CHAPTER 14 Summary

BIG IDEA Patterns of refraction demonstrate the wave behavior of light. This predictable behavior is important for the design of any device involving lenses.

SECTION 1 Refraction

KEY TERMS

- According to Snell's law, as a light ray travels from one medium into another medium where its speed is different, the light ray will change its direction unless it travels along the normal.
- When light passes from a medium with a smaller index of refraction to one with a larger index of refraction, the ray bends toward the normal. For the opposite situation, the ray bends away from the normal.

Key terms: refraction; index of refraction

SECTION 2 Thin Lenses

KEY TERM

- The image produced by a converging lens is real and inverted when the object is outside the focal point and virtual and upright when the object is inside the focal point. Diverging lenses always produce upright, virtual images.
- The location of an image created by a lens can be found using either a ray diagram or the thin-lens equation.

Key term: lens

SECTION 3 Optical Phenomena

KEY TERMS

- Total internal reflection can occur when light attempts to move from a material with a higher index of refraction to one with a lower index of refraction. If the angle of incidence of a ray is greater than the critical angle, the ray is totally reflected at the boundary.
- Mirages and the visibility of the sun after it has physically set are natural phenomena that can be attributed to refraction of light in Earth's atmosphere.

Key terms: total internal reflection; critical angle; dispersion; chromatic aberration

VARIABLE SYMBOLS

Quantities		Units	
θ_i	angle of incidence	°	degrees
θ_r	angle of refraction	°	degrees
n	index of refraction	(unitless)	
p	distance from object to lens	m	meters
q	distance from image to lens	m	meters
h'	image height	m	meters
h	object height	m	meters
θ_c	critical angle	°	degrees

Problem Solving

See **Appendix D: Equations** for a summary of the equations introduced in this chapter. If you need more problem-solving practice, see **Appendix I: Additional Problems.**

CHAPTER 14 Review

Refraction and Snell's Law

REVIEWING MAIN IDEAS

1. Does a light ray traveling from one medium into another always bend toward the normal?

2. As light travels from a vacuum ($n = 1$) to a medium such as glass ($n > 1$), does its wavelength change? Does its speed change? Does its frequency change?

3. What is the relationship between the speed of light and the index of refraction of a transparent substance?

4. Why does a clear stream always appear to be shallower than it actually is?

5. What are the three conditions that must be met for refraction to occur?

CONCEPTUAL QUESTIONS

6. Two colors of light (*X* and *Y*) are sent through a glass prism, and *X* is bent more than *Y*. Which color travels more slowly in the prism?

7. Why does an oar appear to be bent when part of it is in the water?

8. A friend throws a coin into a pool. You close your eyes and dive toward the spot where you saw it from the edge of the pool. When you reach the bottom, will the coin be in front of you or behind you?

9. The level of water ($n = 1.33$) in a clear glass container is easily observed with the naked eye. The level of liquid helium ($n = 1.03$) in a clear glass container is extremely difficult to see with the naked eye. Explain why.

PRACTICE PROBLEMS

For problems 10–14, see Sample Problem A.

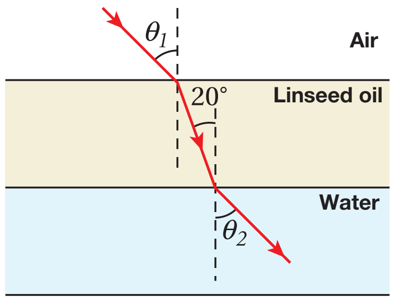
10. Light passes from air into water at an angle of incidence of 42.3°. Determine the angle of refraction in the water.

11. A ray of light enters the top of a glass of water at an angle of 36° with the vertical. What is the angle between the refracted ray and the vertical?

12. A narrow ray of yellow light from glowing sodium ($\lambda_0 = 589$ nm) traveling in air strikes a smooth surface of water at an angle of $\theta_i = 35.0°$. Determine the angle of refraction, θ_r.

13. A ray of light traveling in air strikes a flat 2.00 cm thick block of glass ($n = 1.50$) at an angle of 30.0° with the normal. Trace the light ray through the glass, and find the angles of incidence and refraction at each surface.

14. The light ray shown in the figure below makes an angle of 20.0° with the normal line at the boundary of linseed oil and water. Determine the angles θ_1 and θ_2. Note that $n = 1.48$ for linseed oil.



Ray Diagrams and Thin Lenses

REVIEWING MAIN IDEAS

15. Which type of lens can focus the sun's rays?

16. Why is no image formed when an object is at the focal point of a converging lens?

17. Consider the image formed by a thin converging lens. Under what conditions will the image be
- **a.** inverted?
- **b.** upright?
- **c.** real?
- **d.** virtual?
- **e.** larger than the object?
- **f.** smaller than the object?

18. Repeat a–f of item 17 for a thin diverging lens.

19. Explain this statement: The focal point of a converging lens is the location of an image of a point object at infinity. Based on this statement, can you think of a quick method for determining the focal length of a positive lens?

CONCEPTUAL QUESTIONS

20. If a glass converging lens is submerged in water, will its focal length be longer or shorter than when the lens is in air?

21. In order to get an image that is right-side up, slides must be placed upside down in a slide projector. What type of lens must the slide projector have? Predict whether the slide is inside or outside the focal point of the lens.

22. If there are two converging lenses in a compound microscope, why is the image still inverted?

23. In a Jules Verne novel, a piece of ice is shaped into the form of a magnifying lens to focus sunlight and thereby start a fire. Is this possible?

PRACTICE PROBLEMS

For problems 24–26, see Sample Problem B.

24. An object is placed in front of a diverging lens with a focal length of 20.0 cm. For each object distance, find the image distance and the magnification. Describe each image.
- **a.** 40.0 cm
- **b.** 20.0 cm
- **c.** 10.0 cm

25. A person looks at a gem using a converging lens with a focal length of 12.5 cm. The lens forms a virtual image 30.0 cm from the lens. Determine the magnification. Is the image upright or inverted?

26. An object is placed in front of a converging lens with a focal length of 20.0 cm. For each object distance, predict the image distance and the magnification. Describe each image.
- **a.** 40.0 cm
- **b.** 10.0 cm

Total Internal Reflection, Atmospheric Refraction, and Aberrations

REVIEWING MAIN IDEAS

27. Is it possible to have total internal reflection for light incident from air on water? Explain.

28. What are the conditions necessary for the occurrence of a mirage?

29. On a hot day, what is it that we are seeing when we observe a “water on the road” mirage?

30. Why does the arc of a rainbow appear with red colors on top and violet colors on the bottom?

31. What type of aberration is involved in each of the following situations?
- **a.** The edges of the image appear reddish.
- **b.** The central portion of the image cannot be clearly focused.
- **c.** The outer portion of the image cannot be clearly focused.
- **d.** The central portion of the image is enlarged relative to the outer portions.

CONCEPTUAL QUESTIONS

32. A laser beam passing through a nonhomogeneous sugar solution follows a curved path. Explain.

33. On a warm day, the image of a boat floating on cold water appears above the boat. Explain.

34. Explain why a mirror cannot give rise to chromatic aberration.

35. Why does a diamond show flashes of color when observed under ordinary white light?

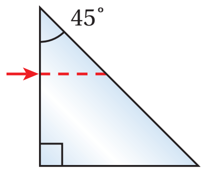
PRACTICE PROBLEMS

For problems 36–38, see Sample Problem C.

36. Calculate the critical angle for light going from glycerine into air.

37. Assuming that $\lambda = 589$ nm, calculate the critical angles for the following materials when they are surrounded by air:
a. zircon
b. fluorite
c. ice

38. Light traveling in air enters the flat side of a prism made of crown glass ($n = 1.52$), as shown at right. Will the light pass through the other side of the prism, or will it be totally internally reflected? Be sure to show your work.



Mixed Review

REVIEWING MAIN IDEAS

39. The angle of incidence and the angle of refraction for light going from air into a material with a higher index of refraction are 63.5° and 42.9°, respectively. What is the index of refraction of this material?

40. A person standing beside a pool shines a light at a friend who is swimming underwater. If the ray in the water makes an angle of 36.2° with the normal, what is the angle of incidence?

41. What is the index of refraction of a material in which the speed of light is 1.85×10^8 m/s? Look at the indices of refraction in **Figure 1.4** to identify this material.

42. Light moves from flint glass into water at an angle of incidence of 28.7°.
a. What is the angle of refraction?
b. At what angle would the light have to be incident to give an angle of refraction of 90.0°?

43. A magnifying glass has a converging lens of focal length 15.0 cm. At what distance from a nickel should you hold this lens to get an image with a magnification of +2.00?

44. The image of the United States postage stamps in the figure above is 1.50 times the size of the actual stamps in front of the lens. Determine the focal length of the lens if the distance from the lens to the stamps is 2.84 cm.

45. Where must an object be placed to have a magnification of 2.00 in each of the following cases? Show your work.
a. a converging lens of focal length 12.0 cm
b. a diverging lens of focal length 12.0 cm

46. A diverging lens is used to form a virtual image of an object. The object is 80.0 cm in front of the lens, and the image is 40.0 cm in front of the lens. Determine the focal length of the lens.

47. A microscope slide is placed in front of a converging lens with a focal length of 2.44 cm. The lens forms an image of the slide 12.9 cm from the slide.
a. How far is the lens from the slide if the image is real?
b. How far is the lens from the slide if the image is virtual?

48. Where must an object be placed to form an image 30.0 cm from a diverging lens with a focal length of 40.0 cm? Determine the magnification of the image.

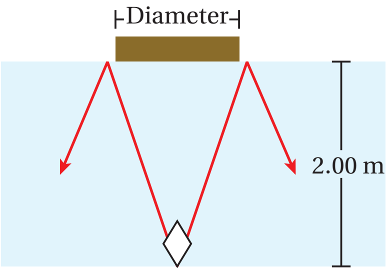
49. The index of refraction for red light in water is 1.331, and that for blue light is 1.340. If a ray of white light traveling in air enters the water at an angle of incidence of 83.0°, what are the angles of refraction for the red and blue components of the light?

50. A ray of light traveling in air strikes the surface of mineral oil at an angle of 23.1° with the normal to the surface. If the light travels at 2.17×10^8 m/s through the oil, what is the angle of refraction? (Hint: Remember the definition of the index of refraction.)

51. A ray of light traveling in air strikes the surface of a liquid. If the angle of incidence is 30.0° and the angle of refraction is 22.0°, find the critical angle for light traveling from the liquid back into the air.

52. The laws of refraction and reflection are the same for sound and for light. The speed of sound is 340 m/s in air and 1510 m/s in water. If a sound wave that is traveling in air approaches a flat water surface with an angle of incidence of 12.0°, what is the angle of refraction?

53. A jewel thief decides to hide a stolen diamond by placing it at the bottom of a crystal-clear fountain. He places a circular piece of wood on the surface of the water and anchors it directly above the diamond at the bottom of the fountain, as shown below. If the fountain is 2.00 m deep, find the minimum diameter of the piece of wood that would prevent the diamond from being seen from outside the water.



54. A ray of light traveling in air strikes the surface of a block of clear ice at an angle of 40.0° with the normal. Part of the light is reflected, and part is refracted. Find the angle between the reflected and refracted light.

55. An object's distance from a converging lens is 10 times the focal length. How far is the image from the lens? Express the answer as a fraction of the focal length.

56. A fiber-optic cable used for telecommunications has an index of refraction of 1.53. For total internal reflection of light inside the cable, what is the minimum angle of incidence to the inside wall of the cable if the cable is in the following:

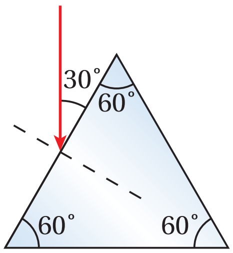
a. air

b. water

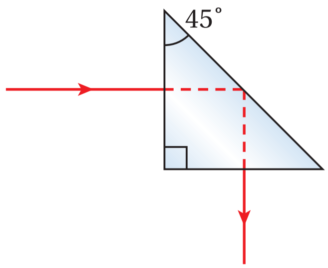
57. A ray of light traveling in air strikes the midpoint of one face of an equiangular glass prism ($n = 1.50$) at an angle of exactly 30.0°, as shown below.

a. Trace the path of the light ray through the glass, and find the angle of incidence of the ray at the bottom of the prism.

b. Will the ray pass through the bottom surface of the prism, or will it be totally internally reflected?



58. Light strikes the surface of a prism, $n = 1.8$, as shown in the figure below. If the prism is surrounded by a fluid, what is the maximum index of refraction of the fluid that will still cause total internal reflection within the prism?

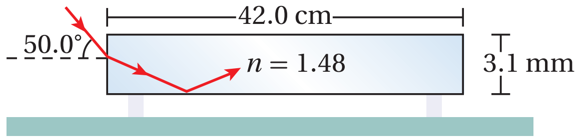


59. A fiber-optic rod consists of a central strand of material surrounded by an outer coating. The interior portion of the rod has an index of refraction of 1.60. If all rays striking the interior walls of the rod with incident angles greater than 59.5° are subject to total internal reflection, what is the index of refraction of the coating?

60. A flashlight on the bottom of a 4.00 m deep swimming pool sends a ray upward and at an angle so that the ray strikes the surface of the water 2.00 m from the point directly above the flashlight. What angle (in air) does the emerging ray make with the water's surface? (Hint: To determine the angle of incidence, consider the right triangle formed by the light ray, the pool bottom, and the imaginary line straight down from where the ray strikes the surface of the water.)

61. A submarine is 325 m horizontally out from the shore and 115 m beneath the surface of the water. A laser beam is sent from the submarine so that it strikes the surface of the water at a point 205 m from the shore. If the beam strikes the top of a building standing directly at the water's edge, find the height of the building. (Hint: To determine the angle of incidence, consider the right triangle formed by the light beam, the horizontal line drawn at the depth of the submarine, and the imaginary line straight down from where the beam strikes the surface of the water.)

62. A laser beam traveling in air strikes the midpoint of one end of a slab of material, as shown in the figure in the next column. The index of refraction of the slab is 1.48. Determine the number of internal reflections of the laser beam before it finally emerges from the opposite end of the slab.



63. A nature photographer is using a camera that has a lens with a focal length of 4.80 cm. The photographer is taking pictures of ancient trees in a forest and wants the lens to be focused on a very old tree that is 10.0 m away.

a. How far must the lens be from the film in order for the resulting picture to be clearly focused?

b. Predict how much the lens would have to be moved to take a picture of another tree that is only 1.75 m away.

64. The distance from the front to the back of your eye is approximately 1.90 cm. If you can see a clear image of a book when it is 35.0 cm from your eye, what is the focal length of the lens/cornea system?

65. Suppose you look out the window and see your friend, who is standing 15.0 m away. To what focal length must your eye muscles adjust the lens of your eye so that you may see your friend clearly? Remember that the distance from the front to the back of your eye is about 1.90 cm.

GRAPHING CALCULATOR PRACTICE

Snell's Law

What happens to a light ray that passes from air into a medium whose index of refraction differs from that of air? Snell's law, as you learned earlier in this chapter, describes the relationship between the angle of refraction and the index of refraction.

$$n_i \sin \theta_i = n_r \sin \theta_r$$

In this equation, n_i is the index of refraction of the medium of the incident light ray, and θ_i is the angle of incidence; n_r is the index of refraction of the medium of the refracted light, and θ_r is the angle of refraction.

In this graphing calculator activity, you will enter the angle of incidence and will view a graph of the index of refraction versus the angle of refraction. You can use this graph to better understand the relationship between the index of refraction and the angle of refraction.

Go online to HMHScience.com to find the skillsheet and program for this graphing calculator activity.

ALTERNATIVE ASSESSMENT

1. Interview an optometrist, optician, or ophthalmologist. Find out what equipment and tools each uses. What kinds of eye problems is each able to correct? What training is necessary for each career?

2. Obtain permission to use a microscope and slides from your school's biology teacher. Identify the optical components (lenses, mirror, object, and light source) and knobs. Find out how they function at different magnifications and what adjustments must be made to obtain a clear image. Sketch a ray diagram for the microscope's image formation. Estimate the size of the images you see, and predict the approximate size of the actual cells or microorganisms you observe. How closely do your estimates match the magnification indicated on the microscope?

3. Construct your own telescope with mailing tubes (one small enough to slide inside the other), two lenses, cardboard disks for mounting the lenses, glue, and masking tape. Test your instrument at night. Try to combine different lenses and explore ways to improve your telescope's performance. Keep records of your results to make a brochure documenting the development of your telescope.

4. Study the history of the camera. Possible topics include the following: How did the camera obscura work? What discovery made the first permanent photograph possible? How do instant cameras work? How do modern digital cameras differ from film cameras? Give a short presentation to the class to share the information.

5. Create a pinhole camera with simple household materials. Find instructions on the Internet for constructing a pinhole camera, and follow them to make your own pinhole camera. Partner with a photography student to develop the pictures in your school's darkroom. Create a visual presentation to share your photographs with the class.

6. Research how phone, television, and radio signals are transmitted over long distances through fiber-optic devices. Obtain information from companies that provide telephone or cable television service. What materials are fiber-optic cables made of? What are their most important properties? Are there limits on the kind of light that travels in these cables? What are the advantages of fiber-optic technology over broadcast transmission? Produce a brochure or informational video to explain this technology to consumers.

7. When the Indian physicist Venkata Raman first saw the Mediterranean Sea, he proposed that its blue color was due to the structure of water molecules rather than to the scattering of light from suspended particles. Later, he won the Nobel Prize for work relating to the implications of this hypothesis. Research Raman's life and work. Find out about his background and the challenges and opportunities he met on his way to becoming a physicist. Create a presentation about him in the form of a report, poster, short video, or computer presentation.

8. Choose a radio telescope to research. Possibilities include the Very Large Array in New Mexico, the Arecibo telescope in Puerto Rico, or the Green Bank Telescope in West Virginia. Use the Internet to learn about observations that have been made with the telescope. How long has the telescope been operating? How large is the telescope? What discoveries have been made with it? Has the telescope been used for any SETI (search for extraterrestrial intelligence) investigations? After your research is complete, write a list of questions that you still have about the telescope. If possible, call the observatory and interview a member of the staff. Write a magazine article with the results of your research.