Let us return to the questions at the beginning of the chapter. The size of an object doesn't change as it moves further away, but it looks smaller to us. The explanation lies in the characteristics of images produced by convex lenses, of which there is one in the eye. The further the object, the smaller is the image on the retina. This is true also of the plane mirror image. Its size is the same as that of the object, but it is further from the eye and so forms a smaller image on the retina.

Incidentally, if you look at the diagram of the plane mirror image (Figure 13.3), you will observe that the virtual image is seen by means of diverging rays that come to the eye. (This is true also of rays coming from any point of a real object.) The convex lens in the eye brings these rays to a focus on the retina, thus producing a real image there. The convex lens in a camera acts in a similar way.

Summary

- Light is an electromagnetic wave.
- The law of reflection states that the angle of incidence is equal to the angle of reflection.
- In geometrical optics, all angles are measured relative to the normal line.
- Refraction is a change in the direction of light caused by a change in the light's velocity as it goes from one transparent medium into another at an oblique angle.
- The absolute index of refraction of a transparent material is equal to the ratio of the velocity of light in air to the velocity of light in that material.
- As light goes from a lower-index material to a higher-index material, it slows down and bends toward the normal.
- As light goes from a higher-index material to a lower-index material, it speeds up and bends away from the normal.
- Real images can be projected onto a screen. Virtual images cannot be projected and are perceived by the brain as existing on the other side of a mirror.
- Real images can be formed by concave mirrors and convex lenses.
- A prism can disperse white light into the colors of the spectrum since the different frequencies of light refract at different angles in the prism.

Practice Exercises

In each case, select the choice that best answers the questions or completes the statement.

1. In the light wave
   (A) the vibrations of the electric and magnetic fields are transverse
   (B) the vibrations of the electric field are transverse; those of the magnetic field are longitudinal

(C) the vibrations of the magnetic field are transverse; those of the electric field are longitudinal
(D) all vibrations are longitudinal
(E) longitudinal vibrations alternate with transverse vibrations

2. If the distance between a point source of light and a surface is tripled, the intensity of illumination on the surface will be
(A) tripled
(B) doubled
(C) reduced to ½
(D) reduced to ⅓
(E) reduced to ⅑

Questions 3–5

X and *Y* are each 2 meters tall. *X* stands 1 meter from a vertical plane mirror; *Y*, 2 meters from the same mirror.

3. The size of *X*'s image as compared with *Y*'s is
(A) 4 times as great
(B) 2 times as great
(C) the same
(D) ½ as great
(E) ¼ as great

4. It will seem to *X* that *Y*'s image, as compared with his own, is
(A) 4 times as great
(B) twice as great
(C) the same size
(D) smaller
(E) beyond compare

5. The distance between *X*'s image and *Y*'s image
(A) is 1 m
(B) is 2 m
(C) is 3 m
(D) is 4 m
(E) can't be calculated because of insufficient data

Questions 6–8

A candle 2 centimeters long is placed upright in front of a concave spherical mirror whose focal length is 10 centimeters. The distance of the candle from the mirror is 30 centimeters.

6. The radius of curvature of the mirror is
(A) 5 cm
(B) 10 cm

(C) 15 cm
(D) 20 cm
(E) 6 cm

7. The image will be
(A) virtual and smaller than the candle
(B) virtual and larger than the candle
(C) virtual and the same size as the candle
(D) real and smaller than the candle
(E) real and larger than the candle

8. If the top half of the mirror is covered with an opaque cloth,
(A) the whole image will disappear
(B) the whole image will be approximately one-half as bright as before
(C) the top half of the image will disappear
(D) the bottom half of the image will disappear
(E) one cannot predict what will happen

---

9. Real images formed by single convex lenses are always
(A) on the same side of the lens as the object
(B) inverted
(C) erect
(D) smaller than the object
(E) larger than the object

10. A virtual image is formed by
(A) a slide projector
(B) a motion-picture projector
(C) a duplicating camera
(D) an ordinary camera
(E) a simple magnifier

11. A person on Earth may see the Sun even when it is somewhat below the horizon primarily because the atmosphere
(A) annuls light
(B) reflects light
(C) absorbs light
(D) refracts light
(E) polarizes light

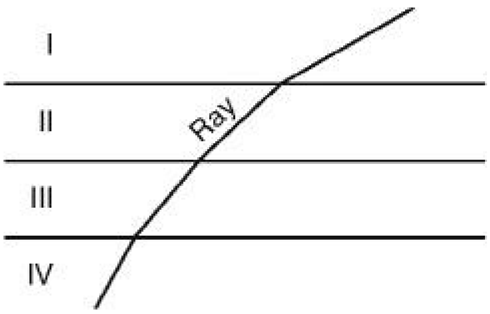
12. Incident rays of light parallel to the principal axis of a convex lens, after refraction by the lens, will
(A) converge at the principal focus
(B) converge inside the principal focus
(C) converge outside the principal focus
(D) converge at the center of curvature
(E) diverge as long as they are close to the lens

13. A red cloth will primarily

(A) reflect red light
(B) refract red light
(C) absorb red light
(D) transmit red light
(E) annul red light

14. Yellow light of a single wavelength can't be
(A) reflected
(B) refracted
(C) dispersed
(D) focused
(E) diffused

15. Some gold is heated to a temperature of 2,000°C. (The melting point of gold is 1,063°C; its boiling point is 2,600°C.) The light emitted by this gold is passed through a triangular glass prism. The result will be
(A) a continuous spectrum with a golden hue all over
(B) a line spectrum with a golden hue all over
(C) a continuous spectrum with a bright gold line
(D) a line spectrum with a bright gold line
(E) none of the above



16. The diagram above shows four separate layers of different transparent liquids. The liquids do not mix. The path of an oblique ray of light through the liquids is shown. The medium in which the speed of the wave is lowest is
(A) I
(B) II
(C) III
(D) IV
(E) indeterminate on the basis of the given information

17. The speed of light in a certain transparent substance is two-fifths of its speed in air. The index of refraction of this substance is
(A) 0.4
(B) 1.4
(C) 2.0
(D) 2.5

(E) 5.0

18. A camera of 6-centimeter focal length is used to photograph a distant scene. The distance from the lens to the image is approximately

(A) 6 cm
(B) 1 m
(C) 80 cm
(D) 4 m
(E) 4 cm

19. A film 2.0 centimeters wide is placed 6.0 centimeters from the lens of a projector. As a result a sharp image is produced 300 centimeters from the lens. The width of the image is

(A) 12 cm
(B) 50 cm
(C) 100 cm
(D) 300 cm
(E) 600 cm

20. If an object is placed 30 centimeters from a convex lens whose focal length is 15 centimeters, the size of the image as compared to the size of the object will be approximately

(A) twice as large
(B) more than twice as large
(C) 1.5 times as large
(D) smaller
(E) the same

21. A small beam of monochromatic light shines on a plate of glass with plane parallel surfaces. The index of refraction of the glass is 1.60. The angle of incidence of the light is 30°. The angle of emergence of the light from the glass is

(A) 18°
(B) 30°
(C) 45°
(D) 48°
(E) 60°

22. In an experiment, an object was placed on the principal axis of a convex lens 25 centimeters away from the lens. A real image 4 times the size of the object was obtained. The focal length of the lens was

(A) 20 cm
(B) 25 cm
(C) 33 cm
(D) 50 cm
(E) 100 cm

23. A ray of light goes obliquely from water to glass. The angle of incidence

in the water is θ_1, the angle of refraction in the glass in θ_2, the index of refraction of water is n_1, and the index of refraction of the glass is n_2. Which of the following is a correct relationship for this case?

(A) $n_1 \sin \theta_1 = \sin \theta_2$

(B) $n_1 \sin \theta_2 = \sin \theta_1$

(C) $n_2 \sin \theta_1 = \sin \theta_2$

(D) $n_2 \sin \theta_2 = \sin \theta_1$

(E) $n_2 \sin \theta_2 = n_1 \sin \theta_1$

Answer Key

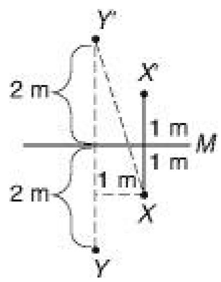
1. **(A)**	9. **(B)**	17. **(D)**
2. **(E)**	10. **(E)**	18. **(A)**
3. **(C)**	11. **(D)**	19. **(C)**
4. **(D)**	12. **(A)**	20. **(E)**
5. **(A)**	13. **(A)**	21. **(B)**
6. **(D)**	14. **(C)**	22. **(A)**
7. **(D)**	15. **(E)**	23. **(E)**
8. **(B)**	16. **(D)**	

Answers Explained

1. **A** Light is an electromagnetic wave. In all electromagnetic waves the electric and magnetic fields vibrate at right angles (transversely) to the direction in which the wave is traveling.
2. **E** The intensity of illumination from a point source varies inversely as the square of the distance. As the distance from the light source increases, the illumination decreases. When the distance is 3 times as great, the illumination is $(\frac{1}{3})^2$, or $\frac{1}{9}$ as much as before.
3. **C** The size of the image in a plane mirror is the same as the size of the object. Therefore, *X*'s image is 2 m tall and so is *Y*'s.
4. **D** Although the actual sizes of the images are the same (see question 3), their apparent sizes will depend on the distances of the images from the observer, just as the apparent sizes of real objects depend on their distances from the observer. The further an object or image is from the observer, the smaller it will *seem*. In this problem, since the image in a plane mirror is as far behind the mirror as the object is in front, *X*'s image is 1 m behind the mirror and 2 m from *X*. For the same reason, *Y*'s image is 2 m behind the mirror and therefore at least 3 m from *X*, who is 1 m in

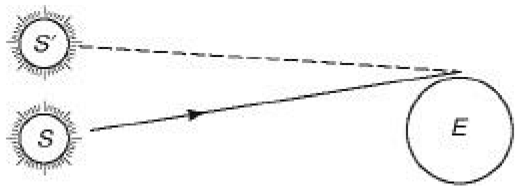
front of the mirror. (Also see question 5.) Therefore, to *X*, *Y*'s image will seem smaller than his own.

5. **A** The distance between the two images is the same as the distance between *X* and *Y*. This may be 1 m or anything greater than 1 m, as illustrated in the diagram, depending on how far over to one side *Y* stands.



6. **D** For a spherical mirror, the focal length = ½ of the radius of curvature. $R = 2f = 2 \times 10$ cm = 20 cm.
7. **D** The situation described in this problem is similar to one for which the ray diagram (Figure 13.13) is drawn and a real image is obtained. Be able to draw such a ray diagram quickly and to deduce pertinent information from it. In this diagram the image is definitely smaller than the object. In Chapter 14 you will see how numerical calculations can be made rather quickly.
8. **B** All the rays starting from one point on the object will, after reflection from a spherical mirror, converge toward one point (for a real image), or will diverge from one common point (for a virtual image). In this way, points on the object are reproduced as points on the image, producing a sharp image. If part of the mirror is covered, less light will be available for each point reproduction, making the image dimmer.
9. **B** Note from the ray diagrams in the chapter that real images formed by single convex lenses are always inverted and on the other side of the lens from the object. The real images may be larger or smaller than, or the same size as, the object, depending on the distance of the object from the lens.
10. **E** Projectors and camera are used to put images on screens or film; images that appear on screens are real images. The simple magnifier (also called magnifying glass or simple microscope) is used to view something without projecting an image on a screen (other than the eye's retina); it produces a virtual image as shown in the ray diagram (Figure 13.14) in the chapter.
11. **D** Light travels somewhat more slowly in air than in vacuum. Sunlight entering the atmosphere obliquely is refracted toward the normal. Since the atmosphere's density increases as it gets closer to Earth, the path of the light in the atmosphere is slightly curved. The drawing below is not to scale, and the effect is exaggerated. The observer projects a line backward to an imaginary position *S*¢, where the Sun will appear to him

—somewhat higher in the sky.



12. **A** This situation gave us the definition for the principal focus of a convex lens: rays parallel to the principal axis, after refraction by a convex lens, pass through a common point on the principal axis called the *principal focus*. The ray diagram (Figure 13.14) in the chapter shows these refracted rays converging on the principal focus. (If these rays pass the principal focus and are not stopped, they will diverge *after* having converged.) (Figure 13.14)
13. **A** Opaque objects are seen by the light they reflect. We say a cloth is red if it appears red when viewed in natural white light; it must, therefore, reflect red light, which is a component of the white light.
14. **C** All light can be reflected, refracted, polarized, and diffused. However, if light contains only one wavelength, it can produce only one color (in this problem, yellow) and can't be dispersed. (Definition of dispersion: breaking up of light into its component colors.)
15. **E** At the temperature given, gold is an incandescent liquid. The light from an incandescent solid or liquid produces a continuous spectrum without any special bright lines due to the color of the cold solid or liquid. The various colors, such as yellow and orange, gradually change from one to the other.
16. **D** A ray passing obliquely into a medium is bent toward the normal if it travels more slowly in the new medium; it is bent away from the normal if it travels faster in the new medium. In the diagram, if the ray is directed from medium I toward medium IV, it is bent closer to the normal in each successive medium. Therefore the ray travels most slowly in medium IV. If the ray is directed from medium IV toward medium I, we may notice that the ray is bent further away from the normal in each successive medium, again indicating that the wave travels fastest in medium I, slowest in medium IV.
17. **D** $\text{Index of refraction} = \dfrac{\text{speed of light in air}}{\text{speed of light in medium}} = \dfrac{v}{2/5v} = 5/2 = 2.5$
18. **A** You may just recall that, if the object is very far from a convex lens, the image is formed practically 1 focal length away from the lens.

Or you may use the lens equation: $\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f}$; the object distance d_o is very large, so we'll use the infinity symbol (∞) for it.

$$1/\infty + 1d_i = 1/f;\ 1/\infty = 0$$
$$1/d_i\ 1/f;\ \text{and } d_i = f$$

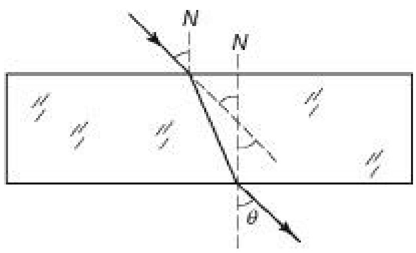
In words, the image distance equals the focal length, in this case 6 cm.

19. **C** $\frac{s_i}{s_o} = \frac{d_i}{d_o}$

$$s_1 = \frac{d_i}{d_o} \times s_o = \frac{300\text{ cm}}{6\text{ cm}} \times 2\text{ cm} = 100\text{ cm}$$

20. **E** You should know that, if an object is 2 focal lengths away from a convex lens, a real image is formed 2 focal lengths away from the lens (on the other side from the object) and the image is the same size as the object. Otherwise, you will have to use valuable time on calculations with the lens equation and size relationship.

21. **B** The angle that the emerging ray makes with the normal is the angle of emergence. We assume here that the entering ray and emerging ray are both in air. Then the two rays are parallel since the glass surfaces are parallel. Therefore, the angle of incidence equals the angle of emergence; both are 30°.



22. **A** $\frac{s_1}{s_0} = 4 = \frac{d_i}{d_o}$

$$d_i = 4d_o, \text{ and } d_o = 25\text{ cm}$$
$$\therefore d_i = 100\text{ cm}$$
$$1/f = 1/d_o + 1/d_i$$
$$1/f = 1/25 + 1/100 = 5/100$$
$$f = 100/5\text{ cm} = 20\text{ cm}$$

Also *note* that the object distance is between f and $2f$, since a real, enlarged image was produced. The only choice that fits this is (A).

23. **E** In refraction, if one of the two media is vacuum, we need only one index

of refraction, that of the substance used, which is its absolute index of refraction, or its index of refraction with respect to vacuum. This is also usually adequate if the substance is solid or liquid and we use air instead of vacuum. However, for the general case we have to use the indexes of refraction of both substances, as pointed out in the text.

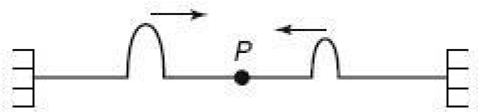
• The polarization of light is evidence for its transverse nature. Longitudinal waves (such as sound) cannot be polarized.

Practice Exercises

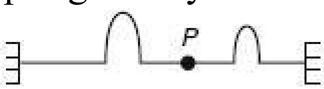
In each case, select the choice that best answers the question or completes the statement.

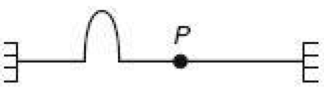
1. Which will be produced when blue light with a wavelength of 4.7 × 10 meters passes through a double slit?
   (A) a continuous spectrum
   (B) two narrow bands of blue light
   (C) alternate blue and black bands
   (D) bands of blue light fringed with green
   (E) bands of blue light fringed with violet

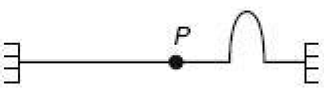
2. Two pulses approach each other in a spring, as shown.

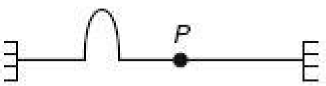


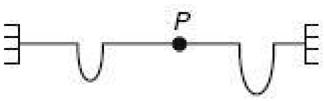
Which of the following diagrams best represents the appearance of the spring shortly after the pulses pass each other at point *P* ?

(A) 

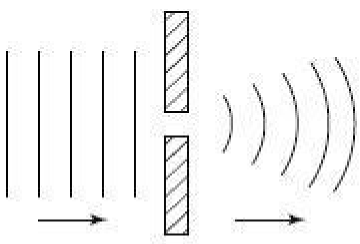
(B) 

(C) 

(D) 

(E) 

3. The diagram represents straight wave fronts passing through a small opening in a barrier. This is an example of



(A) reflection
(B) refraction
(C) polarization
(D) dispersion
(E) diffraction

4. If light of wavelength 5.0×10^{-7} meter shines on a pair of slits 1 millimeter apart, how far from the central maximum will the first bright band appear on a screen 1 meter away?
(A) 5×10^{-4} m
(B) 5×10^{-10} m
(C) 2×10^{3} m
(D) 2×10^{-4} m
(E) 2×10^{-10} m

5. Newton's rings may be observed if you place a curved glass surface on a flat glass surface. A thin film of air is wedged between the glass surfaces. Looking down, you can see several rings around the point where the two glass surfaces touch. Newton's rings are produced by
(A) interference
(B) diffraction
(C) polarization
(D) absorption
(E) shadows

6. Water waves
(A) can be polarized
(B) are polarized
(C) cannot be polarized because they are longitudinal
(D) cannot be polarized because of their frequencies
(E) cannot be polarized because of their amplitudes

Answer Key

1. **(C)**	3. **(E)**	5. **(A)**
2. **(B)**	4. **(A)**	6. **(B)**

Answers Explained

1. **C** The light passes through a double slit; the pattern that forms on the screen where the light falls consists of alternating bands of light separated by black regions. If white light is used, the central band is white and on either side each of the bright bands consists of the spectrum of colors of which

the white light is composed. In this question blue light of a single wavelength is used. Such light cannot be dispersed. Therefore all bands of light on the screen, including the central band, consist of this blue light. These bands are separated by bands of black regions.

2. **B** When two pulses or waves pass each other in a medium, each continues on as though there had been no interference from the other. In this question, therefore, the pulse with the larger amplitude will appear on the right side of *P* and continue traveling toward the right. The pulse with the smaller amplitude appears on the left and continues traveling toward the left.

3. **E** *Diffraction* is the bending of a wave around an obstacle. The shaded parts of the diagram represent the obstacle. As the wave goes through the small opening in the obstacle, it spreads behind the obstacle. The small opening acts like a point source of a wave.

4. **A** $\frac{y}{d} = \frac{x}{L}$

$$= \frac{x}{1\ \cancel{\text{m}}}$$

$$= \frac{5.0 \times 10^{-7}\ \text{m}}{10^{-3}\ \cancel{\text{m}}}$$

$$x = 5.0 \times 10^{-4}\ \text{m}$$

Don’t forget to change all units to SI!

5. **A** The production of Newton’s rings is an interference phenomenon. The rings are produced by interference between the light reflected from the top surface of the thin air film and the light reflected from the bottom.

6. **B** While water waves are transverse, and thus can be polarized (A), (B) is the better choice, as water waves are already restricted to one plane of vibration (up and down).

Problems & Exercises

25.1 The Ray Aspect of Light

1. Suppose a man stands in front of a mirror as shown in Figure 25.49. His eyes are 1.65 m above the floor, and the top of his head is 0.13 m higher. Find the height above the floor of the top and bottom of the smallest mirror in which he can see both the top of his head and his feet. How is this distance related to the man's height?

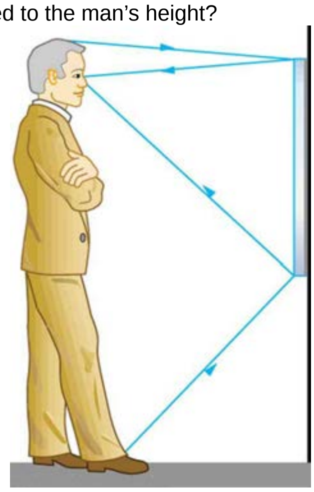


Figure 25.49 A full-length mirror is one in which you can see all of yourself. It need not be as big as you, and its size is independent of your distance from it.

25.2 The Law of Reflection

2. Show that when light reflects from two mirrors that meet each other at a right angle, the outgoing ray is parallel to the incoming ray, as illustrated in the following figure.

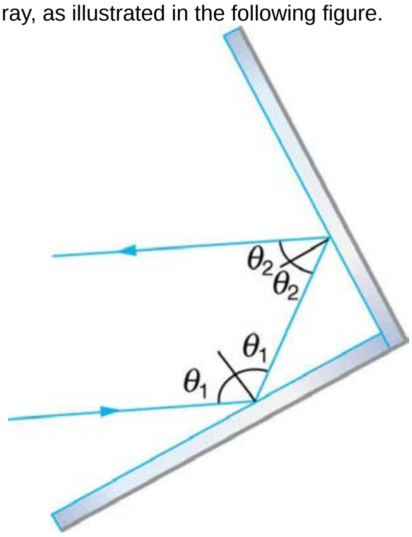


Figure 25.50 A corner reflector sends the reflected ray back in a direction parallel to the incident ray, independent of incoming direction.

3. Light shows staged with lasers use moving mirrors to swing beams and create colorful effects. Show that a light ray reflected from a mirror changes direction by 2θ when the mirror is rotated by an angle θ.

4. A flat mirror is neither converging nor diverging. To prove this, consider two rays originating from the same point and diverging at an angle θ. Show that after striking a plane mirror, the angle between their directions remains θ.

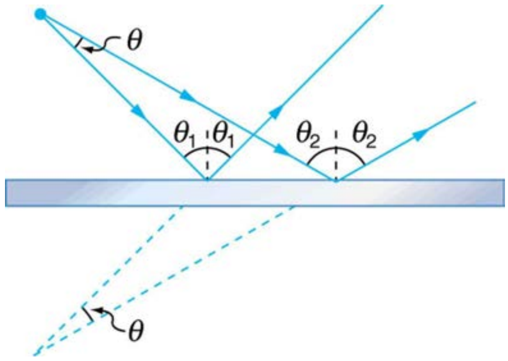


Figure 25.51 A flat mirror neither converges nor diverges light rays. Two rays continue to diverge at the same angle after reflection.

25.3 The Law of Refraction

5. What is the speed of light in water? In glycerine?

6. What is the speed of light in air? In crown glass?

7. Calculate the index of refraction for a medium in which the speed of light is $2.012\times10^8\ \text{m/s}$, and identify the most likely substance based on Table 25.1.

8. In what substance in Table 25.1 is the speed of light $2.290\times10^8\ \text{m/s}$?

9. There was a major collision of an asteroid with the Moon in medieval times. It was described by monks at Canterbury Cathedral in England as a red glow on and around the Moon. How long after the asteroid hit the Moon, which is $3.84\times10^5\ \text{km}$ away, would the light first arrive on Earth?

10. A scuba diver training in a pool looks at his instructor as shown in **Figure 25.52**. What angle does the ray from the instructor's face make with the perpendicular to the water at the point where the ray enters? The angle between the ray in the water and the perpendicular to the water is 25.0°.

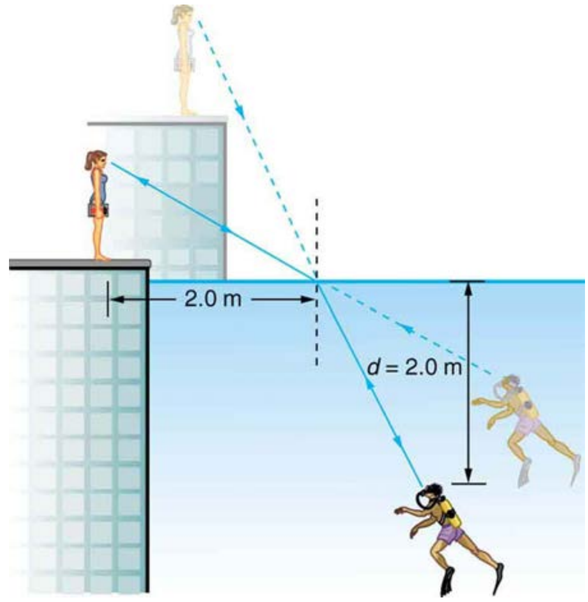


Figure 25.52 A scuba diver in a pool and his trainer look at each other.

11. Components of some computers communicate with each other through optical fibers having an index of refraction $n = 1.55$. What time in nanoseconds is required for a signal to travel 0.200 m through such a fiber?

12. (a) Using information in **Figure 25.52**, find the height of the instructor's head above the water, noting that you will first have to calculate the angle of incidence. (b) Find the apparent depth of the diver's head below water as seen by the instructor.

13. Suppose you have an unknown clear substance immersed in water, and you wish to identify it by finding its index of refraction. You arrange to have a beam of light enter it at an angle of 45.0°, and you observe the angle of refraction to be 40.3°. What is the index of refraction of the substance and its likely identity?

14. On the Moon's surface, lunar astronauts placed a corner reflector, off which a laser beam is periodically reflected. The distance to the Moon is calculated from the round-trip time. What percent correction is needed to account for the delay in time due to the slowing of light in Earth's atmosphere? Assume the distance to the Moon is precisely $3.84\times10^8\ \text{m}$, and Earth's atmosphere (which varies in density with altitude) is equivalent to a layer 30.0 km thick with a constant index of refraction $n = 1.000293$.

15. Suppose **Figure 25.53** represents a ray of light going from air through crown glass into water, such as going into a fish tank. Calculate the amount the ray is displaced by the glass (Δx), given that the incident angle is 40.0° and the glass is 1.00 cm thick.

16. **Figure 25.53** shows a ray of light passing from one medium into a second and then a third. Show that θ_3 is the same as it would be if the second medium were not present (provided total internal reflection does not occur).

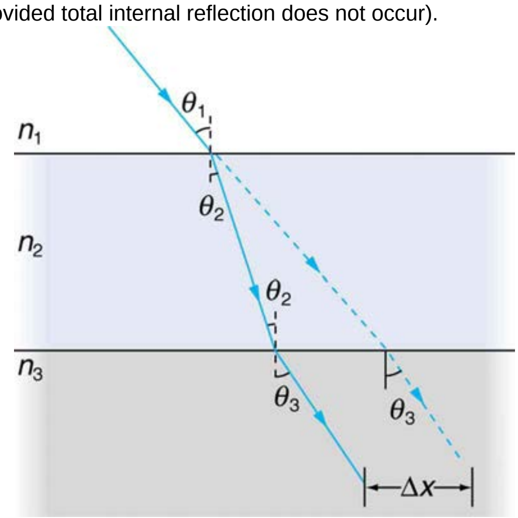


Figure 25.53 A ray of light passes from one medium to a third by traveling through a second. The final direction is the same as if the second medium were not present, but the ray is displaced by Δx (shown exaggerated).

17. Unreasonable Results

Suppose light travels from water to another substance, with an angle of incidence of 10.0° and an angle of refraction of 14.9°. (a) What is the index of refraction of the other substance? (b) What is unreasonable about this result? (c) Which assumptions are unreasonable or inconsistent?

18. Construct Your Own Problem

Consider sunlight entering the Earth's atmosphere at sunrise and sunset—that is, at a 90° incident angle. Taking the boundary between nearly empty space and the atmosphere to be sudden, calculate the angle of refraction for sunlight. This lengthens the time the Sun appears to be above the horizon, both at sunrise and sunset. Now construct a problem in which you determine the angle of refraction for different models of the atmosphere, such as various layers of varying density. Your instructor may wish to guide you on the level of complexity to consider and on how the index of refraction varies with air density.

19. Unreasonable Results

Light traveling from water to a gemstone strikes the surface at an angle of 80.0° and has an angle of refraction of 15.2°. (a) What is the speed of light in the gemstone? (b) What is unreasonable about this result? (c) Which assumptions are unreasonable or inconsistent?

25.4 Total Internal Reflection

20. Verify that the critical angle for light going from water to air is 48.6°, as discussed at the end of **Example 25.4**, regarding the critical angle for light traveling in a polystyrene (a type of plastic) pipe surrounded by air.

21. (a) At the end of **Example 25.4**, it was stated that the critical angle for light going from diamond to air is 24.4°. Verify this. (b) What is the critical angle for light going from zircon to air?

22. An optical fiber uses flint glass clad with crown glass. What is the critical angle?

23. At what minimum angle will you get total internal reflection of light traveling in water and reflected from ice?

24. Suppose you are using total internal reflection to make an efficient corner reflector. If there is air outside and the incident angle is 45.0°, what must be the minimum index of refraction of the material from which the reflector is made?

25. You can determine the index of refraction of a substance by determining its critical angle. (a) What is the index of refraction of a substance that has a critical angle of 68.4° when submerged in water? What is the substance, based on **Table 25.1**? (b) What would the critical angle be for this substance in air?

26. A ray of light, emitted beneath the surface of an unknown liquid with air above it, undergoes total internal reflection as shown in **Figure 25.54**. What is the index of refraction for the liquid and its likely identification?

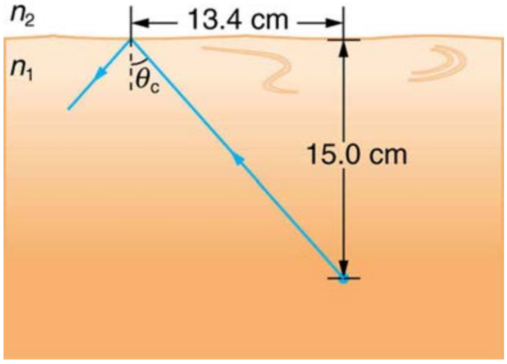


Figure 25.54 A light ray inside a liquid strikes the surface at the critical angle and undergoes total internal reflection.

27. A light ray entering an optical fiber surrounded by air is first refracted and then reflected as shown in **Figure 25.55**. Show that if the fiber is made from crown glass, any incident ray will be totally internally reflected.

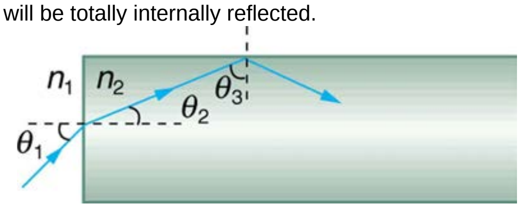


Figure 25.55 A light ray enters the end of a fiber, the surface of which is perpendicular to its sides. Examine the conditions under which it may be totally internally reflected.

25.5 Dispersion: The Rainbow and Prisms

28. (a) What is the ratio of the speed of red light to violet light in diamond, based on **Table 25.2**? (b) What is this ratio in polystyrene? (c) Which is more dispersive?

29. A beam of white light goes from air into water at an incident angle of 75.0°. At what angles are the red (660 nm) and violet (410 nm) parts of the light refracted?

30. By how much do the critical angles for red (660 nm) and violet (410 nm) light differ in a diamond surrounded by air?

31. (a) A narrow beam of light containing yellow (580 nm) and green (550 nm) wavelengths goes from polystyrene to air, striking the surface at a 30.0° incident angle. What is the angle between the colors when they emerge? (b) How far would they have to travel to be separated by 1.00 mm?

32. A parallel beam of light containing orange (610 nm) and violet (410 nm) wavelengths goes from fused quartz to water, striking the surface between them at a 60.0° incident angle. What is the angle between the two colors in water?

33. A ray of 610 nm light goes from air into fused quartz at an incident angle of 55.0°. At what incident angle must 470 nm light enter flint glass to have the same angle of refraction?

34. A narrow beam of light containing red (660 nm) and blue (470 nm) wavelengths travels from air through a 1.00 cm thick flat piece of crown glass and back to air again. The beam strikes at a 30.0° incident angle. (a) At what angles do the two colors emerge? (b) By what distance are the red and blue separated when they emerge?

35. A narrow beam of white light enters a prism made of crown glass at a 45.0° incident angle, as shown in **Figure 25.56**. At what angles, θ_R and θ_V, do the red (660 nm) and violet (410 nm) components of the light emerge from the prism?

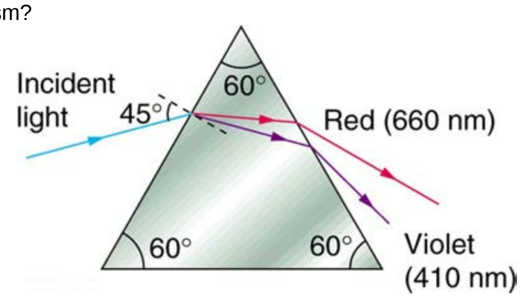


Figure 25.56 This prism will disperse the white light into a rainbow of colors. The incident angle is 45.0°, and the angles at which the red and violet light emerge are θ_R and θ_V.

25.6 Image Formation by Lenses

36. What is the power in diopters of a camera lens that has a 50.0 mm focal length?

37. Your camera's zoom lens has an adjustable focal length ranging from 80.0 to 200 mm. What is its range of powers?

38. What is the focal length of 1.75 D reading glasses found on the rack in a pharmacy?

39. You note that your prescription for new eyeglasses is –4.50 D. What will their focal length be?

40. How far from the lens must the film in a camera be, if the lens has a 35.0 mm focal length and is being used to photograph a flower 75.0 cm away? Explicitly show how you follow the steps in the Problem-Solving Strategy for lenses.

41. A certain slide projector has a 100 mm focal length lens. (a) How far away is the screen, if a slide is placed 103 mm from the lens and produces a sharp image? (b) If the slide is 24.0 by 36.0 mm, what are the dimensions of the image? Explicitly show how you follow the steps in the Problem-Solving Strategy for lenses.

42. A doctor examines a mole with a 15.0 cm focal length magnifying glass held 13.5 cm from the mole (a) Where is the image? (b) What is its magnification? (c) How big is the image of a 5.00 mm diameter mole?

43. How far from a piece of paper must you hold your father's 2.25 D reading glasses to try to burn a hole in the paper with sunlight?

44. A camera with a 50.0 mm focal length lens is being used to photograph a person standing 3.00 m away. (a) How far from the lens must the film be? (b) If the film is 36.0 mm high, what fraction of a 1.75 m tall person will fit on it? (c) Discuss how reasonable this seems, based on your experience in taking or posing for photographs.

45. A camera lens used for taking close-up photographs has a focal length of 22.0 mm. The farthest it can be placed from the film is 33.0 mm. (a) What is the closest object that can be photographed? (b) What is the magnification of this closest object?

46. Suppose your 50.0 mm focal length camera lens is 51.0 mm away from the film in the camera. (a) How far away is an object that is in focus? (b) What is the height of the object if its image is 2.00 cm high?

47. (a) What is the focal length of a magnifying glass that produces a magnification of 3.00 when held 5.00 cm from an object, such as a rare coin? (b) Calculate the power of the magnifier in diopters. (c) Discuss how this power compares to those for store-bought reading glasses (typically 1.0 to 4.0 D). Is the magnifier's power greater, and should it be?

48. What magnification will be produced by a lens of power –4.00 D (such as might be used to correct myopia) if an object is held 25.0 cm away?

49. In **Example 25.7**, the magnification of a book held 7.50 cm from a 10.0 cm focal length lens was found to be 3.00. (a) Find the magnification for the book when it is held 8.50 cm from the magnifier. (b) Do the same for when it is held 9.50 cm from the magnifier. (c) Comment on the trend in m as the object distance increases as in these two calculations.

50. Suppose a 200 mm focal length telephoto lens is being used to photograph mountains 10.0 km away. (a) Where is the image? (b) What is the height of the image of a 1000 m high cliff on one of the mountains?

51. A camera with a 100 mm focal length lens is used to photograph the sun and moon. What is the height of the image of the sun on the film, given the sun is $1.40\times10^6\ \text{km}$ in diameter and is $1.50\times10^8\ \text{km}$ away?

52. Combine thin lens equations to show that the magnification for a thin lens is determined by its focal length and the object distance and is given by $m = f/(f - d_\text{o})$.

25.7 Image Formation by Mirrors

53. What is the focal length of a makeup mirror that has a power of 1.50 D?

54. Some telephoto cameras use a mirror rather than a lens. What radius of curvature mirror is needed to replace a 800 mm focal length telephoto lens?

55. (a) Calculate the focal length of the mirror formed by the shiny back of a spoon that has a 3.00 cm radius of curvature. (b) What is its power in diopters?

56. Find the magnification of the heater element in **Example 25.9**. Note that its large magnitude helps spread out the reflected energy.

57. What is the focal length of a makeup mirror that produces a magnification of 1.50 when a person's face is 12.0 cm away? Explicitly show how you follow the steps in the **Problem-Solving Strategy for Mirrors**.

58. A shopper standing 3.00 m from a convex security mirror sees his image with a magnification of 0.250. (a) Where is his image? (b) What is the focal length of the mirror? (c) What is its radius of curvature? Explicitly show how you follow the steps in the **Problem-Solving Strategy for Mirrors**.

59. An object 1.50 cm high is held 3.00 cm from a person's cornea, and its reflected image is measured to be 0.167 cm high. (a) What is the magnification? (b) Where is the image? (c) Find the radius of curvature of the convex mirror formed by the cornea. (Note that this technique is used by optometrists to measure the curvature of the cornea for contact lens fitting. The instrument used is called a keratometer, or curve measurer.)

60. Ray tracing for a flat mirror shows that the image is located a distance behind the mirror equal to the distance of the object from the mirror. This is stated $d_\text{i} = -d_\text{o}$, since this is a negative image distance (it is a virtual image). (a) What is the focal length of a flat mirror? (b) What is its power?

61. Show that for a flat mirror $h_\text{i} = h_\text{o}$, knowing that the image is a distance behind the mirror equal in magnitude to the distance of the object from the mirror.

62. Use the law of reflection to prove that the focal length of a mirror is half its radius of curvature. That is, prove that $f = R/2$. Note this is true for a spherical mirror only if its diameter is small compared with its radius of curvature.

63. Referring to the electric room heater considered in the first example in this section, calculate the intensity of IR radiation in W/m^2 projected by the concave mirror on a person 3.00 m away. Assume that the heating element radiates 1500 W and has an area of $100\ \text{cm}^2$, and that half of the radiated power is reflected and focused by the mirror.

64. Consider a 250-W heat lamp fixed to the ceiling in a bathroom. If the filament in one light burns out then the remaining three still work. Construct a problem in which you determine the resistance of each filament in order to obtain a certain intensity projected on the bathroom floor. The ceiling is 3.0 m high. The problem will need to involve concave mirrors behind the filaments. Your instructor may wish to guide you on the level of complexity to consider in the electrical components.

Test Prep for AP® Courses

25.1 The Ray Aspect of Light

1. When light from a distant object reflects off of a concave mirror and comes to a focus some distance in front of the mirror, we model light as a _____ to explain and predict the behavior of light and the formation of an image.

a. wave
b. particle
c. ray
d. all of the above

2. Light of wavelength 500 nm is incident on a narrow slit of width 150 nm. Which model of light most accurately predicts the behavior of the light after it passes through the slit? Explain your answer.

25.2 The Law of Reflection

3. An object is 2 meters in front of a flat mirror. Ray 1 from the object travels in a direction toward the mirror and normal to the mirror's surface. Ray 2 from the object travels at an angle of 5° from the direction of ray 1, and it also reflects off the mirror's surface. At what distance behind the mirror do these two reflected rays appear to converge to form an image?

a. 0.2 m
b. 0.5 m
c. 2 m
d. 4 m

4. Two light rays originate from object A, at a distance of 50 cm in front of a flat mirror, diverging at an angle of 10°. Both of the rays strike a flat mirror and reflect. Two light rays originate from object B, at a distance of 50 cm in front of a convex mirror, diverging at an angle of 10°. Both of the rays strike the convex mirror and reflect. For which object do the reflected rays appear to converge behind the mirror closer to the surface of the mirror, thus forming a closer (larger) image? Explain with the help of a sketch or diagram.

25.3 The Law of Refraction

5. When light travels from air into water, which of the following statements is accurate?

a. The wavelength decreases, and the speed decreases.
b. The wavelength decreases, and the speed increases.
c. The wavelength increases, and the speed decreases.
d. The wavelength increases, and the speed increases.

6. When a light ray travels from air into glass, which of the following statements is accurate after the light enters the glass?

a. The ray bends away from the normal, and the speed decreases.
b. The ray bends away from the normal, and the speed increases.
c. The ray bends toward the normal, and the speed increases.
d. The ray bends toward the normal, and the speed decreases.

7.

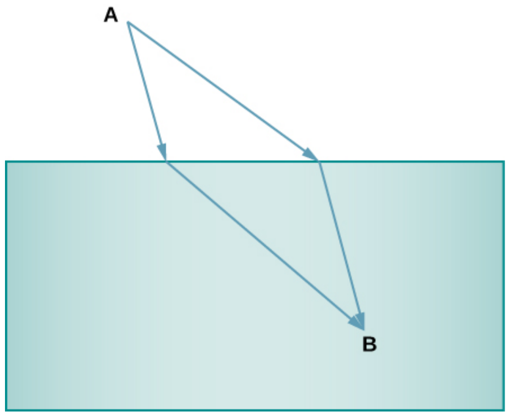


Figure 25.57 Two different potential paths from point A to point B are shown. Point A is in the air, and point B is in water. For which of these paths (upper or lower) would light travel from point A to point B faster? Which of the paths more accurately represents how a light ray would travel from point A to point B? Explain.

8. Students in a lab group are given a plastic cube with a hollow cube-shaped space in the middle that fills about half the volume of the cube. The index of refraction of the plastic is known. The hollow space is filled with a gas, and the students are asked to collect the data needed to find the index of refraction of the gas. The students take the following set of measurements:

Angle of incidence of the light in the air above the plastic block: 30°

Angle of refraction of the beam as it enters the plastic from the air: 45°

Angle of refraction of the beam as it enters the plastic from the gas: 45°

The three measurements are shared with a second lab group. Can the second group determine a value for the index of refraction of the gas from only this data?

a. Yes, because they have information about the beam in air and in the plastic above the gas.
b. Yes, because they have information about the beam on both sides of the gas.
c. No, because they need additional information to determine the angle of the beam in the gas.
d. No, because they do not have multiple data points to analyze.

9. Students in a lab group are given a plastic cube with a hollow cube-shaped space in the middle that fills about half the volume of the cube. The index of refraction of the plastic is known. The hollow space is filled with a gas, and the students are asked to collect the data needed to find the index of refraction of the gas. What information would you need to collect, and how would you use this information in order to deduce the index of refraction of the gas in the cube?

10. Light travels through water and crosses a boundary at a non-normal angle into a different fluid with an unknown index of refraction. Which of the following is true about the path of the light after crossing the boundary?

a. If the index of refraction of the fluid is higher than that of water, the light will speed up and turn toward the normal.
b. If the index of refraction of the fluid is higher than that of water, the light will slow down and turn away from the normal.
c. If the index of refraction of the fluid is lower than that of water, the light will speed up and turn away from the normal.
d. If the index of refraction of the fluid is lower than that of water, the light will slow down and turn toward the normal.

11. A laser is fired from a submarine beneath the surface of a lake (n = 1.33). The laser emerges from the lake into air with an angle of refraction of 67°. How fast is the light moving through the water? What is the angle of incidence of the laser light when it crosses the boundary between the lake and the air?

25.4 Total Internal Reflection

12. As light travels from air into water, what happens to the frequency of the light? Consider how the wavelength and speed of light change; then use the relationship between speed, wavelength, and frequency for a wave. What about light that is reflected off the surface of water? What happens to its wavelength, speed, and frequency?

25.6 Image Formation by Lenses

13. An object is 25 cm in front of a converging lens with a focal length of 25 cm. Where will the resulting image be located?
a. 25 cm in front of the lens
b. 25 cm behind the lens
c. 50 cm behind the lens
d. at infinity (either in front of or behind the lens)

14. A detective holds a magnifying glass 5.0 cm above an object he is studying, creating an upright image twice as large as the object. What is the focal length of the lens used for the magnifying glass?

15. A student wishes to predict the magnification of an image given the distance from the object to a converging lens with an unknown index of refraction. What data must the student collect in order to make such a prediction for any object distance?
a. A specific object distance and the image distance associated with that object distance.
b. A specific image distance and a determination of whether the image formed is upright or inverted.
c. The diameter and index of refraction of the lens.
d. The radius of curvature of each side of the lens.

16. Given a converging lens of unknown focal length and unknown index of refraction, explain what materials you would need and what procedure you would follow in order to experimentally determine the focal length of the lens.

25.7 Image Formation by Mirrors

17. A student is testing the properties of a mirror with an unknown radius of curvature. The student notices that no matter how far an object is placed from the mirror, the image seen in the mirror is always upright and smaller than the object. What can the student deduce about this mirror?
a. The mirror is convex.
b. The mirror is flat.
c. The mirror is concave.
d. More information is required to deduce the shape of the mirror.

18. A student notices a small printed sentence at the bottom of the driver's side mirror on her car. It reads, "Objects in the mirror are closer than they appear." Which type of mirror is this (convex, concave, or flat)? How could you confirm the shape of the mirror experimentally?

19. A mirror shows an upright image twice as large as the object when the object is 10 cm away from the mirror. What is the focal length of the mirror?
a. -10 cm
b. 10 cm
c. 20 cm
d. 40 cm

20. A mirror shows an inverted image that is equal in size to the object when the object is 20 cm away from the mirror. Describe the image that will be formed if this object is moved to a distance of 5 cm away from the mirror.

(a)

Chapter 25

Problems & Exercises

1

Top $1.715\ \text{m}$ from floor, bottom $0.825\ \text{m}$ from floor. Height of mirror is $0.890\ \text{m}$, or precisely one-half the height of the person.

5

$2.25\times10^8\ \text{m/s}$ in water

$2.04\times10^8\ \text{m/s}$ in glycerine

7

1.490, polystyrene

9

$1.28\ \text{s}$

11

$1.03\ \text{ns}$

13

$n = 1.46$, fused quartz

17

(a) 0.898

(b) Can’t have $n < 1.00$ since this would imply a speed greater than c.

(c) Refracted angle is too big relative to the angle of incidence.

19

(a) $\frac{c}{5.00}$

(b) Speed of light too slow, since index is much greater than that of diamond.

(c) Angle of refraction is unreasonable relative to the angle of incidence.

22
66.3°
24
> 1.414
26
1.50, benzene
29
46.5°, red; 46.0°, violet
31
(a) 0.043°

(b) 1.33 m

33
71.3°
35
53.5°, red; 55.2°, violet
37
$5.00\text{ to }12.5\text{ D}$
39
-0.222 m
41
(a) 3.43 m

(b) 0.800 by 1.20 m

42
(a) -1.35 m (on the object side of the lens).

(b) $+10.0$

(c) 5.00 cm

43
44.4 cm
45
(a) 6.60 cm

(b) –0.333

47
(a) $+7.50\text{ cm}$

(b) 13.3 D

(c) Much greater

49
(a) +6.67

(b) +20.0

(c) The magnification increases without limit (to infinity) as the object distance increases to the limit of the focal distance.

51
-0.933 mm
53
+0.667 m
55
(a) $-1.5\times10^{-2}\text{ m}$

(b) -66.7 D

57

+0.360 m (concave)

59

(a) +0.111

(b) -0.334 cm (behind “mirror”)

(c) 0.752cm

61

$$m = \frac{h_\mathrm{i}}{h_\mathrm{o}} = -\frac{d_\mathrm{i}}{d_\mathrm{o}} = -\frac{-d_\mathrm{o}}{d_\mathrm{o}} = \frac{d_\mathrm{o}}{d_\mathrm{o}} = 1 \Rightarrow h_\mathrm{i} = h_\mathrm{o} \tag{25.61}$$

63

$6.82\ \mathrm{kW/m^2}$

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1

(c)

3

(c)

5

(a)

7

Since light bends toward the normal upon entering a medium with a higher index of refraction, the upper path is a more accurate representation of a light ray moving from A to B.

9

First, measure the angle of incidence and the angle of refraction for light entering the plastic from air. Since the two angles can be measured and the index of refraction of air is known, the student can solve for the index of refraction of the plastic.

Next, measure the angle of incidence and the angle of refraction for light entering the gas from the plastic. Since the two angles can be measured and the index of refraction of the plastic is known, the student can solve for the index of refraction of the gas.

11

The speed of light in a medium is simply *c*/*n*, so the speed of light in water is 2.25×10^8 m/s. From Snell’s law, the angle of incidence is 44°.

13

(d)

15

(a)

17

(a)

19

(b)

Problems & Exercises

27.1 The Wave Aspect of Light: Interference

1. Show that when light passes from air to water, its wavelength decreases to 0.750 times its original value.

2. Find the range of visible wavelengths of light in crown glass.

3. What is the index of refraction of a material for which the wavelength of light is 0.671 times its value in a vacuum? Identify the likely substance.

4. Analysis of an interference effect in a clear solid shows that the wavelength of light in the solid is 329 nm. Knowing this light comes from a He-Ne laser and has a wavelength of 633 nm in air, is the substance zircon or diamond?

5. What is the ratio of thicknesses of crown glass and water that would contain the same number of wavelengths of light?

27.3 Young's Double Slit Experiment

6. At what angle is the first-order maximum for 450-nm wavelength blue light falling on double slits separated by 0.0500 mm?

7. Calculate the angle for the third-order maximum of 580-nm wavelength yellow light falling on double slits separated by 0.100 mm.

8. What is the separation between two slits for which 610-nm orange light has its first maximum at an angle of 30.0°?

9. Find the distance between two slits that produces the first minimum for 410-nm violet light at an angle of 45.0°.

10. Calculate the wavelength of light that has its third minimum at an angle of 30.0° when falling on double slits separated by $3.00\ \mu m$. Explicitly, show how you follow the steps in **Problem-Solving Strategies for Wave Optics**.

11. What is the wavelength of light falling on double slits separated by $2.00\ \mu m$ if the third-order maximum is at an angle of 60.0°?

12. At what angle is the fourth-order maximum for the situation in **Exercise 27.6**?

13. What is the highest-order maximum for 400-nm light falling on double slits separated by $25.0\ \mu m$?

14. Find the largest wavelength of light falling on double slits separated by $1.20\ \mu m$ for which there is a first-order maximum. Is this in the visible part of the spectrum?

15. What is the smallest separation between two slits that will produce a second-order maximum for 720-nm red light?

16. (a) What is the smallest separation between two slits that will produce a second-order maximum for any visible light? (b) For all visible light?

17. (a) If the first-order maximum for pure-wavelength light falling on a double slit is at an angle of 10.0°, at what angle is the second-order maximum? (b) What is the angle of the first minimum? (c) What is the highest-order maximum possible here?

18. **Figure 27.56** shows a double slit located a distance x from a screen, with the distance from the center of the screen given by y. When the distance d between the slits is relatively large, there will be numerous bright spots, called fringes. Show that, for small angles (where $\sin\theta \approx \theta$, with θ in radians), the distance between fringes is given by $\Delta y = x\lambda / d$.

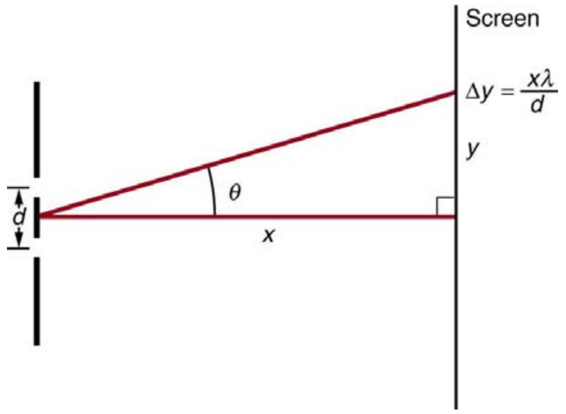

Figure 27.56 The distance between adjacent fringes is $\Delta y = x\lambda / d$, assuming the slit separation d is large compared with λ.

19. Using the result of the problem above, calculate the distance between fringes for 633-nm light falling on double slits separated by 0.0800 mm, located 3.00 m from a screen as in **Figure 27.56**.

20. Using the result of the problem two problems prior, find the wavelength of light that produces fringes 7.50 mm apart on a screen 2.00 m from double slits separated by 0.120 mm (see **Figure 27.56**).

27.4 Multiple Slit Diffraction

21. A diffraction grating has 2000 lines per centimeter. At what angle will the first-order maximum be for 520-nm-wavelength green light?

22. Find the angle for the third-order maximum for 580-nm-wavelength yellow light falling on a diffraction grating having 1500 lines per centimeter.

23. How many lines per centimeter are there on a diffraction grating that gives a first-order maximum for 470-nm blue light at an angle of 25.0°?

24. What is the distance between lines on a diffraction grating that produces a second-order maximum for 760-nm red light at an angle of 60.0°?

25. Calculate the wavelength of light that has its second-order maximum at 45.0° when falling on a diffraction grating that has 5000 lines per centimeter.

26. An electric current through hydrogen gas produces several distinct wavelengths of visible light. What are the wavelengths of the hydrogen spectrum, if they form first-order maxima at angles of 24.2°, 25.7°, 29.1°, and 41.0° when projected on a diffraction grating having 10,000 lines per centimeter? Explicitly show how you follow the steps in **Problem-Solving Strategies for Wave Optics**

27. (a) What do the four angles in the above problem become if a 5000-line-per-centimeter diffraction grating is used? (b) Using this grating, what would the angles be for the second-order maxima? (c) Discuss the relationship between integral reductions in lines per centimeter and the new angles of various order maxima.

28. What is the maximum number of lines per centimeter a diffraction grating can have and produce a complete first-order spectrum for visible light?

29. The yellow light from a sodium vapor lamp *seems* to be of pure wavelength, but it produces two first-order maxima at 36.093° and 36.129° when projected on a 10,000 line per centimeter diffraction grating. What are the two wavelengths to an accuracy of 0.1 nm?

30. What is the spacing between structures in a feather that acts as a reflection grating, given that they produce a first-order maximum for 525-nm light at a 30.0° angle?

31. Structures on a bird feather act like a reflection grating having 8000 lines per centimeter. What is the angle of the first-order maximum for 600-nm light?

32. An opal such as that shown in Figure 27.17 acts like a reflection grating with rows separated by about $8\ \mu m$. If the opal is illuminated normally, (a) at what angle will red light be seen and (b) at what angle will blue light be seen?

33. At what angle does a diffraction grating produces a second-order maximum for light having a first-order maximum at 20.0°?

34. Show that a diffraction grating cannot produce a second-order maximum for a given wavelength of light unless the first-order maximum is at an angle less than 30.0°.

35. If a diffraction grating produces a first-order maximum for the shortest wavelength of visible light at 30.0°, at what angle will the first-order maximum be for the longest wavelength of visible light?

36. (a) Find the maximum number of lines per centimeter a diffraction grating can have and produce a maximum for the smallest wavelength of visible light. (b) Would such a grating be useful for ultraviolet spectra? (c) For infrared spectra?

37. (a) Show that a 30,000-line-per-centimeter grating will not produce a maximum for visible light. (b) What is the longest wavelength for which it does produce a first-order maximum? (c) What is the greatest number of lines per centimeter a diffraction grating can have and produce a complete second-order spectrum for visible light?

38. A He–Ne laser beam is reflected from the surface of a CD onto a wall. The brightest spot is the reflected beam at an angle equal to the angle of incidence. However, fringes are also observed. If the wall is 1.50 m from the CD, and the first fringe is 0.600 m from the central maximum, what is the spacing of grooves on the CD?

39. The analysis shown in the figure below also applies to diffraction gratings with lines separated by a distance d. What is the distance between fringes produced by a diffraction grating having 125 lines per centimeter for 600-nm light, if the screen is 1.50 m away?

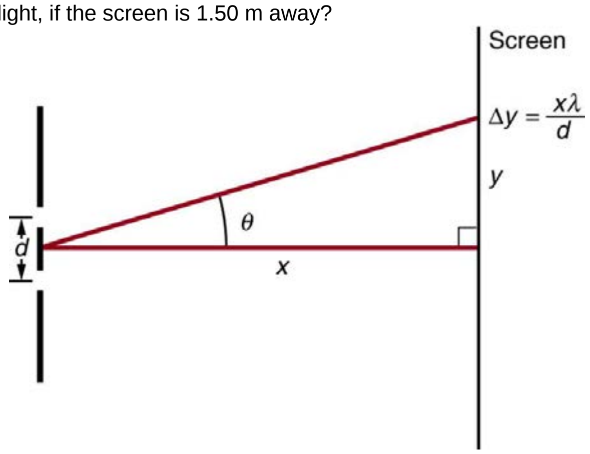

Figure 27.57 The distance between adjacent fringes is $\Delta y = x\lambda / d$, assuming the slit separation d is large compared with λ.

40. Unreasonable Results

Red light of wavelength of 700 nm falls on a double slit separated by 400 nm. (a) At what angle is the first-order maximum in the diffraction pattern? (b) What is unreasonable about this result? (c) Which assumptions are unreasonable or inconsistent?

41. Unreasonable Results

(a) What visible wavelength has its fourth-order maximum at an angle of 25.0° when projected on a 25,000-line-per-centimeter diffraction grating? (b) What is unreasonable about this result? (c) Which assumptions are unreasonable or inconsistent?

42. Construct Your Own Problem

Consider a spectrometer based on a diffraction grating. Construct a problem in which you calculate the distance between two wavelengths of electromagnetic radiation in your spectrometer. Among the things to be considered are the wavelengths you wish to be able to distinguish, the number of lines per meter on the diffraction grating, and the distance from the grating to the screen or detector. Discuss the practicality of the device in terms of being able to discern between wavelengths of interest.

27.5 Single Slit Diffraction

43. (a) At what angle is the first minimum for 550-nm light falling on a single slit of width $1.00\ \mu m$? (b) Will there be a second minimum?

44. (a) Calculate the angle at which a $2.00\text{-}\mu m$-wide slit produces its first minimum for 410-nm violet light. (b) Where is the first minimum for 700-nm red light?

45. (a) How wide is a single slit that produces its first minimum for 633-nm light at an angle of 28.0°? (b) At what angle will the second minimum be?

46. (a) What is the width of a single slit that produces its first minimum at 60.0° for 600-nm light? (b) Find the wavelength of light that has its first minimum at 62.0°.

47. Find the wavelength of light that has its third minimum at an angle of 48.6° when it falls on a single slit of width $3.00\ \mu m$.

48. Calculate the wavelength of light that produces its first minimum at an angle of 36.9° when falling on a single slit of width $1.00\ \mu m$.

49. (a) Sodium vapor light averaging 589 nm in wavelength falls on a single slit of width $7.50\ \mu m$. At what angle does it produces its second minimum? (b) What is the highest-order minimum produced?

50. (a) Find the angle of the third diffraction minimum for 633-nm light falling on a slit of width $20.0\ \mu m$. (b) What slit width would place this minimum at 85.0°? Explicitly show how you follow the steps in **Problem-Solving Strategies for Wave Optics**

51. (a) Find the angle between the first minima for the two sodium vapor lines, which have wavelengths of 589.1 and 589.6 nm, when they fall upon a single slit of width $2.00\ \mu m$.

(b) What is the distance between these minima if the diffraction pattern falls on a screen 1.00 m from the slit? (c) Discuss the ease or difficulty of measuring such a distance.

52. (a) What is the minimum width of a single slit (in multiples of λ) that will produce a first minimum for a wavelength λ?

(b) What is its minimum width if it produces 50 minima? (c) 1000 minima?

53. (a) If a single slit produces a first minimum at 14.5°, at what angle is the second-order minimum? (b) What is the angle of the third-order minimum? (c) Is there a fourth-order minimum? (d) Use your answers to illustrate how the angular width of the central maximum is about twice the angular width of the next maximum (which is the angle between the first and second minima).

54. A double slit produces a diffraction pattern that is a combination of single and double slit interference. Find the ratio of the width of the slits to the separation between them, if the first minimum of the single slit pattern falls on the fifth maximum of the double slit pattern. (This will greatly reduce the intensity of the fifth maximum.)

55. Integrated Concepts

A water break at the entrance to a harbor consists of a rock barrier with a 50.0-m-wide opening. Ocean waves of 20.0-m wavelength approach the opening straight on. At what angle to the incident direction are the boats inside the harbor most protected against wave action?

56. Integrated Concepts

An aircraft maintenance technician walks past a tall hangar door that acts like a single slit for sound entering the hangar. Outside the door, on a line perpendicular to the opening in the door, a jet engine makes a 600-Hz sound. At what angle with the door will the technician observe the first minimum in sound intensity if the vertical opening is 0.800 m wide and the speed of sound is 340 m/s?

27.6 Limits of Resolution: The Rayleigh Criterion

57. The 300-m-diameter Arecibo radio telescope pictured in **Figure 27.28** detects radio waves with a 4.00 cm average wavelength.

(a) What is the angle between two just-resolvable point sources for this telescope?

(b) How close together could these point sources be at the 2 million light year distance of the Andromeda galaxy?

58. Assuming the angular resolution found for the Hubble Telescope in **Example 27.5**, what is the smallest detail that could be observed on the Moon?

59. Diffraction spreading for a flashlight is insignificant compared with other limitations in its optics, such as spherical aberrations in its mirror. To show this, calculate the minimum angular spreading of a flashlight beam that is originally 5.00 cm in diameter with an average wavelength of 600 nm.

60. (a) What is the minimum angular spread of a 633-nm wavelength He-Ne laser beam that is originally 1.00 mm in diameter?

(b) If this laser is aimed at a mountain cliff 15.0 km away, how big will the illuminated spot be?

(c) How big a spot would be illuminated on the Moon, neglecting atmospheric effects? (This might be done to hit a corner reflector to measure the round-trip time and, hence, distance.) Explicitly show how you follow the steps in **Problem-Solving Strategies for Wave Optics**.

61. A telescope can be used to enlarge the diameter of a laser beam and limit diffraction spreading. The laser beam is sent through the telescope in opposite the normal direction and can then be projected onto a satellite or the Moon.

(a) If this is done with the Mount Wilson telescope, producing a 2.54-m-diameter beam of 633-nm light, what is the minimum angular spread of the beam?

(b) Neglecting atmospheric effects, what is the size of the spot this beam would make on the Moon, assuming a lunar distance of $3.84\times10^8\ m$?

62. The limit to the eye's acuity is actually related to diffraction by the pupil.

(a) What is the angle between two just-resolvable points of light for a 3.00-mm-diameter pupil, assuming an average wavelength of 550 nm?

(b) Take your result to be the practical limit for the eye. What is the greatest possible distance a car can be from you if you can resolve its two headlights, given they are 1.30 m apart?

(c) What is the distance between two just-resolvable points held at an arm's length (0.800 m) from your eye?

(d) How does your answer to (c) compare to details you normally observe in everyday circumstances?

63. What is the minimum diameter mirror on a telescope that would allow you to see details as small as 5.00 km on the Moon some 384,000 km away? Assume an average wavelength of 550 nm for the light received.

64. You are told not to shoot until you see the whites of their eyes. If the eyes are separated by 6.5 cm and the diameter of your pupil is 5.0 mm, at what distance can you resolve the two eyes using light of wavelength 555 nm?

65. (a) The planet Pluto and its Moon Charon are separated by 19,600 km. Neglecting atmospheric effects, should the 5.08-m-diameter Mount Palomar telescope be able to resolve these bodies when they are $4.50\times10^{9}\text{ km}$ from Earth? Assume an average wavelength of 550 nm.

(b) In actuality, it is just barely possible to discern that Pluto and Charon are separate bodies using an Earth-based telescope. What are the reasons for this?

66. The headlights of a car are 1.3 m apart. What is the maximum distance at which the eye can resolve these two headlights? Take the pupil diameter to be 0.40 cm.

67. When dots are placed on a page from a laser printer, they must be close enough so that you do not see the individual dots of ink. To do this, the separation of the dots must be less than Raleigh's criterion. Take the pupil of the eye to be 3.0 mm and the distance from the paper to the eye of 35 cm; find the minimum separation of two dots such that they cannot be resolved. How many dots per inch (dpi) does this correspond to?

68. Unreasonable Results

An amateur astronomer wants to build a telescope with a diffraction limit that will allow him to see if there are people on the moons of Jupiter.

(a) What diameter mirror is needed to be able to see 1.00 m detail on a Jovian Moon at a distance of $7.50\times10^{8}\text{ km}$ from Earth? The wavelength of light averages 600 nm.

(b) What is unreasonable about this result?

(c) Which assumptions are unreasonable or inconsistent?

69. Construct Your Own Problem

Consider diffraction limits for an electromagnetic wave interacting with a circular object. Construct a problem in which you calculate the limit of angular resolution with a device, using this circular object (such as a lens, mirror, or antenna) to make observations. Also calculate the limit to spatial resolution (such as the size of features observable on the Moon) for observations at a specific distance from the device. Among the things to be considered are the wavelength of electromagnetic radiation used, the size of the circular object, and the distance to the system or phenomenon being observed.

27.7 Thin Film Interference

70. A soap bubble is 100 nm thick and illuminated by white light incident perpendicular to its surface. What wavelength and color of visible light is most constructively reflected, assuming the same index of refraction as water?

71. An oil slick on water is 120 nm thick and illuminated by white light incident perpendicular to its surface. What color does the oil appear (what is the most constructively reflected wavelength), given its index of refraction is 1.40?

72. Calculate the minimum thickness of an oil slick on water that appears blue when illuminated by white light perpendicular to its surface. Take the blue wavelength to be 470 nm and the index of refraction of oil to be 1.40.

73. Find the minimum thickness of a soap bubble that appears red when illuminated by white light perpendicular to its surface. Take the wavelength to be 680 nm, and assume the same index of refraction as water.

74. A film of soapy water ($n=1.33$) on top of a plastic cutting board has a thickness of 233 nm. What color is most strongly reflected if it is illuminated perpendicular to its surface?

75. What are the three smallest non-zero thicknesses of soapy water ($n=1.33$) on Plexiglas if it appears green (constructively reflecting 520-nm light) when illuminated perpendicularly by white light? Explicitly show how you follow the steps in **Problem Solving Strategies for Wave Optics**.

76. Suppose you have a lens system that is to be used primarily for 700-nm red light. What is the second thinnest coating of fluorite (magnesium fluoride) that would be non-reflective for this wavelength?

77. (a) As a soap bubble thins it becomes dark, because the path length difference becomes small compared with the wavelength of light and there is a phase shift at the top surface. If it becomes dark when the path length difference is less than one-fourth the wavelength, what is the thickest the bubble can be and appear dark at all visible wavelengths? Assume the same index of refraction as water. (b) Discuss the fragility of the film considering the thickness found.

78. A film of oil on water will appear dark when it is very thin, because the path length difference becomes small compared with the wavelength of light and there is a phase shift at the top surface. If it becomes dark when the path length difference is less than one-fourth the wavelength, what is the thickest the oil can be and appear dark at all visible wavelengths? Oil has an index of refraction of 1.40.

79. **Figure 27.34** shows two glass slides illuminated by pure-wavelength light incident perpendicularly. The top slide touches the bottom slide at one end and rests on a 0.100-mm-diameter hair at the other end, forming a wedge of air. (a) How far apart are the dark bands, if the slides are 7.50 cm long and 589-nm light is used? (b) Is there any difference if the slides are made from crown or flint glass? Explain.

80. **Figure 27.34** shows two 7.50-cm-long glass slides illuminated by pure 589-nm wavelength light incident perpendicularly. The top slide touches the bottom slide at one end and rests on some debris at the other end, forming a wedge of air. How thick is the debris, if the dark bands are 1.00 mm apart?

81. Repeat **Exercise 27.70**, but take the light to be incident at a 45° angle.

82. Repeat **Exercise 27.71**, but take the light to be incident at a 45° angle.

83. Unreasonable Results

To save money on making military aircraft invisible to radar, an inventor decides to coat them with a non-reflective material having an index of refraction of 1.20, which is between that of air and the surface of the plane. This, he reasons, should be much cheaper than designing Stealth bombers. (a) What thickness should the coating be to inhibit the reflection of 4.00-cm wavelength radar? (b) What is unreasonable about this result? (c) Which assumptions are unreasonable or inconsistent?

27.8 Polarization

84. What angle is needed between the direction of polarized light and the axis of a polarizing filter to cut its intensity in half?

85. The angle between the axes of two polarizing filters is 45.0°. By how much does the second filter reduce the intensity of the light coming through the first?

86. If you have completely polarized light of intensity 150 W/m^2, what will its intensity be after passing through a polarizing filter with its axis at an 89.0° angle to the light's polarization direction?

87. What angle would the axis of a polarizing filter need to make with the direction of polarized light of intensity 1.00 kW/m^2 to reduce the intensity to 10.0 W/m^2?

88. At the end of **Example 27.8**, it was stated that the intensity of polarized light is reduced to 90.0% of its original value by passing through a polarizing filter with its axis at an angle of 18.4° to the direction of polarization. Verify this statement.

89. Show that if you have three polarizing filters, with the second at an angle of 45° to the first and the third at an angle of 90.0° to the first, the intensity of light passed by the first will be reduced to 25.0% of its value. (This is in contrast to having only the first and third, which reduces the intensity to zero, so that placing the second between them increases the intensity of the transmitted light.)

90. Prove that, if I is the intensity of light transmitted by two polarizing filters with axes at an angle θ and I' is the intensity when the axes are at an angle $90.0^\circ - \theta,$ then $I + I' = I_0,$ the original intensity. (Hint: Use the trigonometric identities $\cos(90.0^\circ - \theta) = \sin\theta$ and $\cos^2\theta + \sin^2\theta = 1.$)

91. At what angle will light reflected from diamond be completely polarized?

92. What is Brewster's angle for light traveling in water that is reflected from crown glass?

93. A scuba diver sees light reflected from the water's surface. At what angle will this light be completely polarized?

94. At what angle is light inside crown glass completely polarized when reflected from water, as in a fish tank?

95. Light reflected at 55.6° from a window is completely polarized. What is the window's index of refraction and the likely substance of which it is made?

96. (a) Light reflected at 62.5° from a gemstone in a ring is completely polarized. Can the gem be a diamond? (b) At what angle would the light be completely polarized if the gem was in water?

97. If θ_b is Brewster's angle for light reflected from the top of an interface between two substances, and θ'_b is Brewster's angle for light reflected from below, prove that $\theta_\text{b} + \theta'_\text{b} = 90.0^\circ.$

98. Integrated Concepts

If a polarizing filter reduces the intensity of polarized light to 50.0% of its original value, by how much are the electric and magnetic fields reduced?

99. Integrated Concepts

Suppose you put on two pairs of Polaroid sunglasses with their axes at an angle of 15.0°. How much longer will it take the light to deposit a given amount of energy in your eye compared with a single pair of sunglasses? Assume the lenses are clear except for their polarizing characteristics.

100. Integrated Concepts

(a) On a day when the intensity of sunlight is 1.00 kW/m^2, a circular lens 0.200 m in diameter focuses light onto water in a black beaker. Two polarizing sheets of plastic are placed in front of the lens with their axes at an angle of $20.0^\circ.$ Assuming the sunlight is unpolarized and the polarizers are 100% efficient, what is the initial rate of heating of the water in $^\circ\text{C/s}$, assuming it is 80.0% absorbed? The aluminum beaker has a mass of 30.0 grams and contains 250 grams of water. (b) Do the polarizing filters get hot? Explain.

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27.2 Huygens's Principle: Diffraction

1. Which of the following statements is true about Huygens's principle of secondary wavelets?

a. It can be used to explain the particle behavior of waves.
b. It states that each point on a wavefront can be considered a new wave source.
c. It can be used to find the velocity of a wave.
d. All of the above.

2. Explain why the amount of bending that occurs during diffraction depends on the width of the opening through which light passes.

27.3 Young's Double Slit Experiment

3. Superposition of which of the following light waves may produce interference fringes? Select *two* answers.

$\text{Wave}_1 = A_1\sin(2\omega t)$

$\text{Wave}_2 = A_2\sin(4\omega t)$

$\text{Wave}_3 = A_3\sin(2\omega t + \theta)$

$\text{Wave}_4 = A_4\sin(4\omega t + \theta)$.

a. Wave_1 and Wave_2
b. Wave_2 and Wave_4
c. Wave_3 and Wave_1
d. Wave_4 and Wave_3

4. In a double slit experiment with monochromatic light, the separation between the slits is 2 mm. If the screen is moved by 100 mm toward the slits, the distance between the central bright line and the second bright line changes by 32 µm. Calculate the wavelength of the light used for the experiment.

5. In a double slit experiment, a student measures the maximum and minimum intensities when two waves with equal amplitudes are used. The student then doubles the amplitudes of the two waves and performs the measurements again. Which of the following will remain unchanged?

a. The intensity of the bright fringe
b. The intensity of the dark fringe
c. The difference in the intensities of consecutive bright and dark fringes
d. None of the above

6. Draw a figure to show the resultant wave produced when two coherent waves (with equal amplitudes x) interact in phase. What is the amplitude of the resultant wave? If the phase difference between the coherent waves is changed to 60º, what will be new amplitude?

7. What will be the amplitude of the central fringe if the amplitudes of the two waves in a double slit experiment are a and $3a$?

a. $2a$
b. $4a$
c. $8a^2$
d. $16a^2$

8. If the ratio of amplitudes of the two waves in a double slit experiment is 3:4, calculate the ratio of minimum intensity (dark fringe) to maximum intensity (bright fringe).

27.4 Multiple Slit Diffraction

9. Which of the following cannot be a possible outcome of passing white light through several evenly spaced parallel slits?

a. The central maximum will be white but the higher-order maxima will disperse into a rainbow of colors.
b. The central maximum and higher-order maxima will be of equal widths.
c. The lower wavelength components of light will have less diffraction compared to higher wavelength components for all maxima except the central one.
d. None of the above.

10. White light is passed through a diffraction grating to a screen some distance away. The nth-order diffraction angle for the longest wavelength (760 nm) is 53.13º. Find the nth-order diffraction angle for the shortest wavelength (380 nm). What will be the change in the two angles if the distance between the screen and the grating is doubled?

27.5 Single Slit Diffraction

11. A diffraction pattern is formed on a screen when light of wavelength 410 nm is passed through a single slit of width 1 µm. If the source light is replaced by another light of wavelength 700 nm, what should be the width of the slit so that the new light produces a pattern with the same spacing?

a. 0.6 µm
b. 1 µm
c. 1.4 µm
d. 1.7 µm

12. Monochromatic light passing through a single slit forms a diffraction pattern on a screen. If the second minimum occurs at an angle of 15º, find the angle for the fourth minimum.

27.6 Limits of Resolution: The Rayleigh Criterion

13. What is the relationship between the width (W) of the central diffraction maximum formed through a circular aperture and the size (S) of the aperture?

a. W increases as S increases.
b. W decreases as S increases.
c. W can increase or decrease as S decreases.
d. W can neither increase nor decrease as S decreases.

14. Light from two sources passes through a circular aperture to form images on a screen. State the Rayleigh criterion for the images to be just resolvable and draw a figure to visually explain it.

27.7 Thin Film Interference

15. Which of the following best describes the cause of thin film interference?

a. Light reflecting from a medium having an index of refraction less than that of the medium in which it is traveling.
b. Light reflecting from a medium having an index of refraction greater than that of the medium in which it is traveling.
c. Light changing its wavelength and speed after reflection.
d. Light reflecting from the top and bottom surfaces of a film.

16. A film of magnesium fluoride (n = 1.38) is used to coat a glass camera lens (n = 1.52). If the thickness of the film is 105 nm, calculate the wavelength of visible light that will have the most limited reflection.

27.8 Polarization

17. Which of the following statements is true for the direction of polarization for a polarized light wave?

a. It is parallel to the direction of propagation and perpendicular to the direction of the electric field.
b. It is perpendicular to the direction of propagation and parallel to the direction of the electric field.
c. It is parallel to the directions of propagation and the electric field.
d. It is perpendicular to the directions of propagation and the electric field.

18. In an experiment, light is passed through two polarizing filters. The image below shows the first filter and axis of polarization.

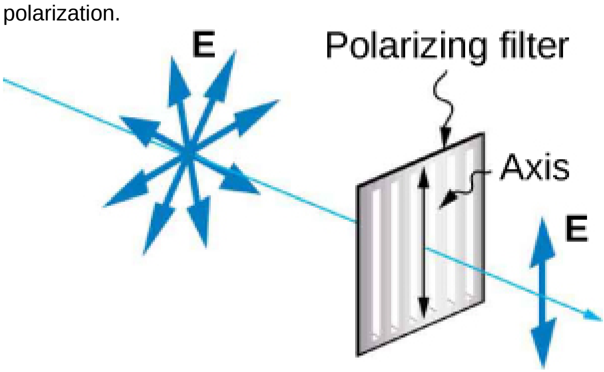

Figure 27.58

The intensity of the resulting light (after the first filter) is recorded as *I*. Three configurations (at different angles) are set up for the second filter, and the intensity of light is recorded for each configuration. The results are shown in the table below:

Table 27.2

Set up	Angle of second filter compared to first filter	Intensity of light after second filter
Configuration A	θ_1	I
Configuration B	θ_2	$0.5I$
Configuration C	θ_3	0

Complete the table by calculating θ_1, θ_2, and θ_3.

(c)

Chapter 27

Problems & Exercises

1

$1 / 1.333 = 0.750$

3

1.49, Polystyrene

5

0.877 glass to water

6

0.516°

8

1.22×10^{-6} m

10

600 nm

12

2.06°

14

1200 nm (not visible)

16

(a) 760 nm

(b) 1520 nm

18

For small angles $\sin \theta - \tan \theta \approx \theta$ (in radians) .

For two adjacent fringes we have,

$$d \ \sin \theta_{\mathrm{m}} = m\lambda$$

and

$$d \ \sin \theta_{\mathrm{m}+1} = (m+1)\lambda$$

Subtracting these equations gives

$$d\left(\sin \theta_{\mathrm{m}+1} - \sin \theta_{\mathrm{m}}\right) = [(m+1) - m]\lambda$$

$$d\left(\theta_{\mathrm{m}+1} - \theta_{\mathrm{m}}\right) = \lambda$$

$$\tan \theta_{\mathrm{m}} = \frac{y_{\mathrm{m}}}{x} \approx \theta_{\mathrm{m}} \Rightarrow d\left(\frac{y_{\mathrm{m}+1}}{x} - \frac{y_{\mathrm{m}}}{x}\right) = \lambda$$

$$d\frac{\Delta y}{x} = \lambda \Rightarrow \Delta y = \frac{x\lambda}{d}$$

20

450 nm

21

5.97°

23

8.99×10^{3}

25

707 nm

27

(a) 11.8°, 12.5°, 14.1°, 19.2°

(b) 24.2°, 25.7°, 29.1°, 41.0°

(c) Decreasing the number of lines per centimeter by a factor of x means that the angle for the x-order maximum is the same as the original angle for the first- order maximum.

29
589.1 nm and 589.6 nm
31
28.7°
33
43.2°
35
90.0°
37

(a) The longest wavelength is 333.3 nm, which is not visible.

(b) 333 nm (UV)

(c) 6.58×10^{3} cm

39
1.13×10^{-2} m
41

(a) 42.3 nm

(b) Not a visible wavelength

The number of slits in this diffraction grating is too large. Etching in integrated circuits can be done to a resolution of 50 nm, so slit separations of 400 nm are at the limit of what we can do today. This line spacing is too small to produce diffraction of light.

43

(a) 33.4°

(b) No

45

(a) 1.35×10^{-6} m

(b) 69.9°

47
750 nm
49

(a) 9.04°

(b) 12

51

(a) 0.0150°

(b) 0.262 mm

(c) This distance is not easily measured by human eye, but under a microscope or magnifying glass it is quite easily measurable.

53

(a) 30.1°

(b) 48.7°

(c) No

(d) $2\theta_1 = (2)(14.5^{\circ}) = 29^{\circ}, \theta_2 - \theta_1 = 30.05^{\circ}-14.5^{\circ}=15.56^{\circ}$. Thus, $29^{\circ} \approx (2)(15.56^{\circ}) = 31.1^{\circ}$.

55
23.6° and 53.1°
57

(a) 1.63×10^{-4} rad

(b) 326 ly

59
1.46×10^{-5} rad
61

(a) 3.04×10^{-7} rad

(b) Diameter of 235 m

63
5.15 cm
65

(a) Yes. Should easily be able to discern.

(b) The fact that it is just barely possible to discern that these are separate bodies indicates the severity of atmospheric aberrations.

70
532 nm (green)
72
83.9 nm
74
620 nm (orange)
76
380 nm
78
33.9 nm
80
4.42×10^{-5} m
82
The oil film will appear black, since the reflected light is not in the visible part of the spectrum.
84
45.0°
86
$45.7\ \text{mW/m}^2$
88
90.0%
90
I_0
92
48.8°
94
41.2°
96

(a) 1.92, not diamond (Zircon)

(b) 55.2°

98
$B_2 = 0.707\ B_1$
100

(a) 2.07×10^{-2} °C/s

(b) Yes, the polarizing filters get hot because they absorb some of the lost energy from the sunlight.

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1
(b)
3
(b) and (c)
5
(b)

7

(b)

9

(b)

11

(d)

13

(b)

15

(d)

17

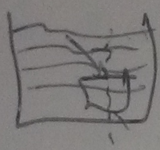
(b)

Optics Problems Solved.

11/ $n = \frac{c}{v} \rightarrow v = \frac{c}{n} = 1.93 \cdot 10^{8}\ m/s$

$t = \frac{d}{v} = \frac{0.2}{1.93\,10^{8}} = 1.03\,10^{-9}\ s = 1.03\ ns$

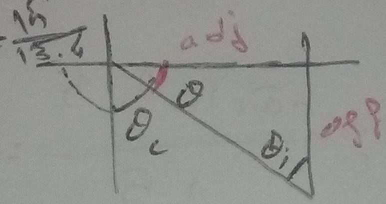
13/



$n_2 \sin\theta_2 = n_1 \sin\theta_1$

$n_2 = \frac{1.33 \cdot \sin 45}{\sin(40.3)} = 1.46$ ... fused quartz

26/ $\tan\theta = \frac{opp}{adj} = \frac{15}{13.4}$



$\tan\theta = 1.119$

$\theta = \tan^{-1}(1.119) = 48^\circ \rightarrow \theta_i = 90 - 48 = 42^\circ = \theta_c$

$n_2 = \frac{n_w \cdot \sin\theta_1}{\sin\theta_i} = \frac{1 \cdot \sin(2 \cdot 42)}{\sin(42)} = 1.49 \rightarrow$ Benzene

41/a/ $\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f} \rightarrow d_i = \frac{1}{\frac{1}{f} - \frac{1}{d_o}} = 3433\ mm = 3.43\ m$

3b/ $\frac{S_i}{S_o} = \frac{d_i}{d_o} \rightarrow \frac{s_i}{s_o} = \frac{h_i}{h_o} = \frac{w_i}{w_o}$

$\rightarrow h_i = \frac{d_i}{d_o} \cdot h_o = \frac{3433 \cdot 36}{103} = 1199\ mm = 1.2\ m$

$w_i = \frac{d_i}{d_o} w_o = \frac{3433 \cdot 24}{103} = 800\ mm = 0.8\ m$

46/a/ $d_o = \frac{1}{\frac{1}{f} - \frac{1}{d_i}} = 66\ mm.$

b/ $m = -\frac{d_i}{d_o} = -\frac{1}{2}$

58/a/ $f = \frac{-1}{2} = -1.5$

b/ $P = \frac{1}{f} = \frac{1}{-1.5 \cdot 10^{-2}} = -66.7$ Diopters

Power is related to the effect of optical devices on light, measured in Diopters $\left[\frac{1}{m}\right]$ or $[m^{-1}]$

59/a/ $m = \frac{-d_i}{d_o} = \frac{h_i}{h_o} = 0.1113$

b/ $d_i = -m \cdot d_o = -0.1113 \cdot 3 = -0.337$ cm

the distance to the image is negative so the image is virtual and is located behind the mirror.

c/ $R = 2f$

$$f = \frac{1}{\frac{1}{d_i} + \frac{1}{d_o}} = \frac{1}{-\frac{1}{0.334} + \frac{1}{3}} = -0.376 \text{ cm}$$

$R = 2f = 0.752$ cm.

1b/ $\lambda m = d\sin\theta$

$m = 1 \longrightarrow \lambda_{max} = d\,(\sin\theta)_{max}$ $=1$

$\longrightarrow \lambda_{max} = 1.2\ \mu m = 1200\ nm$

out of the visible spectrum

11/ $\lambda = \frac{d\sin\theta}{m} = \frac{2 \cdot \sin(60)}{3} = 0.577\ \mu m = 577\ nm$

21/ 2000 lines/cm $\longrightarrow d = \frac{1}{2000} = 5.10^{-4}\ cm = 5\,10^{-6}\ m$

$\sin\theta = \frac{\lambda \cdot m}{d} = \frac{5.2 \cdot 10^{-7} \times 1}{5.10^{-6}} = 0.104$

$\theta = \sin^{-1}\theta = 5.96°$

29/ $\lambda = \frac{d\sin\theta}{m}$

$m = 1$; $d = \frac{1}{10000} = 10^{-4}\ cm = 10^{-6}\ m$

$\longrightarrow \lambda_1 = 10^{-6}\sin(36.093) = 5.891 \cdot 10^{-7} = 589\ nm$

$\lambda_2 = 589.6\ nm.$

39/ $d = \frac{1}{125} = 8.10^{-5}\ m$

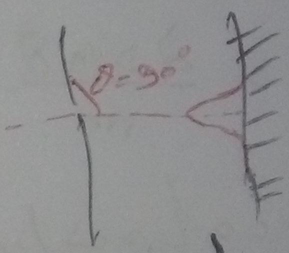
$\Delta y = \frac{x\lambda}{d} = \frac{1.5 \cdot 600\,10^{-9}}{8.10^{-5}}$

$\Delta y = 0.0112\ m$

43) a) $\sin\theta = \frac{m\lambda}{D} = \frac{1 \cdot 550 \cdot 10^{-9}}{10^{-6}} = 0.55$

$\sin^{-1}\theta = 33.36^\circ$

b) we first have to ~~[illegible]~~ look for the Total number of minima so the angle has to be 90° in order to do so, $\sin(90^\circ) = 1$



$\rightarrow m = \frac{D}{\lambda} = \frac{1000\ nm}{550\ nm} = 1.8$

→ so only one minimum is allowed, no second.