The Language of Physics

Optics
The study of light (p. 747).

Wave front
A line connecting points all having the same phase of vibration. Wave fronts from a point source of light are spherical. Far away from the source, the waves appear plane (p. 747).

Geometrical optics
The analysis of an optical system in terms of light rays that travel in straight lines (p. 748).

Wave optics or physical optics
The analysis of an optical system in terms of the wave nature of light (p. 748).

Quantum optics
The study of light in terms of little bundles of electromagnetic energy, called photons (p. 748).

Huygens' principle
Each point on a wave front may be considered as a source of secondary spherical wavelets. These secondary wavelets propagate at the same speed as the initial wave. The new position of the wave front at a later time is found by drawing the tangent to all of these secondary wavelets at the later time (p. 748).

The law of reflection
The angle of incidence is equal to the angle of reflection. The incident ray, the normal, and the reflected ray all lie in the same plane (p. 750).

Real image
An image formed by rays converging to a point. A real image can be projected onto a screen (p. 750).

Virtual image
An image formed by rays diverging from a point. A virtual image cannot be projected onto a screen (p. 750).

Optical image
A reproduction of an object by an optical system. To describe an image three words are necessary: its nature (real or virtual), its orientation (erect, inverted, or perverted), and its size (enlarged, true, or reduced) (p. 751).

Spherical mirror
A reflecting surface whose radius of curvature is the radius of the sphere from which the mirror is formed. A plane mirror is a special case of a spherical mirror with a radius of curvature that is infinite (p. 753).

Principle of reversibility
If a ray traces a certain path through an optical system in one direction, then a ray sent backward through the system along the same path, traverses the original path and exits along the line that the original ray entered (p. 753).

Focal length
The point where all rays parallel and close to the principal axis converge. The focal length of a concave spherical mirror is equal to one-half of its radius of curvature (p. 753).

Magnification
The ratio of the size of an image to the size of its object (p. 756).

Summary of Important Equations

The wavelength, frequency, and speed of light

$$\lambda \nu = c \tag{26.1}$$

Law of reflection

$$i = r \tag{26.4}$$

Focal length of a spherical mirror

$$f = \frac{R}{2} \tag{26.14}$$

Mirror equation

$$\frac{1}{f} = \frac{1}{p} + \frac{1}{q} \tag{26.20}$$

Magnification

$$M = \frac{h_i}{h_o} = -\frac{q}{p} \tag{26.21}$$

Height of image

$$h_i = M h_o \tag{26.22}$$

Questions for Chapter 26

1. If you hold this textbook in front of a plane mirror the letters will all be reversed from left to right. Why are they not also reversed from top to bottom?
2. Explain the difference between a real image and a virtual image.
†3. How can Huygens' principle be justified?
4. What effect does changing the object distance have on the size of an image in a plane mirror?
5. It is easy to see an image formed by the reflection of light from a smooth surface such as a mirror. What type of reflection would occur if the surface were rough?
6. In the barbershop, mirrors are placed on the wall in front and behind the customer. How are the mirrors arranged so that the customer can see the back of his head?
7. Explain the process of formation of an image for a concave spherical mirror as the object starts at infinity and moves toward the mirror. What happens to the magnification?
8. You would like to place a mirror in the corner of your store so that you can see every thing going on in the store. What type of mirror should you use?
†9. Using Huygens' principle, describe what happens to a wave front of light when it hits the edge of a surface.
†10. Two plane mirrors are placed at 90° to each other. Explain how, when you look directly toward the vertex of the two mirrors, you see yourself as others see you. That is, left is left and right is right. Draw a diagram to help in the analysis.
11. How can you make a toy periscope with two plane mirrors?
12. The Hubble Space Telescope, launched by NASA in May 1990 to take pictures of the universe never seen before, developed a serious flaw. The telescope was not able to focus properly. The cause of the problem was spherical aberration of either the primary or secondary mirror. What is spherical aberration and how does it affect the telescope?

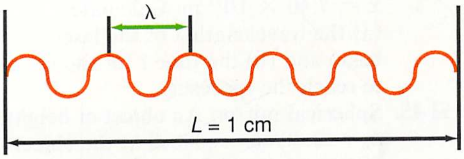
Problems for Chapter 26

26.1 Light as an Electromagnetic Wave

1. What is the frequency of (a) violet light of 380.0-nm wavelength and (b) red light of 720.0-nm wavelength?

2. What is the wavelength of the electromagnetic radiation of the following frequencies: (a) 100 kHz, (b) 10.0 MHz, (c) 4.00×10^{14} Hz, and (d) 6.00×10^{15} Hz.

3. How many light waves of 450-nm wavelength can you fit into a distance of 1.00 cm?



4. How long does it take light to reach earth from (a) the sun and (b) the moon?

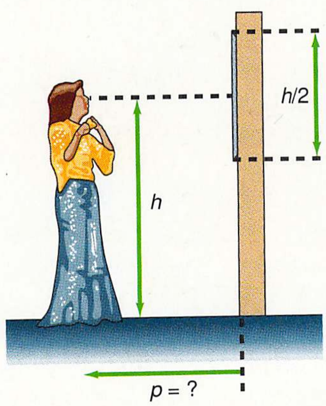
26.3 The Plane Mirror

5. An object 10.0 cm high is placed 20.0 cm in front of a plane mirror. Where is the image located and how big is it?

6. What is the minimum height of a mirror such that a student, 5′8″ tall, can see his entire body?

7. Repeat problem 6, but take into account that the eyes of the student are 4.00 in. below the top of his head.

8. A student stands in front of a plane mirror that is equal to half of her height, but when looking straight ahead, her eyes look directly into the center of the mirror. How far back from the mirror must she move in order to see her entire body in the mirror?



26.4 The Concave Spherical Mirror

9. What is the focal length of a spherical mirror if the radius of curvature is 25.0 cm?

10. An object 10.0 cm high is placed 50.0 cm in front of a concave spherical mirror of 15.0-cm focal length. Find the image by (a) a ray diagram and (b) the mirror equation. Is the image real or virtual? Is the image erect or inverted? What is the size of the image?

†11. Find the image with a concave spherical mirror of 10.0-cm focal length if the object is located at (a) 60.0 cm, (b) 40.0 cm, (c) 20.0 cm, (d) 10.0 cm, and (e) 5.00 cm. Draw a ray diagram for each case.

12. Find the magnification for each case in problem 11.

13. If the object is 5.00 cm high, find the height of the images in each case in problem 12.

†14. A concave spherical mirror has a focal length of 20.0 cm. Find the image distance, magnification, and height of the image when the object is located at (a) 100 cm, (b) 80.0 cm, (c) 40.0 cm, (d) 20.0 cm, and (e) 10.0 cm. Draw a ray diagram for each case.

15. An object is placed 15.0 cm in front of a concave spherical mirror mounted on an optical bench in the laboratory. A screen is moved along the optical bench until the object and image are located at the same point. Find the focal length of the mirror.

16. Find the focal length of a concave spherical mirror that has a magnification of 2.00 when an object is placed 20.0 cm in front of it.

17. An object 10.0 cm high is placed 10.0 cm in front of a concave spherical mirror of 15.0-cm focal length. Find the image by a ray diagram and the mirror equation. How high is the image?

18. Where should an object 5.00 cm high be placed in front of a 25.0-cm concave spherical mirror in order for its image to be erect and 10.0 cm high?

19. For a concave spherical mirror of 20.0-cm focal length, find two locations of an object such that the height of the image is four times the height of the object.

20. An object is placed 40.0 cm in front of a concave spherical mirror and its image is found 25.0 cm in front of the mirror. What is the focal length of the mirror?

21. A concave spherical mirror has a focal length of 15.0 cm. Where should an object be placed such that the height of the image is a quarter of the height of the object?

22. An object is placed 10.0 cm in front of a concave spherical mirror of 15.0-cm focal length. Find the location of the image and its magnification.

23. Find the radius of curvature of a shaving mirror such that when the object is placed 15.0 cm in front of the mirror, the image has a magnification of 2.

24. A concave spherical mirror has a focal length of 15.0 cm. Where should an object be placed to give a magnification of (a) 2.00 and (b) −2.00?

26.5 The Convex Spherical Mirror

25. A reflecting Christmas tree ball has a diameter of 8.00 cm. What is the focal length of such an ornament?

26. An object 10.0 cm high is placed 30.0 cm in front of a convex spherical mirror of −10.0-cm focal length. Find the image by a ray diagram and the mirror equation. Find the height of the image.

†27. Find the image with a convex spherical mirror of 10.0-cm focal length if the object is located at (a) 60.0 cm, (b) 40.0 cm, (c) 20.0 cm, (d) 10.0 cm, and (e) 5.00 cm. Draw a ray diagram for each case.

28. An object is 12.0 cm in front of a convex spherical mirror, and the image is formed 24.0 cm behind the mirror. Find the focal length of the mirror.

29. Where should an object be placed in front of a convex spherical mirror of 15.5-cm focal length in order to get a virtual image with a magnification of one-half?

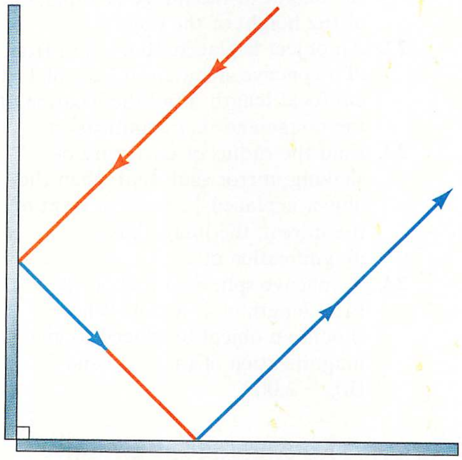
30. The distance between a real object and a virtual image formed by a convex spherical mirror is 50.0 cm. If the focal length of the mirror is $f = -25.0$ cm, find the two possible positions for the mirror.

Additional Problems

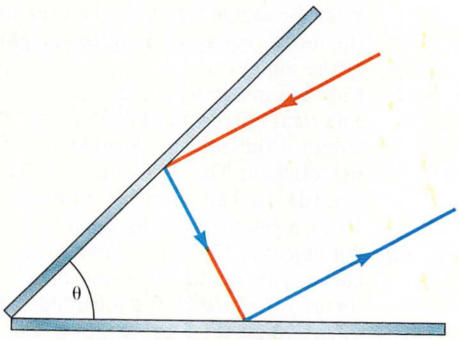
†31. A plane mirror is rotated through an angle θ. Show that the reflected ray will always be rotated through an angle of 2θ.

32. Show that a plane mirror is a special case of a concave spherical mirror whose radius of curvature is infinite. What does the mirror equation reduce to?

†33. Two mirrors make an angle of 90° with each other. Show that if a ray of light is incident on the first mirror at an angle of incidence i, the reflected ray from the second mirror makes an angle of reflection of $90° - i$.



†34. Two mirrors make an angle of θ with each other. Show that if a ray of light is incident on the first mirror at an angle of incidence i, the reflected ray from the second mirror makes an angle of reflection of $\theta - i$.



†35. Show that when an object is placed in front of a concave spherical mirror of focal length f and experiences a magnification M, the image is located at the image distance given by

$$q = f(1 - M)$$

36. An object is placed 25.0 cm in front of a concave spherical mirror. The image is found to be a quarter of the size of the object. Find the focal length of the mirror.

37. An object is magnified by a factor of 2 when it is placed 15.0 cm in front of a concave spherical mirror. Find the radius of curvature of the mirror.

38. A dentist uses a small concave spherical mirror to see a cavity in a tooth. If the image is to be magnified by a factor of 3 when the tooth is 2.50 cm in front of the mirror, what should be the focal length of such a mirror?

39. An optical system is designed so that an object for a convex spherical mirror of focal length $f = -15.0$ cm is 20.0 cm *behind* the mirror (a virtual object). Find the image distance and the magnification, and determine whether the image is real or virtual, erect or inverted.

40. Repeat problem 39 with an object located only 5.00 cm *behind* the mirror.

†41. Use a compass to draw a concave spherical mirror 10.0 cm in radius. Draw light rays parallel to the principal axis at every 1.00 cm above and below the principal axis. Using a protractor, carefully measure the angles of incidence and reflection for each of these rays, and see where they cross the principal axis. What does this tell you about the underlying assumption in the mirror equation? How does this relate to spherical aberration of the mirror?

†42. Draw a graph of the image distance q as a function of the object distance p for a concave spherical mirror of focal length 10.0 cm. Show the regions that represent the concave mirror and the convex mirror. Show the regions where the images are real and where they are virtual.

†43. Draw a graph of the magnification M of a concave spherical mirror as a function of the object distance p. Repeat for a convex spherical mirror.

Interactive Tutorials

44. A tower on earth transmits a laser beam of frequency $f = 5.00 \times 10^{14}$ Hz to a spaceship at a distance $x = 7.40 \times 10^{11}$ m. Calculate (a) the wavelength λ of the laser beam and (b) the time t for the beam to reach the spaceship.

45. Spherical mirror. An object of height $h_o = 3.00$ cm is placed at the object distance $p = 10.0$ cm of a spherical mirror of radius of curvature $R = 8.00$ cm. Find (a) the focal length f of the mirror, (b) the image distance q, (c) the magnification M, and (d) the height h_i of the resulting image.

46. Spherical mirror. An object of height $h_o = 8.50$ cm is placed at the object distance $p = 35.0$ cm of a spherical mirror of focal length $f = 15.0$ cm. Find (a) the radius of curvature R of the mirror, (b) the image distance q, (c) the magnification M, and (d) the height h_i of the resulting image.