concave mirror has a focal length of 10.0 cm. What is its radius of curvature?

$$r = 2f = 2(10.0 \text{ cm}) = 20.0 \text{ cm}$$

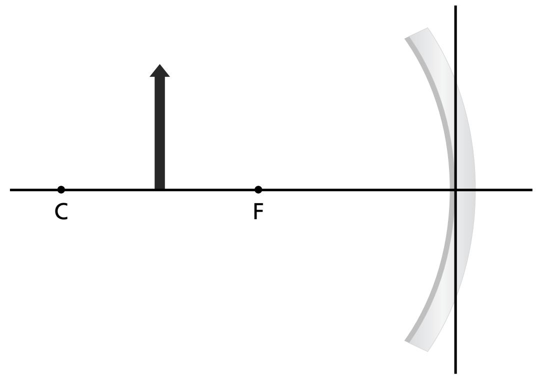
62. An object located 18 cm from a convex mirror produces a virtual image 9 cm from the mirror. What is the magnification of the image?

$$m = \frac{-d_i}{d_o}$$
$$= \frac{-(-9 \text{ cm})}{18 \text{ cm}}$$
$$= 0.5$$

63. **Fun House** A boy is standing near a convex mirror in a fun house at a fair. He notices that his image appears to be 0.60 m tall. If the magnification of the mirror is $\frac{1}{3}$, what is the boy's height?

$$m = \frac{h_i}{h_o}$$
$$h_o = \frac{h_i}{m}$$
$$= \frac{0.60 \text{ m}}{\left(\frac{1}{3}\right)}$$
$$= 1.8 \text{ m}$$

64. Describe the image produced by the object in **Figure 17-21** as real or virtual, inverted or upright, and smaller or larger than the object.



■ **Figure 17-21**

real; inverted; larger

Level 2

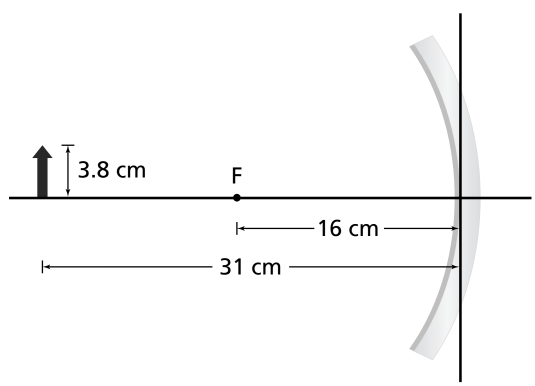
65. **Star Image** Light from a star is collected by a concave mirror. How far from the mirror is the image of the star if the radius of curvature is 150 cm?

Stars are far enough away that the light coming into the mirror can be considered to be parallel and parallel light will converge at the focal point.

Since $r = 2f$,

$$f = \frac{r}{2} = \frac{150 \text{ cm}}{2} = 75 \text{ cm}$$

66. Find the image position and height for the object shown in **Figure 17-22.**



■ **Figure 17-22**

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$
$$d_i = \frac{d_o f}{d_o - f}$$
$$= \frac{(31 \text{ cm})(16 \text{ cm})}{31 \text{ cm} - 16 \text{ cm}}$$

$$= 33\text{ cm}$$

$$m \equiv \frac{h_i}{h_o} = \frac{-d_i}{d_o}$$

$$h_i = \frac{-d_i h_o}{d_o}$$

$$= \frac{-(33\text{ cm})(3.8\text{ cm})}{31\text{ cm}}$$

$$= -4.1\text{ cm}$$

67. **Rearview Mirror** How far does the image of a car appear behind a convex mirror, with a focal length of −6.0 m, when the car is 10.0 m from the mirror?

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

$$d_i = \frac{d_o f}{d_o - f}$$

$$= \frac{(10.0\text{ m})(-6.0\text{ m})}{10.0\text{ m} - (-6.0\text{ m})}$$

$$= -3.8\text{ m}$$

68. An object is 30.0 cm from a concave mirror of 15.0 cm focal length. The object is 1.8 cm tall. Use the mirror equation to find the image position. What is the image height?

$$\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f}$$

$$d_i = \frac{d_o f}{d_o - f}$$

$$= \frac{(30.0\text{ cm})(15.0\text{ cm})}{30.0\text{ cm} - 15.0\text{ cm}}$$

$$= 30.0\text{ cm}$$

$$m \equiv \frac{h_i}{h_o} = \frac{-d_i}{d_o}$$

$$h_i = \frac{-d_i h_o}{d_o}$$

$$= \frac{-(30.0\text{ cm})(1.8\text{ cm})}{(30.0\text{ cm})}$$

$$= -1.8\text{ cm}$$

69. **Dental Mirror** A dentist uses a small mirror with a radius of 40 mm to locate a cavity in a patient's tooth. If the mirror is concave and is held 16 mm from the tooth, what is the magnification of the image?

$$f = \frac{r}{2} = \frac{(40\text{ mm})}{2} = 20\text{ mm}$$

$$\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f}$$

$$d_i = \frac{d_o f}{d_o - f} = \frac{(16\text{ mm})(20\text{ mm})}{16\text{ mm} - 20\text{ mm}} = -80\text{ mm}$$

$$m = \frac{-d_i}{d_o} = \frac{-(-80\text{ mm})}{16\text{ mm}} = 5$$

70. A 3.0-cm-tall object is 22.4 cm from a concave mirror. If the mirror has a radius of curvature of 34.0 cm, what are the image position and height?

$$f = \frac{r}{2}$$

$$= \frac{34.0\text{ cm}}{2}$$

$$= 17.0\text{ cm}$$

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

$$d_i = \frac{d_o f}{d_o - f}$$

$$= \frac{(22.4\text{ cm})(17.0\text{ cm})}{22.4\text{ cm} - 17.0\text{ cm}}$$

$$= 70.5\text{ cm}$$

$$m = \frac{h_i}{h_o} = \frac{-d_i}{d_o}$$

$$h_i = \frac{-d_i h_o}{d_o}$$

$$= \frac{-(70.5\text{ cm})(3.0\text{ cm})}{22.4\text{ cm}}$$

$$= -9.4\text{ cm}$$

Level 3

71. **Jeweler's Mirror** A jeweler inspects a watch with a diameter of 3.0 cm by placing it 8.0 cm in front of a concave mirror of 12.0-cm focal length.

a. Where will the image of the watch appear?

$$\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f}$$

$$d_i = \frac{d_o f}{d_o - f} = \frac{(8.0\ \text{cm})(12.0\ \text{cm})}{8.0\ \text{cm} - 12.0\ \text{cm}}$$

$$= -24\ \text{cm}$$

b. What will be the diameter of the image?

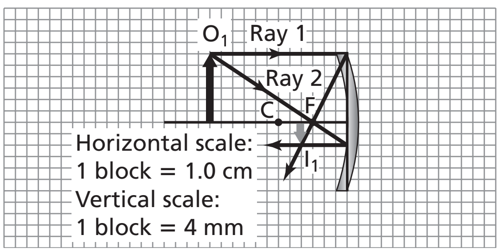
$$\frac{h_i}{h_o} = \frac{-d_i}{d_o}$$

$$h_i = \frac{-d_i h_o}{d_o} = \frac{-(-24\ \text{cm})(3.0\ \text{cm})}{8.0\ \text{cm}}$$

$$= 9.0\ \text{cm}$$

72. Sunlight falls on a concave mirror and forms an image that is 3.0 cm from the mirror. An object that is 24 mm tall is placed 12.0 cm from the mirror.

a. Sketch the ray diagram to show the location of the image.



b. Use the mirror equation to calculate the image position.

$$\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f}$$

$$d_i = \frac{f d_o}{d_o - f} = \frac{(3.0\ \text{cm})(12.0\ \text{cm})}{12.0\ \text{cm} - 3.0\ \text{cm}}$$

$$= 4.0\ \text{cm}$$

c. How tall is the image?

$$m = \frac{-d_i}{d_o} = \frac{-4.0\ \text{cm}}{12.0\ \text{cm}} = -0.33$$

$$h_i = m h_o = (-0.33)(24\ \text{mm})$$

$$= -8.0\ \text{mm}$$

73. Shiny spheres that are placed on pedestals on a lawn are convex mirrors. One such sphere has a diameter of 40.0 cm. A 12-cm-tall robin sits in a tree that is 1.5 m from the sphere. Where is the image of the robin and how tall is the image?

$r = 20.0\ \text{cm}, f = -10.0\ \text{cm}$

$$\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f}$$

$$d_i = \frac{f d_o}{d_o - f}$$

$$= \frac{(-10.0\ \text{cm})(150\ \text{cm})}{150\ \text{cm} - (-10.0\ \text{cm})} = -9.4\ \text{cm}$$

$$m = \frac{-d_i}{d_o} = \frac{-(-9.4\ \text{cm})}{150\ \text{cm}} = +0.063$$

$$h_i = m h_o = (0.063)(12\ \text{cm}) = 0.75\ \text{cm}$$

Mixed Review

pages 480–481

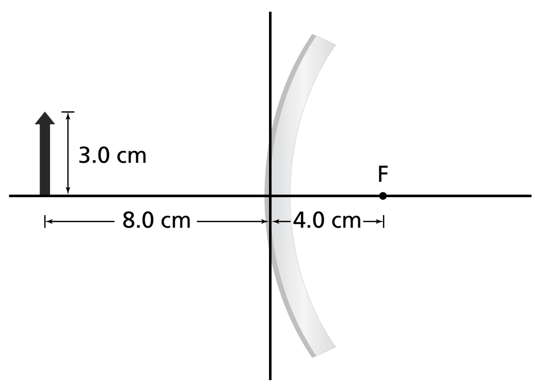
Level 1

74. A light ray strikes a plane mirror at an angle of 28° to the normal. If the light source is moved so that the angle of incidence increases by 34°, what is the new angle of reflection?

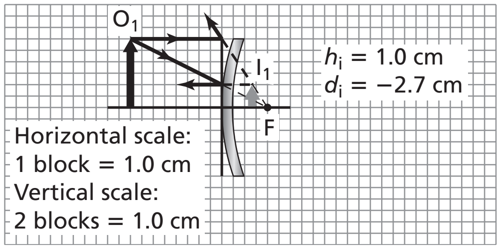
$$\theta_i = \theta_{i,\ \text{initial}} + 34°$$
$$= 28° + 34°$$
$$= 62°$$

$$\theta_r = \theta_i$$
$$= 62°$$

75. Copy **Figure 17-23** on a sheet of paper. Draw rays on the diagram to determine the height and location of the image.



■ **Figure 17-23**



The image height is 1.0 cm, and its location is 2.7 cm from the mirror.

Level 2

76. An object is located 4.4 cm in front of a concave mirror with a 24.0-cm radius. Locate the image using the mirror equation.

$$f = \frac{r}{2}$$
$$= \frac{24.0\text{ cm}}{2}$$
$$= 12.0\text{ cm}$$
$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$
$$d_i = \frac{d_o f}{d_o - f}$$
$$= \frac{(4.4\text{ cm})(12.0\text{ cm})}{4.4\text{ cm} - 12.0\text{ cm}}$$
$$= -6.9\text{ cm}$$

77. A concave mirror has a radius of curvature of 26.0 cm. An object that is 2.4 cm tall is placed 30.0 cm from the mirror.

a. Where is the image position?

$$f = \frac{r}{2}$$
$$= \frac{26.0\text{ cm}}{2}$$
$$= 13.0\text{ cm}$$
$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$
$$d_i = \frac{d_o f}{d_o - f}$$
$$= \frac{(30.0\text{ cm})(13.0\text{ cm})}{30.0\text{ cm} - 13.0\text{ cm}}$$
$$= 22.9\text{ cm}$$

b. What is the image height?

$$m = \frac{h_i}{h_o}$$
$$h_i = \frac{-d_i h_o}{d_o}$$
$$= \frac{-(22.9\text{ cm})(2.4\text{ cm})}{30.0\text{ cm}}$$
$$= -1.8\text{ cm}$$

78. What is the radius of curvature of a concave mirror that magnifies an object by a factor of +3.2 when the object is placed 20.0 cm from the mirror?

$$m = \frac{h_i}{h_o}$$
$$d_i = -md_o$$
$$= -(3.2)(20.0\text{ cm})$$
$$= -64\text{ cm}$$
$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$
$$f = \frac{d_o d_i}{d_o + d_i}$$
$$= \frac{(20.0\text{ cm})(-64\text{ cm})}{20.0\text{ cm} + (-64\text{ cm})}$$
$$= 29\text{ cm}$$
$$r = 2f$$
$$= (2)(29\text{ cm})$$
$$= 58\text{ cm}$$

79. A convex mirror is needed to produce an image one-half the size of an object and located 36 cm behind the mirror. What focal length should the mirror have?

$$m = \frac{h_i}{h_o} = \frac{-d_i}{d_o}$$
$$d_o = \frac{-d_i h_o}{h_i}$$
$$= \frac{-(-36\text{ cm})h_o}{\left(\frac{h_o}{2}\right)}$$
$$= 72\text{ cm}$$
$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

$$f = \frac{d_o d_i}{d_o + d_i}$$

$$= \frac{(72\text{ cm})(-36\text{ cm})}{72\text{ cm} + (-36\text{ cm})}$$

$$= -72\text{ cm}$$

80. **Surveillance Mirror** A convenience store uses a surveillance mirror to monitor the store's aisles. Each mirror has a radius of curvature of 3.8 m.

a. What is the image position of a customer who stands 6.5 m in front of the mirror?

A mirror that is used for surveillance is a convex mirror. So the focal length is the negative of half the radius of curvature.

$$f = \frac{-r}{2}$$

$$= \frac{-3.8\text{ m}}{2}$$

$$= -1.9\text{ m}$$

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

$$d_i = \frac{d_o f}{d_o - f}$$

$$= \frac{(6.5\text{ m})(-1.9\text{ m})}{6.5\text{ m} - (-1.9\text{ m})}$$

$$= -1.5\text{ m}$$

b. What is the image height of a customer who is 1.7 m tall?

$$m = \frac{h_i}{h_o} = \frac{-d_i}{d_o}$$

$$h_i = \frac{-d_i h_o}{d_o}$$

$$= \frac{-(-1.5\text{ m})(1.7\text{ m})}{6.5\text{ m}}$$

$$= 0.38\text{ m}$$

Level 3

81. **Inspection Mirror** A production-line inspector wants a mirror that produces an image that is upright with a magnification of 7.5 when it is located 14.0 mm from a machine part.

a. What kind of mirror would do this job?

An enlarged, upright image results only from a concave mirror, with the object inside the focal length.

b. What is its radius of curvature?

$$m = \frac{-d_i}{d_o}$$

$$d_i = -md_o = -(7.5)(14.0\text{ mm})$$

$$= -105\text{ mm}$$

$$\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f}$$

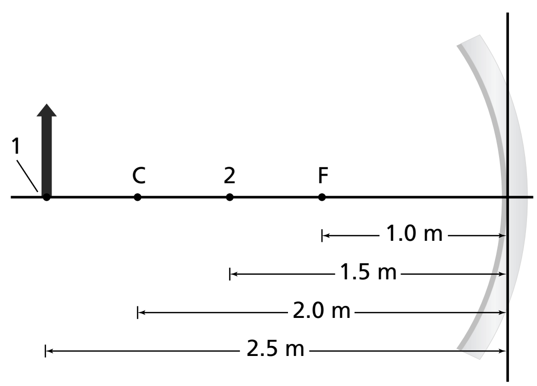
$$f = \frac{d_o d_i}{d_i + d_o} = \frac{(14.0\text{ mm})(-105\text{ mm})}{14.0\text{ mm} + (-105\text{ mm})}$$

$$= 16\text{ mm}$$

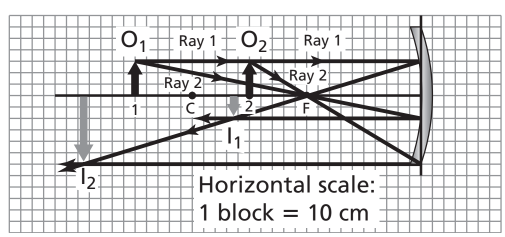
$$r = 2f = (2)(16\text{mm})$$

$$= 32\text{ mm}$$

82. The object in **Figure 17-24** moves from position 1 to position 2. Copy the diagram onto a sheet of paper. Draw rays showing how the image changes.



■ **Figure 17-24**



83. A ball is positioned 22 cm in front of a spherical mirror and forms a virtual image. If the spherical mirror is replaced with a plane mirror, the image appears 12 cm closer to the mirror. What kind of spherical mirror was used?

The object position for both mirrors is 22 cm. So, the image position for the plane mirror is −22 cm.

Because the spherical mirror forms a virtual image, the image is located behind the mirror. Thus, the image position for the spherical mirror is negative.

$$d_i = d_{i,\ plane} - 12\ cm$$
$$= -22\ cm - 12\ cm$$
$$= -34\ cm$$

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

$$f = \frac{d_o d_i}{d_o + d_i}$$
$$= \frac{(22\ cm)(-34\ cm)}{22\ cm + (-34\ cm)}$$
$$= 62\ cm$$

The focal length is positive, so the spherical mirror is a concave mirror.

84. A 1.6-m-tall girl stands 3.2 m from a convex mirror. What is the focal length of the mirror if her image appears to be 0.28 m tall?

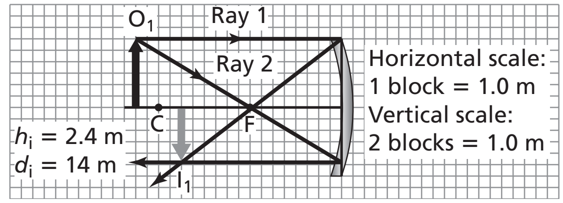
$$m = \frac{h_i}{h_o} = \frac{-d_i}{d_o}$$

$$d_i = \frac{-h_i d_o}{h_o}$$
$$= \frac{-(0.28\ m)(3.2\ m)}{1.6\ m}$$
$$= -0.56\ m$$

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

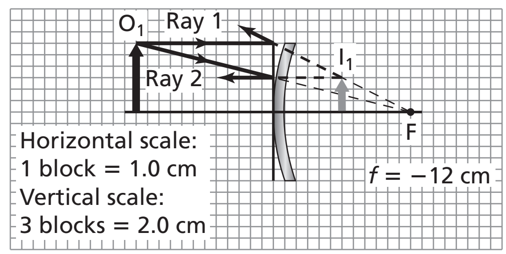
$$f = \frac{d_o d_i}{d_o + d_i}$$
$$= \frac{(3.2\ m)(-0.56\ m)}{3.2\ m + (-0.56\ m)}$$
$$= -0.68\ m$$

85. **Magic Trick** A magician uses a concave mirror with a focal length of 8.0 m to make a 3.0-m-tall hidden object, located 18.0 m from the mirror, appear as a real image that is seen by his audience. Draw a scale ray diagram to find the height and location of the image.



The image is 2.4 m tall, and it is 14 m from the mirror.

86. A 4.0-cm-tall object is placed 12.0 cm from a convex mirror. If the image of the object is 2.0 cm tall, and the image is located at −6.0 cm, what is the focal length of the mirror? Draw a ray diagram to answer the question. Use the mirror equation and the magnification equation to verify your answer.



$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

$$f = \frac{d_o d_i}{d_o + d_i}$$
$$= \frac{(12.0\ cm)(-6.0\ cm)}{12.0\ cm + (-6.0\ cm)}$$
$$= -12\ cm$$

Thinking Critically

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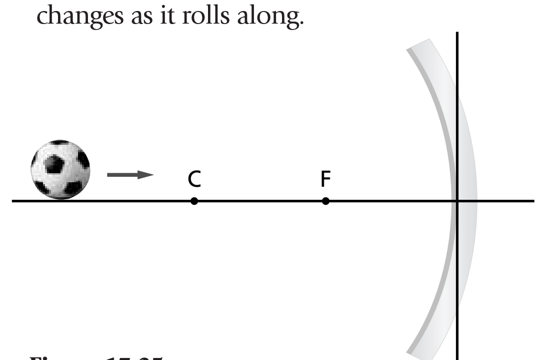
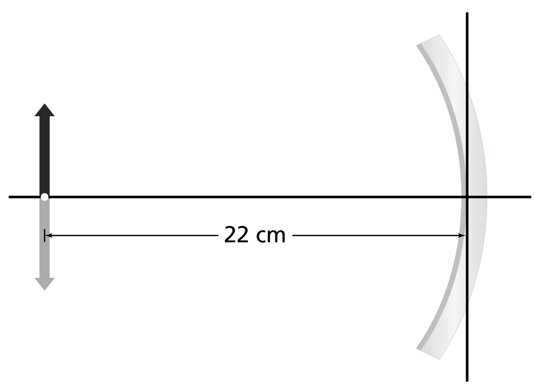
87. **Apply Concepts** The ball in **Figure 17-25** slowly rolls toward the concave mirror on the right. Describe how the size of the ball's image changes as it rolls along.



■ **Figure 17-25**

Beyond C, the image is smaller than the ball. As the ball rolls toward the mirror, the image size increases. The image is the same size as the ball when the ball is at C. The image size continues to increase until there is no image when the ball is at F. Past F, the size of the image decreases until it equals the ball's size when the ball touches the mirror.

88. Analyze and Conclude The object in **Figure 17-26** is located 22 cm from a concave mirror. What is the focal length of the mirror?



■ **Figure 17-26**

$$f = \frac{r}{2}$$
$$= \frac{d_o}{2}$$
$$= \frac{22\text{ cm}}{2}$$
$$= 11\text{ cm}$$

89. Use Equations Show that as the radius of curvature of a concave mirror increases to infinity, the mirror equation reduces to the relationship between the object position and the image position for a plane mirror.

As $f \to \infty$, $1/f \to 0$. The mirror equation then becomes $1/d_o = -1/d_i$, or $d_o = -d_i$.

90. Analyze and Conclude An object is located 6.0 cm from a plane mirror. If the plane mirror is replaced with a concave mirror, the resulting image is 8.0 cm farther behind the mirror. Assuming that the object is located between the focal point and the concave mirror, what is the focal length of the concave mirror?

$$d_{i,\text{ initial}} = d_{o,\text{ initial}}$$
$$= 6.0\text{ cm}$$

$$d_i = d_{i,\text{ initial}} + (-8.0\text{ cm})$$
$$= -6.0\text{ cm} + (-8.0\text{ cm})$$
$$= -14.0\text{ cm}$$

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

$$f = \frac{d_o d_i}{d_o + d_i}$$

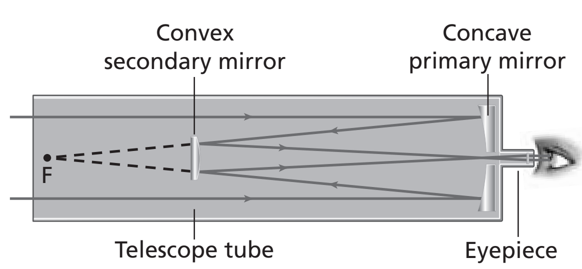
$$f = \frac{(6.0\text{ cm})(-14.0\text{ cm})}{6.0\text{ cm} + (-14.0\text{ cm})}$$

$$f = 1.0\times10^1\text{ cm}$$

91. Analyze and Conclude The layout of the two-mirror system shown in Figure 17-11 is that of a Gregorian telescope. For this question, the larger concave mirror has a radius of curvature of 1.0 m, and the smaller mirror is located 0.75 m away. Why is the secondary mirror concave?

The smaller mirror is concave to produce a real image at the eyepiece that is upright. The light rays are inverted by the first concave mirror and then inverted again by the secondary concave mirror.

92. Analyze and Conclude An optical arrangement used in some telescopes is the Cassegrain focus, shown in **Figure 17-27.** This telescope uses a convex secondary mirror that is positioned between the primary mirror and the focal point of the primary mirror.



■ **Figure 17-27**

a. A single convex mirror produces only virtual images. Explain how the convex mirror in this telescope functions within the system of mirrors to produce real images.

The convex mirror is placed to intercept the rays from a concave mirror before they converge. The convex mirror places the point of convergence in the opposite direction back toward the concave mirror, and lengthens the total distance the light travels before converging. This effectively increases the focal length compared to using the concave mirror by itself, thus increasing the total magnification.

b. Are the images produced by the Cassegrain focus upright or inverted? How does this relate to the number of times that the light crosses?

Inverted; each time the light rays cross the image inverts.

Writing in Physics

page 482

93. Research a method used for grinding, polishing, and testing mirrors used in reflecting telescopes. You may report either on methods used by amateur astronomers who make their own telescope optics, or on a method used by a project at a national laboratory. Prepare a one-page report describing the method, and present it to the class.

Answers will vary depending on the mirrors and methods chosen by the students. Amateur methods usually involve rubbing two "blanks" against each other with varying grits between them. Methods used at national labs vary.

94. Mirrors reflect light because of their metallic coating. Research and write a summary of one of the following:

a. the different types of coatings used and the advantages and disadvantages of each

Answers will vary. Student answers should include information about shininess as well as tarnish resistance.

b. the precision optical polishing of aluminum to such a degree of smoothness that no glass is needed in the process of making a mirror

Answers will vary. Student answers might include information about deformation of a mirror from its own weight as size increases and how a mirror made of aluminum could impact this problem.

Cumulative Review

page 482

95. A child runs down the school hallway and then slides on the newly waxed floor. He was running at 4.7 m/s before he started sliding and he slid 6.2 m before stopping. What was the coefficient of friction of the waxed floor? (Chapter 11)

The work done by the waxed floor equals the child's initial kinetic energy.

$$KE = \frac{1}{2}mv^2 = W = Fd = \mu_k mgd$$

The mass of the child cancels out, giving

$$\mu_k = \frac{v^2}{2gd} = \frac{(4.7\text{ m/s})^2}{(2)(9.80\text{ m/s}^2)(6.2\text{ m})} = 0.18$$

96. A 1.0 g piece of copper falls from a height of 1.0×10^4 m from an airplane to the ground. Because of air resistance it reaches the ground moving at a velocity of 70.0 m/s. Assuming that half of the energy lost by the piece was distributed as thermal energy to the copper, how much did it heat during the fall? (Chapter 12)

Potential energy of the piece

$$E = mgh = (0.0010\text{ kg})(9.80\text{ m/s}^2)(1.0\times10^4\text{ m}) = 9.8\text{ J}$$

Final energy

$$E_f = \frac{1}{2}mv^2 = \frac{1}{2}(0.0010\text{ kg})(70.0\text{ m/s})^2 = 2.4\text{ J}$$

Heat added to the piece

$Q = \frac{1}{2}(E - E_f)$

$= \frac{1}{2}(9.8\ \text{J} - 2.4\ \text{J})$

$= 3.7\ \text{J}$

$\Delta T = \frac{Q}{mc}$

$= \frac{3.7\ \text{J}}{(0.0010\ \text{kg})(385\ \text{J/kg°C})}$

$= 9.5°\text{C}$

97. It is possible to lift a person who is sitting on a pillow made from a large sealed plastic garbage bag by blowing air into the bag through a soda straw. Suppose that the cross-sectional area of the person sitting on the bag is 0.25 m^2 and the person's weight is 600 N. The soda straw has a cross-sectional area of 2×10^{-5} m^2. With what pressure must you blow into the straw to lift the person that is sitting on the sealed garbage bag? (Chapter 13)

Apply Pascal's principle.

$\Delta F_2 = \Delta F_1\frac{A_1}{A_2}$

$= (600\ \text{N})\left(\frac{2\times10^{-5}\ \text{m}^2}{0.25\ \text{m}^2}\right) = 0.048\ \text{N}$

$\Delta P = \frac{\Delta F_2}{A_2} = \frac{0.048\ \text{N}}{2\times10^{-5}\ \text{m}^2} = 2.4\ \text{kPa}$

or 2 kPa to one significant digit

not a very large pressure at all

98. What would be the period of a 2.0-m-long pendulum on the Moon's surface? The Moon's mass is 7.34×10^{22} kg, and its radius is 1.74×10^6 m. What is the period of this pendulum on Earth? (Chapter 14)

$g_m = \frac{Gm_m}{d^2{}_m}$

$= \frac{(6.67\times10^{-11}}{\text{N·m}^2\text{/kg}^2)(7.34\times10^{22}\ \text{kg})}$

$= 1.62\ \text{m/s}^2$

$T_{\text{Moon}} = 2\pi\sqrt{\frac{l}{g}} = 2\pi\sqrt{\frac{2.0\ \text{m}}{1.62\ \text{m/s}^2}} = 7.0\ \text{s}$

$T_{\text{Earth}} = 2\pi\sqrt{\frac{l}{g}} = 2\pi\sqrt{\frac{2.0\ \text{m}}{9.80\ \text{m/s}^2}} = 2.8\ \text{s}$

99. Organ pipes An organ builder must design a pipe organ that will fit into a small space. (Chapter 15)

a. Should he design the instrument to have open pipes or closed pipes? Explain.

The resonant frequency of an open pipe is twice that of a closed pipe of the same length. Therefore, the pipes of a closed-pipe organ need be only half as long as open pipes to produce the same range of fundamental frequencies.

b. Will an organ constructed with open pipes sound the same as one constructed with closed pipes? Explain.

No. While the two organs will have the same fundamental tones, closed pipes produce only the odd harmonics, so they will have different timbres than open pipes.

100. Filters are added to flashlights so that one shines red light and the other shines green light. The beams are crossed. Explain in terms of waves why the light from both flashlights is yellow where the beams cross, but revert back to their original colors beyond the intersection point. (Chapter 16)

Waves can interfere, add, and then pass through unaffected. Chapter 14 showed the amplitude of waves adding. In this case, the waves retain their color information as they cross through each other.

Challenge Problem

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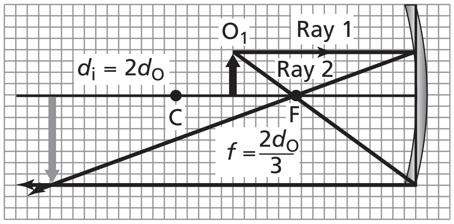
An object of height h_o is located at d_o relative to a concave mirror with focal length *f*.

1. Draw and label a ray diagram showing the focal length and location of the object if the image is located twice as far from the mirror as the object. Prove your answer mathematically. Calculate the focal length as a function of object position for this placement.



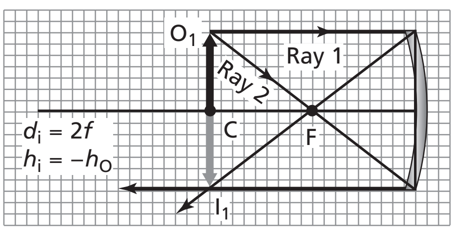
$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

$$f = \frac{d_o d_i}{d_o + d_i}$$

$$= \frac{d_o(2d_o)}{d_o - 2d_o}$$

$$= \frac{2d_o}{3}$$

2. Draw and label a ray diagram showing the location of the object if the image is located twice as far from the mirror as the focal point. Prove your answer mathematically. Calculate the image height as a function of the object height for this placement.



$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

$$d_o = \frac{fd_i}{d_i - f}$$

$$= \frac{f(2f)}{2f - f}$$

$$= 2f$$

$$m \equiv \frac{h_i}{h_o} = \frac{-d_i}{d_o}$$

$$h_i = \frac{-d_i h_o}{d_o}$$

$$= \frac{-(2f)h_o}{2f}$$

$$= -h_o$$

3. Where should the object be located so that no image is formed?

The object should be placed at the focal point.