of the wave increase, decrease, or remain the same? Give a reason for your choice.

7. One end of each of two identical strings is attached to a wall. Each string is being pulled tight by someone at the other end. A transverse pulse is sent traveling along one of the strings. A bit later an identical pulse is sent traveling along the other string. What, if anything, can be done to make the second pulse catch up with and pass the first pulse? Account for your answer.

8. In Section 4.10 the concept of a "massless" rope is discussed. Would it take any time for a transverse wave to travel the length of a massless rope? Justify your answer.

9. In a traveling sound wave, are there any particles that are *always* at rest as the wave passes by? Justify your answer.

10. Do you expect an echo to return to you more quickly or less quickly on a hot day as compared to a cold day, other things being equal? Account for your answer.

11. A loudspeaker produces a sound wave. Does the wavelength of the sound increase, decrease, or remain the same, when the wave travels from air into water? Justify your answer. *(Hint: The frequency does not change as the sound enters the water.)*

12. JELL-O starts out as a liquid and then sets to a gel. What would you expect to happen to the speed of sound in this material as the JELL-O sets? Does it increase, decrease, or remain the same? Give your reasoning.

13. Some animals rely on an acute sense of hearing for survival, and the visible part of the ear on such animals is often relatively large. Explain how this anatomical feature helps to increase the sensitivity of the animal's hearing for low-intensity sounds.

14. A source is emitting sound uniformly in all directions. There are no reflections anywhere. A *flat* surface faces the source. Is the sound intensity the same at all points on the surface? Give your reasoning.

15. If two people talk simultaneously and each creates an intensity level of 65 dB at a certain point, does the total intensity level at this point equal 130 dB? Account for your answer.

16. Two cars, one behind the other, are traveling in the same direction at the same speed. Does either driver hear the other's horn at a frequency that is different from that heard when both cars are at rest? Justify your answer.

17. A source of sound produces the same frequency underwater as it does in air. This source has the same velocity in air as it does underwater. The observer of the sound is stationary, both in air and underwater. Is the Doppler effect greater in air or underwater when the source (a) approaches and (b) moves away from the observer? Explain.

18. A music fan at a swimming pool is listening to a radio on a diving platform. The radio is playing a constant frequency tone when this fellow, clutching his radio, jumps. Describe the Doppler effect heard by (a) a person left behind on the platform and (b) a person down below floating on a rubber raft. In each case, specify (1) whether the observed frequency is greater or smaller than the frequency produced by the radio, (2) whether the observed frequency is constant, and (3) how the observed frequency changes during the fall, if it does change. Give your reasoning.

19. When a car is at rest, its horn emits a frequency of 600 Hz. A person standing in the middle of the street hears the horn with a frequency of 580 Hz. Should the person jump out of the way? Account for your answer.

20. The text discusses how the Doppler effect arises when (1) the observer is stationary and the source moves and (2) the observer moves and the source is stationary. A car is speeding toward a large wall and sounds the horn. Is the Doppler effect present in the echo that the driver hears? If it is present, from which of the above situations does it arise, (1) or (2) or both? Explain.

PROBLEMS

ssm **Solution is in the Student Solutions Manual.** **www** **Solution is available on the World Wide Web at http://www.wiley.com/college/cutnell**
This icon represents a biomedical application.

Section 16.1 The Nature of Waves, Section 16.2 Periodic Waves

1. **ssm** A person standing in the ocean notices that after a wave crest passes by, ten more crests pass in a time of 120 s. What is the frequency of the wave?

2. The magnetic tape of a cassette deck moves with a speed of 0.048 m/s ($1\frac{7}{8}$ inches per second). The recording head records a 15-kHz tone on the tape. What is the wavelength λ of the magnetized regions?

* **3.** **ssm** In Figure 16.2 the hand moves the end of the Slinky up and down through two complete cycles in one second. The wave moves along the Slinky at a speed of 0.50 m/s. Find the distance between two adjacent crests on the wave.

4. Consider the freight train in Figure 16.7. Suppose 15 boxcars pass by in a time of 12.0 s and each has a length of 14.0 m. (a) What is the frequency at which each boxcar passes? (b) What is the speed of the train?

5. A longitudinal wave with a frequency of 3.0 Hz takes 1.7 s to travel the length of a 2.5-m Slinky (see Figure 16.3). Determine the wavelength of the wave.

* **6.** Tsunamis are fast-moving waves often generated by underwater earthquakes. In the deep ocean their amplitude is barely noticeable, but upon reaching shore, they can rise up to the astonishing height of a six-story building. One tsunami, generated off the Aleutian islands in Alaska, had a wavelength of 750 km and traveled a distance of 3700 km in 5.3 h. (a) What was the speed

(in m/s) of the wave? For reference, the speed of a 747 jetliner is about 250 m/s. Find the wave's (b) frequency and (c) period.

7. **ssm** Suppose the amplitude and frequency of the transverse wave in Figure 16.2*c* are, respectively, 1.3 cm and 5.0 Hz. Find the *total vertical distance* (in cm) through which the colored dot moves in 3.0 s.

8. A person fishing from a pier observes that four wave crests pass by in 7.0 s and estimates the distance between two successive crests as 4.0 m. The timing starts with the first crest and ends with the fourth. What is the speed of the wave?

***9.** The speed of a transverse wave on a string is 450 m/s, while the wavelength is 0.18 m. The amplitude of the wave is 2.0 mm. How much time is required for a particle of the string to move through a total distance of 1.0 km?

***10.** In Figure 16.3*c* the colored "dot" exhibits simple harmonic motion as the longitudinal wave passes. The wave has an amplitude of 5.4×10^{-3} m and a frequency of 4.0 Hz. Find the maximum acceleration of the dot.

****11.** A water-skier is moving at a speed of 12.0 m/s. When she skis in the same direction as a traveling wave, she springs upward every 0.600 s because of the wave crests. When she skis in the direction opposite to that in which the wave moves, she springs upward every 0.500 s in response to the crests. The speed of the skier is greater than the speed of the wave. Determine (a) the speed and (b) the wavelength of the wave.

Section 16.3 The Speed of a Wave on a String

12. A 0.75-m string is stretched so the tension is 2.3 N. A transverse wave with a frequency of 150 Hz and a wavelength of 0.40 m travels on the string. What is the mass of the string?

13. **ssm** The linear density of the A string on a violin is 7.8×10^{-4} kg/m. A wave on the string has a frequency of 440 Hz and a wavelength of 65 cm. What is the tension in the string?

14. A vibrator moves one end of a rope up and down to generate a wave. The tension in the rope is 58 N. The frequency is then doubled. To what value must the tension be adjusted, so the new wave has the same wavelength as the old one?

15. **ssm** **www** The middle C string on a piano is under a tension of 944 N. The period and wavelength of a wave on this string are 3.82 ms and 1.26 m, respectively. Find the linear density of the string.

16. Two wires are parallel, and one is directly above the other. Each has a length of 50.0 m and a mass per unit length of 0.020 kg/m. However, the tension in wire A is 6.00×10^2 N, while the tension in wire B is 3.00×10^2 N. Transverse wave pulses are generated simultaneously, one at the left end of wire A and one at the right end of wire B. The pulses travel toward each other. How much time does it take until the pulses pass each other?

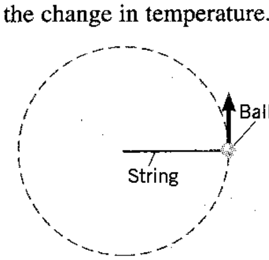
17. To measure the acceleration due to gravity on a distant planet, an astronaut hangs a 0.085-kg ball from the end of a wire. The wire has a length of 1.5 m and a linear density of 3.1×10^{-4} kg/m. Using electronic equipment, the astronaut measures the time for a transverse pulse to travel the length of the wire and obtains a value of 0.083 s. The mass of the wire is negligible compared to the mass of the ball. Determine the acceleration due to gravity.

***18.** Review Conceptual Example 3 before starting this problem. The amplitude of a transverse wave on a string is 4.5 cm. The ratio of the maximum particle speed to the speed of the wave is 3.1. What is the wavelength (in cm) of the wave?

***19.** **ssm** Two blocks are connected by a wire that has a mass per unit length of 8.50×10^{-4} kg/m. One block has a mass of 19.0 kg, while the other has a mass of 42.0 kg. These blocks are being pulled across a horizontal frictionless floor by a horizontal force **P** that is applied to the less massive block. A transverse wave travels on the wire between the blocks with a speed of 352 m/s (relative to the wire). The mass of the wire is negligible compared to the mass of the blocks. Find the magnitude of **P**.

****20.** A copper wire, whose cross-sectional area is 1.1×10^{-6} m^2, has a linear density of 7.0×10^{-3} kg/m and is strung between two walls. At the ambient temperature, a transverse wave travels with a speed of 46 m/s on this wire. The coefficient of linear expansion for copper is 17×10^{-6} (C°)$^{-1}$, and Young's modulus for copper is 1.1×10^{11} N/m^2. What will be the speed of the wave when the temperature is lowered by 14 C°? Ignore any change in the linear density caused by the change in temperature.

****21.** The drawing shows a 15.0-kg ball being whirled in a circular path on the end of a string. The motion occurs on a frictionless, horizontal table. The angular speed of the ball is $\omega = 12.0$ rad/s. The string has a mass of 0.0230 kg. How much time does it take for a wave on the string to travel from the center of the circle to the ball?



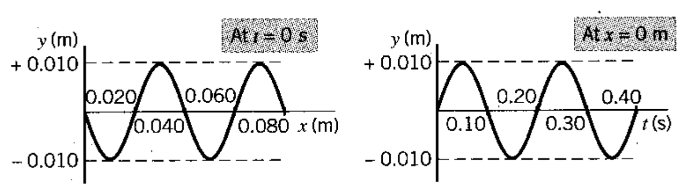
Section 16.4 The Mathematical Description of a Wave

(Note: The phase angles $(2\pi ft - 2\pi x/\lambda)$ and $(2\pi ft + 2\pi x/\lambda)$ are measured in radians, not degrees.)

22. A wave is moving in the $+x$ direction. Assuming that the wave has the following properties, write the equation of the wave (similar to Equation 16.3 or 16.4): speed = 7.1 m/s, amplitude = 0.15 m, wavelength = 0.28 m.

23. **ssm** A wave has the following properties: amplitude = 0.37 m, period = 0.77 s, wave speed = 12 m/s. The wave is traveling in the $-x$ direction. What is the mathematical expression (similar to Equation 16.3 or 16.4) for the wave?

24. The drawing shows two graphs that represent a transverse wave on a string. The wave is moving in the $+x$ direction. Using the information contained in these graphs, write the mathematical expression (similar to Equation 16.3 or 16.4) for the wave.



25. The displacement (in meters) of a wave is $y = 0.26 \sin(\pi t - 3.7\pi x)$, where t is in seconds and x is in meters. (a) Is the wave traveling in the $+x$ or $-x$ direction? (b) What is the displacement y when $t = 38$ s and $x = 13$ m?

***26.** The tension in a string is 15 N, and its linear density is 0.85 kg/m. A wave on the string travels toward the $-x$ direction; it has an amplitude of 3.6 cm and a frequency of 12 Hz. What are the (a) speed and (b) wavelength of the wave? (c) Write down a mathematical expression (like Equation 16.3 or 16.4) for the wave, substituting numbers for the variables A, f, and λ.

***27. ssm** A transverse wave is traveling on a string. The displacement y of a particle from its equilibrium position is given by $y = (0.021 \text{ m}) \sin(25t - 2.0x)$. Note that the phase angle $25t - 2.0x$ is in radians, t is in seconds, and x is in meters. The linear density of the string is 1.6×10^{-2} kg/m. What is the tension in the string?

****28.** A transverse wave on a string has an amplitude of 0.20 m and a frequency of 175 Hz. Consider the particle of the string at $x = 0$ m. It begins with a displacement of $y = 0$ m when $t = 0$ s, according to Equation 16.3 or 16.4. How much time passes between the first two instants when this particle has a displacement of $y = 0.10$ m?

Section 16.5 The Nature of Sound,
Section 16.6 The Speed of Sound

29. ssm The speed of a sound in a container of hydrogen at 201 K is 1220 m/s. What would be the speed of sound if the temperature were raised to 405 K? Assume that hydrogen behaves like an ideal gas.

30. A sonar unit on a submarine sends out a pulse of sound into seawater. The pulse returns 1.30 s later. What is the distance to the object that reflects the pulse back to the submarine?

31. The right-most key on a piano produces a sound wave that has a frequency of 4185.6 Hz. Assuming that the speed of sound in air is 343 m/s, find the corresponding wavelength.

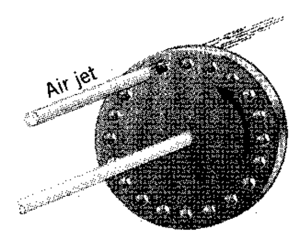
32. Have you ever listened for an approaching train by kneeling next to a railroad track and putting your "ear to the rail?" Young's modulus for steel is $Y = 2.0 \times 10^{11}$ N/m^2, and the density of steel is $\rho = 7860$ kg/m^3. On a day when the temperature is 20 °C, how many times greater is the speed of sound in the rail than in the air?

33. ssm Argon (molecular mass = 39.9 u) is a monatomic gas. Assuming that it behaves like an ideal gas at 298 K ($\gamma = 1.67$), find (a) the rms speed of argon atoms and (b) the speed of sound in argon.

34. A sound wave is incident on a pool of fresh water. The sound enters the water perpendicularly and travels a distance of 0.45 m before striking a 0.15-m-thick copper block lying on the bottom. The sound passes through the block, reflects from the bottom surface of the block, and returns to the top of the water along the same path. How much time elapses between when the sound enters and leaves the water?

35. An explosion occurs at the end of a pier. The sound reaches the other end of the pier by traveling through three media: air, fresh water, and a slender handrail of solid steel. The speeds of sound in air, water, and the handrail are 343, 1482, and 5040 m/s, respectively. The sound travels a distance of 125 m in each medium. (a) Through which medium does the sound arrive first, second, and third? (b) After the first sound arrives, how much later do the second and third sounds arrive?

36. As the drawing illustrates, a siren can be made by blowing a jet of air through 20 equally spaced holes in a rotating disk. The time it takes for successive holes to move past the air jet is the period of the sound. The siren is to produce a 2200-Hz tone. What must be the angular speed ω (in rad/s) of the disk?



37. At what temperature is the speed of sound in helium (atomic mass = 4.003 u) the same as the speed of sound in oxygen at 0 °C? Consider helium to be an ideal gas ($\gamma = 1.67$).

***38.** Review the rule of thumb in Conceptual Example 5. Suppose the speed of light were 961 m/s, instead of 3.0×10^8 m/s, but the speed of sound remained at 343 m/s. The new rule of thumb is stated as follows:

> After you see a flash of lightning, count off the seconds until the thunder is heard. Divide the number of seconds by the number X. The result gives the approximate distance (in miles) to the thunderstorm.

What is the number X?

***39. ssm** A long slender bar is made from an unknown material. The length of the bar is 0.83 m, its cross-sectional area is 1.3×10^{-4} m^2, and its mass is 2.1 kg. A sound wave travels from one end of the bar to the other end in 1.9×10^{-4} s. From which one of the materials listed in Table 10.1 is the bar most likely to be made?

***40.** When an earthquake occurs, two types of sound waves are generated and travel through the earth. The primary, or P, wave has a speed of about 8.0 km/s and the secondary, or S, wave has a speed of about 4.5 km/s. A seismograph, located some distance away, records the arrival of the P wave and then, 78 s later, records the arrival of the S wave. Assuming that the waves travel in a straight line, how far is the seismograph from the earthquake?

***41. ssm** A hunter is standing on flat ground between two vertical cliffs that are directly opposite one another. He is closer to one cliff than the other. He fires a gun and, after a while, hears three echoes. The second echo arrives 1.6 s after the first, and the third echo arrives 1.1 s after the second. Assuming that the speed of sound is 343 m/s and that there are no reflections of sound from the ground, find the distance between the cliffs.

***42.** At a height of ten meters above the surface of a lake, a sound pulse is generated. The echo from the bottom of the lake returns to the point of origin 0.140 s later. The air and water temperatures are 20 °C. How deep is the lake?

*43. A monatomic ideal gas ($\gamma = 1.67$) is contained within a box whose volume and pressure are 2.5 m^3 and 3.5×10^5 Pa, respectively. The total mass of the gas is 2.3 kg. Find the speed of sound in the gas.

*44. Both krypton (Kr) and neon (Ne) can be approximated as monatomic ideal gases. The atomic mass of krypton is 83.8 u, while that of neon is 20.2 u. A loudspeaker produces a sound whose wavelength in krypton is 1.25 m. If the loudspeaker were used to produce sound of the same frequency in neon at the same temperature, what would be the wavelength?

**45. In a mixture of argon (atomic mass = 39.9 u) and neon (atomic mass = 20.2 u), the speed of sound is 363 m/s at 3.00×10^2 K. Assume that both monatomic gases behave as ideal gases. Find the percentage of the atoms that are argon and the percentage that are neon.

**46. The sonar unit on a boat is designed to measure the depth of fresh water ($\rho = 1.00 \times 10^3$ kg/m^3, $B_{ad} = 2.20 \times 10^9$ Pa). When the boat moves into salt water ($\rho = 1025$ kg/m^3, $B_{ad} = 2.37 \times 10^9$ Pa), the sonar unit is no longer calibrated properly. In salt water, the sonar unit indicates the water depth to be 10.0 m. What is the actual depth of the water?

47. **ssm www As a prank, someone drops a water-filled balloon out of a window. The balloon is released from rest at a height of 10.0 m above the ears of a man who is the target. Because of a guilty conscience, however, the prankster shouts a warning after the balloon is released. The warning will do no good, however, if shouted after the balloon reaches a certain point, even if the man could react infinitely quickly. Assuming that the air temperature is 20 °C and ignoring the effect of air resistance on the balloon, determine how far above the man's ears this point is.

Section 16.7 Sound Intensity

48. A typical adult ear has a surface area of 2.1×10^{-3} m^2. The sound intensity during a normal conversation is about 3.2×10^{-6} W/m^2 at the listener's ear. Assume the sound strikes the surface of the ear perpendicularly. How much power is intercepted by the ear?

49. **ssm www** At a distance of 3.8 m from a siren, the sound intensity is 3.6×10^{-2} W/m^2. Assuming that the siren radiates sound uniformly in all directions, find the total power radiated.

50. The average sound intensity inside a busy restaurant is 3.2×10^{-5} W/m^2. How much energy goes into each ear (area = 2.1×10^{-3} m^2) during a one-hour meal?

51. A rocket in a fireworks display explodes high in the air. The sound spreads out uniformly in all directions. The intensity of the sound is 2.0×10^{-6} W/m^2 at a distance of 120 m from the explosion. Find the distance from the source at which the intensity is 0.80×10^{-6} W/m^2.

52. Suppose in Conceptual Example 8 (see Figure 16.25) that the person is producing 1.1 mW of sound power. Some of the sound is reflected from the floor and ceiling. The intensity of this reflected sound at a distance of 3.0 m from the source is 4.4×10^{-6} W/m^2. What is the total sound intensity due to both the direct and reflected sounds, at this point?

53. **ssm** A loudspeaker has a circular opening with a radius of 0.0950 m. The electrical power needed to operate the speaker is 25.0 W. The average sound intensity at the opening is 17.5 W/m^2. What percentage of the electrical power is converted by the speaker into sound power?

*54. Deep ultrasonic heating is used to promote healing of torn tendons. It is produced by applying ultrasonic sound to the body. The sound transducer (generator) is circular with a radius of 1.8 cm, and it produces a sound intensity of 5.9×10^3 W/m^2. How much time is required for the transducer to emit 4800 J of sound energy?

*55. A dish of lasagna is being heated in a microwave oven. The effective area of the lasagna that is exposed to the microwaves is 1.6×10^{-2} m^2. The mass of the lasagna is 0.25 kg, and its specific heat capacity is 3400 J/(kg · C°). The temperature rises by 80.0 C° in 7.0 minutes. What is the intensity of the microwaves in the oven?

*56. When a helicopter is hovering 1450 m directly overhead, an observer on the ground measures a sound intensity I. Assume that sound is radiated uniformly from the helicopter and that ground reflections are negligible. How far must the helicopter fly in a straight line parallel to the ground before the observer measures a sound intensity of $\frac{1}{4}I$?

57. **ssm A rocket, starting from rest, travels straight up with an acceleration of 58.0 m/s^2. When the rocket is at a height of 562 m, it produces sound that eventually reaches a ground-based monitoring station directly below. The sound is emitted uniformly in all directions. The monitoring station measures a sound intensity I. Later, the station measures an intensity $\frac{1}{3}I$. Assuming that the speed of sound is 343 m/s, find the time that has elapsed between the two measurements.

Section 16.8 Decibels

58. The volume control on a stereo amplifier is adjusted so the sound intensity level increases from 23 to 61 dB. What is the ratio of the final sound intensity to the original sound intensity?

59. The bellow of a territorial bull hippopotamus has been measured at 115 dB above the threshold of hearing. What is the sound intensity?

60. A recording engineer works in a soundproofed room that is 44.0 dB quieter than the outside. If the sound intensity in the room is 1.20×10^{-10} W/m^2, what is the intensity outside?

61. **ssm** When a person wears a hearing aid, the sound intensity level increases by 30.0 dB. By what factor does the sound intensity increase?

62. The equation $\beta = (10 \text{ dB}) \log (I/I_0)$, which defines the decibel, is sometimes written in terms of power P (in watts) rather than intensity I (in watts/meter^2). The form $\beta = (10 \text{ dB}) \log (P/P_0)$ can be used to compare two power levels in terms of decibels. Suppose that stereo amplifier A is rated at P = 250 watts per channel, while amplifier B has a rating of P_0 = 45

watts per channel. (a) Expressed in decibels, how much more powerful is A compared to B? (b) Will A sound more than twice as loud as B? Justify your answer.

63. ssm A listener doubles his distance from a source that emits sound uniformly in all directions. By how many decibels does the sound intensity level change?

64. For information, read problem 62 before working this problem. Stereo manufacturers express the power output of a stereo amplifier using the decibel, abbreviated as dBW, where the "W" indicates that a reference power level of $P_0 = 1.00$ W has been used. If an amplifier has a power rated at 17.5 dBW, how many watts of power can this amplifier deliver?

***65.** Sound is coming through an open window whose dimensions are 1.1 m × 0.75 m. The sound intensity level is 95 dB above the threshold of hearing. How much sound *energy* comes through the window in one hour?

***66.** When a single person shouts at a football game, the sound intensity level at the center of the field is 60.0 dB. When all the people shout together, the intensity level increases to 109 dB. Assuming that each person generates the same sound intensity at the center of the field, how many people are at the game?

***67.** A portable radio is sitting at the edge of a balcony 5.1 m above the ground. The unit is emitting sound uniformly in all directions. By accident, it falls from rest off the balcony and continues to play on the way down. A gardener is working in a flower bed directly below the falling unit. From the instant the unit begins to fall, how much time is required for the sound intensity level heard by the gardener to increase by 10.0 dB?

****68.** A source emits sound uniformly in all directions. A radial line is drawn from this source. On this line, determine the positions of two points, 1.00 m apart, such that the intensity level at one point is 2.00 dB greater than that at the other.

****69. ssm** Suppose that when a certain sound intensity level (in dB) triples, the sound intensity (in W/m^2) also triples. Determine this sound intensity level.

Section 16.9 The Doppler Effect

70. A source is generating circular waves on the surface of a lake. The waves have a wavelength of 13.4 m and travel outward at a speed of 6.70 m/s. You are in a boat whose speed is 4.20 m/s and heading directly toward the source of the waves. What do you observe for the frequency of the waves?

71. The security alarm on a parked car goes off and produces a frequency of 960 Hz. The speed of sound is 343 m/s. As you drive toward this parked car, pass it, and drive away, you observe the frequency to change by 95 Hz. At what speed are you driving?

72. Suppose you are stopped for a traffic light, and an ambulance approaches you from behind with a speed of 18 m/s. The siren on the ambulance produces sound with a frequency of 955 Hz. The speed of sound in air is 343 m/s. What is the wavelength of the sound reaching your ears?

73. ssm From a vantage point very close to the track at a stock car race, you hear the sound emitted by a moving car. You detect a frequency that is 0.86 times smaller than that emitted by the car when it is stationary. The speed of sound is 343 m/s. What is the speed of the car?

***74.** A loudspeaker in a parked car is producing sound whose frequency is 20 510 Hz. The sound cannot be heard because the frequency is too high. When the car is moving, however, a person standing on the street hears the sound. (a) Is the car moving toward or away from the person? Why? (b) If the speed of sound is 343 m/s, what is the minimum speed of the car if the person is a student with normal hearing?

***75. ssm** An aircraft carrier has a speed of 13.0 m/s relative to the water. A jet is catapulted from the deck and has a speed of 67.0 m/s relative to the water. The engines produce a 1550-Hz whine, and the speed of sound is 343 m/s. What is the frequency of the sound heard by the crew on the ship?

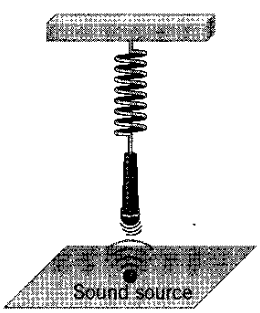
***76.** A microphone is moving in air toward a stationary source of sound (speed of sound = 343 m/s). The detected frequency is 83.0 Hz greater than the emitted frequency. When the microphone moves at the same speed toward the same stationary source in a liquid, the detected frequency is only 23.0 Hz greater than the emitted frequency. What is the speed of sound in the liquid?

***77.** A bungee jumper jumps from rest and screams with a frequency of 589 Hz. The air temperature is 20 °C. What is the frequency heard by the people on the ground below when she has fallen a distance of 11.0 m? Assume that the bungee cord has not yet taken effect, so she is in free-fall.

***78.** Two submarines are underwater and approaching each other head-on. Sub A has a speed of 12 m/s and sub B has a speed of 8 m/s. Sub A sends out a 1550-Hz sonar wave that travels at a speed of 1522 m/s. (a) What is the frequency detected by sub B? (b) Part of the sonar wave is reflected from B and returns to A. What frequency does A detect for this reflected wave?

***79. ssm** A motorcycle starts from rest and accelerates along a straight line at 2.81 m/s^2. The speed of sound is 343 m/s. A siren at the starting point remains stationary. How far has the motorcycle gone when the driver hears the frequency of the siren at 90.0% of the value it has when the motorcycle is stationary?

****80.** A microphone is attached to a spring that is suspended from the ceiling, as the drawing indicates. Directly below on the floor is a stationary 440-Hz source of sound. The microphone vibrates up and down in simple harmonic motion with a period of 2.0 s. The difference between the maximum and minimum sound frequencies detected by the microphone is 2.1 Hz. Ignoring any reflections of sound in the room and using 343 m/s for the speed of sound, determine the amplitude of the simple harmonic motion.



ADDITIONAL PROBLEMS

81. An amplified guitar has a sound intensity level that is 14 dB greater than the same unamplified sound. What is the ratio of the amplified intensity to the unamplified intensity?

82. To navigate, a porpoise emits a sound wave that has a wavelength of 2.5 cm. The speed at which sound travels in seawater is 1470 m/s. Find the period of the wave.

83. ssm At 20 °C the densities of fresh water and ethanol are, respectively, 998 and 789 kg/m^3. Find the ratio of the adiabatic bulk modulus of fresh water to the adiabatic bulk modulus of ethanol at 20 °C.

84. A transverse wave is traveling with a speed of 300 m/s on a horizontal string. If the tension in the string is increased by a factor of four, what is the speed of the wave?

85. At a football game, a stationary spectator is watching the halftime show. A trumpet player in the band is playing a 784-Hz tone while marching directly toward the spectator at a speed of 0.83 m/s. On a day when the speed of sound is 343 m/s, what frequency does the spectator hear?

86. A person lying on an air mattress in the ocean rises and falls through one complete cycle every five seconds. The crests of the wave causing the motion are 20.0 m apart. Determine (a) the frequency and (b) the speed of the wave.

87. ssm Humans can detect a difference in sound intensity levels as small as 1.0 dB. What is the ratio of the sound intensities?

88. Suppose that sound is emitted uniformly in all directions by a public address system. The intensity at a location 22 m away from the sound source is 3.0×10^{-4} W/m^2. What is the intensity at a spot that is 78 m away?

89. The distance between a loudspeaker and the left ear of a listener is 2.70 m. (a) Calculate the time required for sound to travel this distance if the air temperature is 20 °C. (b) Assuming that the sound frequency is 523 Hz, how many wavelengths of sound are contained in this distance?

90. A wave has a displacement (in meters) of $y = (0.45)\sin(8.0\pi t + \pi x)$, where t and x are expressed in seconds and meters, respectively. (a) Find the amplitude, the frequency, the wavelength, and the speed of the wave. (b) Is this wave traveling in the $+x$ or $-x$ direction?

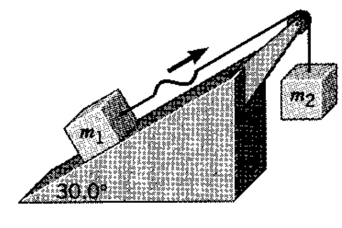
91. ssm A speeder looks in his rearview mirror. He notices that a police car has pulled behind him and is matching his speed of 38 m/s. The siren on the police car has a frequency of 860 Hz when the police car and the listener are stationary. The speed of sound is 343 m/s. What frequency does the speeder hear when the siren is turned on in the moving police car?

92. The wavelength of a sound wave in air is 2.74 m at 20 °C. What is the wavelength of this sound wave in fresh water at 20 °C? *(Hint: The frequency of the sound is the same in both media.)*

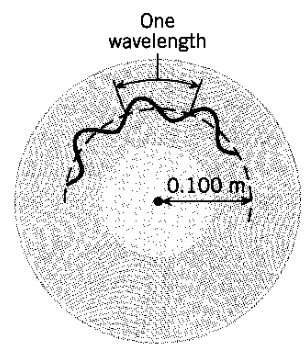
93. A rocket engine emits 2.0×10^5 J of sound energy every second. The sound is emitted uniformly in all directions. What is the sound intensity level, measured relative to the threshold of hearing, at a distance of 85 m away from the engine?

***94.** Two identical rifles are shot at the same time, and the sound intensity level is 80.0 dB. What would be the sound intensity level if only one rifle were shot? *(Hint: The answer is not 40.0 dB.)*

****95. ssm www** The drawing shows a frictionless incline and pulley. The two blocks are connected by a wire (mass per unit length = 0.0250 kg/m) and remain stationary. A transverse wave on the wire has a speed of 75.0 m/s. Neglecting the weight of the wire relative to the tension in the wire, find the masses m_1 and m_2 of the blocks.



***96.** A 3.49 rad/s ($33\frac{1}{3}$ rpm) record has a 5.00-kHz tone cut in the groove. If the groove is located 0.100 m from the center of the record (see drawing), what is the "wavelength" in the groove?



Problem 96

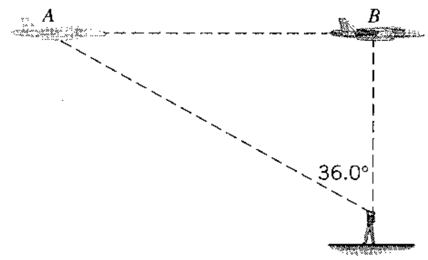
***97.** A steel cable of cross-sectional area 2.83×10^{-3} m^2 is kept under a tension of 1.00×10^4 N. The density of steel is 7860 kg/m^3 (this is *not* the linear density). At what speed does a transverse wave move along the cable?

***98.** Review Conceptual Example 3 before starting this problem. A horizontal wire is under a tension of 315 N and has a mass per unit length of 6.50×10^{-3} kg/m. A transverse wave with an amplitude of 2.50 mm and a frequency of 585 Hz is traveling on this wire. As the wave passes, a particle of the wire moves up and down in simple harmonic motion. Obtain (a) the speed of the wave and (b) the maximum speed with which the particle moves up and down.

***99. ssm** Review Conceptual Example 8 as background for this problem. A loudspeaker is generating sound in a room. At a certain point, the sound waves coming directly from the speaker (without reflecting from the walls) create an intensity level of 75.0 dB. The waves reflected from the walls create, by themselves, an intensity level of 72.0 dB at the same point. What is the total intensity level? *(Hint: The answer is not 147.0 dB.)*

***100.** The sound intensity level of a person speaking normally is about 65 dB above the threshold of hearing. What is the minimum number of people speaking simultaneously, each with this intensity level, that is necessary to produce a sound intensity level at least 78 dB above the threshold of hearing?

****101.** A jet is flying horizontally, as the drawing shows. When the plane is directly overhead at B, a person on the ground hears the sound coming from A in the drawing. The average temperature of the air is 20 °C. If the speed of the plane at A is 164 m/s, what is its speed at B, assuming that it has a constant acceleration?



**102. Civil engineers use a transit theodolite when surveying. A modern version of this device determines distance by measuring the time required for an ultrasonic pulse to reach a target, reflect from it, and return. Effectively, such a theodolite is calibrated properly when it is programmed with the speed of sound appropriate for the ambient air temperature. (a) Suppose the round-trip time for the pulse is 0.580 s on a day when the air temperature is 293 K, the temperature for which the instrument is calibrated. How far is the target from the theodolite? (b) Assume that air behaves as an ideal gas. If the air temperature were 298 K, rather than the calibration temperature of 293 K, what percentage error would there be in the distance measured by the theodolite?

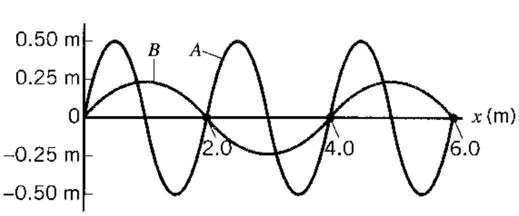
CONCEPTS & CALCULATIONS

GROUP LEARNING PROBLEMS

Note: Each of these problems consists of Concept Questions followed by a related quantitative Problem. They are designed for use by students working alone or in small learning groups. The Concept Questions involve little or no mathematics and are intended to stimulate group discussions. They focus on the concepts with which the problems deal. Recognizing the concepts is the essential initial step in any problem-solving technique.

103. Concept Questions The drawing shows a snapshot of two waves traveling to the right at the same speed. (a) Rank the waves according to their wavelengths, largest first. (b) Which wave, if either, has the higher frequency? (c) If a particle were attached to each wave, like that in Figure 16.10, which particle would have the greater maximum speed as it moves up and down? Justify your answers.

Problem (a) From the data in the drawing, determine the wavelength of each wave. (b) If the speed of the waves is 12 m/s, calculate the frequency of each one. (c) What is the maximum speed for a particle attached to each wave? Check that your answers are consistent with those for the Concept Questions.



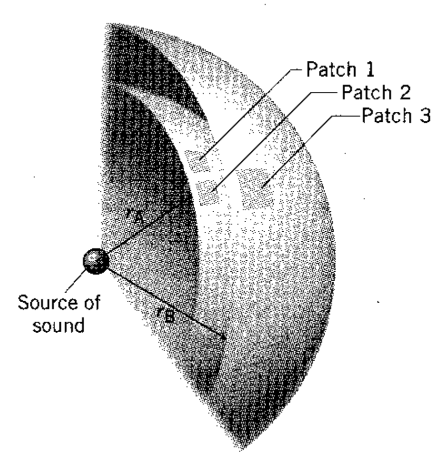
104. Concept Questions Example 4 in the text discusses an ultrasonic ruler that displays the distance between the ruler and an object, such as a wall. The ruler sends out a pulse of ultrasonic sound and measures the time it takes for the pulse to reflect from the object and return. The ruler uses this time, along with a preset value for the speed of sound in air, to determine the distance. Suppose you use this ruler underwater, rather than in air. (a) Is the speed of sound in water greater than, less than, or equal to the speed of sound in air? (b) Is the reading on the ruler greater than, less than, or equal to the actual distance? Provide reasons for your answers.

Problem The actual distance from the ultrasonic ruler to an object is 25.0 m. The adiabatic bulk modulus and density of seawater are $B = 2.31 \times 10^9$ Pa and $\rho = 1025$ kg/m^3, respectively. Assume that the ruler uses a preset value of 343 m/s for the speed of sound in air, and determine the distance reading on its display. Verify that your answer is consistent with your answer to the Concept Questions.

105. Concept Question Suppose you are part of a team that is trying to break the "sound barrier" with a jet-powered car, which means that it must travel faster than the speed of sound in air. Would you attempt this feat early in the morning when the temperature is cool, later in the afternoon when the temperature is warmer, or does it even matter what the temperature is?

Problem In the morning, the air temperature is 0 °C and the speed of sound is 331 m/s. What must be the speed of your car if it is to break the sound barrier when the temperature has risen to 43 °C in the afternoon? Assume that air behaves like an ideal gas.

106. Concept Questions A source of sound is located at the center of two concentric spheres, parts of which are shown in the drawing. The source emits sound uniformly in all directions. On the spheres are drawn three small patches that may, or may not, have equal areas. However, the same sound power passes through each patch. (a) Rank the sound intensity at each patch, greatest first. (b) Rank the area of each patch, largest first. Provide reasons for your answers.



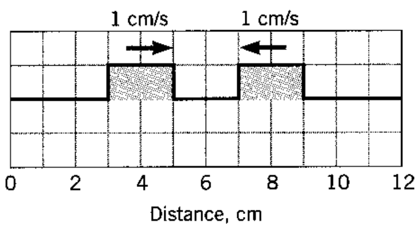
Problem The source produces 2.3 W of sound power, and the radii of the concentric spheres are $r_A = 0.60$ m and $r_B = 0.80$ m.

PROBLEMS

ssm **Solution is in the Student Solutions Manual.** **www** **Solution is available on the World Wide Web at http://www.wiley.com/college/cutnell**
This icon represents a biomedical application.

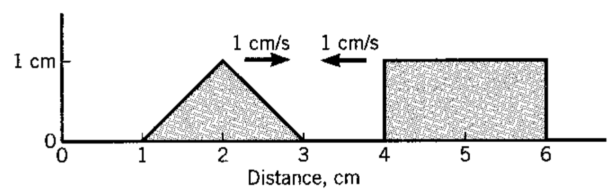
Section 17.1 The Principle of Linear Superposition, Section 17.2 Constructive and Destructive Interference of Sound Waves

1. **ssm** The drawing shows a string on which two rectangular pulses are traveling at a constant speed of 1 cm/s at time $t = 0$. Using the principle of linear superposition, draw the shape of the string at $t = 1$ s, 2 s, 3 s, and 4 s.

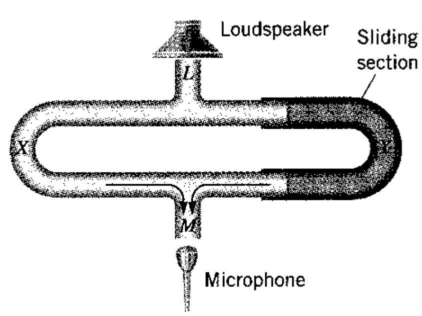


2. Repeat problem 1, assuming that the pulse on the right is pointing downward rather than upward.

3. Two pulses are traveling toward each other, each having a speed of 1 cm/s. At $t = 0$, their positions are shown in the drawing. When $t = 1$ s, what is the height of the resultant pulse at (a) $x = 3$ cm and at (b) $x = 4$ cm?



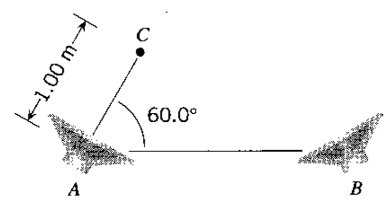
4. The sound produced by the loudspeaker in the drawing has a frequency of 12 000 Hz and arrives at the microphone via two different paths. The sound travels through the left tube *LXM*, which has a fixed length. Simultaneously, the sound travels through the right tube *LYM*, the length of which can be changed by moving the sliding section. At *M*, the sound waves coming from the two paths interfere. As the length of the path *LYM* is changed, the sound loudness detected by the microphone changes. When the sliding section is pulled out by 0.020 m, the loudness changes from a maximum to a minimum. Find the speed at which sound travels through the gas in the tube.



5. **ssm** Review Example 1 in the text. Speaker *A* is moved further to the left, while *ABC* remains a right triangle. What is the separation between the speakers when constructive interference occurs again at point *C*?

6. In Figure 17.7, suppose that the separation between speakers *A* and *B* is 5.00 m and the speakers are vibrating in-phase. They are playing identical 125-Hz tones, and the speed of sound is 343 m/s. What is the largest possible distance between speaker B and the observer at *C*, such that he observes destructive interference?

7. **ssm** **www** The drawing shows a loudspeaker *A* and point *C*, where a listener is positioned. A second loudspeaker *B* is located somewhere to the right of *A*. Both speakers vibrate in phase and are playing a 68.6-Hz tone. The speed of sound is 343 m/s. What is the closest to speaker *A* that speaker *B* can be located, so that the listener hears no sound?



***8.** Review Conceptual Example 2 in preparation for this problem. Assume that the two loudspeakers in Figure 17.7 are vibrating *out of phase* instead of in phase. The speed of sound is 343 m/s. What is the smallest frequency that will produce destructive interference at point *C*?

****9.** Speakers *A* and *B* are vibrating in phase. They are directly facing each other, are 7.80 m apart, and are each playing a 73.0-Hz tone. The speed of sound is 343 m/s. On the line *between* the speakers there are three points where constructive interference occurs. What are the distances of these three points from speaker *A*?

Section 17.3 Diffraction

10. Sound emerges through a doorway, as in Figure 17.11. The width of the doorway is 77 cm, and the speed of sound is 343 m/s. Find the diffraction angle θ when the frequency of the sound is (a) 5.0 kHz and (b) 5.0×10^2 Hz.

11. **ssm** A speaker has a diameter of 0.30 m. (a) Assuming that the speed of sound is 343 m/s, find the diffraction angle θ for a 2.0-kHz tone. (b) What speaker diameter *D* should be used to generate a 6.0-kHz tone whose diffraction angle is as wide as that for the 2.0-kHz tone in part (a)?

12. In a diffraction horn loudspeaker, the sound exits through a rectangular opening, like a small doorway. The width *D* of a diffraction horn and the diameter of a circular speaker are equal.

The sound produced by the two speakers has the same diffraction angle θ. What is the ratio of the wavelength of the sound produced by the diffraction horn to that produced by the circular speaker?

13. Sound exits a diffraction horn loudspeaker through a rectangular opening, like a small doorway. A person is sitting at an angle θ off to the side of a diffraction horn that has a width D of 0.060 m. The speed of sound is 343 m/s. This individual does not hear a sound wave that has a frequency of 8100 Hz. When she is sitting at an angle $\theta/2$, there is a different frequency that she does not hear. What is it?

***14.** A 3.00-kHz tone is being produced by a speaker with a diameter of 0.175 m. The air temperature changes from 0 to 29 °C. Assuming air to be an ideal gas, find the *change* in the diffraction angle θ.

***15.** A row of seats is parallel to a stage at a distance of 8.7 m from it. At the center and front of the stage is a diffraction horn loudspeaker. This speaker sends out its sound through an opening that is like a small doorway with a width D of 7.5 cm. The speaker is playing a tone that has a frequency of 1.0×10^4 Hz. The speed of sound is 343 m/s. What is the separation between two seats, located on opposite sides of the center of the row, at which the tone cannot be heard?

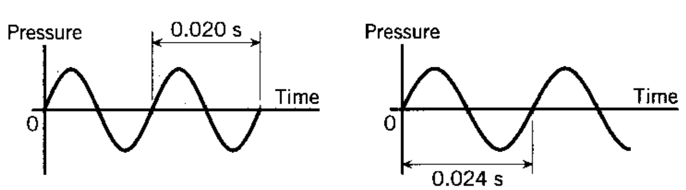
Section 17.4 Beats

16. When a tuning fork is sounded together with a 492-Hz tone, a beat frequency of 2 Hz is heard. Then a small piece of putty is stuck to the tuning fork, and the tuning fork is again sounded along with the 492-Hz tone. The beat frequency decreases. What is the frequency of the tuning fork?

17. ssm Two ultrasonic sound waves combine and form a beat frequency that is in the range of human hearing. The frequency of one of the ultrasonic waves is 70 kHz. What is (a) the smallest possible and (b) the largest possible value for the frequency of the other ultrasonic wave?

18. Two out-of-tune flutes play the same note. One produces a tone that has a frequency of 262 Hz, while the other produces 266 Hz. When a tuning fork is sounded together with the 262-Hz tone, a beat frequency of 1 Hz is produced. When the same tuning fork is sounded together with the 266-Hz tone, a beat frequency of 3 Hz is produced. What is the frequency of the tuning fork?

19. ssm Two pure tones are sounded together. The drawing shows the pressure variations of the two sound waves, measured with respect to atmospheric pressure. What is the beat frequency?



20. When a guitar string is sounded along with a 440-Hz tuning fork, a beat frequency of 5 Hz is heard. When the same string is sounded along with a 436-Hz tuning fork, the beat frequency is 9 Hz. What is the frequency of the string?

***21.** A sound wave is traveling in seawater, where the adiabatic bulk modulus and density are 2.31×10^9 Pa and 1025 kg/m^3, respectively. The wavelength of the sound is 3.35 m. A tuning fork is struck underwater and vibrates at 440.0 Hz. What would be the beat frequency heard by an underwater swimmer?

****22.** Two tuning forks X and Y have different frequencies and produce an 8-Hz beat frequency when sounded together. When X is sounded along with a 392-Hz tone, a 3-Hz beat frequency is detected. When Y is sounded along with the 392-Hz tone, a 5-Hz beat frequency is heard. What are the frequencies f_X and f_Y when (a) f_X is greater than f_Y and (b) f_X is less than f_Y?

Section 17.5 Transverse Standing Waves

23. ssm The A string on a string bass is tuned to vibrate at a fundamental frequency of 55.0 Hz. If the tension in the string were increased by a factor of four, what would be the new fundamental frequency?

24. If the string in Figure 17.18 is vibrating at a frequency of 4.0 Hz and the distance between two successive nodes is 0.30 m, what is the speed of the waves on the string?

25. The G string on a guitar has a fundamental frequency of 196 Hz and a length of 0.62 m. This string is pressed against the proper fret to produce the note C, whose fundamental frequency is 262 Hz. What is the distance L between the fret and the end of the string at the bridge of the guitar (see Figure 17.20*b*)?

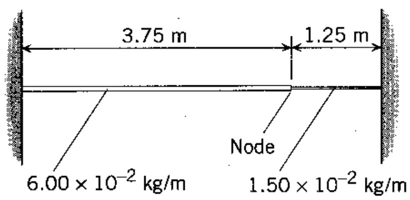
26. The fundamental frequency of a string fixed at both ends is 256 Hz. How long does it take for a wave to travel the length of this string?

27. ssm Ideally, the strings on a violin are stretched with the same tension. Each has the same length between its two fixed ends. The musical notes and corresponding fundamental frequencies of two of these strings are G (196.0 Hz) and E (659.3 Hz). The linear density of the E string is 3.47×10^{-4} kg/m. What is the linear density of the G string?

28. A 41-cm length of wire has a mass of 6.0 g. It is stretched between two fixed supports and is under a tension of 160 N. What is the fundamental frequency of this wire?

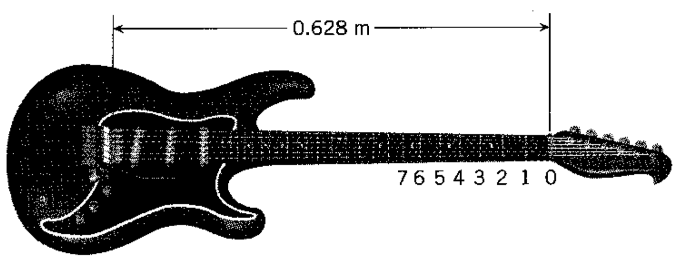
29. A string of length 2.50 m is fixed at both ends. When the string vibrates at a frequency of 85.0 Hz, a standing wave with five loops is formed. (a) What is the wavelength of the waves that travel on the string? (b) What is the speed of the waves? (c) What would be the fundamental frequency of this string?

***30.** Two strings have different lengths and linear densities, as the drawing shows. They are joined together and stretched so that the tension in each string is 190.0 N. The free ends of the joined string are fixed in place. Find the lowest frequency that permits standing waves in both strings with a node at the junction. The standing wave pattern in each string may have a different number of loops.

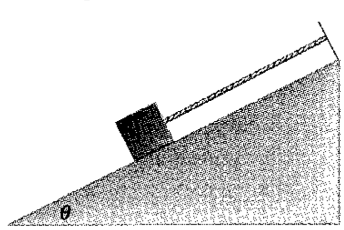


***31.** **ssm** The E string on an electric bass guitar has a length of 0.628 m and, when producing the note E, vibrates at a fundamental frequency of 41.2 Hz. Players sometimes add to their instruments a device called a "D-tuner." This device allows the E string to be used to produce the note D, which has a fundamental frequency of 36.7 Hz. The D-tuner works by extending the length of the string, keeping all other factors the same. By how much does a D-tuner extend the length of the E string?

****32.** Review Conceptual Example 5 before attempting this problem. As the drawing shows, the length of a guitar string is 0.628 m. The frets are numbered for convenience. A performer can play a musical scale on a single string because the spacing *between the frets* is designed according to the following rule: When the string is pushed against any fret j, the fundamental frequency of the shortened string is larger by a factor of the twelfth root of two $(\sqrt[12]{2})$ than it is when the string is pushed against the fret $j - 1$. Assuming that the tension in the string is the same for any note, find the spacing (a) between fret 1 and fret 0 and (b) between fret 7 and fret 6.



****33.** **ssm www** The drawing shows an arrangement in which a block (mass = 15.0 kg) is held in position on a frictionless incline by a cord (length = 0.600 m). The mass per unit length of the cord is 1.20×10^{-2} kg/m, so the mass of the cord is negligible compared to the mass of the block. The cord is being vibrated at a frequency of 165 Hz (vibration source not shown in the drawing). What are the values of the angle θ between 15.0° and 90.0° at which a standing wave exists on the cord?



Section 17.6 Longitudinal Standing Waves,
Section 17.7 Complex Sound Waves

34. Sound enters the ear, travels through the auditory canal, and reaches the eardrum. The auditory canal is approximately a tube open at only one end. The other end is closed by the eardrum. A typical length for the auditory canal in an adult is about 2.9 cm. The speed of sound is 343 m/s. What is the fundamental frequency of the canal? (Interestingly, the fundamental frequency is in the frequency range where human hearing is most sensitive.)

35. A piccolo and a flute can be approximated as cylindrical tubes with both ends open. The lowest fundamental frequency produced by one kind of piccolo is 587.3 Hz, while that produced by a flute is 261.6 Hz. What is the ratio of the length of the piccolo to that of the flute?

36. The range of human hearing is roughly from twenty hertz to twenty kilohertz. Based on these limits and a value of 343 m/s for the speed of sound, what are the lengths of the longest and shortest pipes (open at both ends and producing sound at their fundamental frequencies) that you expect to find in a pipe organ?

37. **ssm** A tube of air is open at only one end and has a length of 1.5 m. This tube sustains a standing wave at its third harmonic. What is the distance between one node and the adjacent antinode?

38. A tube with a cap on one end, but open at the other end, produces a standing wave whose fundamental frequency is 130.8 Hz. The speed of sound is 343 m/s. (a) If the cap is removed, what is the new fundamental frequency? (b) How long is the tube?

39. **ssm** Both neon (Ne) and helium (He) are monatomic gases and can be assumed to be ideal gases. The fundamental frequency of a tube of neon is 268 Hz. What is the fundamental frequency of the tube if the tube is filled with helium, all other factors remaining the same?

***40.** A tube, open at both ends, contains an unknown ideal gas for which $\gamma = 1.40$. At 293 K, the shortest tube in which a standing wave can be set up with a 294-Hz tuning fork has a length of 0.248 m. Find the mass of a gas molecule.

***41.** Two loudspeakers face each other, vibrate in phase, and produce identical 440-Hz tones. A listener walks from one speaker toward the other at a constant speed and hears the loudness change (loud–soft–loud) at a frequency of 3.0 Hz. The speed of sound is 343 m/s. What is the walking speed?

***42.** A person hums into the top of a well and finds that standing waves are established at frequencies of 42, 70.0, and 98 Hz. The frequency of 42 Hz is not necessarily the fundamental frequency. The speed of sound is 343 m/s. How deep is the well?

***43.** **ssm www** A vertical tube is closed at one end and open to air at the other end. The air pressure is 1.01×10^5 Pa. The tube has a length of 0.75 m. Mercury (mass density =

13 600 kg/m^3) is poured into it to shorten the effective length for standing waves. What is the absolute pressure at the bottom of the mercury column, when the fundamental frequency of the shortened, air-filled tube is equal to the third harmonic of the original tube?

**44. A tube, open at only one end, is cut into two shorter (non-equal) lengths. The piece open at both ends has a fundamental frequency of 425 Hz, while the piece open only at one end has a fundamental frequency of 675 Hz. What is the fundamental frequency of the original tube?

ADDITIONAL PROBLEMS

45. A stretched rubber band has a length of 0.10 m and a fundamental frequency of 440 Hz. What is the speed at which waves travel on the rubber band?

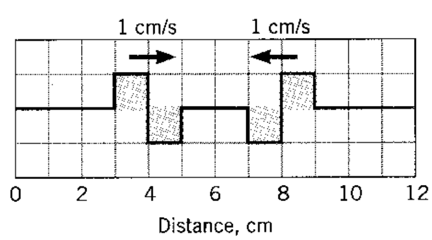
46. The fundamental frequency of a vibrating system is 400 Hz. For each of the following systems, give the three lowest frequencies (excluding the fundamental) at which standing waves can occur: (a) a string fixed at both ends, (b) a cylindrical pipe with both ends open, and (c) a cylindrical pipe with only one end open.

47. ssm Two loudspeakers are vibrating in phase. They are set up as in Figure 17.7, and point C is located as shown there. The speed of sound is 343 m/s. The speakers play the same tone. What is the smallest frequency that will produce destructive interference at point C?

48. A tuning fork vibrates at a frequency of 524 Hz. An out-of-tune piano string vibrates at 529 Hz. How much time separates successive beats?

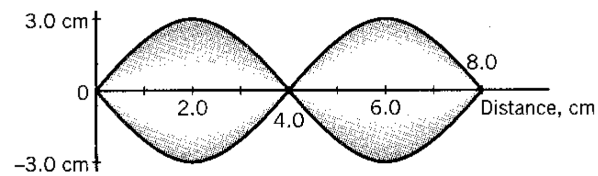
49. The fundamental frequencies of two air columns are the same. Column A is open at both ends, while column B is open at only one end. The length of column A is 0.60 m. What is the length of column B?

50. Repeat problem 1, assuming that the pulses have the shape (half up and half down) shown in the drawing.



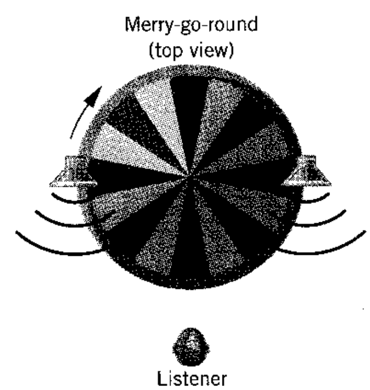
51. ssm On a cello, the string with the largest linear density (1.56×10^{-2} kg/m) is the C string. This string produces a fundamental frequency of 65.4 Hz and has a length of 0.800 m between the two fixed ends. Find the tension in the string.

***52.** The graph shows a transverse standing wave on a string. (a) What is the wavelength of each wave that combines to form the standing wave? (b) If the velocity of one of the component waves is +12.0 cm/s, what is the velocity of the other? (c) What is the frequency of each component wave? (d) Suppose that a "dot" is attached to the string at $x = 2.0$ cm. Determine the maximum speed (in cm/s) of this dot as it vibrates up and down.



***53.** A cylindrical pipe is *closed at both ends*. Derive an expression for the frequencies of the allowed standing waves, similar in form to Equations 17.4 and 17.5, in terms of the speed of sound v, the length of the pipe L, and the harmonic number n. State which integer values of n are allowed.

****54.** Two loudspeakers are mounted on a merry-go-round whose radius is 9.01 m. When stationary, the speakers both play a tone whose frequency is 100.0 Hz. As the drawing illustrates, they are situated at opposite ends of a diameter. The speed of sound is 343.00 m/s, and the merry-go-round revolves once every 20.0 s. What is the beat frequency that is detected by the listener when the merry-go-round is near the position shown?



****55. ssm www** The note that is three octaves above middle C is supposed to have a fundamental frequency of 2093 Hz. On a certain piano the steel wire that produces this note has a cross-sectional area of 7.85×10^{-7} m^2. The wire is stretched between two pegs. When the piano is tuned properly to produce the correct frequency at 25.0 °C, the wire is under a tension of 818.0 N. Suppose the temperature drops to 20.0 °C. In addition, as an approximation, assume that the wire is kept from contracting as the temperature drops. Consequently, the tension in the wire changes. What beat frequency is produced when this piano and another instrument (properly tuned) sound the note simultaneously?

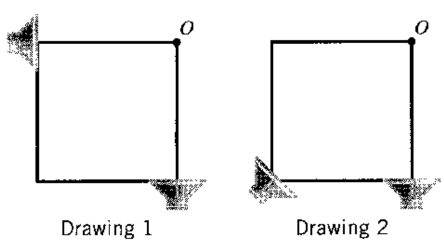
CONCEPTS & CALCULATIONS

GROUP LEARNING PROBLEMS

Note: Each of these problems consists of Concept Questions followed by a related quantiative Problem. They are designed for use by students working alone or in small learning groups. The Concept Questions involve little or no mathematics and are intended to stimulate group discussions. They focus on the concepts with which the problems deal. Recognizing the concepts is the essential initial step in any problem-solving technique.

56. Concept Questions Both drawings show the same square, at one corner of which an observer O is stationed. Two loudspeakers are located at corners of the square, either as in drawing 1 or as in drawing 2. The speakers produce the same single-frequency tone in either drawing and are in phase. Constructive interference occurs in drawing 1, but destructive interference occurs in drawing 2. (a) Will only certain frequencies lead to the constructive interference in drawing 1, or will it occur for any frequency at all? (b) Will only certain frequencies lead to the destructive interference in drawing 2, or will it occur for any frequency at all? Justify your answers.

Problem One side of the square has a length of $L = 0.75$ m. The speed of sound is 343 m/s. Find the single smallest frequency that will produce both constructive interference in drawing 1 and destructive interference in drawing 2.



57. Concept Questions (a) When sound emerges from a loudspeaker, is the diffraction angle determined by the wavelength, the diameter of the speaker, or a combination of these two factors? (b) How is the wavelength of a sound related to its frequency? Explain your answers.

Problem The following two lists give diameters and sound frequencies for three loudspeakers. Pair each diameter with a frequency, so that the diffraction angle is the same for each of the speakers. The speed of sound is 343 m/s. Find the common diffraction angle.

Diameter, D	Frequency, f
0.050 m	6.0 kHz
0.10 m	4.0 kHz
0.15 m	12.0 kHz

58. Concept Questions Two cars have identical horns, each emitting a frequency f_s. One of the cars is moving toward a bystander waiting at a corner, and the other is parked. The two horns sound simultaneously. (a) From the moving horn, does the bystander hear a frequency that is greater than, less than, or equal to f_s? (b) From the stationary horn, does the bystander hear a frequency that is greater than, less than, or equal to f_s? (c) Does the bystander hear a beat frequency from the combined sound of the two horns? Account for your answers.

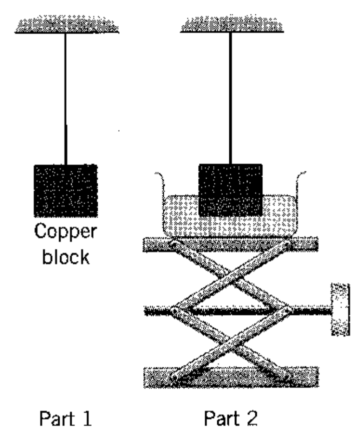
Problem The frequency that the horns emit is $f_s = 395$ Hz. The speed of the moving car is 12.0 m/s and the speed of sound is 343 m/s. What is the beat frequency heard by the bystander?

59. Concept Questions Two wires are stretched between two fixed supports and have the same length. On wire A there is a second-harmonic standing wave whose frequency is 660 Hz. However, the same frequency of 660 Hz is the third harmonic on wire B. (a) Is the fundamental frequency of wire A greater than, less than, or equal to the fundamental frequency of wire B? Explain. (b) How is the fundamental frequency related to the length L of the wire and the speed v at which individual waves travel back and forth on the wire? (c) Do the individual waves travel on wire A with a greater, smaller, or the same speed as on wire B? Give your reasoning.

Problem The common length of the wires is 1.2 m. Find the speed at which individual waves travel on each wire. Verify that your answer is consistent with your answers to the Concept Questions.

60. Concept Questions A copper block is suspended in air from a wire in Part 1 of the drawing. A container of mercury is then raised up around the block as in Part 2. (a) The fundamental freqeuncy of the wire is given by Equation 17.3 with $n = 1$: $f_1 = v/(2L)$. How is the speed v at which individual waves travel on the wire related to the tension in the wire? (b) Is the tension in the wire in Part 2 less than, greater than, or equal to the tension in Part 1? (c) Is the fundamental frequency of the wire in Part 2 less than, greater than, or equal to the fundamental frequency in Part 1? Justify each of your answers.

Problem In Part 2 of the drawing one-half of the block's volume is submerged in the mercury. The density of copper is 8890 kg/m^3, and the density of mercury is 13 600 kg/m^3. Find the ratio of the fundamental frequency of the wire in Part 2 to the fundamental



frequency in Part 1. Check to see that your answer is consistent with your answers to the Concept Questions.

61. Concept Questions One method for measuring the speed of sound uses standing waves. A cylindrical tube is open at both ends, and one end admits sound from a tuning fork. A movable plunger is inserted into the other end. The distance between the end of the tube where the tuning fork is and the plunger is L. For a fixed frequency, the plunger is moved until the smallest value of L is measured that allows a standing wave to be formed. (a) When a standing wave is formed in the tube, is there a node or an antinode at the end of the tube where the tuning fork is? (b) When a standing wave is formed, is there a node or an antinode at the plunger? (c) How is the smallest value of L related to the wavelength of the sound? Explain your answers.

Problem The tuning fork produces a 485-Hz tone, and the smallest value observed for L is 0.264 m. What is the speed of the sound in the gas in the tube?

PROBLEMS

Problems that are not marked with a star are considered the easiest to solve. Problems that are marked with a single star (*) are more difficult, while those marked with a double star (**) are the most difficult. Note: All charges are point charges, unless specified otherwise.

ssm Solution is in the Student Solutions Manual. www Solution is available on the World Wide Web at http://www.wiley.com/college/cutnell
This icon represents a biomedical application.

Section 18.1 The Origin of Electricity, Section 18.2 Charged Objects and the Electric Force, Section 18.3 Conductors and Insulators, Section 18.4 Charging by Contact and by Induction

1. ssm How many electrons must be removed from an electrically neutral silver dollar to give it a charge of $+2.4\ \mu C$?

2. A rod has a charge of $-2.0\ \mu C$. How many electrons must be removed so that the charge becomes $+3.0\ \mu C$?

3. A metal sphere has a charge of $+8.0\ \mu C$. What is the net charge after 6.0×10^{13} electrons have been placed on it?

4. Object A is metallic and electrically neutral. It is charged by induction so that it acquires a charge of -3.0×10^{-6} C. Object B is identical to object A and is also electrically neutral. It is charged by induction so that it acquires a charge of $+3.0 \times 10^{-6}$ C. Find the *difference* in mass between the charged objects and state which has the greater mass.

5. ssm Consider three identical metal spheres, A, B, and C. Sphere A carries a charge of $+5q$. Sphere B carries a charge of $-q$. Sphere C carries no net charge. Spheres A and B are touched together and then separated. Sphere C is then touched to sphere A and separated from it. Lastly, sphere C is touched to sphere B and separated from it. (a) How much charge ends up on sphere C? What is the total charge on the three spheres (b) before they are allowed to touch each other and (c) after they have touched?

***6.** Water has a mass per mole of 18.0 g/mol, and each water molecule (H_2O) has 10 electrons. (a) How many electrons are there in one liter ($1.00 \times 10^{-3}\ m^3$) of water? (b) What is the net charge of all these electrons?

Section 18.5 Coulomb's Law

7. ssm www Two very small spheres are initially neutral and separated by a distance of 0.50 m. Suppose that 3.0×10^{13} electrons are removed from one sphere and placed on the other. (a) What is the magnitude of the electrostatic force that acts on each sphere? (b) Is the force attractive or repulsive? Why?

8. The nucleus of the helium atom contains two protons that are separated by about 3.0×10^{-15} m. Find the magnitude of the electrostatic force that each proton exerts on the other. (The protons remain together in the nucleus because the repulsive electrostatic force is balanced by an attractive force called the strong nuclear force.)

9. The force of repulsion that two like charges exert on each other is 3.5 N. What will the force be if the distance between the charges is increased to five times its original value?

10. In a vacuum, two particles have charges of q_1 and q_2, where $q_1 = +3.5\ \mu C$. They are separated by a distance of 0.26 m, and particle 1 experiences an attractive force of 3.4 N. What is q_2 (magnitude and sign)?

11. ssm Three charges are fixed to an xy coordinate system. A charge of $+18\ \mu C$ is on the y axis at $y = +3.0$ m. A charge of $-12\ \mu C$ is at the origin. Lastly, a charge of $+45\ \mu C$ is on the x axis at $x = +3.0$ m. Determine the magnitude and direction of the net electrostatic force on the charge at $x = +3.0$ m. Specify the direction relative to the $-x$ axis.

12. A charge of $-3.00\ \mu C$ is fixed at the center of a compass. Two additional charges are fixed on the circle of the compass (radius = 0.100 m). The charges on the circle are $-4.00\ \mu C$ at the position due north and $+5.00\ \mu C$ at the position due east. What is the magnitude and direction of the net electrostatic force acting on the charge at the center? Specify the direction relative to due east.

13. An equilateral triangle has sides of 0.15 m. Charges of -9.0, $+8.0$, and $+2.0\ \mu C$ are located at the corners of the triangle. Find the magnitude of the net electrostatic force exerted on the 2.0-μC charge.

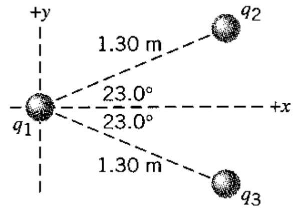
14. Two tiny conducting spheres are identical and carry charges of $-20.0\ \mu C$ and $+50.0\ \mu C$. They are separated by a distance of 2.50 cm. (a) What is the magnitude of the force that each sphere experiences, and is the force attractive or repulsive? (b) The spheres are brought into contact and then separated to a distance of 2.50 cm. Determine the magnitude of the force that each sphere now experiences, and state whether the force is attractive or repulsive.

15. ssm www Two particles, with identical positive charges and a separation of 2.60×10^{-2} m, are released from rest. Immediately after the release, particle 1 has an acceleration $\mathbf{a}_1$ whose magnitude is $4.60 \times 10^3\ m/s^2$, while particle 2 has an acceleration $\mathbf{a}_2$ whose magnitude is $8.50 \times 10^3\ m/s^2$. Particle 1 has a mass of 6.00×10^{-6} kg. Find (a) the charge on each particle and (b) the mass of particle 2.

***16.** A point charge of $-0.70\ \mu C$ is fixed to one corner of a square. An identical charge is fixed to the diagonally opposite corner. A point charge q is fixed to each of the remaining corners. The net force acting on either of the charges q is zero. Find the magnitude and algebraic sign of q.

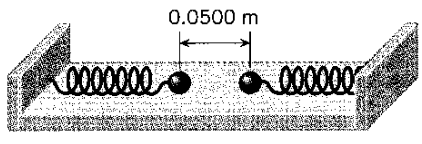
***17.** Two small objects, A and B, are fixed in place and separated by 2.00 cm in a vacuum. Object A has a charge of $+1.00\ \mu C$, and object B has a charge of $-1.00\ \mu C$. How many electrons must be removed from A and put onto B to make the electrostatic force that acts on each object an attractive force whose magnitude is 45.0 N?

*18. The drawing shows three point charges fixed in place. The charge at the coordinate origin has a value of $q_1 = +8.00\ \mu C$; the other two have identical magnitudes, but opposite signs: $q_2 = -5.00\ \mu C$ and $q_3 = +5.00\ \mu C$.



(a) Determine the net force (magnitude and direction) exerted on q_1 by the other two charges. (b) If q_1 had a mass of 1.50 g and it were free to move, what would be its acceleration?

*19. **ssm** Two spheres are mounted on identical horizontal springs and rest on a frictionless table, as in the drawing. When the spheres are uncharged, the spacing between them is 0.0500 m, and the springs are unstrained. When each sphere has a charge of $+1.60\ \mu C$, the spacing doubles. Assuming that the spheres have a negligible diameter, determine the spring constant of the springs.

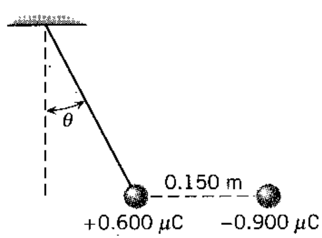


*20. Two positive charges, when combined, give a total charge of $+9.00\ \mu C$. When the charges are separated by 3.00 m, the force exerted by one charge on the other has a magnitude of 8.00×10^{-3} N. Find the amount of each charge.

*21. An electrically neutral model airplane is flying in a horizontal circle on a 3.0-m guideline, which is nearly parallel to the ground. The line breaks when the kinetic energy of the plane is 50.0 J. Reconsider the same situation, except that now there is a point charge of $+q$ on the plane and a point charge of $-q$ at the other end of the guideline. In this case, the line breaks when the kinetic energy of the plane is 51.8 J. Find the magnitude of the charges.

**22. Two objects are identical and small enough that their sizes can be ignored relative to the distance between them, which is 0.200 m. In a vacuum, each object carries a different charge, and they attract each other with a force of 1.20 N. The objects are brought into contact, so the net charge is shared equally, and then they are returned to their initial positions. Now it is found that the objects repel one another with a force whose magnitude is equal to that of the initial attractive force. What is the initial charge on each object? Note that there are two answers.

23. **ssm A small spherical insulator of mass 8.00×10^{-2} kg and charge $+0.600\ \mu C$ is hung by a thin wire of negligible mass. A charge of $-0.900\ \mu C$ is held 0.150 m away from the sphere and directly to the right of it, so the wire makes an angle θ with the vertical (see the drawing). Find (a) the angle θ and (b) the tension in the wire.



**24. Two identical, small insulating balls are suspended by separate 0.25-m threads that are attached to a common point on the ceiling. Each ball has a mass of 8.0×10^{-4} kg. Initially the balls are uncharged and hang straight down. They are then given identical positive charges and, as a result, spread apart with an angle of 36° between the threads. Determine (a) the charge on each ball and (b) the tension in the threads.

Section 18.6 The Electric Field, Section 18.7 Electric Field Lines, Section 18.8 The Electric Field Inside a Conductor: Shielding

25. An electric field of 260 000 N/C points due west at a certain spot. What are the magnitude and direction of the force that acts on a charge of $-7.0\ \mu C$ at this spot?

26. Review Conceptual Example 12 as an aid in working this problem. Charges of $-4q$ are fixed to opposite corners of a square. A charge of $+5q$ is fixed to one of the remaining corners, and a charge of $+3q$ is fixed to the last corner. Assuming that ten electric field lines emerge from the $+5q$ charge, sketch the field lines in the vicinity of the four charges.

27. **ssm** A charge of $+3.0 \times 10^{-5}$ C is located at a place where there is an electric field that points due east and has a magnitude of 15 000 N/C. What are the magnitude and direction of the force acting on the charge?

28. Two charges are placed on the x axis. One charge ($q_1 = +8.5\ \mu C$) is at $x_1 = +3.0$ cm and the other ($q_2 = -21\ \mu C$) is at $x_1 = +9.0$ cm. Find the net electric field (magnitude and direction) at (a) $x = 0$ cm and (b) $x = +6.0$ cm.

29. Two charges, -16 and $+4.0\ \mu C$, are fixed in place and separated by 3.0 m. (a) At what spot along a line through the charges is the net electric field zero? Locate this spot relative to the positive charge. *(Hint: The spot does not necessarily lie between the two charges.)* (b) What would be the force on a charge of $+14\ \mu C$ placed at this spot?

30. An electric field with a magnitude of 160 N/C exists at a spot that is 0.15 m away from a charge. At a place that is 0.45 m away from this charge, what is the electric field strength?

31. **ssm** A 3.0-μC point charge is placed in an external uniform electric field of 1.6×10^4 N/C. At what distance from the charge is the net electric field zero?

32. A charge of $q = +7.50\ \mu C$ is located in an electric field. The x and y components of the electric field are $E_x = 6.00 \times 10^3$ N/C and $E_y = 8.00 \times 10^3$ N/C, respectively. (a) What is the magnitude of the force on the charge? (b) Determine the angle that the force makes with the $+x$ axis.

33. The magnitude of the electric field between the plates of a parallel plate capacitor is 2.4×10^5 N/C. Each plate carries a charge whose magnitude is 0.15 μC. What is the area of each plate?

34. Two charges are located on the x axis: $q_1 = +6.0\ \mu C$ at $x_1 = +4.0$ cm, and $q_2 = +6.0\ \mu C$ at $x_2 = -4.0$ cm. Two other charges are located on the y axis: $q_3 = +3.0\ \mu C$ at $y_3 = +5.0$ cm, and $q_4 = -8.0\ \mu C$ at $y_4 = +7.0$ cm. Find the net electric field (magnitude and direction) at the origin.

35. **ssm** A small drop of water is suspended motionless in air by a uniform electric field that is directed upward and has a

magnitude of 8480 N/C. The mass of the water drop is 3.50×10^{-9} kg. (a) Is the excess charge on the water drop positive or negative? Why? (b) How many excess electrons or protons reside on the drop?

36. Review Conceptual Example 11 before attempting this problem. The magnitude of each of the charges in Figure 18.21 is 8.60×10^{-12} C. The lengths of the sides of the rectangles are 3.00 cm and 5.00 cm. Find the magnitude of the electric field at the center of the rectangle in Figure 18.21*a* and *b*.

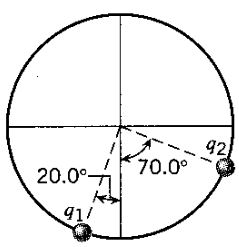
***37.** A proton is moving parallel to a uniform electric field. The electric field accelerates the proton and increases its linear momentum to 5.0×10^{-23} kg·m/s from 1.5×10^{-23} kg·m/s in a time of 6.3×10^{-6} s. What is the magnitude of the electric field?

***38.** An electron is released from rest at the negative plate of a parallel plate capacitor. The charge per unit area on each plate is $\sigma = 1.8 \times 10^{-7}$ C/m², and the plates are separated by a distance of 1.5×10^{-2} m. How fast is the electron moving just before it reaches the positive plate?

***39. ssm www** A rectangle has a length of $2d$ and a height of d. Each of the following three charges is located at a corner of the rectangle: $+q_1$ (upper left corner), $+q_2$ (lower right corner), and $-q$ (lower left corner). The net electric field at the (empty) upper right corner is zero. Find the magnitudes of q_1 and q_2. Express your answers in terms of q.

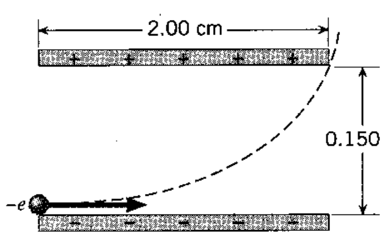
***40.** A small object, which has a charge $q = 7.5\ \mu$C and mass $m = 9.0 \times 10^{-5}$ kg, is placed in a constant electric field. Starting from rest, the object accelerates to a speed of 2.0×10^3 m/s in a time of 0.96 s. Determine the magnitude of the electric field.

***41.** The drawing shows two positive charges q_1 and q_2 fixed to a circle. At the center of the circle they produce a net electric field that is directed upward along the vertical axis. Determine the ratio q_2/q_1.

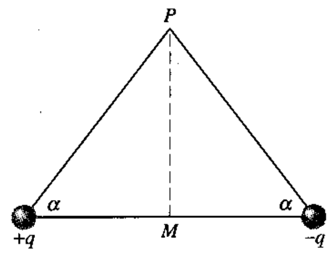


Problem 41

****42.** The drawing shows an electron entering the lower left side of a parallel plate capacitor and exiting at the upper right side. The initial speed of the electron is 7.00×10^6 m/s. The capacitor is 2.00 cm long, and its plates are separated by 0.150 cm. Assume that the electric field between the plates is uniform everywhere and find its magnitude.



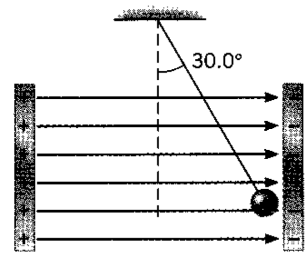
****43. ssm** Two point charges of the same magnitude but opposite signs are fixed to either end of the base of an isosceles triangle, as the drawing shows. The electric field at the midpoint M between the charges has a magnitude E_M. The field directly above the midpoint at point P has a magnitude E_P. The ratio of these two field magnitudes is $E_M/E_P = 9.0$. Find the angle α in the drawing.



Problem 43

****44.** The magnitude of the electric field between the plates of a parallel plate capacitor is 480 N/C. A silver dollar is placed between the plates and oriented parallel to the plates. (a) Ignoring the edges of the coin, find the induced charge density σ on each face of the coin. (b) Assuming the coin has a radius of 1.9 cm, find the magnitude of the total charge on each face of the coin.

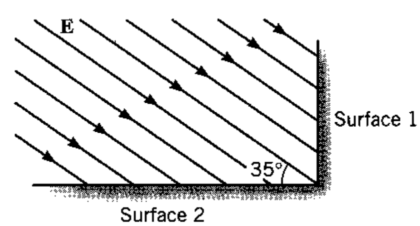
****45.** A small plastic ball of mass 6.50×10^{-3} kg and charge $+0.150\ \mu$C is suspended from an insulating thread and hangs between the plates of a capacitor (see the drawing). The ball is in equilibrium, with the thread making an angle of 30.0° with respect to the vertical. The area of each plate is 0.0150 m². What is the magnitude of the charge on each plate?



Section 18.9 Gauss' Law

46. A spherical surface completely surrounds a collection of charges. Find the electric flux through the surface if the collection consists of (a) a single $+3.5 \times 10^{-6}$ C charge, (b) a single -2.3×10^{-6} C charge, and (c) both of the charges in (a) and (b).

47. ssm The drawing shows an edge-on view of two planar surfaces that intersect and are mutually perpendicular. Surface 1 has an area of 1.7 m², while surface 2 has an area of 3.2 m². The electric field **E** in the drawing is uniform and has a magnitude of 250 N/C. Find the electric flux through (a) surface 1 and (b) surface 2.



48. A rectangular surface (0.16 m × 0.38 m) is oriented in a uniform electric field of 580 N/C. What is the maximum possible electric flux through the surface?

49. A surface completely surrounds a $+2.0 \times 10^{-6}$ C charge. Find the electric flux through this surface when the surface is (a) a sphere with a radius of 0.50 m, (b) a sphere with a radius of 0.25 m, and (c) a cube with edges that are 0.25 m long.

50. A vertical wall (5.9 m × 2.5 m) in a house faces due east. A uniform electric field has a magnitude of 150 N/C. This field is parallel to the ground and points 35° north of east. What is the electric flux through the wall?

***51. ssm** A cube is located with one corner at the origin of an x, y, z, coordinate system. One of the cube's faces lies in the x, y plane, another in the y, z plane, and another in the x, z plane. In other words, the cube is in the first octant of the coordinate system. The edges of the cube are 0.20 m long. A uniform electric field is parallel to the x, y plane and points in the direction of the $+y$ axis. The magnitude of the field is 1500 N/C. (a) Find the electric flux through each of the six faces of the cube. (b) Add the six values obtained in part (a) to show that the electric flux through the cubical surface is zero, as Gauss' law predicts, since there is no net charge within the cube.

***52.** Two spherical shells have a common center. A -1.6×10^{-6}-C charge is spread uniformly over the inner shell, which has a radius of 0.050 m. A $+5.1 \times 10^{-6}$-C charge is spread uniformly over the outer shell, which has a radius of 0.15 m. Find the magnitude and direction of the electric field at a distance (measured from the common center) of (a) 0.20 m, (b) 0.10 m, and (c) 0.025 m.

****53.** A long, thin, straight wire of length L has a positive charge Q distributed uniformly along it. Use Gauss' law to show that the electric field created by this wire at a radial distance r has a magnitude of $E = \lambda/(2\pi\epsilon_0 r)$, where $\lambda = Q/L$. *(Hint: For a Gaussian surface, use a cylinder aligned with its axis along the wire and note that the cylinder has a flat surface at either end, as well as a curved surface.)*

ADDITIONAL PROBLEMS

54. Review the important features of electric field lines discussed in Conceptual Example 12. Three point charges ($+q$, $+2q$, and $-3q$) are at the corners of an equilateral triangle. Sketch in six electric field lines between the three charges.

55. ssm Two charges attract each other with a force of 1.5 N. What will be the force if the distance between them is reduced to one-ninth of its original value?

56. Conceptual Example 13 in the text deals with the hollow spherical conductor in Figure 18.31. The conductor is initially electrically neutral, and then a charge $+q$ is placed at the center of the hollow space. Suppose the conductor initially has a net charge of $+2q$ instead of being neutral. What is the total charge on the interior and on the exterior surface when the $+q$ charge is placed at the center?

57. A charge $+q$ is located at the origin, while an identical charge is located on the x axis at $x = +0.50$ m. A third charge of $+2\ q$ is located on the x axis at such a place that the net electrostatic force on the charge at the origin doubles, its direction remaining unchanged. Where should the third charge be located?

58. Three charges are located on the $+x$ axis as follows: $q_1 = +25\ \mu C$ at $x = 0$ m, $q_2 = +11\ \mu C$ at $x = +2.0$ m, and $q_3 = +45\ \mu C$ at $x = +3.5$ m. (a) Find the electrostatic force (magnitude and direction) acting on q_2. (b) Suppose q_2 were $-11\ \mu C$, rather than $+11\ \mu C$. Without performing any further detailed calculations, specify the magnitude and direction of the force exerted on q_2. Give your reasoning.

59. ssm www A tiny ball (mass = 0.012 kg) carries a charge of $-18\ \mu C$. What electric field (magnitude and direction) is needed to cause the ball to float above the ground?

60. A long, thin rod (length = 4.0 m) lies along the x axis, with its midpoint at the origin. In a vacuum, a $+8.0\ \mu C$ point charge is fixed to one end of the rod, while a $-8.0\ \mu C$ point charge is fixed to the other end. Everywhere in the x, y plane there is a constant external electric field (magnitude = 5.0×10^3 N/C) that is perpendicular to the rod. With respect to the z axis, find the magnitude of the net torque applied to the rod.

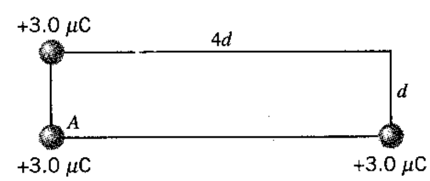
61. ssm Two tiny spheres have the same mass and carry charges of the same magnitude. The mass of each sphere is 2.0×10^{-6} kg. The gravitational force that each sphere exerts on the other is balanced by the electric force. (a) What algebraic signs can the charges have? (b) Determine the charge magnitude.

***62.** Two charges are placed between the plates of a parallel plate capacitor. One charge is $+q_1$ and the other is $q_2 = +5.00\ \mu C$. The charge per unit area on each plate has a magnitude of $\sigma = 1.30 \times 10^{-4}$ C/m^2. The force on q_1 due to q_2 equals the force on q_1 due to the electric field of the parallel plate capacitor. What is the distance r between the two charges?

***63.** A small object has a mass of 2.0×10^{-3} kg and a charge of $-25\ \mu C$. It is placed at a certain spot where there is an electric field. When released, the object experiences an acceleration of 3.5×10^3 m/s^2 in the direction of the $+x$ axis. Determine the magnitude and direction of the electric field.

***64.** Two small charged objects are attached to a horizontal spring, one at each end. The magnitudes of the charges are equal, and the spring constant is 220 N/m. The spring is observed to be stretched by 0.020 m relative to its unstrained length of 0.32 m. Determine (a) the possible algebraic signs and (b) the magnitude of the charges.

***65. ssm** In the rectangle in the drawing, a charge is to be placed at the empty corner to make the net force on the charge at corner A point along the vertical direction. What charge (magnitude and algebraic sign) must be placed at the empty corner?



***66.** A uniform electric field has a magnitude of 2.3×10^3 N/C. In a vacuum, a proton begins with a speed of 2.5×10^4 m/s and moves in the direction of this field. Find the speed of the proton after it has moved a distance of 2.0 mm.

****67.** There are four charges, each with a magnitude of 2.0 μC. Two are positive and two are negative. The charges are fixed to the corners of a 0.30-m square, one to a corner, in such a way that the net force on any charge is directed toward the center of the square. Find the magnitude of the net electrostatic force experienced by any charge.

CONCEPTS & CALCULATIONS

GROUP LEARNING PROBLEMS

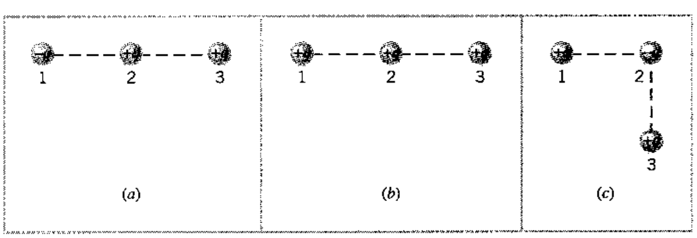
Note: Each of these problems consists of Concept Questions followed by a related quantitative Problem. They are designed for use by students working alone or in small learning groups. The Concept Questions involve little or no mathematics and are intended to stimulate group discussions. They focus on the concepts with which the problems deal. Recognizing the concepts is the essential initial step in any problem-solving technique.

68. Concept Questions Two identical metal spheres have charges of q_1 and q_2. They are brought together so they touch, and then they are separated. (a) How is the net charge on the two spheres before they touch related to the net charge after they touch? (b) After they touch and are separated, is the charge on each sphere the same? Why?

Problem Four identical metal spheres have charges of $q_A = -8.0\ \mu C$, $q_B = -2.0\ \mu C$, $q_C = +5.0\ \mu C$, and $q_D = +12.0\ \mu C$. (a) Two of the spheres are brought together so they touch and then they are separated. Which spheres are they, if the final charge on each one is $+5.0\ \mu C$? (b) In a similar manner, which three spheres are brought together and then separated, if the final charge on each one is $+3.0\ \mu C$? (c) How many electrons would have to be added to one of the spheres in part (b) to make it electrically neutral?

69. Concept Questions The drawings show three charges that have the same magnitude, but different signs. In all cases the distance between charges 1 and 2 and between 2 and 3 is the same. (a) Draw the electrical force that each charge exerts on charge 2. Each force should be drawn in the correct direction, and its magnitude should be correct relative to that of the other force. (b) Rank the magnitudes of the net electrical force on charge 2, largest first. Explain.

Problem The magnitude of the charges is $q = 8.6\ \mu C$, and the distance between them is 3.8 mm. Determine the magnitude of the net force on charge 2 for each of the three drawings. Verify that your answers are consistent with your answers to the Concept Questions.



70. Concept Questions Suppose you want to neutralize the gravitational attraction between the earth and the moon by placing equal amounts of charge on each. (a) Should the charges be both positive, both negative, or one positive and the other negative? Why? (b) Do you need to know the distance between the earth and the moon to find the magnitude of the charge? Why or why not?

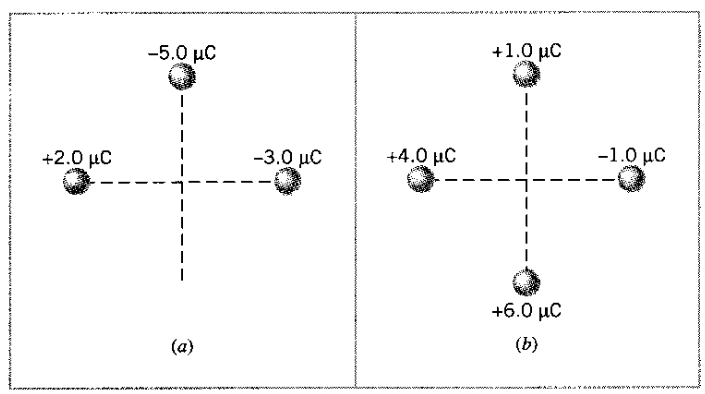
Problem The masses of the earth and moon are 5.98×10^{24} and 7.35×10^{22} kg, respectively. Identical amounts of charge are placed on each body, such that the net force (gravitational plus electrical) on each is zero. What is the magnitude of the charge?

71. Concept Questions Suppose you want to determine the electric field in a certain region of space. You have a small object of known charge and an instrument that measures the magnitude and direction of the force exerted on the object by the electric field. How would you determine the magnitude and direction of the electric field if the object were (a) positively charged and (b) negatively charged?

Problem The object has a charge of $+20.0\ \mu C$ and the instrument indicates that the electric force exerted on it is $40.0\ \mu N$, due east. What is the magnitude and direction of the electric field? (b) What is the magnitude and direction of the electric field if the object has a charge of $-10.0\ \mu C$ and the instrument indicates that the force is $20.0\ \mu N$ due west?

72. Concept Question The drawing shows two situations in which charges are placed on the x and y axes. They are all located at the same distance from the origin. Without doing any calculations, does the electric field at the origin in part (a) have a magnitude that is greater than, less than, or equal to the magnitude of the field at the origin in part (b)? Justify your answer.

Problem The distance between each of the charges and the origin is 6.1 cm. For each of the situations shown in the drawing, determine the magnitude of the electric field at the origin. Check to see that your results are consistent with your answer to the Concept Question.



73. Concept Questions A proton and an electron are moving due east in a constant electric field that also points due east. (a) Does each experience an electric force of the same magnitude and direction? (b) What is the direction of the proton's acceleration and the direction of the electron's acceleration? (c) Is the magnitude of the proton's acceleration greater than, less than, or the same as that of the electron's acceleration? Explain your answers.

Problem The electric field points due east and has a magnitude of 8.0×10^4 N/C. Determine the magnitude of the acceleration of the proton and the electron. Check that your answers are consistent with part *c* of the Concept Questions.

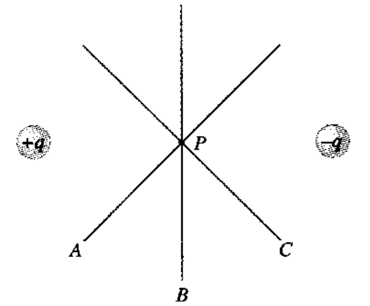
peated. Which is traveling faster when the collision occurs, the proton or the electron? Justify your answer.

9. The potential is constant throughout a given region of space. Is the electric field zero or nonzero in this region? Explain.

10. In a region of space where the electric field is constant everywhere, as it is inside a parallel plate capacitor, is the potential constant everywhere? Account for your answer.

11. A positive test charge is placed in an electric field. In what direction should the charge be moved relative to the field, such that the charge experiences a constant electric potential? Explain.

12. The location marked P in the drawing lies midway between the point charges $+q$ and $-q$. The blue lines labeled A, B, and C are edge-on views of three planes. Which one of these planes is an equipotential surface? Why?



Question 12

13. Imagine that you are moving a positive test charge along the line between two identical point charges. With regard to the electric potential, is the midpoint on the line analogous to the top of a mountain or the bottom of a valley when the two point charges are (a) positive and (b) negative? In each case, explain your answer.

14. Repeat question 13, assuming that you are moving a negative instead of a positive test charge.

15. The potential at a point in space has a certain value, which is not zero. Is the electric potential energy the same for every charge that is placed at that point? Give your reasoning.

16. A proton and an electron are released from rest at the midpoint between the plates of a charged parallel plate capacitor. Except for these particles, nothing else is between the plates. Ignore the attraction between the proton and the electron, and decide which particle strikes a capacitor plate first. Why?

17. A parallel plate capacitor is charged up by a battery. The battery is then disconnected, but the charge remains on the plates. The plates are then pulled apart. Explain whether each of the following quantities increases, decreases, or remains the same as the distance between the plates increases: (a) the capacitance of the capacitor, (b) the potential difference between the plates, (c) the electric field between the plates, and (d) the electric potential energy stored by the capacitor. Give reasons for your answers.

PROBLEMS

Note: All charges are assumed to be point charges unless specified otherwise.

ssm Solution is in the Student Solutions Manual. www Solution is available on the World Wide Web at http://www.wiley.com/college/cutnell
This icon represents a biomedical application.

Section 19.1 Potential Energy, Section 19.2 The Electric Potential Difference

1. ssm Suppose that the electric potential outside a living cell is higher than that inside the cell by 0.070 V. How much work is done by the electric force when a sodium ion (charge $= +e$) moves from the outside to the inside?

2. A particle has a charge of $+1.5\ \mu C$ and moves from point A to point B, a distance of 0.20 m. The particle experiences a constant electric force, and its motion is along the line of action of the force. The difference between the particle's electric potential energy at A and B is $EPE_A - EPE_B = +9.0 \times 10^{-4}$ J. (a) Find the magnitude and direction of the electric force that acts on the particle. (b) Find the magnitude and direction of the electric field that the particle experiences.

3. Just as you touch a metal door knob, a spark of electricity (electrons) jumps from your hand to the knob. The electric potential of the knob is 2.0×10^4 V greater than that of your hand. The work done by the electric force on the electrons is 1.5×10^{-7} J. How many electrons jump from your hand to the knob?

4. The anode (positive terminal) of an X-ray tube is at a potential of +125 000 V with respect to the cathode (negative terminal). (a) How much work (in joules) is done by the electric force when an electron is accelerated from the cathode to the anode? (b) If the electron is initially at rest, what kinetic energy does the electron have when it arrives at the anode?

5. ssm In a television picture tube, electrons strike the screen after being accelerated from rest through a potential difference of 25 000 V. The speeds of the electrons are quite large, and for accurate calculations of the speeds, the effects of special relativity must be taken into account. Ignoring such effects, find the electron speed just before the electron strikes the screen.

6. A particle with a charge of $-1.5\ \mu C$ and a mass of 2.5×10^{-6} kg is released from rest at point A and accelerates toward point B, arriving there with a speed of 42 m/s. (a) What is the potential difference $V_B - V_A$ between A and B? (b) Which point is at the higher potential? Give your reasoning.

7. An electric car accelerates for 8.0 s by drawing energy from its 320-V battery pack. During this time, 1300 C of charge pass through the battery pack. Find the minimum horsepower rating of the car.

***8.** A typical 12-V car battery can deliver about 7.5×10^5 C of charge before dying. This is not very much. To get a feel for this, calculate the maximum number of kilograms of water (100 °C) that could be boiled into steam (100 °C) using energy from this battery.

***9.** **ssm** **www** The potential at location A is 452 V. A positively charged particle is released there from rest and arrives at location B with a speed v_B. The potential at location C is 791 V, and when released from rest from this spot, the particle arrives at B with twice the speed it previously had, or $2v_B$. Find the potential at B.

****10.** A particle is uncharged and is thrown vertically upward from ground level with a speed of 25.0 m/s. As a result, it attains a maximum height h. The particle is then given a positive charge $+q$ and reaches the same maximum height h when thrown vertically upward with a speed of 30.0 m/s. The electric potential at the height h exceeds the electric potential at ground level. Finally, the particle is given a negative charge $-q$. Ignoring air resistance, determine the speed with which the negatively charged particle must be thrown vertically upward, so that it attains exactly the maximum height h. In all three situations, be sure to include the effect of gravity.

Section 19.3 The Electric Potential Difference Created by Point Charges

11. **ssm** There is an electric potential of +130 V at a spot that is 0.25 m away from a charge. Find the magnitude and sign of the charge.

12. Two charges A and B are fixed in place, at different distances from a certain spot. At this spot the potentials due to the two charges are equal. Charge A is 0.18 m from the spot, while charge B is 0.43 m from it. Find the ratio q_B/q_A of the charges.

13. An electron and a proton are initially very far apart (effectively an infinite distance apart). They are then brought together to form a hydrogen atom, in which the electron orbits the proton at an average distance of 5.29×10^{-11} m. What is $EPE_{final} - EPE_{initial}$, which is the change in the electric potential energy?

14. Location A is 2.00 m from a charge of -3.00×10^{-8} C, while location B is 3.00 m from the charge. Find the potential difference $V_B - V_A$ between the two points, and state which point is at the higher potential.

15. **ssm** **www** Two identical point charges are fixed to diagonally opposite corners of a square that is 0.500 m on a side. Each charge is $+3.0 \times 10^{-6}$ C. How much work is done by the electric force as one of the charges moves to an empty corner?

16. Two positive point charges are held in place, 0.74 m apart. They are then moved so that their electric potential energy doubles. What is the new separation between the charges?

17. A charge of $+9q$ is fixed to one corner of a square, while a charge of $-8q$ is fixed to the opposite corner. Expressed in terms of q, what charge should be fixed to the center of the square, so the potential is zero at each of the two empty corners?

18. Review Conceptual Example 7 as background for this problem. Two charges are fixed in place with a separation d. One charge is positive and has twice the magnitude of the other charge, which is negative. The positive charge lies to the left of the negative charge, as in Figure 19.11. Relative to the negative charge, locate the two spots on the line through the charges where the total potential is zero.

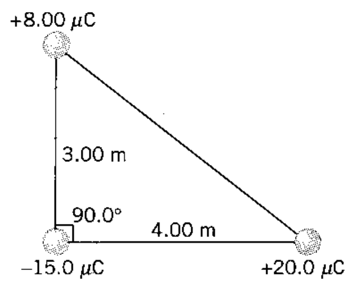
***19.** **ssm** A charge of -3.00 μC is fixed in place. From a horizontal distance of 0.0450 m, a particle of mass 7.20×10^{-3} kg and charge -8.00 μC is fired with an initial speed of 65.0 m/s directly toward the fixed charge. How far does the particle travel before its speed is zero?

***20.** Four identical charges (+2.0 μC each) are brought from infinity and fixed to a straight line. The charges are located 0.40 m apart. Determine the electric potential energy of this group.

***21.** Two protons are moving directly toward one another. When they are very far apart, their initial speeds are 1.5×10^6 m/s. What is the distance of closest approach?

***22.** Identical point charges of +1.7 μC are fixed to diagonally opposite corners of a square. A third charge is then fixed at the center of the square, such that it causes the potentials at the empty corners to change signs without changing magnitudes. Find the sign and magnitude of the third charge.

***23.** **ssm** Determine the electric potential energy for the array of three charges shown in the drawing, relative to its value when the charges are infinitely far away.



Problem 23

****24.** A positive charge $+q_1$ is located to the left of a negative charge $-q_2$. On a line passing through the two charges, there are two places where the total potential is zero. The first place is between the charges and is 4.00 cm to the left of the negative charge. The second place is 7.00 cm to the right of the negative charge. (a) What is the distance between the charges? (b) Find q_1/q_2, the ratio of the magnitudes of the charges.

****25.** Charges q_1 and q_2 are fixed in place, q_2 being located at a distance d to the right of q_1. A third charge q_3 is then fixed to the line joining q_1 and q_2 at a distance d to the right of q_2. The third charge is chosen so the potential energy of the group is zero; that is, the potential energy has the same value as that of the three charges when they are widely separated. Determine q_3, assuming that (a) $q_1 = q_2 = q$ and (b) $q_1 = q$ and $q_2 = -q$. Express your answers in terms of q.

****26.** Two particles each have a mass of 6.0×10^{-3} kg. One has a charge of $+5.0 \times 10^{-6}$ C, and the other has a charge of -5.0×10^{-6} C. They are initially held at rest at a distance of 0.80 m apart. Both are then released and accelerate toward each other. How fast is each particle moving when the separation between them is one-half its initial value?

Section 19.4 Equipotential Surfaces and Their Relation to the Electric Field

27. **ssm** An equipotential surface that surrounds a $+3.0 \times 10^{-7}$ C point charge has a radius of 0.15 m. What is the potential of this surface?

28. What point charge is at the center of a +36-V equipotential surface that has a radius of 0.18 m?

29. A spark plug in an automobile engine consists of two metal conductors that are separated by a distance of 0.75 mm. When an electric spark jumps between them, the magnitude of the electric field is 4.7×10^7 V/m. What is the magnitude of the potential difference ΔV between the conductors?

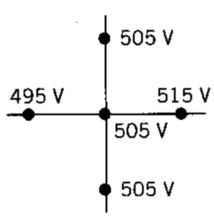
30. The inner and outer surfaces of a cell membrane carry a negative and positive charge, respectively. Because of these charges, a potential difference of about 0.070 V exists across the membrane. The thickness of the membrane is 8.0×10^{-9} m. What is the magnitude of the electric field in the membrane?

31. ssm Two points, A and B, are separated by 0.016 m. The potential at A is +95 V, and that at B is +28 V. Determine the magnitude and direction of the electric field between the two points.

***32.** At a distance of 1.60 m from a point charge of $+2.00 \times 10^{-6}$ C, there is an equipotential surface. At greater distances there are additional equipotential surfaces. The potential difference between any two successive surfaces is 1.00×10^3 V. Starting at a distance of 1.60 m and moving radially outward, how many of the additional equipotential surfaces are crossed by the time the electric field has shrunk to one-half its initial value? Do not include the starting surface.

***33.** The electric field has a constant value of 3.0×10^3 V/m and is directed downward. The field is the same everywhere. The potential at a point P within this region is 135 V. Find the potential at the following points: (a) 8.0×10^{-3} m directly above P, (b) 3.3×10^{-3} m directly below P, (c) 5.0×10^{-3} m directly to the right of P.

***34.** The drawing shows the potential at five points on a set of axes. Each of the four outer points is 6.0×10^{-3} m from the point at the origin. From the data shown, find the magnitude and direction of the electric field in the vicinity of the origin.



Problem 34

***35. ssm** Equipotential surface A has a potential of 5650 V, while equipotential surface B has a potential of 7850 V. A particle has a mass of 5.00×10^{-2} kg and a charge of $+4.00 \times 10^{-5}$ C. The particle has a speed of 2.00 m/s on surface A. An outside force is applied to the particle, and it moves to surface B, arriving there with a speed of 3.00 m/s. How much work is done by the outside force in moving the particle from A to B?

Section 19.5 Capacitors and Dielectrics

36. What voltage is required to store 7.2×10^{-5} C of charge on the plates of a 6.0-μF capacitor?

37. ssm The electric potential energy stored in the capacitor of a defibrillator is 73 J, and the capacitance is 120 μF. What is the potential difference across the capacitor plates?

38. A capacitor stores 5.3×10^{-5} C of charge when connected to a 6.0-V battery. How much charge does the capacitor store when connected to a 9.0-V battery?

39. ssm The membrane that surrounds a certain type of living cell has a surface area of 5.0×10^{-9} m^2 and a thickness of 1.0×10^{-8} m. Assume that the membrane behaves like a parallel plate capacitor and has a dielectric constant of 5.0. (a) The potential on the outer surface of the membrane is +60.0 mV greater than that on the inside surface. How much charge resides on the outer surface? (b) If the charge in part (a) is due to K^+ ions (charge $+e$), how many such ions are present on the outer surface?

40. A capacitor has a capacitance of 2.5×10^{-8} F. In the charging process, electrons are removed from one plate and placed on the other plate. When the potential difference between the plates is 450 V, how many electrons have been transferred?

41. The electronic flash attachment for a camera contains a capacitor for storing the energy used to produce the flash. In one such unit, the potential difference between the plates of a 750-μF capacitor is 330 V. (a) Determine the energy that is used to produce the flash in this unit. (b) Assuming that the flash lasts for 5.0×10^{-3} s, find the effective power or "wattage" of the flash.

42. Two identical capacitors store different amounts of energy: capacitor A stores 310 J and capacitor B stores 34 J. The voltage across the plates of capacitor B is 12 V. Find the voltage across the plates of capacitor A.

***43. ssm** What is the potential difference between the plates of a 3.3-F capacitor that stores sufficient energy to operate a 75-W light bulb for one minute?

***44.** Two hollow metal spheres are concentric with each other. The inner sphere has a radius of 0.1500 m and a potential of 85.0 V. The radius of the outer sphere is 0.1520 m and its potential is 82.0 V. If the region between the spheres is filled with Teflon, find the electric energy contained in this space.

***45.** The dielectric strength of an insulating material is the maximum electric field strength to which the material can be subjected without electrical breakdown occurring. Suppose a parallel plate capacitor is filled with a material whose dielectric constant is 3.5 and whose dielectric strength is 1.4×10^7 N/C. If this capacitor is to store 1.7×10^{-7} C of charge on each plate without suffering breakdown, what must be the radius of its circular plates?

***46.** Review Conceptual Example 11 before attempting this problem. An empty capacitor is connected to a 12.0-V battery and charged up. The capacitor is then disconnected from the battery, and a slab of dielectric material ($\kappa = 2.8$) is inserted between the plates. Find the amount by which the potential difference across the plates changes. Specify whether the change is an increase or a decrease.

****47. ssm www** The potential difference between the plates of a capacitor is 175 V. Midway between the plates, a proton and an electron are released. The electron is released from rest. The proton is projected perpendicularly toward the negative plate with an initial speed. The proton strikes the negative plate at the same instant the electron strikes the positive plate. Ignore the attraction between the two particles, and find the initial speed of the proton.

****48.** The plate separation of a charged capacitor is 0.0800 m. A proton and an electron are released from rest at the midpoint between the plates. Ignore the attraction between the two particles, and determine how far the proton has traveled by the time the electron strikes the positive plate.

ADDITIONAL PROBLEMS

49. At a distance of 0.20 m from a charge, the electric potential is 164 V. What is the potential at a distance of 0.80 m?

50. An electric force moves a charge of $+1.80 \times 10^{-4}$ C from point A to point B and performs 5.80×10^{-3} J of work on the charge. (a) What is the difference ($\text{EPE}_A - \text{EPE}_B$) between the electric potential energies of the charge at the two points? (b) Determine the potential difference ($V_A - V_B$) between the two points. (c) State which point is at the higher potential.

51. ssm A parallel plate capacitor has a capacitance of 7.0 μF when filled with a dielectric. The area of each plate is 1.5 m^2 and the separation between the plates is 1.0×10^{-5} m. What is the dielectric constant of the dielectric?

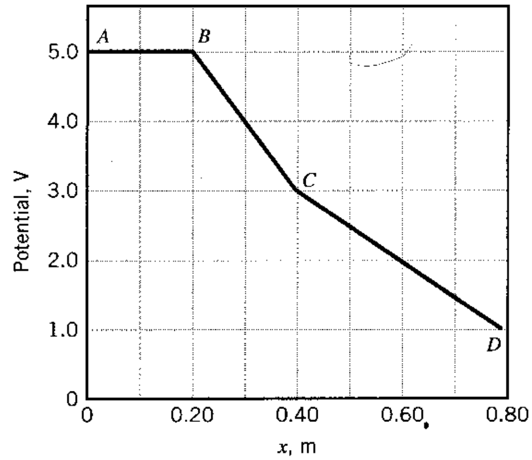
52. Point A is at a potential of +250 V, and point B is at a potential of −150 V. An α-particle is a helium nucleus that contains two protons and two neutrons; the neutrons are electrically neutral. An α-particle starts from rest at A and accelerates toward B. When the α-particle arrives at B, what kinetic energy (in electron volts) does it have?

53. An axon is the relatively long tail-like part of a neuron, or nerve cell. The outer surface of the axon membrane (dielectric constant = 5, thickness = 1×10^{-8} m) is charged positively, and the inner portion is charged negatively. Thus, the membrane is a kind of capacitor. Assuming that an axon can be treated like a parallel plate capacitor with a plate area of 5×10^{-6} m^2, what is its capacitance?

54. A charge of +125 μC is fixed at the center of a square that is 0.64 m on a side. How much work is done by the electric force as a charge of +7.0 μC moves from one corner of the square to any other empty corner? Explain.

55. ssm www When you walk across a rug on a dry day, your body can become electrified, and its electric potential can change. When the potential becomes large enough, a spark of negative charges can jump between your hand and a metal surface. A spark occurs when the electric field strength created by the charges on your body reaches the dielectric strength of the air. The dielectric strength of the air is 3.0×10^{6} N/C and is the electric field strength at which the air suffers electrical breakdown. Suppose a spark 3.0 mm long jumps between your hand and a metal doorknob. Assuming that the electric field is uniform, find the potential difference ($V_{\text{knob}} - V_{\text{hand}}$) between your hand and the doorknob.

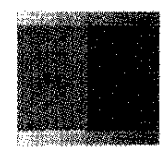
***56.** The drawing shows the electric potential as a function of distance along the x axis. Determine the magnitude of the electric field in the region (a) A to B, (b) B to C, and (c) C to D.



***57.** An empty capacitor has a capacitance of 2.7 μF and is connected to a 12-V battery. A dielectric material ($\kappa = 4.0$) is inserted between the plates of this capacitor. What is the magnitude of the surface charge on the dielectric that is adjacent to either plate of the capacitor? *(Hint: The surface charge is equal to the difference in the charge on the plates with and without the dielectric.)*

****58.** One particle has a mass of 3.00×10^{-3} kg and a charge of +8.00 μC. A second particle has a mass of 6.00×10^{-3} kg and the same charge. The two particles are initially held in place and then released. The particles fly apart, and when the separation between them is 0.100 m, the speed of the 3.00×10^{-3}-kg particle is 125 m/s. Find the initial separation between the particles.

****59. ssm** The drawing shows a parallel plate capacitor. One-half of the region between the plates is filled with a material that has a dielectric constant κ_1. The other half is filled with a material that has a dielectric constant κ_2. The area of each plate is A, and the plate separation is d. The potential difference across the plates is V. Note especially that the charge stored by the capacitor is $q_1 + q_2 = CV$, where q_1 and q_2 are the charges on the area of the plates in contact with materials 1 and 2, respectively. Show that $C = \epsilon_0 A(\kappa_1 + \kappa_2)/(2d)$.



****60.** A positive charge of $+q_1$ is located 3.00 m to the left of a negative charge $-q_2$. The charges have different magnitudes. On the line through the charges, the net *electric field* is zero at a spot 1.00 m to the right of the negative charge. On this line there are also two spots where the potential is zero. Locate these two spots relative to the negative charge.

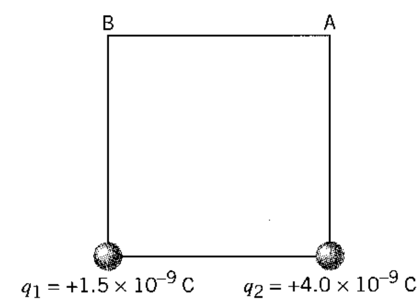
CONCEPTS & CALCULATIONS

GROUP LEARNING PROBLEMS

Note: Each of these problems consists of Concept Questions followed by a related quantitative Problem. They are designed for use by students working alone or in small learning groups. The Concept Questions involve little or no mathematics and are intended to stimulate group discussions. They focus on the concepts with which the problems deal. Recognizing the concepts is the essential initial step in any problem-solving technique.

61. Concept Questions The drawing shows a square, on two corners of which are fixed different positive charges. A third charge that is negative is brought to one of the empty corners. (a) At which of the empty corners, A or B, is the potential greater? (b) Is the electric potential energy of the third charge positive or negative? (c) For which location of the third charge, corner A or B, is the magnitude of the electric potential energy greater? Explain your answers.

Problem The length of a side of the square is $L = 0.25$ m. Find the electric potential energy of a charge $q_3 = -6.0 \times 10^{-9}$ C placed at corner A and then at corner B. Compare your answers for consistency with your answers to the Concept Questions.



62. Concept Questions Charges of $-q$ and $+2q$ are fixed in place, with a distance d between them. A dashed line is drawn through the negative charge, perpendicular to the line between the charges. On the dashed line, at a distance L from the negative charge, there is at least one spot where the total potential is zero. (a) At this spot, is the magnitude of the potential from the positive charge greater than, less than, or equal to the magnitude of the potential from the negative charge? (b) Is the distance from the positive charge to the zero-potential spot greater than, less than, or equal to L? (c) How many spots on the dashed line are there where the total potential is zero? Account for your answers.

Problem The distance between the charges is $d = 2.00$ m. Find L.

63. Concept Questions An electron and a proton, starting from rest, are accelerated through an electric potential difference of the same magnitude. In the process, the electron acquires a speed v_e, while the proton acquires a speed v_p. (a) As each particle accelerates from rest, it gains kinetic energy. Does it gain or lose electric potential energy? (b) Does the electron gain more, less, or the same amount of kinetic energy as the proton does? (c) Is v_e greater than, less than, or equal to v_p? Justify your answers.

Problem Find the ratio v_e/v_p. Verify that your answer is consistent with your answers to the Concept Questions.

64. Concept Questions A positive point charge is surrounded by an equipotential surface A, which has a radius of r_A. A positive test charge moves from surface A to another equipotential surface B, which has a radius of r_B. In the process, the electric force does negative work. (a) Does the electric force acting on the test charge have the same or opposite direction as the displacement of the test charge? (b) Is r_B greater than or less than r_A? Explain your answers.

Problem The positive point charge is $q = +7.2 \times 10^{-8}$ C, and the test charge is $q_0 = +4.5 \times 10^{-11}$ C. The work done as the test charge moves from surface A to surface B is $W_{AB} = -8.1 \times 10^{-9}$ J. The radius of surface A is $r_A = 1.8$ m. Find r_B. Check to see that your answer is consistent with your answers to the Concept Questions.

65. Concept Questions Two capacitors have the same plate separation. However, one has square plates, while the other has circular plates. The square plates are a length L on each side, and the diameter of the circular plates is L. (a) If the same dielectric material were between the plates in each capacitor, which one would have the greater capacitance? (b) By putting different dielectric materials between the capacitor plates, the two capacitors can be made to have the same capacitance. Which capacitor should contain the dielectric material with the greater dielectric constant? Give your reasoning in each case.

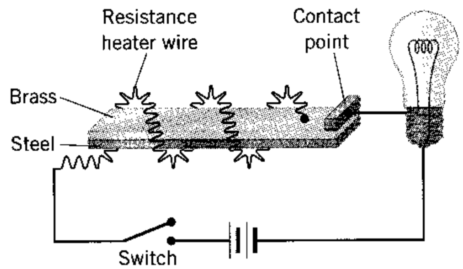
Problem The capacitors have the same capacitance because they contain different dielectric materials. The dielectric constant of the material between the square plates has a value of $\kappa_{\text{square}} = 3.00$. What is the dielectric constant κ_{circle} of the material between the circular plates? Be sure that your answer is consistent with your answers to the Concept Questions.

66. Concept Questions Capacitor A and capacitor B each have the same voltage across their plates. However, the energy of capacitor A can melt m kilograms of ice at 0 °C, while the energy of capacitor B can boil away the same amount of water at 100 °C. (a) Which requires more energy, melting the ice or boiling the water? (b) Which capacitor has the greater capacitance? Explain your answers.

Problem The capacitance of capacitor A is 9.3 μF. What is the capacitance of capacitor B? Be sure that your answer is consistent with your answers to the Concept Questions.

7. Often, the instructions for an electrical appliance do not state how many watts of power the appliance uses. Instead, a statement such as "10 A, 120 V" is given. Explain why this statement is equivalent to telling you the power consumption.

8. The drawing shows a circuit that includes a bimetallic strip (made from brass and steel, see Section 12.4) with a resistance heater wire wrapped around it.



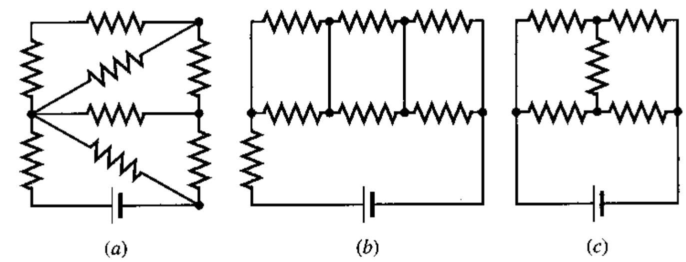
When the switch is initially closed, a current appears in the circuit, because charges flow through the heater wire (which becomes hot), the strip itself, the contact point, and the light bulb. The bulb glows in response. As long as the switch remains closed, does the bulb continue to glow, eventually turn off permanently, or flash on and off? Account for your answer.

9. The power rating of a 1000-W heater specifies the power consumed when the heater is connected to an ac voltage of 120 V. Explain why the power consumed by two of these heaters connected in series with a voltage of 120 V is not 2000 W.

10. A number of light bulbs are to be connected to a single electrical outlet. Will the bulbs provide more brightness if they are connected in series or in parallel? Why?

11. A car has two headlights. The filament of one burns out. However, the other headlight stays on. Draw a circuit diagram that shows how the lights are connected to the battery. Give your reasoning.

12. In one of the circuits in the drawing, none of the resistors is in series or in parallel. Which is it? Explain.



13. You have four identical resistors, each with a resistance of R. You are asked to connect these four together so that the equivalent resistance of the resulting combination is R. How many ways can you do it? There is more than one way. Justify your answers.

14. Compare the resistance of an ideal ammeter with the resistance of an ideal voltmeter and explain why the resistances are so different.

15. Describe what would happen to the current in a circuit if a voltmeter, inadvertently mistaken for an ammeter, were inserted into the circuit.

16. The time constant of a series RC circuit is $\tau = RC$. Verify that an ohm times a farad is equivalent to a second.

PROBLEMS

Note: For problems that involve ac conditions, the current and voltage are rms values and the power is an average value, unless indicated otherwise.

ssm Solution is in the Student Solutions Manual. www Solution is available on the World Wide Web at http://www.wiley.com/college/cutnell
This icon represents a biomedical application.

Section 20.1 Electromotive Force and Current, Section 20.2 Ohm's Law

1. ssm A portable compact disc player is designed to play for 2.0 h on a fully charged battery pack. If the battery pack provides a total of 180 C of charge, how much current does the player use in operating?

2. A defibrillator is used during a heart attack to restore the heart to its normal beating pattern (see Section 19.5). A defibrillator passes 18 A of current through the torso of a person in 2.0 ms. (a) How much charge moves during this time? (b) How many electrons pass through the wires connected to the patient?

3. The filament of a light bulb has a resistance of 580 Ω. A voltage of 120 V is connected across the filament. How much current is in the filament?

4. A toaster has a resistance of 14 Ω and is plugged into a 120-V outlet. What is the current in the toaster?

5. ssm The heating element of a clothes drier has a resistance of 11 Ω and is connected across a 240-V electrical outlet. What is the current in the heating element?

6. A battery charger is connected to a dead battery and delivers a current of 6.0 A for 5.0 hours, keeping the voltage across the battery terminals at 12 V in the process. How much energy is delivered to the battery?

***7.** The resistance of a bagel toaster is 14 Ω. To prepare a bagel, the toaster is operated for one minute from a 120-V outlet. How much energy is delivered to the toaster?

***8.** A car battery has a rating of 220 ampere · hours (A · h). This rating is one indication of the *total charge* that the battery can provide to a circuit before failing. (a) What is the total charge (in coulombs) that this battery can provide? (b) Determine the maximum current that the battery can provide for 38 minutes.

****9. ssm** A beam of protons is moving toward a target in a particle accelerator. This beam constitutes a current whose value is

0.50 μA. (a) How many protons strike the target in 15 seconds? (b) Each proton has a kinetic energy of 4.9×10^{-12} J. Suppose the target is a 15-gram block of aluminum, and all the kinetic energy of the protons goes into heating it up. What is the change in temperature of the block at the end of 15 s?

Section 20.3 Resistance and Resistivity

10. High-voltage power lines are a familiar sight throughout the country. The aluminum wire used for some of these lines has a cross-sectional area of 4.9×10^{-4} m^2. What is the resistance of ten kilometers of this wire?

11. ssm www Two wires have the same length and the same resistance. One is made from aluminum and the other from copper. Obtain the ratio of the cross-sectional area of the aluminum wire to that of the copper wire.

12. A coil of wire has a resistance of 38.0 Ω at 25 °C and 43.7 Ω at 55 °C. What is the temperature coefficient of resistivity?

13. A cylindrical copper cable carries a current of 1200 A. There is a potential difference of 1.6×10^{-2} V between two points on the cable that are 0.24 m apart. What is the radius of the cable?

14. A cylindrical wire of length 2.80 m and radius 1.03 mm carries a current of 1.35 A. The voltage across the ends of the wire is 0.0320 V. From what material in Table 20.1 is the wire made?

15. A wire of unknown composition has a resistance of $R_0 = 35.0\ \Omega$ when immersed in water at 20.0 °C. When the wire is placed in boiling water, its resistance rises to 47.6 Ω. What is the temperature of a hot summer day when the wire has a resistance of 37.8 Ω?

***16.** A tungsten wire has a radius of 0.075 mm and is heated from 20.0 to 1320 °C. The temperature coefficient of resistivity is $\alpha = 4.5 \times 10^{-3}$ (C°)$^{-1}$. When 120 V is applied across the ends of the hot wire, a current of 1.5 A is produced. How long is the wire? Neglect any effects due to thermal expansion.

***17. ssm www** A wire has a resistance of 21.0 Ω. It is melted down, and from the same volume of metal a new wire is made that is three times longer than the original wire. What is the resistance of the new wire?

***18.** A toaster uses a Nichrome heating wire. When the toaster is turned on at 20 °C, the initial current is 1.50 A. A few seconds later, the toaster warms up and the current has a value of 1.30 A. The average temperature coefficient of resistivity for Nichrome wire is 4.5×10^{-4} (C°)$^{-1}$. What is the temperature of the heating wire?

***19. ssm www** Two wires have the same cross-sectional area and are joined end to end to form a single wire. One is tungsten, which has a temperature coefficient of resistivity of $\alpha = 0.0045$ (C°)$^{-1}$. The other is carbon, for which $\alpha = -0.0005$ (C°)$^{-1}$. The total resistance of the composite wire is the sum of the resistances of the pieces. The total resistance of the composite does *not change with temperature*. What is the ratio of the lengths of the tungsten and carbon sections? Ignore any changes in length due to thermal expansion.

****20.** An aluminum wire is hung between two towers and has a length of 175 m. A current of 125 A exists in the wire, and the potential difference between the ends of the wire is 0.300 V. The density of aluminum is 2700 kg/m^3. Find the mass of the wire.

Section 20.4 Electric Power

21. An automobile battery is being charged at a voltage of 12.0 V and a current of 19.0 A. How much power is being produced by the charger?

22. A cigarette lighter in a car is a resistor that, when activated, is connected across the 12-V battery. Suppose a lighter dissipates 33 W of power. Find (a) the resistance of the lighter and (b) the current that the battery delivers to the lighter.

23. ssm In doing a load of clothes, a clothes drier uses 16 A of current at 240 V for 45 min. A personal computer, in contrast, uses 2.7 A of current at 120 V. With the energy used by the clothes drier, how long (in hours) could you use this computer to "surf" the internet?

24. There are approximately 110 million TVs in the United States. Each uses, on average, 75 W of power and is turned on for 6.0 hours a day. If electrical energy costs $0.10 per KWh, how much money is spent every day in keeping the TVs turned on?

25. An electric blanket is connected to a 120-V outlet and consumes 140 W of power. What is the current in the wire in the blanket?

26. A blow-drier and a vacuum cleaner each operate with an ac voltage of 120 V. The current rating of the blow-drier is 11 A, while that of the vacuum cleaner is 4.0 A. Determine the power consumed by (a) the blow-drier and (b) the vacuum cleaner. (c) Determine the ratio of the energy used by the blow-drier in 15 minutes to the energy used by the vacuum cleaner in one-half an hour.

***27. ssm** Tungsten has a temperature coefficient of resistivity of 0.0045 (C°)$^{-1}$. A tungsten wire is connected to a source of constant voltage via a switch. At the instant the switch is closed, the temperature of the wire is 28 °C, and the initial power dissipated in the wire is P_0. At what wire temperature has the power dissipated in the wire decreased to $\frac{1}{2}P_0$?

***28.** A piece of Nichrome wire has a radius of 6.5×10^{-4} m. It is used in a laboratory to make a heater that dissipates 4.00×10^2 W of power when connected to a voltage source of 120 V. Ignoring the effect of temperature on resistance, estimate the necessary length of wire.

****29.** An iron wire has a resistance of 12 Ω at 20.0 °C and a mass of 1.3×10^{-3} kg. A current of 0.10 A is sent through the wire for one minute and causes the wire to become hot. Assuming that all the electrical energy is dissipated in the wire and remains there, find the final temperature of the wire. *(Hint: Use the average resistance of the wire during the heating process, and see Table 12.2 for the specific heat capacity of iron. Note $\alpha = 0.0050$ (C°)$^{-1}$.)*

Section 20.5 Alternating Current

30. The average power dissipated in a stereo speaker is 55 W. Assuming that the speaker can be treated as a 4.0-Ω resistance, find the peak value of the ac voltage applied to the speaker.

31. The current in a circuit is ac and has a peak value of 2.50 A. Determine the rms current.

32. A light bulb is connected to a 120.0-V wall socket. The current in the bulb depends on the time t according to the relation $I = (0.707\ \text{A})\sin[(314\ \text{Hz})t]$, where the peak current is 0.707 A. (a) What is the frequency of the alternating current? (b) Determine the resistance of the bulb's filament. (c) What is the average power consumed by the light bulb?

33. **ssm** The heating element in an iron has a resistance of 16 Ω and is connected to a 120-V wall socket. (a) What is the average power consumed by the iron, and (b) the peak power?

34. Review Conceptual Example 7 as an aid in solving this problem. A portable electric heater uses 18 A of current. The manufacturer recommends that an extension cord attached to the heater dissipates no more than 2.0 W of power per meter of length. What is the smallest radius of copper wire that can be used in the extension cord? *(Note: An extension cord contains two wires.)*

35. An electric furnace runs nine hours a day to heat a house during January (31 days). The heating element has a resistance of 5.3 Ω and carries a current of 25 A. The cost of electricity is \$0.10/kWh. Find the monthly cost of running the furnace.

* 36. On its highest setting, a heating element on an electric stove (see Figure 20.9) is connected to an ac voltage of 240 V. This element has a resistance of 29 Ω. (a) Find the power dissipated in the element. (b) Assuming that three-fourths of the heat produced by the element is used to heat a pot of water (the rest being wasted), find the time required to bring 1.9 kg of water (half a gallon) at 15 °C to a boil.

* 37. **ssm** The *recovery time* of a hot water heater is the time required to heat all the water in the unit to the desired temperature. Suppose that a 52-gal ($1.00\ \text{gal} = 3.79 \times 10^{-3}\ \text{m}^3$) unit starts with cold water at 11 °C and delivers hot water at 53 °C. The unit is electric and utilizes a resistance heater (120 V ac, 3.0 Ω) to heat the water. Assuming that no heat is lost to the environment, determine the recovery time (in hours) of the unit.

** 38. To save on heating costs, the owner of a green house keeps 660 kg of water around in barrels. During a winter day, the water is heated by the sun to 10.0 °C. During the night the water freezes into ice at 0.0 °C in nine hours. What is the minimum ampere rating of an electric heating system (240 V) that would provide the same heating effect as the water does?

Section 20.6 Series Wiring

39. **ssm** Three resistors, 25, 45, and 75 Ω, are connected in series, and a 0.51-A current passes through them. What is (a) the equivalent resistance and (b) the potential difference across the three resistors?

40. The current in a 47-Ω resistor is 0.12 A. This resistor is in series with a 28-Ω resistor, and the series combination is connected across a battery. What is the battery voltage?

41. A 36.0-Ω resistor and an 18.0-Ω resistor are connected in series across a 15.0-V battery. What is the voltage across (a) the 36.0-Ω resistor and (b) the 18.0-Ω resistor?

42. A 60.0-W lamp is placed in series with a resistor and a 120.0-V source. If the voltage across the lamp is 25 V, what is the resistance R of the resistor?

43. **ssm** The current in a series circuit is 15.0 A. When an additional 8.00-Ω resistor is inserted in series, the current drops to 12.0 A. What is the resistance in the original circuit?

44. Three resistors, 9.0, 5.0, and 1.0 Ω, are connected in series across a 24-V battery. Find (a) the current in, (b) the voltage across, and (c) the power dissipated in each resistor.

* 45. Three resistors are connected in series across a battery. The value of each resistance and its maximum power rating are as follows: 5.0 Ω and 20.0 W, 30.0 Ω and 10.0 W, and 15.0 Ω and 10.0 W. (a) What is the greatest voltage that the battery can have without one of the resistors burning up? (b) How much power does the battery deliver to the circuit in (a)?

* 46. One heater uses 340 W of power when connected by itself to a battery. Another heater uses 240 W of power when connected by itself to the same battery. How much total power do the heaters use when they are both connected in series across the battery?

** 47. Two resistances, R_1 and R_2, are connected in series across a 12-V battery. The current increases by 0.20 A when R_2 is removed, leaving R_1 connected across the battery. However, the current increases by just 0.10 A when R_1 is removed, leaving R_2 connected across the battery. Find (a) R_1 and (b) R_2.

Section 20.7 Parallel Wiring

48. What resistance must be placed in parallel with a 155-Ω resistor to make the equivalent resistance 115 Ω?

49. **ssm** A 16-Ω loudspeaker and an 8.0-Ω loudspeaker are connected in parallel across the terminals of an amplifier. Assuming the speakers behave as resistors, determine the equivalent resistance of the two speakers.

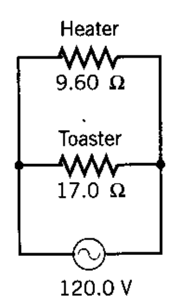
50. For the 3-way bulb (50 W, 100 W, 150 W) discussed in Conceptual Example 10, find the resistance of each of the two filaments. Assume that the wattage ratings are not limited by significant figures and ignore any heating effects on the resistances.

51. **ssm** Two resistors, 42.0 and 64.0 Ω, are connected in parallel. The current through the 64.0-Ω resistor is 3.00 A. (a) Determine the current in the other resistor. (b) What is the total power consumed by the two resistors?

52. A wire whose resistance is R is cut into three equally long pieces, which are then connected in parallel. In terms of R, what is the resistance of the parallel combination?

53. A coffee cup heater and a lamp are connected in parallel to the same 120-V outlet. Together, they use a total of 84 W of power. The resistance of the heater is 6.0×10^2 Ω. Find the resistance of the lamp.

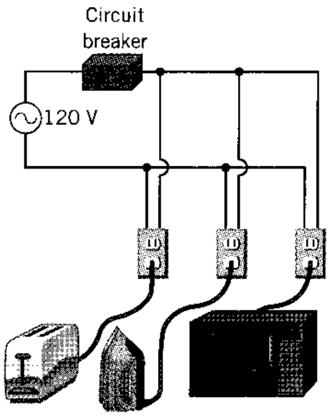
54. The drawing shows an electric heater (R = 9.60 Ω) and a toaster (R = 17.0 Ω). (a) What is the voltage across the heater? (b) Determine the current in the toaster. (c) What is the total power supplied to the heater and the toaster?



Problem 54

* 55. **ssm** The total current delivered to a number of devices connected in parallel is the sum of the individual currents in each device. Circuit breakers are resettable automatic switches that protect against a dangerously

large total current by "opening" to stop the current at a specified safe value. A 1650-W toaster, a 1090-W iron, and a 1250-W microwave oven are turned on in a kitchen. As the drawing shows, they are all connected through a 20-A circuit breaker to an ac voltage of 120 V. (a) Find the equivalent resistance of the three devices. (b) Obtain the total current delivered by the source and determine whether the breaker will "open" to prevent an accident.



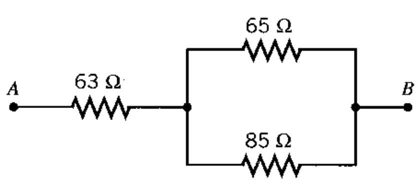
*56. A resistor (resistance = R) is connected first in parallel and then in series with a 2.00-Ω resistor. A battery delivers five times as much current to the parallel combination than it does to the series combination. Determine the two possible values for R.

**57. The rear window defogger of a car consists of thirteen thin wires (resistivity = 88.0×10^{-8} Ω·m) embedded in the glass. The wires are connected in parallel to the 12.0-V battery, and each has a length of 1.30 m. The defogger can melt 2.10×10^{-2} kg of ice at 0 °C into water at 0 °C in two minutes. Assume that all the power dissipated in the wires is used immediately to melt the ice. Find the cross-sectional area of each wire.

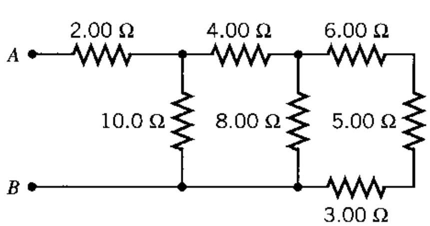
Section 20.8 Circuits Wired Partially in Series and Partially in Parallel

58. A 14-Ω coffee maker and a 16-Ω frying pan are connected in series across a 120-V source of voltage. A 23-Ω bread maker is also connected across the 120-V source and is in parallel with the series combination. Find the total current supplied by the source of voltage.

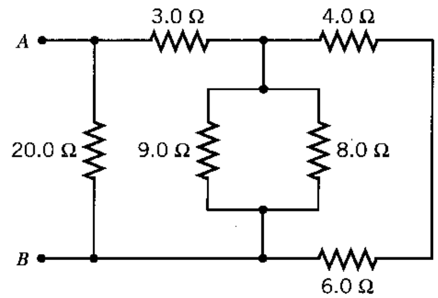
59. ssm For the combination of resistors shown in the drawing, determine the equivalent resistance between points A and B.



60. Find the equivalent resistance between points A and B in the drawing.

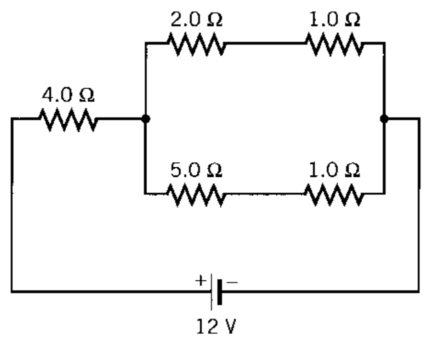


61. ssm Determine the equivalent resistance between the points A and B for the group of resistors in the drawing.

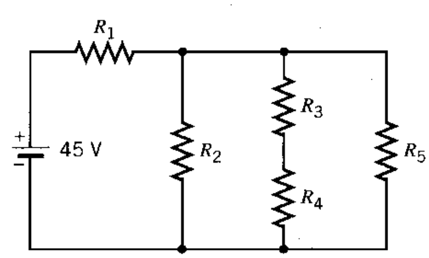


62. A 60.0-Ω resistor is connected in parallel with a 120.0-Ω resistor. This parallel group is connected in series with a 20.0-Ω resistor. The total combination is connected across a 15.0-V battery. Find (a) the current and (b) the power dissipated in the 120.0-Ω resistor.

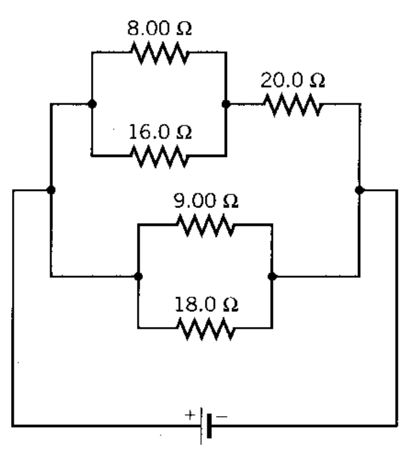
***63.** Determine the power dissipated in the 5.0-Ω resistor in the circuit shown in the drawing.



***64.** The circuit in the drawing contains five identical resistors. The 45-V battery delivers 58 W of power to the circuit. What is the resistance R of each resistor?



***65. ssm www** The current in the 8.00-Ω resistor in the drawing is 0.500 A. Find the current in (a) the 20.0-Ω resistor and in (b) the 9.00-Ω resistor.



**66. Three identical resistors are connected in parallel. The equivalent resistance increases by 700 Ω when one resistor is removed and connected in series with the remaining two, which are still in parallel. Find the resistance of each resistor.

Section 20.9 Internal Resistance

67. A 1.40-Ω resistor is connected across a 9.00-V battery. The voltage between the terminals of the battery is observed to be only 8.30 V. Find the internal resistance of the battery.

68. A new "D" battery has an emf of 1.5 V. When a wire of negligible resistance is connected between the terminals of the battery, a current of 28 A is produced. Find the internal resistance of the battery.

69. **ssm** A battery has an internal resistance of 0.50 Ω. A number of identical light bulbs, each with a resistance of 15 Ω, are connected in parallel across the battery terminals. The terminal voltage of the battery is observed to be one-half the emf of the battery. How many bulbs are connected?

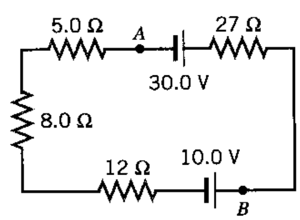
70. A battery delivering a current of 55.0 A to a circuit has a terminal voltage of 23.4 V. The electric power being dissipated by the internal resistance of the battery is 34.0 W. Find the emf of the battery.

71. A battery has an emf of 12.0 V and an internal resistance of 0.15 Ω. What is the terminal voltage when the battery is connected to a 1.50-Ω resistor?

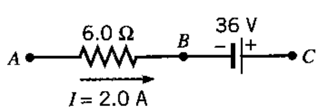
*__72.__ A 75.0-Ω and a 45.0-Ω resistor are connected in parallel. When this combination is connected across a battery, the current delivered by the battery is 0.294 A. When the 45.0-Ω resistor is disconnected, the current from the battery drops to 0.116 A. Determine (a) the emf and (b) the internal resistance of the battery.

Section 20.10 Kirchhoff's Rules

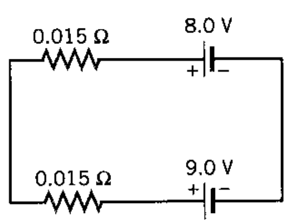
73. **ssm** Consider the circuit in the drawing. Determine (a) the magnitude of the current in the circuit and (b) the magnitude of the voltage between the points labeled *A* and *B*. (c) State which point, *A* or *B*, is at the higher potential.



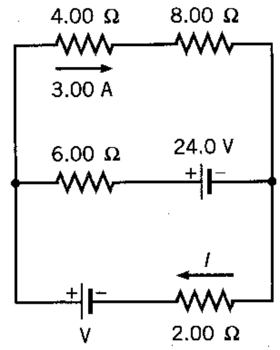
74. A current of 2.0 A exists in the partial circuit shown in the drawing. What is the magnitude of the potential difference between the points (a) *A* and *B*, and (b) *A* and *C*?



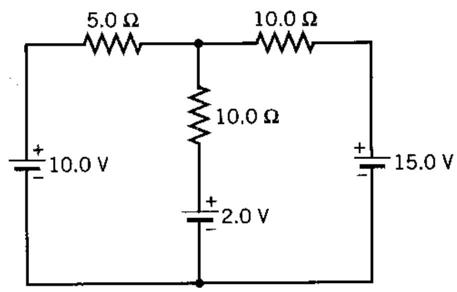
75. Two batteries, each with an internal resistance of 0.015 Ω, are connected as in the drawing. In effect, the 9.0-V battery is being used to charge the 8.0-V battery. What is the current in the circuit?



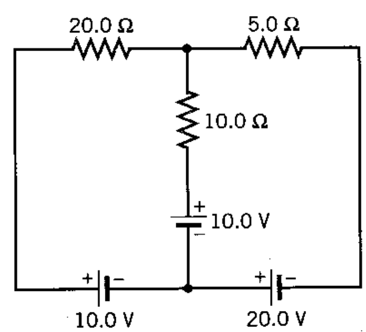
76. For the circuit shown in the drawing, find the current *I* through the 2.00-Ω resistor and the voltage *V* of the battery to the left of this resistor.



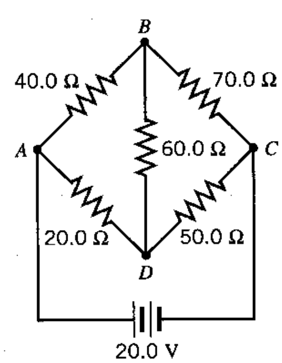
*__77.__ **ssm** Determine the voltage across the 5.0-Ω resistor in the drawing. Which end of the resistor is at the higher potential?



*__78.__ For the circuit in the drawing, find the current in the 10.0-Ω resistor. Specify the direction of the current.



**79. The circuit in the drawing is known as a Wheatstone bridge circuit. Find the voltage between points *B* and *D*, and state which point is at the higher potential.



Section 20.11 The Measurement of Current and Voltage

80. A galvanometer has a full-scale current of 0.100 mA and a coil resistance of 50.0 Ω. This instrument is used with a shunt resistor to form an ammeter that will register full scale for a current of 60.0 mA. Determine the resistance of the shunt resistor.

81. ssm A voltmeter utilizes a galvanometer that has a 180-Ω coil resistance and a full-scale current of 8.30 mA. The voltmeter measures voltages up to 30.0 V. Determine the resistance that is connected in series with the galvanometer.

82. The coil of a galvanometer has a resistance of 20.0 Ω, and its meter deflects full scale when a current of 6.20 mA passes through it. To make the galvanometer into an ammeter, a 24.8-mΩ shunt resistor is added to it. What is the maximum current that this ammeter can read?

83. The equivalent resistance of a voltmeter is 140 000 Ω. The voltmeter uses a galvanometer that has a full-scale current of 180 μA. What is the maximum voltage that can be measured by the voltmeter?

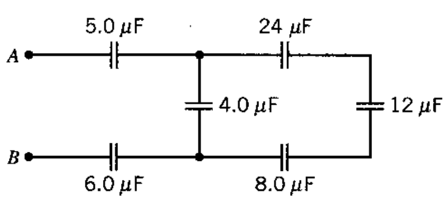
***84.** Two scales on a voltmeter measure voltages up to 20.0 and 30.0 V, respectively. The resistance connected in series with the galvanometer is 1680 Ω for the 20.0-V scale and 2930 Ω for the 30.0-V scale. Determine the coil resistance and the full-scale current of the galvanometer that is used in the voltmeter.

****85. ssm** In measuring a voltage, a voltmeter uses some current from the circuit. Consequently, the voltage measured is only an approximation to the voltage present when the voltmeter is not connected. Consider a circuit consisting of two 1550-Ω resistors connected in series across a 60.0-V battery. (a) Find the voltage across one of the resistors. (b) A voltmeter has a full-scale voltage of 60.0 V and uses a galvanometer with a full-scale deflection of 5.00 mA. Determine the voltage that this voltmeter registers when it is connected across the resistor used in part (a).

Section 20.12 Capacitors in Series and Parallel

86. A 4.0-μF and an 8.0-μF capacitor are connected in parallel across a 25-V battery. Find (a) the equivalent capacitance and (b) the total charge stored on the two capacitors.

87. Determine the equivalent capacitance between A and B for the group of capacitors in the drawing.



88. Three capacitors (4.0, 6.0, and 12.0 μF) are connected in series across a 50.0-V battery. Find the voltage across the 4.0-μF capacitor.

89. ssm A 3.0-μF capacitor and a 4.0-μF capacitor are connected in series across a 40.0-V battery. A 10.0-μF capacitor is also connected directly across the battery terminals. Find the total charge that the battery delivers to the capacitors.

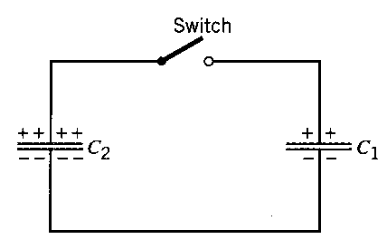
90. Three capacitors have identical geometries. One is filled with a material whose dielectric constant is 2.50. Another is filled with a material whose dielectric constant is 4.00. The third capacitor is filled with a material whose dielectric constant κ is such that this single capacitor has the same capacitance as the series combination of the other two. Determine κ.

91. Suppose two capacitors (C_1 and C_2) are connected in series. Show that the sum of the energies stored in these capacitors is equal to the energy stored in the equivalent capacitor. *[Hint: The energy stored in a capacitor can be expressed as $q^2/(2C)$.]*

***92.** A 3.00-μF and a 5.00-μF capacitor are connected in series across a 30.0-V battery. A 7.00-μF capacitor is then connected in parallel across the 3.00-μF capacitor. Determine the voltage across the 7.00-μF capacitor.

***93. ssm** A 7.0-μF and a 3.0-μF capacitor are connected in series across a 24-V battery. What voltage is required to charge a parallel combination of the two capacitors to the same total energy?

****94.** The drawing shows two fully charged capacitors (C_1 = 2.00 μF, q_1 = 6.00 μC; C_2 = 8.00 μF, q_2 = 12.0 μC). The switch is closed, and charge flows until equilibrium is reestablished (i.e., until both capacitors have the same voltage across their plates). Find the resulting voltage across either capacitor.

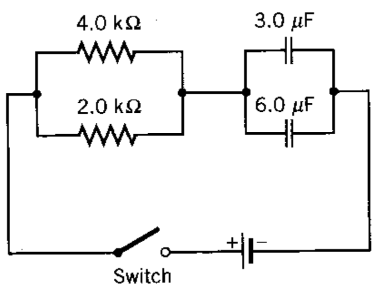


Section 20.13 *RC* Circuits

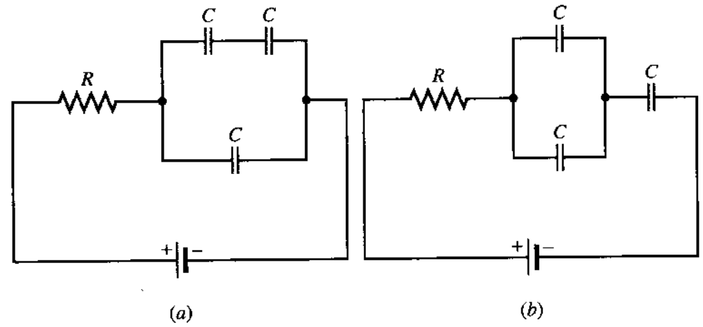
95. ssm In a heart pacemaker, a pulse is delivered to the heart 81 times per minute. The capacitor that controls this pulsing rate discharges through a resistance of 1.8×10^6 Ω. One pulse is delivered every time the fully charged capacitor loses 63.2% of its original charge. What is the capacitance of the capacitor?

96. An electronic flash attachment for a camera produces a flash by using the energy stored in a 750-μF capacitor. Between flashes, the capacitor recharges through a resistor whose resistance is chosen so the capacitor recharges with a time constant of 3.0 s. Determine the value of the resistance.

97. The circuit in the drawing contains two resistors and two capacitors that are connected to a battery via a switch. When the switch is closed, the capacitors begin to charge up. What is the time constant for the charging process?



*98. Three identical capacitors are connected with a resistor in two different ways. When they are connected as in part *a* of the drawing, the time constant to charge up this circuit is 0.34 s. What is the time constant when they are connected with the same resistor as in part *b*?



**99. How many time constants must elapse before a capacitor in a series *RC* circuit is charged to within 0.10% of its equilibrium charge?

ADDITIONAL PROBLEMS

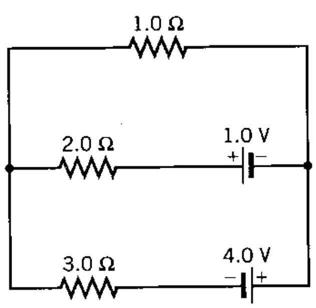
100. The heating element in an iron has a resistance of 24 Ω. The iron is plugged into a 120-V outlet. What is the power dissipated by the iron?

101. **ssm** Three capacitors (3.0, 7.0, and 9.0 μF) are connected in series. What is their equivalent capacitance?

102. A lightning bolt delivers a charge of 35 C to the ground in a time of 1.0×10^{-3} s. What is the current?

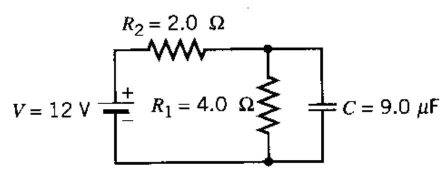
103. **ssm** In the arctic, electric socks are useful. A pair of socks uses a 9.0-V battery pack for each sock. A current of 0.11 A is drawn from each battery pack by wire woven into the socks. Find the resistance of the wire in one sock.

104. Find the magnitude and direction of the current in the 2.0-Ω resistor in the drawing.



105. In Section 12.3 it was mentioned that temperatures are often measured with electrical resistance thermometers made of platinum wire. Suppose that the resistance of a platinum resistance thermometer is 125 Ω when its temperature is 20.0 °C. The wire is then immersed in boiling chlorine, and the resistance drops to 99.6 Ω. The temperature coefficient of resistivity of platinum is $\alpha = 3.72 \times 10^{-3}$ (C°)$^{-1}$. What is the temperature of the boiling chlorine?

106. The circuit in the drawing shows two resistors, a capacitor, and a battery. When the capacitor is fully charged, what is the magnitude *q* of the charge on one of its plates?



107. A galvanometer with a coil resistance of 12.0 Ω and a full-scale current of 0.150 mA is used with a shunt resistor to make an ammeter. The ammeter registers a maximum current of 4.00 mA. Find the equivalent resistance of the ammeter.

*108. Two cylindrical rods, one copper and the other iron, are identical in lengths and cross-sectional areas. They are joined, end-to-end, to form one long rod. A 12-V battery is connected across the free ends of the copper–iron rod. What is the voltage between the ends of the copper rod?

*109. **ssm** Eight different values of resistance can be obtained by connecting together three resistors (1.00, 2.00, and 3.00 Ω) in all possible ways. What are they?

*110. A cylindrical aluminum pipe of length 1.50 m has an inner radius of 2.00×10^{-3} m and an outer radius of 3.00×10^{-3} m. The interior of the pipe is completely filled with copper. What is the resistance of this unit? *(Hint: Imagine that the pipe is connected between the terminals of a battery and decide whether the aluminum and copper parts of the pipe are in series or in parallel.)*

*111. **ssm** An extension cord is used with an electric weed trimmer that has a resistance of 15.0 Ω. The extension cord is made of copper wire that has a cross-sectional area of 1.3×10^{-6} m^2.

The combined length of the two wires in the extension cord is 92 m. (a) Determine the resistance of the extension cord. (b) The extension cord is plugged into a 120-V socket. What voltage is applied to the trimmer itself?

*112. A resistor has a resistance R, and a battery has an internal resistance r. When the resistor is connected across the battery, ten percent less power is dissipated in R than there would be if the battery had no internal resistance. Find the ratio r/R.

*113. An iron wire has a resistance of 5.90 Ω at 20.0 °C, and a gold wire has a resistance of 6.70 Ω at the same temperature. The temperature coefficient of resistivity for iron is 0.0050 $(C°)^{-1}$, while for gold it is 0.0034 $(C°)^{-1}$. At what temperature do the wires have the same resistance?

*114. A 47-Ω resistor can dissipate up to 0.25 W of power without burning up. What is the smallest number of such resistors that can be connected in series across a 9.0-V battery without any one of them burning up?

115. **ssm A sheet of gold foil (negligible thickness) is placed between the plates of a capacitor and has the same area as each of the plates. The foil is parallel to the plates, at a position one-third of the way from one to the other. Before the foil is inserted, the capacitance is C_0. What is the capacitance after the foil is in place? Express your answer in terms of C_0.

**116. A digital thermometer uses a thermistor as the temperature-sensing element. A thermistor is a kind of semiconductor and has a large negative temperature coefficient of resistivity α. Suppose $\alpha = -0.060\ (C°)^{-1}$ for the thermistor in a digital thermometer used to measure the temperature of a patient. The resistance of the thermistor decreases to 85% of its value at the normal body temperature of 37.0 °C. What is the patient's temperature?

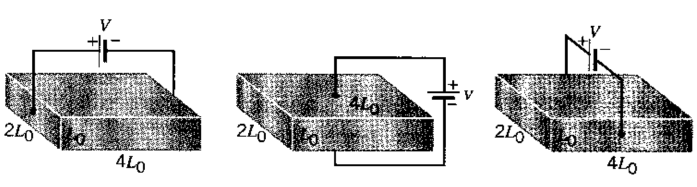
CONCEPTS & CALCULATIONS

GROUP LEARNING PROBLEMS

Note: Each of these problems consists of Concept Questions followed by a related quantitative Problem. They are designed for use by students working alone or in small learning groups. The Concept Questions involve little or no mathematics and are intended to stimulate group discussions. They focus on the concepts with which the problems deal. Recognizing the concepts is the essential initial step in any problem-solving technique.

117. **Concept Questions** The resistance and the magnitude of the current depend on the path that the current takes. The drawing shows three situations in which the current takes different paths through a piece of material. Rank them according to (a) resistance and (b) current, largest first. Give your reasoning.

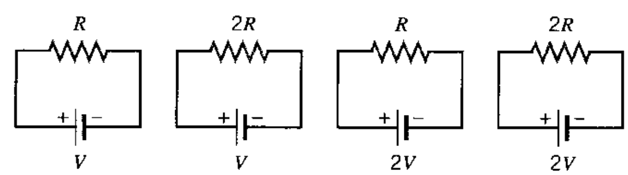
Problem Each of the rectangular pieces is made from a material whose resistivity is $\rho = 1.50 \times 10^{-2}\ \Omega \cdot m$, and the unit of length in the drawing is $L_0 = 5.00$ cm. If the material is connected to a 3.00-V battery, find (a) the resistance and (b) the current in each case. Verify that your answers are consistent with your answers to the Concept Questions.



(a) (b) (c)

118. **Concept Questions** Each of the four circuits in the drawing consists of a single resistor whose resistance is either R or $2R$, and a single battery whose voltage is either V or $2V$. Rank the circuits according to (a) the power and (b) the current delivered to the resistor, largest to smallest. Explain your answers.

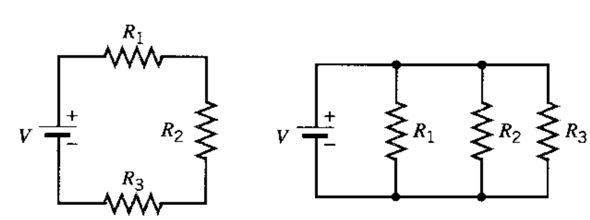
Problem The unit of voltage in each circuit is $V = 12.0$ V and the unit of resistance is $R = 6.00\ \Omega$. Determine (a) the power dissipated in each resistor and (b) the current delivered to each resistor. Check to see that your answers are consistent with your answers to the Concept Questions.



(a) (b) (c) (d)

119. **Concept Questions** The drawing shows three different resistors in two different circuits. The resistances are such that $R_1 > R_2 > R_3$. (a) For the circuit on the left, rank the current through each resistor and the voltage across each one, largest first. (b) Repeat part (a) for the circuit on the right. Justify your answers.

Problem The battery has a voltage of $V = 24.0$ V, and the resistors have values of $R_1 = 50.0\ \Omega$, $R_2 = 25.0\ \Omega$, and $R_3 = 10.0\ \Omega$. (a) For the circuit on the left, determine the current through and the voltage across each resistor. (b) Repeat part (a) for the circuit on the right. Be sure your answers are consistent with your answers to the Concept Questions.

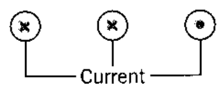


(a) (b)

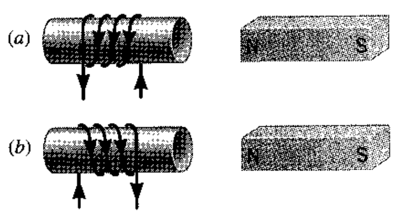
current in the circuit causes the light bulb to glow. Does the bulb glow continually, glow briefly and then go out, or repeatedly turn on and off like a turn signal on a car? Explain.

14. In Figure 21.28, assume that the current I_1 is larger than the current I_2. In parts a and b, decide whether there are places where the total magnetic field is zero. State whether they are located to the left of both wires, between the wires, or to the right of both wires. Give your reasoning.

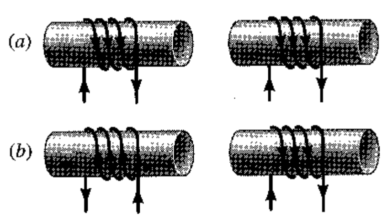
15. The drawing shows an end-on view of three parallel wires that are perpendicular to the plane of the paper. In two of the wires the current is directed into the paper, while in the remaining wire the current is directed out of the paper. The two outermost wires are held rigidly in place. Which way will the middle wire move? Explain.



16. For each electromagnet at the left of the drawing, explain whether it will be attracted to or repelled from the permanent magnet at the right.

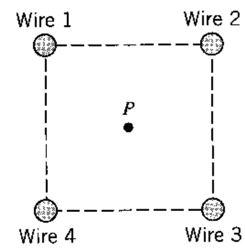


17. For each electromagnet at the left of the drawing, explain whether it will be attracted to or repelled from the adjacent electromagnet at the right.



18. Refer to Figure 21.5. If the earth's magnetism is assumed to originate from a large circular loop of current within the earth, how is the plane of this current loop oriented relative to the magnetic axis, and what is the direction of the current around the loop?

19. There are four wires viewed end-on in the drawing. They are long, straight, and perpendicular to the plane of the paper. Their cross sections lie at the corners of a square. Currents of the same magnitude are in each of these wires. Choose the direction of the current for each wire, so that when any single current is turned off, the total magnetic field at point P (the center of the square) is directed toward a corner of the square. Account for your answer.



20. Suppose you have two bars, one of which is a permanent magnet and the other of which is not a magnet, but is made from a ferromagnetic material like iron. The two bars look exactly alike. (a) Using a third bar, which is known to be a magnet, how can you determine which of the look-alike bars is the permanent magnet and which is not? (b) Can you determine the identities of the look-alike bars with the aid of a third bar that is not a magnet, but is made from a ferromagnetic material? Give reasons for your answers.

21. In a TV commercial that advertises a soda pop, a strong electromagnet picks up a delivery truck carrying cans of the soft drink. The picture switches to the interior of the truck, where cans are seen to fly upward and stick to the roof just beneath the electromagnet. Are these cans made entirely of aluminum? Justify your answer.

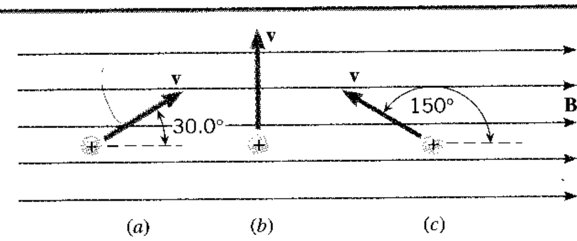
PROBLEMS

ssm Solution is in the Student Solutions Manual. **www** Solution is available on the World Wide Web at http://www.wiley.com/college/cutnell
This icon represents a biomedical application.

Section 21.1 Magnetic Fields, Section 21.2 The Force That a Magnetic Field Exerts on a Moving Charge

1. ssm A charge of 12 μC, traveling with a speed of 9.0×10^6 m/s in a direction perpendicular to a magnetic field, experiences a magnetic force of 8.7×10^{-3} N. What is the magnitude of the field?

2. A particle with a charge of $+8.4$ μC and a speed of 45 m/s enters a uniform magnetic field whose magnitude is 0.30 T. For each of the cases in the drawing, find the magnitude and direction of the magnetic force on the particle.



3. A charge $q_1 = 25.0$ μC moves with a speed of 4.50×10^3 m/s perpendicular to a uniform magnetic field. The charge experiences a magnetic force of 7.31×10^{-3} N. A second charge

$q_2 = 5.00\ \mu C$ travels at an angle of 40.0° with respect to the same magnetic field and experiences a 1.90×10^{-3}-N force. Determine (a) the magnitude of the magnetic field and (b) the speed of q_2.

4. Two charged particles move in the same direction with respect to the same magnetic field. Particle 1 travels three times faster than particle 2. However, each particle experiences a magnetic force of the same magnitude. Find the ratio q_1/q_2 of the magnitudes of the charges.

5. ssm At a certain location, the horizontal component of the earth's magnetic field is 2.5×10^{-5} T, due north. A proton moves eastward with just the right speed, so the magnetic force on it balances its weight. Find the speed of the proton.

6. When a charged particle moves at an angle of 25° with respect to a magnetic field, it experiences a magnetic force of magnitude F. At what angle (less than 90°) with respect to this field will this particle, moving at the same speed, experience a magnetic force of magnitude $2F$?

7. An electron is moving through a magnetic field whose magnitude is 8.70×10^{-4} T. The electron experiences only a magnetic force and has an acceleration of magnitude $3.50 \times 10^{14}\ m/s^2$. At a certain instant, it has a speed of 6.80×10^6 m/s. Determine the angle θ (less than 90°) between the electron's velocity and the magnetic field.

***8.** There is a 0.200-T magnetic field directed along the $+x$ axis and a field of unknown magnitude along the $+y$ axis. A particle carrying a charge of 6.50×10^{-5} C experiences a maximum force of 0.455 N when traveling at a speed of 2.00×10^4 m/s through the region where the fields are. Find the magnitude of the unknown field.

***9. ssm www** The electrons in the beam of a television tube have a kinetic energy of 2.40×10^{-15} J. Initially, the electrons move horizontally from west to east. The vertical component of the earth's magnetic field points down, toward the surface of the earth, and has a magnitude of 2.00×10^{-5} T. (a) In what direction are the electrons deflected by this field component? (b) What is the acceleration of an electron in part (a)?

Section 21.3 The Motion of a Charged Particle in a Magnetic Field, Section 21.4 The Mass Spectrometer

10. An electron moves at a speed of 6.0×10^6 m/s perpendicular to a constant magnetic field. The path is a circle of radius 1.3×10^{-3} m. (a) Draw a sketch showing the magnetic field and the electron's path. (b) What is the magnitude of the field? (c) Find the magnitude of the electron's acceleration.

11. An ionized helium atom has a mass of 6.6×10^{-27} kg and a speed of 4.4×10^5 m/s. The atom moves perpendicular to a 0.75-T magnetic field on a circular path of radius 0.012 m. Determine whether the charge of the ionized helium atom is $+e$ or $+2e$.

12. A magnetic field has a magnitude of 1.2×10^{-3} T, and an electric field has a magnitude of 4.6×10^3 N/C. Both fields point in the same direction. A positive 1.8-μC charge moves at a speed of 3.1×10^6 m/s in a direction that is perpendicular to both fields. Determine the magnitude of the net force that acts on the charge.

13. ssm A beam of protons moves in a circle of radius 0.25 m. The protons move perpendicular to a 0.30-T magnetic field. (a) What is the speed of each proton? (b) Determine the magnitude of the centripetal force that acts on each proton.

14. The solar wind is a thin, hot gas given off by the sun. Charged particles in this gas enter the magnetic field of the earth and can experience a magnetic force. Suppose a charged particle traveling with a speed of 9.0×10^6 m/s encounters the earth's magnetic field at an altitude where the field has a magnitude of 1.2×10^{-7} T. Assuming that the particle's velocity is perpendicular to the magnetic field, find the radius of the circular path on which the particle would move if it were (a) an electron and (b) a proton.

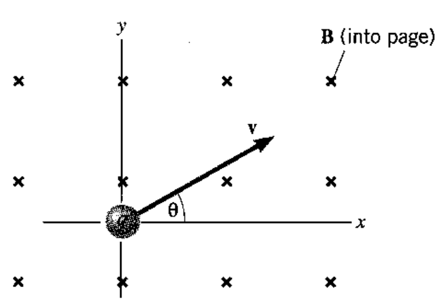
15. ssm www A charged particle with a charge-to-mass ratio of $q/m = 5.7 \times 10^8$ C/kg travels on a circular path that is perpendicular to a magnetic field whose magnitude is 0.72 T. How much time does it take for the particle to complete one revolution?

16. Review Conceptual Example 2 before attempting this problem. Derive an expression for the magnitude v of the velocity "selected" by the velocity selector. This expression should give v in terms of the strengths E and B of the electric and magnetic fields, respectively.

17. Suppose that an ion source in a mass spectrometer produces *doubly* ionized gold ions (Au^{2+}), each with a mass of 3.27×10^{-25} kg. The ions are accelerated from rest through a potential difference of 1.00 kV. Then, a 0.500-T magnetic field causes the ions to follow a circular path. Determine the radius of the path.

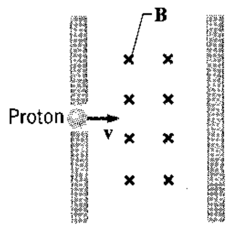
***18.** The ion source in a mass spectrometer produces both singly and doubly ionized species, X^+ and X^{2+}. The difference in mass between these species is too small to be detected. Both species are accelerated through the same electric potential difference, and both experience the same magnetic field, which causes them to move on circular paths. The radius of the path for the species X^+ is r_1, while the radius for species X^{2+} is r_2. Find the ratio r_1/r_2 of the radii.

***19. ssm** A particle of charge $+7.3\ \mu C$ and mass 3.8×10^{-8} kg is traveling perpendicular to a 1.6-T magnetic field, as the drawing shows. The speed of the particle is 44 m/s. (a) What is the value of the angle θ, such that the particle's subsequent path will intersect the y axis at the greatest possible value of y? (b) Determine this value of y.



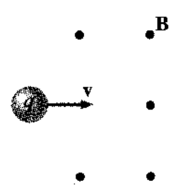
*20. Review Conceptual Example 2 as background for this problem. A charged particle moves through a velocity selector at a constant speed in a straight line. The electric field of the velocity selector is 3.80×10^3 N/C, while the magnetic field is 0.360 T. When the electric field is turned off, the charged particle travels on a circular path whose radius is 4.30 cm. Find the charge-to-mass ratio of the particle.

*21. A proton with a speed of 2.2×10^6 m/s is shot into a region between two plates that are separated by a distance of 0.18 m. As the drawing shows, a magnetic field exists between the plates, and it is perpendicular to the velocity of the proton. What must be the magnitude of the magnetic field, so the proton just misses colliding with the opposite plate?



*22. As preparation for this problem, review Conceptual Example 4. The radius of the track for particle 3 (kinetic energy = KE_3) is exactly 22 times larger than the initial radius of the track for particle 1 (initial kinetic energy = KE_1). Determine the ratio KE_3/KE_1.

*23. **ssm** Review Conceptual Example 2 as an aid in understanding this problem. The drawing shows a positively charged particle entering a 0.52-T magnetic field. The particle has a speed of 270 m/s and moves perpendicular to the magnetic field. Just as the particle enters the magnetic field, an electric field is turned on. What must be the magnitude and direction of the electric field such that the *net* force on the particle is twice the magnetic force?



*24. An α-particle is the nucleus of a helium atom; the orbiting electrons are missing. The α-particle contains two protons and two neutrons, and has a mass of 6.64×10^{-27} kg. Suppose an α-particle is accelerated from rest through a potential difference and then enters a region where its velocity is perpendicular to a 0.0210-T magnetic field. With what angular speed ω does the α-particle move on its circular path?

**25. Refer to question 11 (not problem 11) before starting this problem. Suppose that the target discussed there is located at the coordinates $x = -0.10$ m and $y = -0.10$ m. In addition, suppose that the particle is a proton and the magnetic field has a magnitude of 0.010 T. The speed at which the particle is projected is the same for either of the two paths leading to the target. Find the speed.

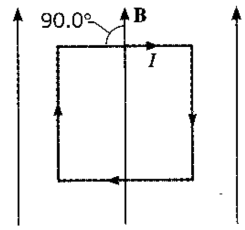
Section 21.5 The Force on a Current in a Magnetic Field

26. A wire carries a current of 0.66 A. This wire makes an angle of 58° with respect to a magnetic field of magnitude 4.7×10^{-5} T. The wire experiences a magnetic force of magnitude 7.1×10^{-5} N. What is the length of the wire?

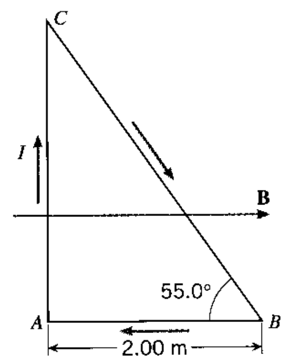
27. **ssm** An electric power line carries a current of 1400 A in a location where the earth's magnetic field is 5.0×10^{-5} T. The line makes an angle of 75° with respect to the field. Determine the magnitude of the magnetic force on a 120-m length of line.

28. A straight wire in a magnetic field experiences a force of 0.030 N when the current in the wire is 2.7 A. What is the current in the wire when it experiences a force of 0.047 N?

29. A square coil of wire containing a single turn is placed in a uniform 0.25-T magnetic field, as the drawing shows. Each side has a length of 0.32 m, and the current in the coil is 12 A. Determine the magnitude of the magnetic force on each of the four sides.



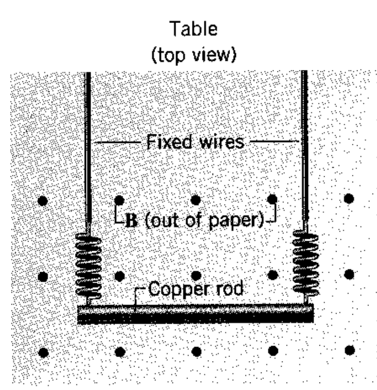
30. The triangular loop of wire shown in the drawing carries a current of $I = 4.70$ A. A uniform magnetic field is directed parallel to side AB of the triangle and has a magnitude of 1.80 T. (a) Find the magnitude and direction of the magnetic force exerted on each side of the triangle. (b) Determine the magnitude of the net force exerted on the triangle.



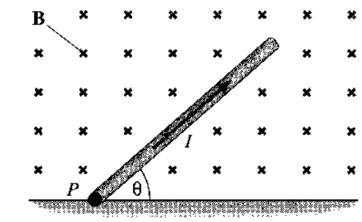
31. **ssm** A wire of length 0.655 m carries a current of 21.0 A. In the presence of a 0.470-T magnetic field, the wire experiences a force of 5.46 N. What is the angle (less than 90°) between the wire and the magnetic field?

32. The x, y, and z components of a magnetic field are $B_x = 0.10$ T, $B_y = 0.15$ T, and $B_z = 0.17$ T. A 25-cm wire is oriented along the z axis and carries a current of 4.3 A. What is the magnitude of the magnetic force that acts on this wire?

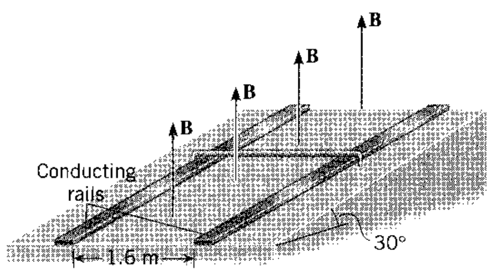
*33. **ssm** A copper rod of length 0.85 m is lying on a frictionless table (see the drawing). Each end of the rod is attached to a fixed wire by an unstretched spring whose spring constant is $k = 75$ N/m. A magnetic field with a strength of 0.16 T is oriented perpendicular to the surface of the table. (a) What must be the direction of the current in the copper rod that causes the springs to stretch? (b) If the current is 12 A, by how much does each spring stretch?



*34. The drawing shows a thin, uniform rod, which has a length of 0.40 m and a mass of 0.080 kg. This rod lies in the plane of the paper and is attached to the floor by a hinge at point P. A uniform magnetic field of 0.31 T is directed perpendicularly into the plane of the paper. There is a current $I = 3.8$ A in the rod, which does not rotate clockwise or counterclockwise. Find the angle θ. *(Hint: The magnetic force may be taken to act at the center of gravity.)*



**35. The two conducting rails in the drawing are tilted upward so they each make an angle of 30.0° with respect to the ground. The vertical magnetic field has a magnitude of 0.050 T. The 0.20-kg aluminum rod (length = 1.6 m) slides *without friction* down the rails at a constant velocity. How much current flows through the bar?



Section 21.6 The Torque on a Current-Carrying Coil

36. A 0.50-m length of wire is formed into a single-turn, square loop in which there is a current of 12 A. The loop is placed in a magnetic field of 0.12 T, as in Figure 21.22a. What is the maximum torque that the loop can experience?

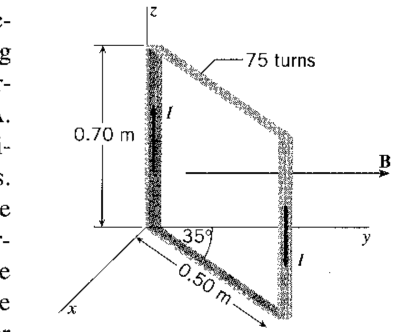
37. **ssm** A circular coil of wire has a radius of 0.10 m. The coil has 50 turns and a current of 15 A, and is placed in a magnetic field whose magnitude is 0.20 T. (a) Determine the magnetic moment of the coil. (b) What is the maximum torque the coil can experience in this field?

38. Two coils have the same number of circular turns and carry the same current. Each rotates in a magnetic field as in Figure 21.21. Coil 1 has a radius of 5.0 cm and rotates in a 0.18-T field. Coil 2 rotates in a 0.42-T field. Each coil experiences the same maximum torque. What is the radius (in cm) of coil 2?

39. Suppose the current-carrying triangle in problem 30 is free to rotate about an axis that is attached along side AC. Using the data in that problem, find (a) the magnetic moment of the triangle and (b) the magnitude of the net torque exerted on it by the magnetic field.

40. A coil carries a current and experiences a torque due to a magnetic field. The value of the torque is 80.0% of the maximum possible torque. (a) What is the smallest angle between the magnetic field and the normal to the plane of the coil? (b) Make a drawing, showing how this coil would be oriented relative to the magnetic field. Be sure to include the angle in the drawing.

41. **ssm www** The rectangular loop in the drawing consists of 75 turns and carries a current of $I = 4.4$ A. A 1.8-T magnetic field is directed along the $+y$ axis. The loop is free to rotate about the z axis. (a) Determine the magnitude of the net torque exerted on the loop and (b) state whether the 35° angle will increase or decrease.



42. The maximum torque experienced by a coil in a 0.75-T magnetic field is 8.4×10^{-4} N·m. The coil is circular and consists of only one turn. The current in the coil is 3.7 A. What is the length of the wire from which the coil is made?

*43. The coil in Figure 21.22a contains 380 turns and has an area per turn of 2.5×10^{-3} m^2. The magnetic field is 0.12 T, and the current in the coil is 0.16 A. A brake shoe is pressed perpendicularly against the shaft to keep the coil from turning. The coefficient of static friction between the shaft and the brake shoe is 0.70. The radius of the shaft is 0.010 m. What is the magnitude of the minimum normal force that the brake shoe exerts on the shaft?

*44. A square coil and a rectangular coil are each made from the same length of wire. Each contains a single turn. The long sides of the rectangle are twice as long as the short sides. Find the ratio $\tau_{square}/\tau_{rectangle}$ of the maximum torques that these coils experience in the same magnetic field when they contain the same current.

45. **ssm In the model of the hydrogen atom due to Niels Bohr, the electron moves around the proton at a speed of 2.2×10^6 m/s in a circle of radius 5.3×10^{-11} m. Considering the orbiting electron to be a small current loop, determine the magnetic moment associated with this motion. *(Hint: The electron travels around the circle in a time equal to the period of the motion.)*

Section 21.7 Magnetic Fields Produced by Currents

46. A long, straight wire carries a current of 48 A. The magnetic field produced by this current at a certain point is 8.0×10^{-5} T. How far is the point from the wire?

47. In a lightning bolt, 15 C of charge flows in a time of 1.5×10^{-3} s. Assuming that the lightning bolt can be represented as a long, straight line of current, what is the magnitude of the magnetic field at a distance of 25 m from the bolt?

48. What must be the radius of a circular loop of wire so the magnetic field at its center is 1.8×10^{-4} T when the loop carries a current of 12 A?

49. **ssm** A long solenoid consists of 1400 turns of wire and has a length of 0.65 m. There is a current of 4.7 A in the wire. What is the magnitude of the magnetic field within the solenoid?

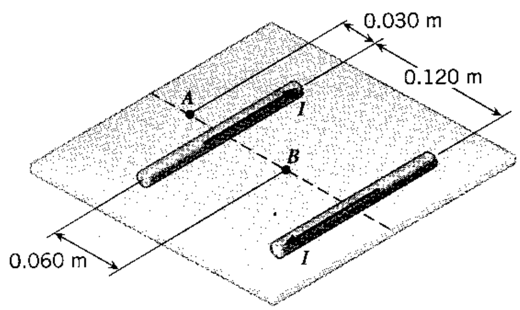
50. Suppose in Figure 21.28a that $I_1 = I_2 = 25$ A and that the separation between the wires is 0.016 m. By applying an external

magnetic field (created by a source other than the wires) it is possible to cancel the mutual repulsion of the wires. This external field must point along the vertical direction. (a) Does the external field point up or down? Explain. (b) What is the magnitude of the external field?

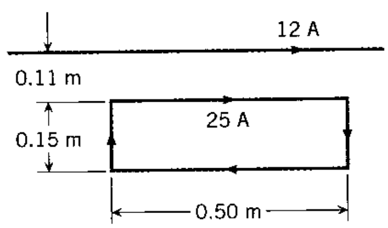
51. **ssm** Two rigid rods are oriented parallel to each other and to the ground. The rods carry the same current in the same direction. The length of each rod is 0.85 m, while the mass of each is 0.073 kg. One rod is held in place above the ground, and the other floats beneath it at a distance of 8.2×10^{-3} m. Determine the current in the rods.

52. Two circular loops of wire, each containing a single turn, have the same radius of 4.0 cm and a common center. The planes of the loops are perpendicular. Each carries a current of 1.7 A. What is the magnitude of the net magnetic field at the common center?

53. Two long, straight wires are separated by 0.120 m. The wires carry currents of 8.0 A in opposite directions, as the drawing indicates. Find the magnitude of the net magnetic field at the points labeled (a) *A* and (b) *B*.



***54.** As background for this problem, review Conceptual Example 9. A rectangular current loop is located near a long, straight wire that carries a current of 12 A (see the drawing). The current in the loop is 25 A. Determine the magnitude of the net magnetic force that acts on the loop.

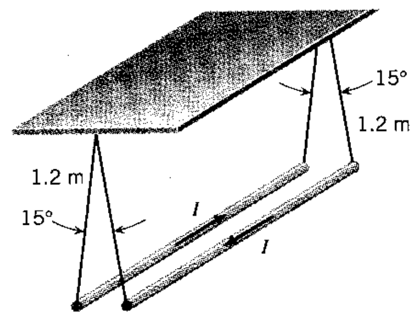


***55.** Two circular coils are concentric and lie in the same plane. The inner coil contains 120 turns of wire, has a radius of 0.012 m, and carries a current of 6.0 A. The outer coil contains 150 turns and has a radius of 0.017 m. What must be the magnitude and direction (relative to the current in the inner coil) of the current in the outer coil, such that the net magnetic field at the common center of the two coils is zero?

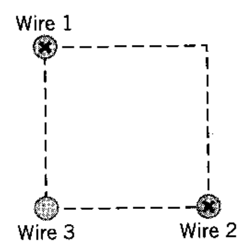
***56.** Two parallel rods are each 0.50 m in length. They are attached at their centers to a spring that is initially neither stretched nor compressed. The spring has a spring constant of 150 N/m. When 950 A of current is in each rod in the same direction, the spring is observed to be compressed by 2.0 cm. Treat the rods as long, straight wires and find the separation between them when the current is present.

***57.** **ssm** A piece of copper wire has a resistance per unit length of 5.90×10^{-3} Ω/m. The wire is wound into a thin, flat coil of many turns that has a radius of 0.140 m. The ends of the wire are connected to a 12.0-V battery. Find the magnetic field strength at the center of the coil.

****58.** The drawing shows two long, straight wires that are suspended from a ceiling. The mass per unit length of each wire is 0.050 kg/m. Each of the four strings suspending the wires has a length of 1.2 m. When the wires carry identical currents in opposite directions, the angle between the strings holding the two wires is 15°. What is the current in each wire?



****59.** The drawing shows an end-on view of three wires. They are long, straight, and perpendicular to the plane of the paper. Their cross sections lie at the corners of a square. The currents in wires 1 and 2 are $I_1 = I_2 = I$ and are directed into the paper. What is the direction of the current in wire 3, and what is the ratio I_3/I, such that the net magnetic field at the empty corner is zero?



Section 21.8 Ampere's Law

60. Suppose a uniform magnetic field is everywhere perpendicular to this page. The field points directly upward toward you. A circular path is drawn on the page. Use Ampere's law to show that there can be no net current passing through the circular surface.

61. **ssm** The wire in Figure 21.40 carries a current of 12 A. Suppose that a second long, straight wire is placed right next to this wire. The current in the second wire is 28 A. Use Ampere's law to find the magnitude of the magnetic field at a distance of $r = 0.72$ m from the wires when the currents are (a) in the same direction and (b) in opposite directions.

***62.** A very long, hollow cylinder is formed by rolling up a thin sheet of copper. Electric charges flow along the copper sheet parallel to the axis of the cylinder. The arrangement is, in effect, a hollow tube of current *I*. Use Ampere's law to show that the magnetic field (a) is $\mu_0 I/(2\pi r)$ outside the cylinder at a distance *r* from the axis and (b) is zero at any point within the hollow interior of the cylinder. *(Hint: For closed paths, use* *circles perpendicular to and centered on the axis of the cylinder.)*

**63. A long, cylindrical conductor is solid throughout and has a radius R. Electric charges flow parallel to the axis of the cylinder and pass uniformly through the entire cross section. The arrangement is, in effect, a solid tube of current I_0. The current per unit cross-sectional area (i.e., the current density) is $I_0/(\pi R^2)$. Use Ampere's law to show that the magnetic field inside the conductor at a distance r from the axis is $\mu_0 I_0 r/(2\pi R^2)$. *(Hint: For a closed path, use a circle of radius r perpendicular to and centered on the axis. Note that the current through any surface is the area of the surface times the current density.)*

ADDITIONAL PROBLEMS

64. In a television set, electrons are accelerated from rest through a potential difference of 19 kV. The electrons then pass through a 0.28-T magnetic field that deflects them to the appropriate spot on the screen. Find the magnitude of the maximum magnetic force that an electron can experience.

65. ssm A long solenoid has 1400 turns per meter of length, and it carries a current of 3.5 A. A small circular coil of wire is placed inside the solenoid with the normal to the coil oriented at an angle of 90.0° with respect to the axis of the solenoid. The coil consists of 50 turns, has an area of 1.2×10^{-3} m^2, and carries a current of 0.50 A. Find the torque exerted on the coil.

66. A proton, traveling with a velocity of 4.5×10^6 m/s due east, experiences a maximum magnetic force of 8.0×10^{-14} N due south. (a) What are the magnitude and direction of the magnetic field? (b) Answer part (a), assuming the proton is replaced by an electron.

67. The proton has an intrinsic magnetic moment of 1.4×10^{-26} A · m^2. If the magnetic moment makes an angle of $\phi = 64°$ with respect to a 0.65-T magnetic field, what is the torque exerted on the proton?

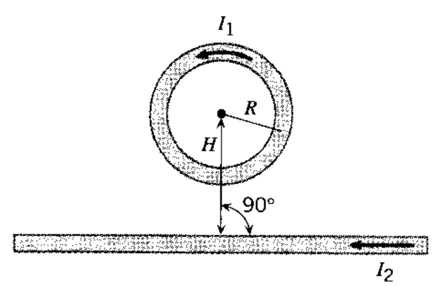
68. A long, straight wire carrying a current of 305 A is placed in a uniform magnetic field whose magnitude is 7.00×10^{-3} T. The wire is perpendicular to the field. Find a point in space where the net magnetic field is zero. Locate this point by specifying its perpendicular distance from the wire.

69. ssm Due to friction with the air, an airplane has acquired a net charge of 1.70×10^{-5} C. The plane moves with a speed of 2.80×10^2 m/s at an angle θ with respect to the earth's magnetic field, the magnitude of which is 5.00×10^{-5} T. The magnetic force on the airplane has a magnitude of 2.30×10^{-7} N. Find the angle θ. (There are two possible angles.)

70. Near the equator in South America the earth's magnetic field has a strength of 3.2×10^{-5} T; the field is parallel to the surface of the earth and points due north. A straight wire, 46 m in length, has an east-west orientation and experiences a magnetic force of 0.058 N, directed vertically down (toward the earth). What is the magnitude and direction of the current in the wire?

71. An ion source in a mass spectrometer produces deuterons. (A deuteron is a particle that has approximately twice the mass of a proton but the same charge.) Each deuteron is accelerated from rest through a potential difference of 2.00×10^3 V, after which it enters a 0.600-T magnetic field. Find the radius of its circular path.

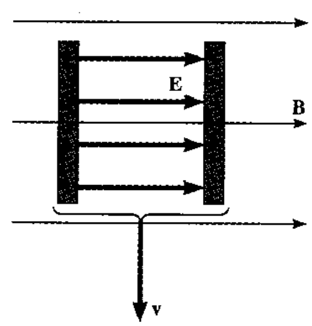
72. A circular loop of wire and a long, straight wire carry currents of I_1 and I_2 (see the drawing), where $I_2 = 6.6I_1$. The loop and the straight wire lie in the same plane. The net magnetic field at the center of the loop is zero. Find the distance H, expressing your answer in terms of R, the radius of the loop.



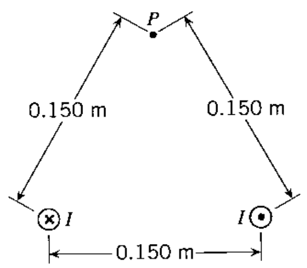
***73. ssm www** A particle of mass 6.0×10^{-8} kg and charge $+7.2$ μC is traveling due east. It enters perpendicularly a magnetic field whose magnitude is 3.0 T. After entering the field, the particle completes one-half of a circle and exits the field traveling due west. How much time does the particle spend in the magnetic field?

***74.** Two long, straight, parallel wires A and B are separated by a distance of one meter. They carry currents in opposite directions, and the current in wire A is one-third of that in wire B. On a line drawn perpendicular to the wires, find the point where the net magnetic field is zero. Determine this point relative to wire A.

***75.** The drawing shows a parallel plate capacitor that is moving with a speed of 32 m/s through a 3.6-T magnetic field. The velocity **v** is perpendicular to the magnetic field. The electric field within the capacitor has a value of 170 N/C, and each plate has an area of 7.5×10^{-4} m^2. What is the magnetic force (magnitude and direction) exerted on the positive plate of the capacitor?



**76. The drawing shows two wires that carry the same current of $I = 85.0$ A and are oriented perpendicular to the plane of the paper. The current in one wire is directed out of the paper, while the current in the other is directed into the paper. Find the magnitude and direction of the net magnetic field at point P.



**77. ssm A charge of 4.0×10^{-6} C is placed on a small conducting sphere that is located at the end of a thin insulating rod whose length is 0.20 m. The rod rotates with an angular speed of $\omega = 150$ rad/s about an axis that passes perpendicularly through its other end. Find the magnetic moment of the rotating charge. *(Hint: The charge travels around a circle in a time equal to the period of the motion.)*

CONCEPTS & CALCULATIONS

GROUP LEARNING PROBLEMS

Note: Each of these problems consists of Concept Questions followed by a related quantitative Problem. They are designed for use by students working alone or in small learning groups. The Concept Questions involve little or no mathematics and are intended to stimulate group discussions. They focus on the concepts with which the problems deal. Recognizing the concepts is the essential initial step in any problem-solving technique.

78. Concept Questions (a) A charge moves along the $+x$ axis and experiences no magnetic force, although there is a magnetic field. What can you conclude about the direction of the magnetic field? (b) A moving charge experiences the maximum possible magnetic force when moving in a magnetic field. What can you conclude about the angle θ that the charge's velocity makes with respect to the magnetic field? Explain your answers.

Problem A particle that has a 8.2-μC charge moves with a velocity of magnitude 5.0×10^5 m/s. When the velocity points along the $+x$ axis, the particle experiences no magnetic force, although there is a magnetic field present. The maximum possible magnetic force that the charge could experience has a magnitude of 0.48 N. Find the magnitude and direction of the magnetic field. Note that there are two possible answers for the direction of the field. Make sure that your answers are consistent with your answers to the Concept Questions.

79. Concept Questions (a) A proton is projected perpendicularly into a magnetic field with a certain velocity and follows a circular path. Then an electron is projected perpendicularly into the same magnetic field with the same velocity. Does the electron follow the exact same circular path that the proton followed? (b) To make the electron follow the exact same circular path, should the field direction be kept the same or reversed, and (c) should the field magnitude be increased, reduced, or kept the same? Account for your answers.

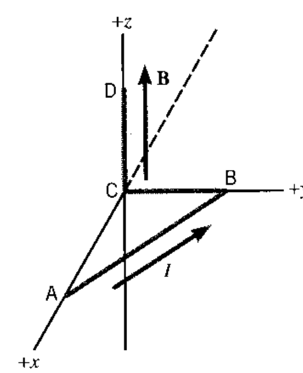
Problem A proton is projected perpendicularly into a magnetic field that has a magnitude of 0.50 T. The field is then adjusted so that an electron will follow the exact same circular path when it is projected perpendicularly into the field with the same velocity that the proton had. What is the magnitude of the field used for the electron? Verify that your answer is consistent with your answers to the Concept Questions.

80. Concept Questions Particle 1 and particle 2 carry the same charge q, but particle 1 has a smaller mass than particle 2. These two particles accelerate from rest through the same electric potential difference V and enter the same magnetic field, which has a magnitude B. The particles travel perpendicular to the field on circular paths. Upon entering the field region, which particle, if either, has the greater (a) kinetic energy and (b) speed? Give your reasoning.

Problem The masses of the particles are $m_1 = 2.3 \times 10^{-8}$ kg and $m_2 = 5.9 \times 10^{-8}$ kg. The radius of the circular path for particle 1 is $r_1 = 12$ cm. What is the radius of the circular path for particle 2?

81. Concept Question The drawing shows a wire comprised of three segments, AB, BC, and CD. There is a current I in the wire. There is also a magnetic field **B** that is the same everywhere and points in the direction of the $+z$ axis. Rank the wire segments according to the magnetic force (largest first) that they experience. Justify your ranking.

Problem The lengths of the wire segments are $L_{AB} = 1.1$ m, $L_{BC} = 0.55$ m, and $L_{CD} = 0.55$ m. The current is $I = 2.8$ A, and the magnitude of the magnetic field is $B = 0.26$ T. Find the magnitude of the force that acts on each segment. Be sure your answers are consistent with your answer to the Concept Question.

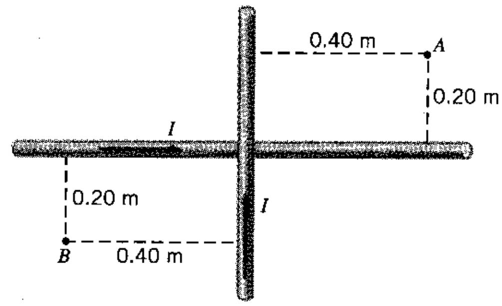


82. Concept Question You have a wire of length L from which to make the square coil of a dc motor. In a given magnetic field a coil of N turns each with area A produces more torque when its total effective area of NA is greater rather than smaller. This follows directly from Equation 21.4. Is more torque obtained by using the length of wire to make a single-turn coil or a two-turn coil? Explain.

Problem The length of the wire is $L = 1.00$ m. The current in the coil is $I = 1.7$ A, and the magnetic field of the motor is 0.34 T. Find the maximum torque when the wire is used to make a single-turn square coil and a two-turn square coil. Verify that your answers are consistent with your answer to the Concept Question.

83. Concept Questions The drawing shows two perpendicular, long, straight wires that lie in the plane of the paper. Each wire carries the same current I. What is the direction of the net magnetic field at (a) point A and (b) point B? (c) Is the magnitude of the net field at point A greater than, less than, or equal to the magnitude of the net field at point B?

Problem The current in each of the wires is $I = 5.6$ A. Find the magnitudes of the net fields at points A and B. Verify that your answers are consistent with your answers to the Concept Questions.

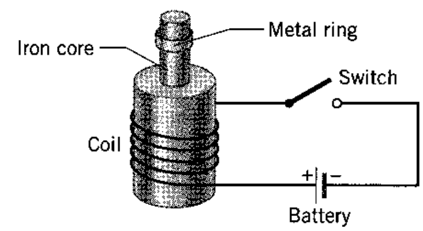


magnetic flux through the coil does not change. But when the robot deviates from the parallel path, an induced emf appears in the coil. The emf is sent to electronic circuits that bring the robot back to the path. Explain why an emf would be induced in the sensor coil.

10. In a car, the generator-like action of the alternator occurs while the engine is running and keeps the battery fully charged. The headlights would discharge an old and failing battery quickly if it were not for the alternator. Explain why the engine of a parked car runs more "quietly" with the headlights off than with them on when the battery is in bad shape.

11. In Figure 22.3 a coil of wire is being stretched. (a) Using Lenz's law, verify that the induced current in the coil has the direction shown in the drawing. (b) Deduce the direction of the induced current if the direction of the external magnetic field in the figure were reversed. Explain.

12. (a) When the switch in the circuit in the drawing is closed, a current is established in the coil and the metal ring "jumps" upward. Explain this behavior. (b) Describe what would happen to the ring if the battery polarity were reversed.



13. The string of an electric guitar vibrates in a standing wave pattern that consists of nodes and antinodes. (Section 17.5 discusses standing waves.) Where should an electromagnetic pickup be located in the standing wave pattern to produce a maximum emf, at a node or an antinode? Why?

14. An electric motor in a hair drier is running at normal speed and, thus, is drawing a relatively small current, as in part (b) of Example 12. What happens to the current drawn by the motor if the shaft is prevented from turning, so the back emf is suddenly reduced to zero? Remembering that the wire in the coil of the motor has some resistance, what happens to the temperature of the coil? Justify your answers.

15. One transformer is a step-up device, while another is step-down. These two units have the same voltage across and the same current in their primary coils. Does either one deliver more power to the circuit attached to the secondary coil? If so, which one? Ignore any heat loss within the transformers and account for your answer.

PROBLEMS

ssm Solution is in the Student Solutions Manual. www Solution is available on the World Wide Web at http://www.wiley.com/college/cutnell
This icon represents a biomedical application.

Section 22.2 Motional Emf

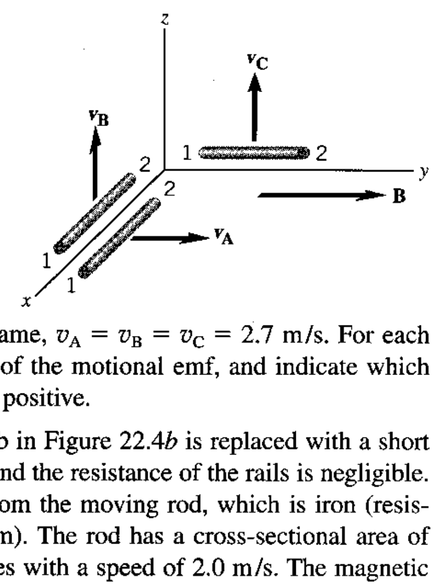
1. ssm A spark can jump between two nontouching conductors if the potential difference between them is sufficiently large. A potential difference of approximately 940 V is required to produce a spark in an air gap of 1.0×10^{-4} m. Suppose the light bulb in Figure 22.4*b* is replaced by such a gap. How fast would a 1.3-m rod have to be moving in a magnetic field of 4.8 T to cause a spark to jump across the gap?

2. Near San Francisco, where the vertically downward component of the earth's magnetic field is 4.8×10^{-5} T, a car is traveling forward at 25 m/s. An emf of 2.4×10^{-3} V is induced between the sides of the car. (a) Which side of the car is positive, the driver's side or the passenger's side? (b) What is the width of the car?

3. The wingspan (tip-to-tip) of a Boeing 747 jetliner is 59 m. The plane is flying horizontally at a speed of 220 m/s. The vertical component of the earth's magnetic field is 5.0×10^{-6} T. Find the emf induced between the wing tips.

4. In 1996 NASA performed an experiment, called the Tethered Satellite experiment. In this experiment a 2.0×10^4-m length of wire was let out by the space shuttle Atlantis to generate a motional emf. The shuttle had an orbital speed of 7.6×10^3 m/s, and the magnitude of the earth's magnetic field at the location of the wire was 5.1×10^{-5} T. If the wire had moved perpendicular to the earth's magnetic field, what would have been the motional emf generated between the ends of the wire?

5. ssm www The drawing shows three identical rods (A, B, and C) moving in different planes. A constant magnetic field of magnitude 0.45 T is directed along the $+y$ axis. The length of each rod is $L = 1.3$ m, and the speeds are the same, $v_A = v_B = v_C = 2.7$ m/s. For each rod, find the magnitude of the motional emf, and indicate which end (1 or 2) of the rod is positive.



***6.** Suppose the light bulb in Figure 22.4*b* is replaced with a short wire of zero resistance, and the resistance of the rails is negligible. The only resistance is from the moving rod, which is iron (resistivity $= 9.7 \times 10^{-8}\ \Omega \cdot m$). The rod has a cross-sectional area of 3.1×10^{-6} m^2 and moves with a speed of 2.0 m/s. The magnetic field has a magnitude of 0.050 T. What is the current in the rod?

***7. ssm** Suppose the light bulb in Figure 22.4*b* is replaced by a 6.0-Ω electric heater that consumes 15 W of power. The conducting bar moves to the right at a constant speed, the field strength is 2.4 T, and the length of the bar between the rails is 1.2 m. (a) How fast is the bar moving? (b) What force must be applied to the bar to keep it moving to the right at the constant speed found in part (a)?

***8.** Refer to the drawing that accompanies conceptual question 6 (not problem 6). Suppose that the voltage of the battery in the circuit is 3.0 V, the magnitude of the magnetic field (directed perpendicularly into the plane of the paper) is 0.60 T, and the length of the rod between the rails is 0.20 m. Assuming that the rails are very long and have negligible resistance, find the maximum speed attained by the rod after the switch is closed.

****9.** Review Conceptual Example 3 and Figure 22.7*b* as an aid in solving this problem. A conducting rod slides down between two frictionless vertical copper tracks at a constant speed of 4.0 m/s perpendicular to a 0.50-T magnetic field. The resistance of the rod and tracks is negligible. The rod maintains electrical contact with the tracks at all times and has a length of 1.3 m. A 0.75-Ω resistor is attached between the tops of the tracks. (a) What is the mass of the rod? (b) Find the change in the gravitational potential energy that occurs in a time of 0.20 s. (c) Find the electrical energy dissipated in the resistor in 0.20 s.

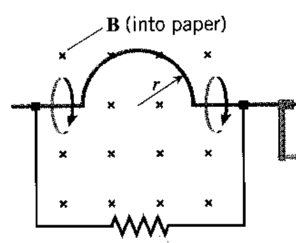
Section 22.3 Magnetic Flux

For problems in this set, assume that the magnetic flux is a positive quantity.

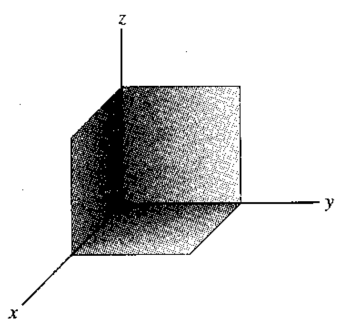
10. A hand is held flat and placed in a uniform magnetic field of magnitude 0.35 T. The hand has an area of 0.0160 m^2 and negligible thickness. Determine the magnetic flux that passes through the hand when the normal to the hand is (a) parallel and (b) perpendicular to the magnetic field.

11. ssm A standard door into a house rotates about a vertical axis through one side, as defined by the door's hinges. A uniform magnetic field is parallel to the ground and perpendicular to this axis. Through what angle must the door rotate so that the magnetic flux that passes through it decreases from its maximum value to one-third of its maximum value?

12. A loop of wire has the shape shown in the drawing. The top part of the wire is bent into a semicircle of radius r = 0.20 m. The normal to the plane of the loop is parallel to a constant magnetic field of magnitude 0.75 T. What is the change $\Delta\Phi$ in the magnetic flux that passes through the loop when, starting with the position shown in the drawing, the semicircle is rotated through half a revolution?

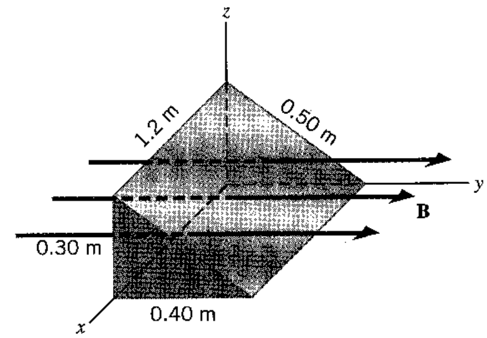


13. The drawing shows three square surfaces, one lying in the xy plane, one in the xz plane, and one in the yz plane. The sides of each square have lengths of 2.0×10^{-2} m. A uniform magnetic field exists in this region, and its components are: B_x = 0.50 T, B_y = 0.80 T, and B_z = 0.30 T. Determine the magnetic flux that passes through the surface that lies in (a) the xy plane, (b) the xz plane, and (c) the yz plane.

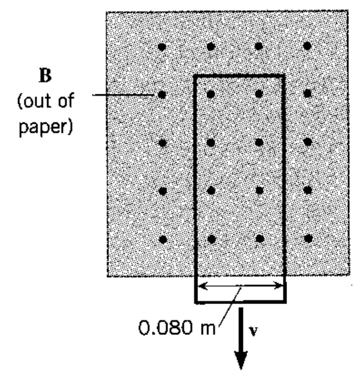


14. A house has a floor area of 112 m^2 and an outside wall that has an area of 28 m^2. The earth's magnetic field here has a horizontal component of 2.6×10^{-5} T that points due north and a vertical component of 4.2×10^{-5} T that points straight down, toward the earth. Determine the magnetic flux through the wall if the wall faces (a) north and (b) east. (c) Calculate the magnetic flux that passes through the floor.

***15. ssm www** A five-sided object, whose dimensions are shown in the drawing, is placed in a uniform magnetic field. The magnetic field has a magnitude of 0.25 T and points along the positive y direction. Determine the magnetic flux through each of the five sides.



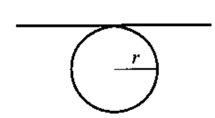
***16.** A rectangular loop of wire is moving toward the bottom of the page with a speed of 0.020 m/s (see the drawing). The loop is leaving a region in which a 2.4-T magnetic field exists; the magnetic field outside this region is zero. During a time of 2.0 s, what is the magnitude of the *change* in the magnetic flux?



Section 22.4 Faraday's Law of Electromagnetic Induction

17. A 300-turn rectangular loop of wire has an area per turn of 5.0×10^{-3} m^2. At t_0 = 0 s a magnetic field is turned on, and its magnitude increases to 0.40 T when t = 0.80 s. The field is directed at an angle of ϕ = 30.0° with respect to the normal of the loop. (a) Find the magnitude of the average emf induced in the loop. (b) If the loop is a closed circuit whose resistance is 6.0 Ω, determine the average induced current.

18. The drawing shows a straight wire, a part of which is bent into the shape of a circle. The radius of the circle is 2.0 cm. A constant magnetic field of magnitude 0.55 T is directed perpendicular to the plane of the paper. Someone grabs the ends of the wire and pulls it taut, so the radius of the circle shrinks to zero in a time of 0.25 s. Find the magnitude of the average induced emf between the ends of the wire.



19. ssm A circular coil (950 turns, radius = 0.060 m) is rotating in a uniform magnetic field. At t = 0 s, the normal to the coil is perpendicular to the magnetic field. At t = 0.010 s, the normal makes an angle of $\phi = 45°$ with the field because the coil has made one-eighth of a revolution. An average emf of magnitude 0.065 V is induced in the coil. Find the magnitude of the magnetic field at the location of the coil.

20. A planar coil of wire has a single turn. The normal to this coil is parallel to a uniform and constant (in time) magnetic field of 1.7 T. An emf that has a magnitude of 2.6 V is induced in this coil because the coil's area A is shrinking. What is the magnitude of $\Delta A/\Delta t$, which is the rate (in m^2/s) at which the area changes?

21. Magnetic resonance imaging (MRI) is a medical technique for producing "pictures" of the interior of the body. The patient is placed within a strong magnetic field. One safety concern is what would happen to the positively and negatively charged particles in the body fluids if an equipment failure caused the magnetic field to be shut off suddenly. An induced emf could cause these particles to flow, producing an electric current within the body. Suppose the largest surface of the body through which flux passes has an area of 0.032 m^2 and a normal that is parallel to a magnetic field of 1.5 T. Determine the smallest time period during which the field can be allowed to vanish if the magnitude of the average induced emf is to be kept less than 0.010 V.

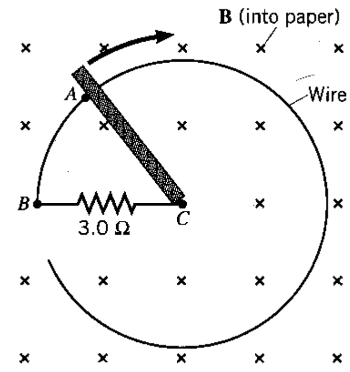
22. A constant magnetic field passes through a single rectangular loop whose dimensions are 0.35 m × 0.55 m. The magnetic field has a magnitude of 2.1 T and is inclined at an angle of 65° with respect to the normal to the plane of the loop. (a) If the magnetic field decreases to zero in a time of 0.45 s, what is the magnitude of the average emf induced in the loop? (b) If the magnetic field remains constant at its initial value of 2.1 T, what is the magnitude of the rate $\Delta A/\Delta t$ at which the area should change so that the average emf has the same magnitude?

23. A 1.5-m-long aluminum rod is rotating about an axis that is perpendicular to one end. A 0.16-T magnetic field is directed parallel to the axis. The rod rotates through one-fourth of a circle in 0.66 s. What is the magnitude of the average emf generated between the ends of the rod during this time?

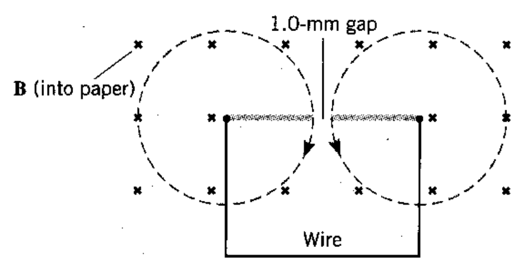
***24.** A piece of copper wire is formed into a single circular loop of radius 12 cm. A magnetic field is oriented parallel to the normal to the loop, and it increases from 0 to 0.60 T in a time of 0.45 s. The wire has a resistance per unit length of 3.3×10^{-2} Ω/m. What is the average electrical energy dissipated in the resistance of the wire?

***25.** **ssm www** A conducting coil of 1850 turns is connected to a galvanometer, and the total resistance of the circuit is 45.0 Ω. The area of each turn is 4.70×10^{-4} m^2. This coil is moved from a region where the magnetic field is zero into a region where it is nonzero, the normal to the coil being kept parallel to the magnetic field. The amount of charge that is induced to flow around the circuit is measured to be 8.87×10^{-3} C. Find the magnitude of the magnetic field. (Such a device can be used to measure the magnetic field strength and is called a *flux meter.*)

***26.** The drawing shows a copper wire (negligible resistance) bent into a circular shape with a radius of 0.50 m. The radial section BC is fixed in place, while the copper bar AC sweeps around at an angular speed of 15 rad/s. The bar makes electrical contact with the wire at all times. The wire and the bar have negligible resistance. A uniform magnetic field exists everywhere, is perpendicular to the plane of the circle, and has a magnitude of 3.8×10^{-3} T. Find the magnitude of the current induced in the loop ABC.

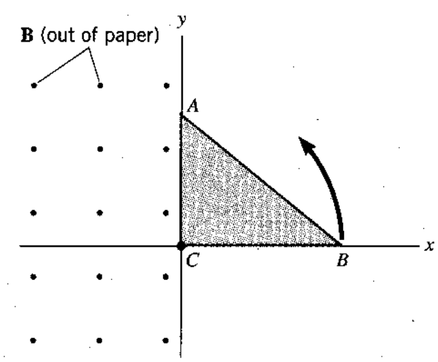


****27.** Two 0.68-m-long conducting rods are rotating at the same speed in opposite directions, and both are perpendicular to a 4.7-T magnetic field. As the drawing shows, the ends of these rods come to within 1.0 mm of each other as they rotate. Moreover, the fixed ends about which the rods are rotating are connected by a wire, so these ends are at the same electric potential. If a potential difference of 4.5×10^3 V is required to cause a 1.0-mm spark in air, what is the angular speed (in rad/s) of the rods when a spark jumps across the gap?



Section 22.5 Lenz's Law

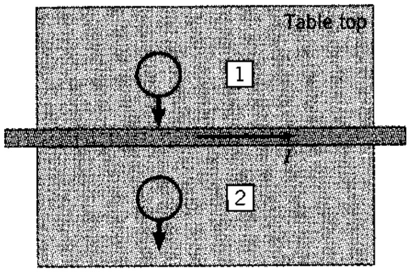
28. The drawing shows that a uniform magnetic field is directed perpendicularly out of the plane of the paper and fills the entire region to the left of the y axis. There is no magnetic field to the right of the y axis. A rigid right triangle ABC is made of copper wire. The triangle rotates counterclockwise about the origin at point C. What is the direction (clockwise or counterclockwise) of the induced current when the triangle is crossing (a) the $+y$ axis, (b) the $-x$ axis, (c) the $-y$ axis, and (d) the $+x$ axis? For each case, justify your answer.



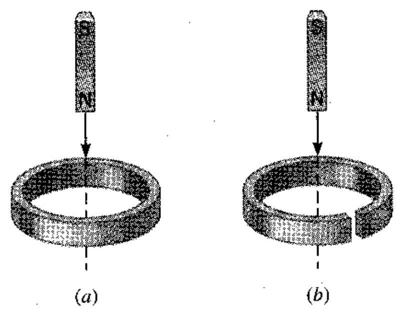
29. **ssm** In Figure 22.1, suppose the north and south poles of the magnet were interchanged. Determine the direction of the current through the ammeter in parts b and c of the picture (left-to-right or right-to-left). Give your rationale.

30. Review the drawing that accompanies Problem 12. The semicircular piece of wire rotates through half a revolution in the direction shown, starting from the position indicated in the drawing. Which end of the resistor, the left or the right end, is positive? Explain your reasoning.

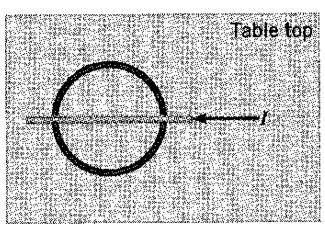
31. **ssm** Review Conceptual Example 9 as an aid in understanding this problem. A long, straight wire lies on a table and carries a current I. As the drawing shows, a small circular loop of wire is pushed across the top of the table from position 1 to position 2. Determine the direction of the induced current, clockwise or counterclockwise, as the loop moves past (a) position 1 and (b) position 2. Justify your answers.



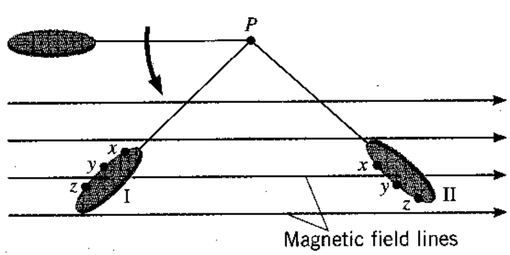
***32.** The drawing shows a bar magnet falling through a metal ring. In part a the ring is solid all the way around, but in part b it has been cut through. (a) Explain why the motion of the magnet in part a is retarded when the magnet is above the ring and below the ring as well. Draw any induced currents that appear in the ring. (b) Explain why the motion of the magnet is unaffected by the ring in part b.



***33.** A circular loop of wire rests on a table. A long, straight wire lies on this loop, directly over its center, as the drawing illustrates. The current I in the straight wire is increasing. In what direction is the induced current, if any, in the loop? Give your reasoning.

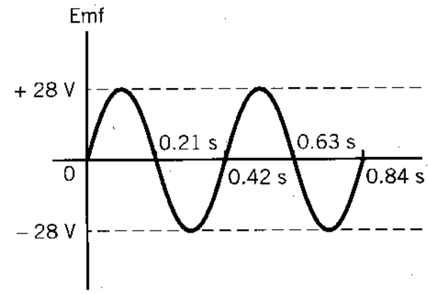


****34.** A wire loop is suspended from a string that is attached to point P in the drawing. When released, the loop swings downward, from left to right, through a uniform magnetic field, with the plane of the loop remaining perpendicular to the plane of the paper at all times. (a) Determine the direction of the current induced in the loop as it swings past the locations labeled I and II. Specify the direction of the current in terms of the points x, y, and z on the loop (e.g., $x \rightarrow y \rightarrow z$ or $z \rightarrow y \rightarrow x$). The points x, y, and z lie behind the plane of the paper. (b) What is the direction of the induced current at the locations II and I when the loop swings back, from right to left? Provide reasons for your answers.



Section 22.7 The Electric Generator

35. **ssm** **www** The drawing shows a plot of the output emf of a generator as a function of time t. The coil of this device has a cross-sectional area per turn of 0.020 m^2 and contains 150 turns. Find (a) the frequency f of the generator in hertz, (b) the angular speed ω in rad/s, and (c) the magnitude of the magnetic field.



36. One generator uses a magnetic field of 0.10 T and has a coil area per turn of 0.045 m^2. A second generator has a coil area per turn of 0.015 m^2. The generator coils have the same number of turns and rotate at the same angular speed. What magnetic field should be used in the second generator, so that its peak emf is the same as that of the first generator?

37. You are requested to design a 60.0-Hz ac generator whose maximum emf is to be 5500 V. The generator is to contain a 150-turn coil whose area per turn is 0.85 m^2. What should be the magnitude of the magnetic field in which the coil rotates?

38. A vacuum cleaner is plugged into a 120.0-V socket and uses 3.0 A of current in normal operation when the back emf generated by the electric motor is 72.0 V. Find the coil resistance of the motor.

39. **ssm** A generator has a square coil consisting of 248 turns. The coil rotates at 79.1 rad/s in a 0.170-T magnetic field. The peak output of the generator is 75.0 V. What is the length of one side of the coil?

40. A 120.0-volt motor draws a current of 7.00 A when running at normal speed. The resistance of the armature wire is 0.720 Ω. (a) Determine the back emf generated by the motor. (b) What is the current at the instant when the motor is just turned on and has not begun to rotate? (c) What series resistance must be added to limit the starting current to 15.0 A?

***41.** **ssm** At its normal operating speed, an electric fan motor draws only 15.0% of the current it draws when it just begins to turn the fan blade. The fan is plugged into a 120.0-V socket. What back emf does the motor generate at its normal operating speed?

***42.** The coil of a generator has a radius of 0.14 m. When this coil is unwound, the wire from which it is made has a length of 5.7 m. The magnetic field of the generator is 0.20 T, and the coil rotates at an angular speed of 25 rad/s. What is the peak emf of this generator?

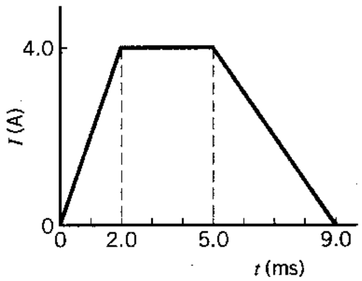
****43.** A motor is designed to operate on 117 V and draws a current of 12.2 A when it first starts up. At its normal operating speed, the motor draws a current of 2.30 A. Obtain (a) the resistance of the armature coil, (b) the back emf developed at normal speed, and (c) the current drawn by the motor at one-third normal speed.

Section 22.8 Mutual Inductance and Self-Inductance

44. The average emf induced in the secondary coil is 0.12 V when the current in the primary coil changes from 3.4 to 1.6 A in 0.14 s. What is the mutual inductance of the coils?

45. ssm Suppose you wish to make a solenoid whose self-inductance is 1.4 mH. The inductor is to have a cross-sectional area of 1.2×10^{-3} m^2 and a length of 0.052 m. How many turns of wire are needed?

46. The current through a 3.2-mH inductor varies with time according to the graph shown in the drawing. What is the average induced emf during the time intervals (a) 0–2.0 ms, (b) 2.0–5.0 ms, and (c) 5.0–9.0 ms?



47. Mutual induction can be used as the basis for a metal detector. A typical setup uses two large coils that are parallel to each other and have a common axis. Because of mutual induction, the ac generator connected to the primary coil causes an emf of 0.46 V to be induced in the secondary coil. When someone without metal objects walks through the coils, the mutual inductance and, thus, the induced emf do not change much. But when a person carrying a handgun walks through, the mutual inductance increases. If the mutual inductance increases by a factor of three, find the new value of the induced emf. The change in emf can be used to trigger an alarm.

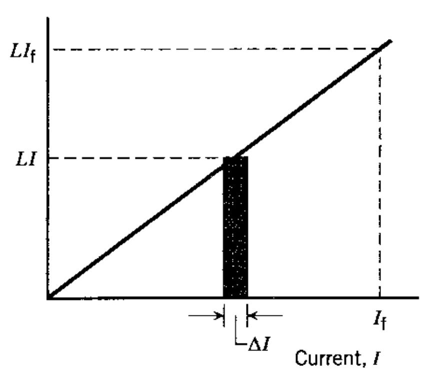
48. Two coils have a mutual inductance of 2.5 mH. In the primary coil the current changes by 3.0 A in 0.040 s. The circuit of the secondary coil has a resistance of 2.0 Ω. Find the magnitude of the average current induced in the secondary coil.

49. ssm The earth's magnetic field, like any magnetic field, stores energy. The maximum strength of the earth's field is about 7.0×10^{-5} T. Find the maximum magnetic energy stored in the space above a city if the space occupies an area of 5.0×10^8 m^2 and has a height of 1500 m.

***50.** A magnetic field has a magnitude of 12 T. What is the magnitude of an electric field that stores the same energy per unit volume as this magnetic field?

***51.** A long, current-carrying solenoid with an air core has 1750 turns per meter of length and a radius of 0.0180 m. A coil of 125 turns is wrapped tightly around the outside of the solenoid. What is the mutual inductance of this system?

***52.** The purpose of this problem is to show that the work W needed to establish a final current I_f in an inductor is $W = \frac{1}{2}LI_f^2$ (Equation 22.10). In Section 22.8 we saw that the amount of work ΔW needed to change the current through an inductor by an amount ΔI is $\Delta W = LI(\Delta I)$, where L is the inductance. The drawing shows a graph of LI versus I. Notice that $LI(\Delta I)$ is the area of the shaded vertical rectangle whose height is LI and whose width is ΔI. Use this fact to show that the total work W needed to establish a current I_f is $W = \frac{1}{2}LI_f^2$.



****53. ssm** A solenoid has a cross-sectional area of 6.0×10^{-4} m^2, consists of 400 turns per meter, and carries a current of 0.40 A. A 10-turn coil is wrapped tightly around the circumference of the solenoid. The ends of the coil are connected to a 1.5-Ω resistor. Suddenly, a switch is opened, and the current in the solenoid dies to zero in a time of 0.050 s. Find the average current induced in the coil.

Section 22.9 Transformers

54. A neon sign requires 12 000 V for its operation. It operates from a 220-V receptacle. (a) What type of transformer, step-up or step-down, is needed? (b) What must be the turns ratio N_s/N_p of the transformer?

55. ssm Electric doorbells found in many homes require 10.0 V to operate. To obtain this voltage from the standard 120-V supply, a transformer is used. Is a step-up or a step-down transformer needed, and what is its turns ratio N_s/N_p?

56. The batteries in a portable CD player are recharged by a unit that plugs into a wall socket. Inside the unit is a step-down transformer with a turns ratio of 1 : 13. The wall socket provides 120 V. What voltage does the secondary coil of the transformer provide?

57. The secondary coil of a step-up transformer provides the voltage that operates an electrostatic air filter. The turns ratio of the transformer is 43 : 1. The primary coil is plugged into a standard 120-V outlet. The current in the secondary coil is 1.5×10^{-3} A. Find the power consumed by the air filter.

58. In some places, insect "zappers," with their blue lights, are a familiar sight on a summer's night. These devices use a high voltage to electrocute insects. One such device uses an ac voltage of 4320 V, which is obtained from a standard 120.0-V outlet by means of a transformer. If the primary coil has 21 turns, how many turns are in the secondary coil?

***59. ssm** A generating station is producing 1.2×10^6 W of power that is to be sent to a small town located 7.0 km away. Each of the two wires that comprise the transmission line has a resistance per kilometer of length of 5.0×10^{-2} Ω/km. (a) Find the power lost in heating the wires if the power is transmitted at 1200 V. (b) A 100 : 1 step-up transformer is used to raise the voltage before the power is transmitted. How much power is now lost in heating the wires?

***60.** In a television set the power needed to operate the picture tube is 95 W and is derived from the secondary coil of a transformer. There is a current of 5.3 mA in the secondary coil. The primary coil is connected to a 120-V receptacle. Find the turns ratio N_s/N_p of the transformer.

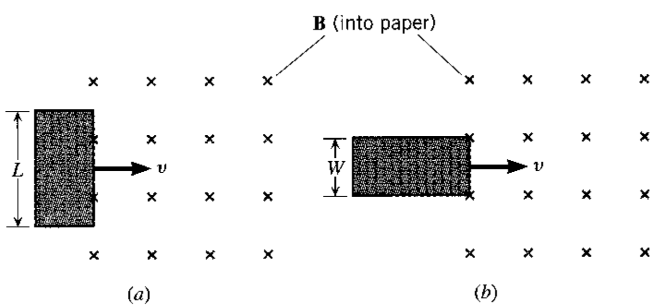
****61.** A generator is connected across the primary coil (N_p turns) of a transformer, while a resistance R_2 is connected across the secondary coil (N_s turns). This circuit is equivalent to a circuit in which a single resistance R_1 is connected directly across the generator, without the transformer. Show that $R_1 = (N_p/N_s)^2 R_2$, by starting with Ohm's law as applied to the secondary coil.

ADDITIONAL PROBLEMS

62. A magnetic field is perpendicular to a 0.040-m × 0.060-m rectangular coil of wire that has one hundred turns. In a time of 0.050 s, an average emf of magnitude 1.5 V is induced in the coil. What is the magnitude of the change in the magnetic field?

63. The maximum strength of the earth's magnetic field is about 7.0×10^{-5} T near the south magnetic pole. In principle, this field could be used with a rotating coil to generate 60.0-Hz ac electricity. What is the minimum number of turns (area per turn = 0.016 m^2) that the coil must have to produce an rms voltage of 120 V?

64. Parts *a* and *b* of the drawing show the same uniform and constant (in time) magnetic field **B** directed perpendicularly into the paper over a rectangular region. Outside this region, there is no field. Also shown is a rectangular coil (one turn), which lies in the plane of the paper. In part *a* the long side of the coil (length = L) is just at the edge of the field region, while in part *b* the short side (width = W) is just at the edge. It is known that $L/W = 3.0$. In both parts of the drawing the coil is pushed into the field with the same velocity **v** until it is completely within the field region. The magnitude of the average emf induced in the coil in part *a* is 0.15 V. What is its magnitude in part *b*?

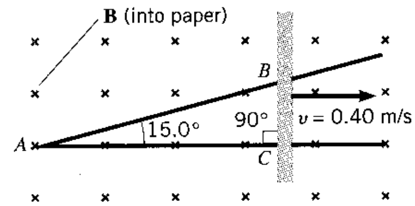


65. ssm Suppose in Figure 22.1 that the bar magnet is held stationary, but the coil of wire is free to move. Which way will current be directed through the ammeter, left-to-right or right-to-left, when the coil is moved (a) to the left and (b) to the right? Explain.

66. The resistances of the primary and secondary coils of a transformer are 56 and 14 Ω, respectively. Both coils are made from lengths of the same copper wire. The circular turns of each coil have the same diameter. Find the turns ratio N_s/N_p.

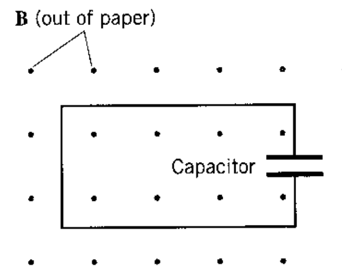
67. ssm The coil of an ac generator has an area per turn of 1.2×10^{-2} m^2 and consists of 500 turns. The coil is situated in a 0.13-T magnetic field and is rotating at an angular speed of 34 rad/s. What is the emf induced in the coil at the instant when the normal to the loop makes an angle of 27° with respect to the direction of the magnetic field?

***68.** A 3.0-μF capacitor has a voltage of 35 V between its plates. What must be the current in a 5.0-mH inductor, such that the energy stored in the inductor equals the energy stored in the capacitor?



***69.** A copper rod is sliding on two conducting rails that make an angle of 15° with respect to each other, as in the drawing. The rod is moving to the right with a constant speed of 0.40 m/s. A 0.42-T uniform magnetic field is perpendicular to the plane of the paper. Determine the magnitude of the average emf induced in the triangle *ABC* during the 5.0-s period after the rod has passed point *A*.

***70.** Indicate the direction of the electric field between the plates of the parallel plate capacitor shown in the drawing if the magnetic field is decreasing in time. Give your reasoning.



Problem 70

***71. ssm** A magnetic field is passing through a loop of wire whose area is 0.018 m^2. The direction of the magnetic field is parallel to the normal to the loop, and the magnitude of the field is increasing at the rate of 0.20 T/s. (a) Determine the magnitude of the emf induced in the loop. (b) Suppose the area of the loop can be enlarged or shrunk. If the magnetic field is increasing as in part (a), at what rate (in m^2/s) should the area be changed at the instant when B = 1.8 T if the induced emf is to be zero? Explain whether the area is to be enlarged or shrunk.

***72.** A long solenoid (cross-sectional area = 1.0×10^{-6} m^2, number of turns per unit length = 2400 turns/m) is bent into a circular shape so it looks like a doughnut. This wire-wound doughnut is called a toroid. Assume that the diameter of the solenoid is small compared to the radius of the toroid, which is 0.050 m. With this assumption, use the results of Example 13 to determine the self-inductance of the toroid.

****73.** The armature of an electric drill motor has a resistance of 15.0 Ω. When connected to a 120.0-V outlet, the motor rotates at its normal speed and develops a back emf of 108 V. (a) What is the current through the motor? (b) If the armature "freezes up" due to a lack of lubrication in the bearings and can no longer rotate, what is the current in the stationary armature? (c) What is the current when the motor runs at only half speed?

****74.** Coil 1 is a flat circular coil that has N_1 turns and a radius R_1. At its center is a much smaller flat, circular coil that has N_2 turns and radius R_2. The planes of the coils are parallel. Assume that coil 2 is so small that the magnetic field due to coil 1 has nearly the same value at all points covered by the area of coil 2. Determine an expression for the mutual inductance between these two coils in terms of μ_0, N_1, R_1, N_2, and R_2.

CONCEPTS & CALCULATIONS

GROUP LEARNING PROBLEMS

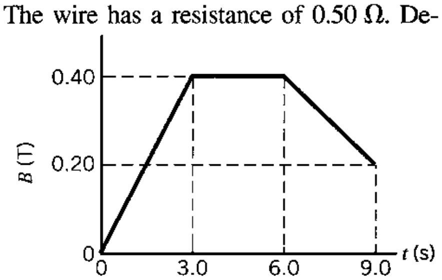
Note: Each of these problems consists of Concept Questions followed by a related quantitative Problem. They are designed for use by students working alone or in small learning groups. The Concept Questions involve little or no mathematics and are intended to stimulate group discussions. They focus on the concepts with which the problems deal. Recognizing the concepts is the essential initial step in any problem-solving techinque.

75. Concept Questions Two circuits contain an emf produced by a moving metal rod, like that in Figure 22.4*b*. The speed of the rod is the same in each circuit, but the bulb in circuit 1 has one-half the resistance of the bulb in circuit 2. The circuits are otherwise identical. Is (a) the motional emf and (b) the current in circuit 1 greater than, the same as, or less than, that in circuit 2? (c) If the speed of the rod in circuit 1 were doubled, how would the power delivered to the light bulb compare to that in circuit 2? Provide a reason for each of your answers.

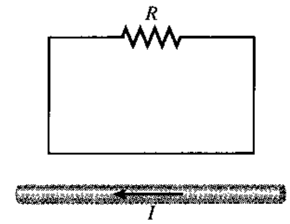
Problem The resistance of the light bulb in circuit 1 is 55 Ω, while that in circuit 2 is 110 Ω. Determine (a) the ratio $\mathscr{E}_1/\mathscr{E}_2$ of the emfs and (b) the ratio I_1/I_2 of the currents. (c) If the speed of the rod in circuit 1 is twice that in circuit 2, what is the ratio P_1/P_2 of the powers? Check to see that your answers are consistent with your answers to the Concept Questions.

76. Concept Questions A magnetic field passes through a stationary wire loop, and its magnitude changes in time according to the graph in the drawing. The direction of the field remains constant, however. There are three equal time intervals indicated in the graph: 0–3.0 s, 3.0–6.0 s, and 6.0–9.0 s. (a) Is the induced emf equal to zero during any of the intervals? (b) During which interval is the magnitude of the induced emf the largest? (c) If the direction of the current induced during the first interval is clockwise, what is the direction during the third interval? In all cases, provide a reason for your answer.

Problem The loop consists of 50 turns of wire and has an area of 0.15 m². The magnetic field is oriented parallel to the normal to the loop. (a) For each interval, determine the magnitude of the induced emf. (b) The wire has a resistance of 0.50 Ω. Determine the induced current for the first and third intervals. Make sure your answers are consistent with your answers to the Concept Questions.



77. Concept Questions The drawing shows a straight wire carrying a current *I*. Above the wire is a rectangular loop that contains a resistor *R*. (a) Does the magnetic field produced by the current *I* penetrate the loop and generate a magnetic flux? (b) When is there an induced current in the loop, if the current *I* is constant or if it is decreasing in time? (c) When there is an induced magnetic field produced by the loop, does it always have a direction that is opposite to the direction of the magnetic field produced by the current *I*? Provide a reason for each answer.



Problem If the current *I* is decreasing in time, what is the direction of the induced current through the resistor *R*—left-to-right or right-to-left? Give your reasoning.

78. Concept Questions A flat coil of wire has an area *A*, *N* turns, and a resistance *R*. It is situated in a magnetic field, such that the normal to the coil is parallel to the magnetic field. The coil is then rotated through an angle of 90°, so that the normal becomes perpendicular to the magnetic field. (a) Why is an emf induced in the coil? (b) What determines the amount of induced current in the coil? (c) How is the amount of charge that flows related to the induced current?

Problem The coil has an area of 1.5×10^{-3} m², 50 turns, and a resistance of 140 Ω. During the time it is rotating, a charge of 8.5×10^{-5} C flows in the coil. What is the magnitude of the magnetic field?

79. Concept Questions A constant current *I* exists in a solenoid whose inductance is *L*. The current is then reduced to zero in a certain amount of time. (a) If the wire from which the solenoid is made has no resistance, is there a voltage across the solenoid during the time when the current is constant? (b) If the wire from which the solenoid is made has no resistance, is there an emf across the solenoid during the time that the current is being reduced to zero? (c) Does the solenoid store electrical energy when the current is constant? If so, express this energy in terms of the current and the inductance. (d) When the current is reduced from its constant value to zero, what is the rate at which energy is removed from the solenoid? Express your answer in terms of the initial current, the inductance, and the time during which the current goes to zero.

Problem A solenoid has an inductance of $L = 3.1$ H and carries a current of $I = 15$ A. (a) If the current goes from 15 to 0 A in a time of 75 ms, what is the emf induced in the solenoid? (b) How much electrical energy is stored in the solenoid? (c) At what rate must the electrical energy be removed from the solenoid when the current is reduced to zero in 75 ms?

80. Concept Questions The rechargeable batteries for a laptop computer need a much smaller voltage than what a wall socket provides. Therefore, a transformer is plugged into the wall socket and produces the necessary voltage for charging the batteries. (a) Is the transformer a step-up or a step-down transformer? (b) Is the current that goes through the batteries greater than, equal to, or smaller than the current coming from the wall socket? (c) If the transformer has a negligible resistance, is the electrical power delivered to the batteries greater than, equal to, or less than the power coming from the wall socket? In all cases, provide a reason for your answer.

Problem The batteries of a laptop computer are rated at 9.0 V, and a current of 225 mA is used to charge them. The wall socket provides a voltage of 120 V. (a) Determine the turns ratio of the transformer. (b) What is the current coming from the wall socket? (c) Find the power delivered by the wall socket and the power sent to the batteries. Be sure your answers are consistent with your answers to the Concept Questions.

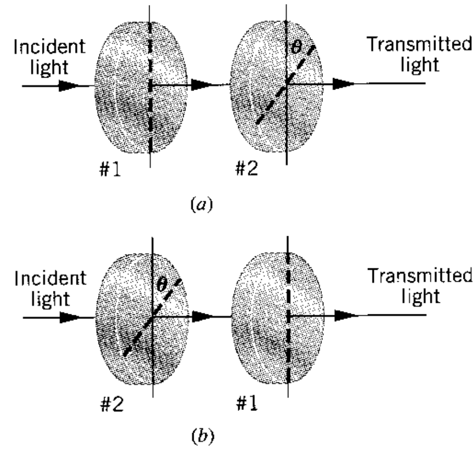
surement, can the astronomer tell whether the star is moving away from the earth or whether the earth is moving away from the star? Explain.

7. Is there any real difference between a polarizer and an analyzer? In other words, can a polarizer be used as an analyzer, and vice versa?

8. Malus' law applies to the setup in Figure 24.20, which shows the analyzer rotated through an angle θ and the polarizer held fixed. Does Malus' law apply when the analyzer is held fixed and the polarizer is rotated? Give your reasoning.

9. In Example 7, we saw that, when the angle between the polarizer and analyzer is 63.4°, the intensity of the transmitted light drops to one-tenth of that of the incident unpolarized light. What happens to the light intensity that is not transmitted?

10. Light is incident from the left on two pieces of polarizing material, 1 and 2. As part *a* of the drawing illustrates, the transmission axis of material 1 is along the vertical direction, while that of material 2 makes an angle of θ with respect to the vertical. In part *b* of the drawing the two polarizing materials are interchanged. (a) Assume that the incident light is unpolarized and determine whether the intensity of the transmitted light in part *a* is greater than, equal to, or less than that in part *b*. (b) Repeat part (a), assuming that the incident light is linearly polarized along the vertical direction. Justify your answers to both parts (a) and (b).



11. You are sitting upright on the beach near a lake on a sunny day, wearing Polaroid sunglasses. When you lie down on your side, facing the lake, the sunglasses don't work as well as they did while you were sitting upright. Why not?

PROBLEMS

ssm Solution is in the Student Solutions Manual. **www** Solution is available on the World Wide Web at http://www.wiley.com/college/cutnell
This icon represents a biomedical application.

Section 24.1 The Nature of Electromagnetic Waves

1. ssm In astronomy, distances are often expressed in light-years. One light-year is the distance traveled by light in one year. The distance to Alpha Centauri, the closest star other than our own sun that can be seen by the naked eye, is 4.3 light-years. Express this distance in meters.

2. (a) Neil A. Armstrong was the first person to walk on the moon. The distance between the earth and the moon is 3.85×10^8 m. Find the time it took for his voice to reach earth via radio waves. (b) Determine the communication time for the first person who will some day walk on Mars, which is 5.6×10^{10} m from earth at the point of closest approach.

3. For an FM radio station broadcasting at a frequency of 88.0 MHz, the capacitance in Figure 24.5 must be adjusted to a value of 33.0×10^{-12} F. Assuming the inductance does not change, determine the value of the capacitance for an FM station broadcasting at 108.0 MHz.

4. An AM station is broadcasting a radio wave whose frequency is 1400 kHz. The value of the capacitance in Figure 24.5 is 8.4×10^{-11} F. What must be the value of the inductance in order that this station can be tuned in by the radio?

***5. ssm** Equation 16.3, $y = A \sin (2\pi ft - 2\pi x/\lambda)$, gives the mathematical representation of a wave oscillating in the y direction and traveling in the positive x direction. Let y in this equation equal the electric field of an electromagnetic wave traveling in a vacuum. The maximum electric field is $A = 156$ N/C, and the frequency is $f = 1.50 \times 10^8$ Hz. Plot a graph of the electric field strength versus position, using for x the following values: 0, 0.50, 1.00, 1.50, and 2.00 m. Plot this graph for (a) a time $t = 0$ s and (b) a time t that is one-fourth of the wave's period.

****6.** A flat coil of wire is used with an LC-tuned circuit as a receiving antenna. The coil has a radius of 0.25 m and consists of 450 turns. The transmitted radio wave has a frequency of 1.2 MHz. The magnetic field of the wave is parallel to the normal to the coil and has a maximum value of 2.0×10^{-13} T. Using Faraday's law of electromagnetic induction and the fact that the magnetic field changes from zero to its maximum value in one-quarter of a wave period, find the magnitude of the average emf induced in the antenna during this time.

Section 24.2 The Electromagnetic Spectrum

7. A truck driver is broadcasting at a frequency of 26.965 MHz with a CB (citizen's band) radio. Determine the wavelength of the electromagnetic wave being used.

8. Determine the range of wavelengths for FM radio waves with frequencies between 88.0 and 108.0 MHz.

9. ssm www Television sets sometimes use a "rabbit-ears" antenna. A rabbit-ears antenna consists of a pair of metal rods. The length of each rod can be adjusted to be one-quarter of a wavelength of an electromagnetic wave whose frequency is 60.0 MHz. How long is each rod?

10. Magnetic resonance imaging or MRI (see Section 21.7) and positron emission tomography or PET scanning (see Section 32.6) are two medical diagnostic techniques. Both employ electromagnetic waves. For these waves, find the ratio of the MRI wavelength (frequency $= 6.38 \times 10^7$ Hz) to the PET scanning wavelength (frequency $= 1.23 \times 10^{20}$ Hz).

11. ssm The human eye is most sensitive to light having a frequency of about 5.5×10^{14} Hz, which is in the yellow-green region of the electromagnetic spectrum. How many wavelengths of this light can fit across the width of your thumb, a distance of about 2.0 cm?

12. TV channel 3 (VHF) broadcasts at a frequency of 63.0 MHz. TV channel 23 (UHF) broadcasts at a frequency of 527 MHz. Find the ratio (VHF/UHF) of the wavelengths for these channels.

***13.** Section 17.5 deals with transverse standing waves on a string. Electromagnetic waves also can form standing waves. In a standing wave pattern formed from microwaves, the distance between a node and an adjacent antinode is 0.50 cm. What is the microwave frequency?

Section 24.3 The Speed of Light

14. Ghost images are formed in a TV picture when the electromagnetic wave from the broadcasting antenna reflects from a building or other large object and arrives at the TV set shortly after the wave coming directly from the broadcasting antenna. If the reflected wave arrives 5.0×10^{-7} s after the direct wave, what is the difference in the distances traveled by the two waves?

15. ssm Two astronauts are 1.5 m apart in their spaceship. One speaks to the other. The conversation is transmitted to earth via electromagnetic waves. The time it takes for sound waves to travel at 343 m/s through the air between the astronauts equals the time it takes for the electromagnetic waves to travel to the earth. How far away from the earth is the spaceship?

16. Review Conceptual Example 3 before attempting this problem. The brightest star in the night sky is Sirius, which is at a distance of 8.3×10^{16} m. When we look at this star, how far back in time are we seeing it? Express your answer in years. (There are $365\frac{1}{4}$ days in one year.)

17. Figure 24.11 illustrates Michelson's setup for measuring the speed of light with the mirrors placed on Mt. San Antonio and Mt. Wilson in California, which are 35 km apart. Using a value of 3.00×10^8 m/s for the speed of light, find the minimum angular speed (in rev/s) for the rotating mirror.

18. A communications satellite is in a synchronous orbit that is 3.6×10^7 m directly above the equator. The satellite is located midway between Quito, Equador, and Belém, Brazil, two cities almost on the equator that are separated by a distance of 3.5×10^6 m. Find the time it takes for a telephone call to go by way of satellite between these cities. Ignore the curvature of the earth.

***19. ssm** A mirror faces a cliff, located some distance away. Mounted on the cliff is a second mirror, directly opposite the first mirror and facing toward it. A gun is fired very close to the first mirror. The speed of sound is 343 m/s. How many times does the flash of the gunshot travel the round-trip distance between the mirrors before the echo of the gunshot is heard?

***20.** A celebrity holds a press conference, which is televised live. A television viewer hears the sound picked up by a microphone directly in front of the celebrity. This viewer is seated 2.3 m from the television set. A reporter at the press conference is located 4.1 m from the microphone and hears the words directly *at the very same instant* that the television viewer hears them. Using a value of 343 m/s for the speed of sound, determine the maximum distance between the television viewer and the celebrity.

Section 24.4 The Energy Carried by Electromagnetic Waves

21. An industrial laser is used to burn a hole through a piece of metal. The average intensity of the light is $\overline{S} = 1.23 \times 10^9$ W/m^2. What is the rms value of (a) the electric field and (b) the magnetic field in the electromagnetic wave emitted by the laser?

22. Suppose the electric field in an electromagnetic wave has a maximum strength of 1470 N/C. What is the maximum strength of the magnetic field of the wave?

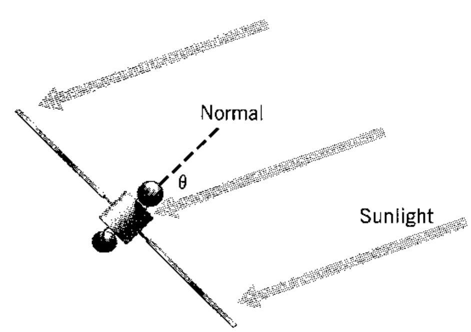
23. ssm The microwave radiation left over from the Big Bang explosion of the universe has an average energy density of 4×10^{-14} J/m^3. What is the rms value of the electric field of this radiation?

24. The electromagnetic wave that delivers a cellular phone call to a car has a magnetic field with an rms value of 1.5×10^{-10} T. The wave passes perpendicularly through an open window, the area of which is 0.20 m^2. How much energy does this wave carry through the window during a 45-s phone call?

25. ssm A future space station in orbit about the earth is being powered by an electromagnetic beam from the earth. The beam has a cross-sectional area of 135 m^2 and transmits an average power of 1.20×10^4 W. What are the rms values of the (a) electric and (b) magnetic fields?

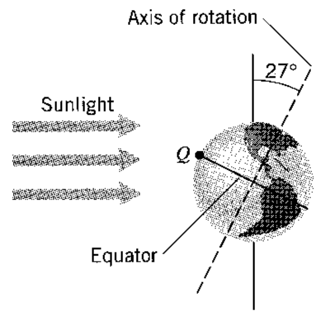
26. The average intensity of sunlight at the top of the earth's atmosphere is 1390 W/m^2. What is the maximum energy that a 25-m × 45-m solar panel could collect in one hour in this sunlight?

***27.** The drawing shows an edge-on view of the solar panels on a communications satellite. The dashed line specifies the normal to the panels. Sunlight strikes the panels at an angle θ with respect to the normal. If the solar power impinging on the panels is 3200 W when $\theta = 55°$, what is it when $\theta = 35°$?



* **28.** A heat lamp emits infrared radiation whose rms electric field is $E_{rms} = 2800$ N/C. (a) What is the average intensity of the radiation? (b) The radiation is focused on a person's leg over a circular area of radius 4.0 cm. What is the average power delivered to the leg? (c) The portion of the leg being radiated has a mass of 0.28 kg and a specific heat capacity of 3500 J/(kg · C°). How long does it take to raise its temperature by 2.0 C°? Assume that there is no other heat transfer into or out of the portion of the leg being heated.

* **29. ssm www** The power radiated by the sun is 3.9×10^{26} W. The earth orbits the sun in a nearly circular orbit of radius 1.5×10^{11} m. The earth's axis of rotation is tilted by 27° relative to the plane of the orbit (see the drawing), so sunlight does not strike the equator perpendicularly. What power strikes a 0.75-m² patch of flat land at the equator at point Q?



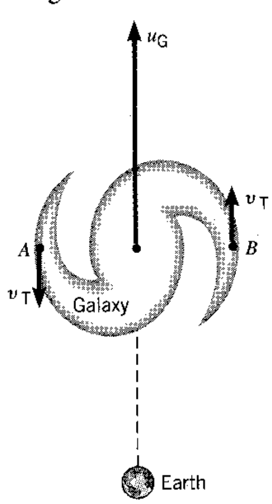
** **30.** The average intensity of sunlight reaching the earth is 1390 W/m². A charge of 2.6×10^{-8} C is placed in the path of this electromagnetic wave. (a) What is the magnitude of the maximum electric force that the charge experiences? (b) If the charge is moving at a speed of 3.7×10^{4} m/s, what is the magnitude of the maximum magnetic force that the charge could experience?

Section 24.5 The Doppler Effect and Electromagnetic Waves

31. A distant galaxy emits light that has a wavelength of 500.7 nm. On earth, the wavelength of this light is measured to be 503.7 nm. (a) Decide whether this galaxy is approaching or receding from the earth. Give your reasoning. (b) Find the speed of the galaxy relative to the earth.

32. A speeder is pulling directly away and increasing his distance from a police car that is moving at 25 m/s with respect to the ground. The radar gun in the police car emits an electromagnetic wave with a frequency of 7.0×10^{9} Hz. The wave reflects from the speeder's car and returns to the police car, where its frequency is measured to be 320 Hz less than the emitted frequency. Find the speeder's speed with respect to the ground.

* **33. ssm** A distant galaxy is simultaneously rotating and receding from the earth. As the drawing shows, the galactic center is receding from the earth at a relative speed of $u_G = 1.6 \times 10^{6}$ m/s. Relative to the center, the tangential speed is $v_T = 0.4 \times 10^{6}$ m/s for locations A and B, which are equidistant from the center. When the frequencies of the light coming from regions A and B are measured on earth, they are not the same and each is different from the emitted frequency of 6.200×10^{14} Hz. Find the measured frequency for the light from (a) region A and (b) region B.

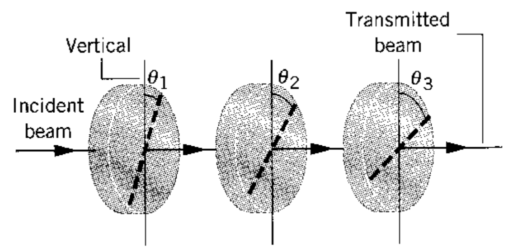


Section 24.6 Polarization

34. Unpolarized light whose intensity is 1.10 W/m² is incident on the polarizer in Figure 24.20. (a) What is the intensity of the light leaving the polarizer? (b) If the analyzer is set at an angle of $\theta = 75°$ with respect to the polarizer, what is the intensity of the light that reaches the photocell?

35. ssm Linearly polarized light is incident on a piece of polarizing material. What is the ratio of the transmitted light intensity to the incident light intensity when the angle between the transmission axis and the incident electric field is (a) 25° and (b) 65°?

36. For each of the three sheets of polarizing material shown in the drawing, the orientation of the transmission axis is labeled relative to the vertical. The incident beam of light is unpolarized and has an intensity of 1260.0 W/m². What is the intensity of the beam transmitted through the three sheets when $\theta_1 = 19.0°$, $\theta_2 = 55.0°$, and $\theta_3 = 100.0°$?



37. Polarized light strikes a piece of polarizing material. The incident light is polarized at an angle of 38° relative to the transmission axis of the material. What percentage of the light intensity is transmitted?

38. Review Conceptual Example 8 before solving this problem. Suppose unpolarized light of intensity 150 W/m² falls on the polarizer in Figure 24.22*a*, and the angle θ in the drawing is 30.0°. What is the light intensity reaching the photocell?

* **39. ssm www** More than one analyzer can be used in a setup like that in Figure 24.20, each analyzer following the previous one. Suppose that the transmission axis of the first analyzer is rotated 27° relative to the transmission axis of the polarizer, and that the transmission axis of each additional analyzer is rotated 27° relative to the transmission axis of the previous one. What is the minimum number of analyzers needed, so the light reaching the photocell has an intensity that is reduced by at least a factor of one hundred relative to that striking the first analyzer?

* **40.** Before attempting this problem, review Conceptual Example 8. The intensity of the light that reaches the photocell in Figure 24.22*a* is 110 W/m², when $\theta = 23°$. What would be the intensity reaching the photocell if the *analyzer* were removed from the setup, everything else remaining the same?

ADDITIONAL PROBLEMS

41. Some of the X-rays produced in an X-ray machine have a wavelength of 2.1 nm. What is the frequency of these electromagnetic waves?

42. A laser emits a narrow beam of light. The radius of the beam is 1.0×10^{-3} m, and the power is 1.2×10^{-3} W. What is the intensity of the laser beam?

43. ssm www The distance between earth and the moon can be determined from the time it takes for a laser beam to travel from earth to a reflector on the moon and back. If the round-trip time can be measured to an accuracy of one-tenth of a nanosecond (1 ns = 10^{-9} s), what is the corresponding error in the earth–moon distance?

44. On a cloudless day, the sunlight that reaches the surface of the earth has an average intensity of about 1.0×10^3 W/m^2. What is the average electromagnetic energy contained in 5.5 m^3 of space just above the earth's surface?

45. The intensity of sunlight at the top of the earth's atmosphere is about 1390 W/m^2. The distance between the sun and earth is 1.50×10^{11} m, while that between the sun and Mars is 2.28×10^{11} m. What is the intensity of sunlight at the surface of Mars?

46. A radio station broadcasts a radio wave whose wavelength is 274 m. (a) What is the frequency of the wave? (b) Is this radio wave AM or FM? (See Figure 24.9.)

47. ssm In the polarizer/analyzer combination in Figure 24.20, 90.0% of the light intensity falling on the analyzer is absorbed. Determine the angle between the transmission axes of the polarizer and the analyzer.

48. Suppose that the police car in Example 6 is moving to the right at 27 m/s, while the speeder is coming up from behind at a speed of 39 m/s, both speeds being with respect to the ground. Assume that the electromagnetic wave emitted by the radar gun has a frequency of 8.0×10^9 Hz. (a) Find the magnitude of the difference between the frequency of the emitted wave and the wave that returns to the police car after reflecting from the speeder's car. (b) Which wave has the greater frequency? Why?

***49.** In a traveling electromagnetic wave, the electric field is represented mathematically as

$$E = E_0 \sin [(1.5 \times 10^{10}\ \mathrm{s}^{-1})\, t - (5.0 \times 10^1\ \mathrm{m}^{-1})\, x]$$

where E_0 is the maximum field strength. (a) What is the frequency of the wave? (b) This wave and the wave that results from its reflection can form a standing wave, in a way similar to that in which standing waves can arise on a string (see Section 17.5). What is the separation between adjacent nodes in the standing wave?

***50.** A beam of polarized light has an average intensity of 15 W/m^2 and is sent through a polarizer. The transmission axis makes an angle of 25° with respect to the direction of polarization. Determine the rms value of the electric field of the transmitted beam.

***51. ssm** The mean distance between earth and the sun is 1.50×10^{11} m. The average intensity of solar radiation incident on the upper atmosphere of the earth is 1390 W/m^2. Assuming the sun emits radiation uniformly in all directions, determine the total power radiated by the sun.

***52.** An argon-ion laser produces a cylindrical beam of light whose average power is 0.750 W. How much energy is contained in a 2.50-m length of the beam?

***53.** A tiny source of light emits light uniformly in all directions. The average power emitted is 60.0 W. For a point located 8.00 m away from this source, determine the rms (a) electric and (b) magnetic field strengths in the light waves.

****54.** Suppose that the light falling on the polarizer in Figure 24.20 is partially polarized (average intensity = $\overline{S}_P$) and partially unpolarized (average intensity = $\overline{S}_U$). The total incident intensity is $\overline{S}_P + \overline{S}_U$, and the percentage polarization is $100\overline{S}_P/(\overline{S}_P + \overline{S}_U)$. When the polarizer is rotated in such a situation, the intensity reaching the photocell varies between a minimum value of $\overline{S}_{min}$ and a maximum value of $\overline{S}_{max}$. Show that the percentage polarization can be expressed as $100(\overline{S}_{max} - \overline{S}_{min})/(\overline{S}_{max} + \overline{S}_{min})$.

CONCEPTS & CALCULATIONS

GROUP LEARNING PROBLEMS

Note: Each of these problems consists of Concept Questions followed by a related quantitative Problem. They are designed for use by students working alone or in small learning groups. The Concept Questions involve little or no mathematics and are intended to stimulate group discussions. They focus on the concepts with which the problems deal. Recognizing the concepts is the essential initial step in any problem-solving technique.

55. Concept Questions A certain type of laser puts out light of known frequency. The light, however, occurs as a series of short pulses, each lasting for a time t_0. (a) How is the wavelength of the light related to its frequency? (b) How is the length (in meters) of each pulse related to the time t_0?

Problem A laser puts out a pulse of light that lasts for 2.7×10^{-11} s. The frequency of the light is 5.2×10^{14} Hz. (a) How many wavelengths are there in one pulse? (b) The light enters a pool of water. Its frequency remains the same, but the light slows down to a speed of 2.3×10^8 m/s. How many wavelengths are there now in one pulse?

56. Concept Questions (a) Suppose that the magnitude E of the electric field in an electromagnetic wave triples. By what factor does the intensity S of the wave change? (b) The magnitude B of the magnetic field is much smaller than E, because, according to Equation 24.3, $B = E/c$, where c is the speed of light in a vacuum. If B triples, by what factor does the intensity change? Account for your answers.

Problem The magnitude of the electric field of an electromagnetic field increases from 315 to 945 N/C. (a) Determine the intensities for the two values of the electric field. (b) What is the magnitude of the magnetic field associated with each electric field? (c) Determine the intensity for each value of the magnetic field. Make sure your answers are consistent with your answers to the Concept Questions.

57. Concept Questions A source is radiating light waves uniformly in all directions. At a certain distance r from the source a person measures the average intensity of the waves. (a) Does the average intensity increase, decrease, or remain the same as r increases? (b) If the magnitude of the electric field is determined from the average intensity, is the electric field the rms value or the peak value? In both cases, justify your answers.

Problem A light bulb emits light uniformly in all directions. The emitted power is 150.0 W. At a distance of 5.00 m from the bulb, what are (a) the average intensity and the magnitudes of the (b) rms and (c) peak electric fields?

58. Concept Questions An electric charge is placed in a laser beam. Does a stationary charge experience a force due to (a) the electric field and (b) the magnetic field of the electromagnetic wave? Now suppose that the charge is moving perpendicular to the magnetic field of the beam. Does it experience (c) an electric force and (d) a magnetic force? Account for your answers.

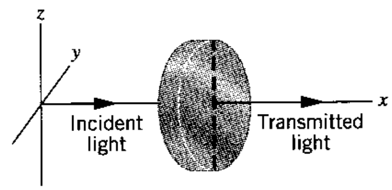
Problem A stationary particle of charge $q = 2.6 \times 10^{-8}$ C is placed in a laser beam whose intensity is 2.5×10^3 W/m^2. Determine the magnitude of the (a) electric and (b) magnetic forces exerted on the charge. If the charge is moving perpendicular to the magnetic field with a speed of 3.7×10^4 m/s, find the magnitudes of the (c) electric and (d) magnetic forces exerted on it. Verify that your answers are consistent with your answers to the Concept Questions.

59. Concept Questions The drawing shows light incident on a polarizer whose transmission axis is parallel to the z axis. The polarizer is rotated clockwise through an angle α between 0 and 90°. While the polarizer is being rotated, does the intensity of the transmitted light increase, decrease, or remain the same if the incident light is (a) unpolarized, (b) polarized parallel to the z axis, and (c) polarized parallel to the y axis? Provide a reason for each of your answers.

Problem The intensity of the incident light is 7.0 W/m^2. Determine the intensity of the transmitted light for each of the six cases shown in the table.

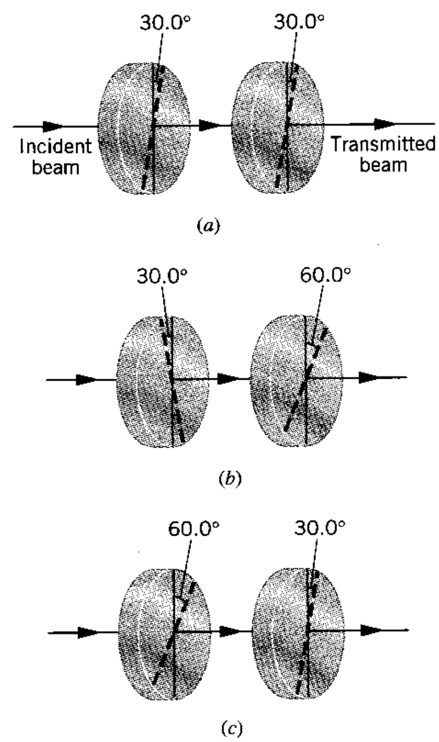
	Intensity of Transmitted Light	
Incident Light	$\alpha = 0°$	$\alpha = 35°$
Unpolarized		
Polarized parallel to z axis		
Polarized parallel to y axis		

Be sure that your answers are consistent with your answers to the Concept Questions.



60. Concept Question The drawing shows three polarizer/analyzer pairs. The incident light on each pair is unpolarized and has the same intensity. Rank the pairs according to the intensity of the transmitted light, largest first. Provide reasons for your answers.

Problem The intensity of the unpolarized incident beam is 48 W/m^2. Find the intensity of the transmitted beams for each of the three cases shown in the drawing. Be sure your answers are consistent with your answer to the Concept Question.

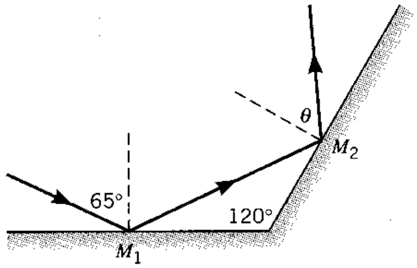


PROBLEMS

ssm **Solution is in the Student Solutions Manual.** **www** **Solution is available on the World Wide Web at http://www.wiley.com/college/cutnell**
This icon represents a biomedical application.

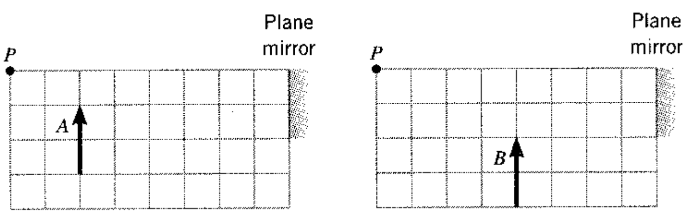
Section 25.2 The Reflection of Light, Section 25.3 The Formation of Images by a Plane Mirror

1. **ssm** Two plane mirrors are separated by 120°, as the drawing illustrates. If a ray strikes mirror M_1 at a 65° angle of incidence, at what angle θ does it leave mirror M_2?



Problem 1

2. Review Conceptual Example 1 as an aid in understanding this problem. The drawings show two arrows, *A* and *B*, that are located in front of a plane mirror. A person at point *P* is viewing the image of each arrow. Which images can be seen in their entirety? Determine your answers by drawing a ray from the head and foot of each arrow that reflects from the mirror according to the law of reflection and reaches point *P*. Only if *both* rays reach point *P* after reflection can the image of that arrow be seen in its entirety.



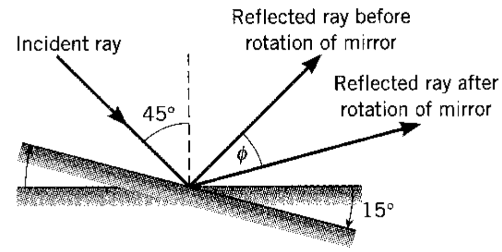
3. A person stands 3.6 m in front of a wall that is covered floor-to-ceiling with a plane mirror. His eyes are 1.8 m above the floor. He holds a flashlight between his feet and manages to point it at the mirror. At what angle of incidence must the light strike the mirror so the light will reach his eyes?

4. Review Conceptual Example 2. Suppose that in Figure 25.9*b* the two perpendicular plane mirrors are represented by the $-x$ and $-y$ axes of an x, y coordinate system. An object is in front of these mirrors at a point whose coordinates are $x = -2.0$ m and $y = -1.0$ m. Find the coordinates that locate each of the three images.

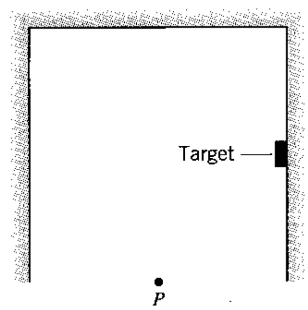
5. **ssm** **www** Two diverging light rays, originating from the same point, have an angle of 10° between them. After the rays reflect from a plane mirror, what is the angle between them? Construct one possible ray diagram that supports your answer.

6. On the $+y$ axis a laser is located at $y = +3.0$ cm. The coordinates of a target are $x = +9.0$ cm and $y = +6.0$ cm. The $+x$ axis represents the edge-on view of a mirror. At what point on the $+x$ axis should the laser be aimed in order to hit the target after reflection?

***7.** A ray of light strikes a plane mirror at a 45° angle of incidence. The mirror is then rotated by 15° into the position shown in red in the drawing, while the incident ray is kept fixed. (a) Through what angle ϕ does the reflected ray rotate? (b) What is the answer to part (a) if the angle of incidence is 60° instead of 45°?



***8.** The drawing shows a top view of a square room. One wall is missing, and the other three are each mirrors. From point *P* in the center of the open side, a laser is fired, with the intent of hitting a small target located at the center of one wall. Identify five directions in which the laser can be fired and score a hit, assuming that the light does not strike any mirror more than once. Draw the rays to confirm your choices.



****9.** **ssm** A lamp is twice as far in front of a plane mirror as a person is. Light from the lamp reaches the person via two paths. It strikes the mirror at a 30.0° angle of incidence and reflects from it before reaching the person. It also travels directly to the person without reflecting. Find the ratio of the travel time along the reflected path to the travel time along the direct path.

Section 25.4 Spherical Mirrors, Section 25.5 The Formation of Images by Spherical Mirrors

10. A 2.0-cm-high object is situated 15.0 cm in front of a concave mirror that has a radius of curvature of 10.0 cm. Using a ray diagram drawn to scale, measure (a) the location and (b) the height of the image. The mirror must be drawn to scale.

11. Repeat problem 10 for a concave mirror with a focal length of 20.0 cm, an object distance of 12.0 cm, and a 2.0-cm-high object.

12. A convex mirror has a focal length of −40.0 cm. A 12.0-cm-tall object is located 40.0 cm in front of this mirror. Using a ray diagram drawn to scale, determine the (a) location and (b) size of the image. Note that the mirror must be drawn to scale.

13. **ssm** Repeat problem 10 for a convex mirror with a radius of curvature of 1.00×10^2 cm, an object distance of 25.0 cm, and a 10.0-cm-high object.

14. Repeat problem 10 for a concave mirror with a focal length of 7.50 cm, an object distance of 11.0 cm, and a 1.0-cm-high object.

***15.** A plane mirror and a concave mirror (f = 8.0 cm) are facing each other and are separated by a distance of 20.0 cm. An object is placed 10.0 cm in front of the plane mirror. Consider the light from the object that reflects first from the plane mirror and then from the concave mirror. Using a ray diagram drawn to scale, find the location of the image that this light produces in the concave mirror. Specify this distance relative to the concave mirror.

Section 25.6 The Mirror Equation and the Magnification Equation

16. A coin is placed 8.0 cm in front of a concave mirror. The mirror produces a real image that has a diameter 4.0 times larger than that of the coin. What is the image distance?

17. ssm A concave mirror has a focal length of 42 cm. The image formed by this mirror is 97 cm in front of the mirror. What is the object distance?

18. A clown is using a concave makeup mirror to get ready for a show and is 27 cm in front of the mirror. The image is 65 cm *behind* the mirror. Find (a) the focal length of the mirror and (b) the magnification.

19. A concave mirror (R = 64.0 cm) is used to project a transparent slide onto a wall. The slide is located at a distance of 38.0 cm from the mirror, and a small flashlight shines light through the slide and onto the mirror. The setup is similar to that in Figure 25.19*a*. (a) How far from the wall should the mirror be located? (b) The height of the object on the slide is 1.20 cm. What is the height of the image? (c) How should the slide be oriented, so that the picture on the wall looks normal?

20. An object that is 25 cm in front of a convex mirror has an image located 17 cm behind the mirror. How far behind the mirror is the image located when the object is 19 cm in front of the mirror?

21. ssm The image behind a convex mirror (radius of curvature = 68 cm) is located 22 cm from the mirror. (a) Where is the object located and (b) what is the magnification of the mirror? Determine whether the image is (c) upright or inverted and (d) larger or smaller than the object.

22. A convex mirror produces an image that is half the size of an object that is placed 13 cm in front of it. What is the focal length of the mirror?

23. ssm www A small postage stamp is placed in front of a concave mirror (radius = R), such that the image distance equals the object distance. (a) In terms of R, what is the object distance? (b) What is the magnification of the mirror? (c) State whether the image is upright or inverted relative to the object. Draw a ray diagram to guide your thinking.

***24.** A dentist's mirror is placed 2.0 cm from a tooth. The *enlarged* image is located 5.6 cm behind the mirror. (a) What kind of mirror (plane, concave, or convex) is being used? (b) Determine the focal length of the mirror. (c) What is the magnification? (d) How is the image oriented relative to the object?

***25.** An object is placed in front of a convex mirror, and the size of the image is one-third that of the object. What is the ratio d_o/f of the object distance to the focal length of the mirror?

***26.** The same object is located at the same distance from two spherical mirrors, A and B. The magnifications produced by the mirrors are m_A = 4.0 and m_B = 2.0. Find the ratio f_A/f_B of the focal lengths of the mirrors.

***27. ssm www** An image formed by a convex mirror (f = −24.0 cm) has a magnification of 0.150. Which way and by how much should the object be moved to double the size of the image?

****28.** A concave mirror has a focal length of 30.0 cm. The distance between an object and its image is 45.0 cm. Find the object and image distances assuming that (a) the object lies beyond the center of curvature and (b) the object lies within the focal point.

****29.** Using the mirror equation and the magnification equation, show that for a convex mirror the image is always (a) virtual (i.e., d_i is always negative) and (b) upright and smaller, relative to the object (i.e., m is positive and less than one).

ADDITIONAL PROBLEMS

30. The image of a very distant car is located 12 cm behind a convex mirror. (a) What is the radius of curvature of the mirror? (b) Draw a ray diagram to scale showing this situation.

31. ssm www When viewed in a spherical mirror, the image of a setting sun is a virtual image. The image lies 12.0 cm behind the mirror. (a) Is the mirror concave or convex? Why? (b) What is the radius of curvature of the mirror?

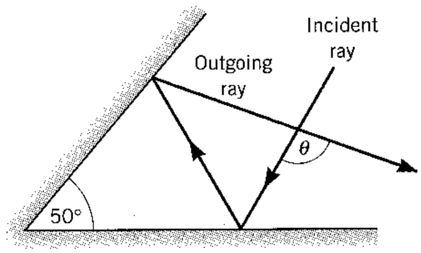
32. Review Conceptual Example 1 before attempting this problem. A person whose eyes are 1.70 m above the floor stands in front of a plane mirror. The top of her head is 0.12 m above her eyes. (a) What is the height of the shortest mirror in which she can see her entire image? (b) How far above the floor should the bottom edge of the mirror be placed?

33. The focal length of a concave mirror is 17 cm. An object is located 38 cm in front of this mirror. Where is the image located?

34. Convex mirrors are being used to monitor the aisles in a store. The mirrors have a radius of curvature of 4.0 m. (a) What is the image distance if a customer is 15 m in front of the mirror? (b) Is the image real or virtual? (c) If a customer is 1.6 m tall, how tall is the image?

35. ssm The image produced by a concave mirror is located 26 cm in front of the mirror. The focal length of the mirror is 12 cm. How far in front of the mirror is the object located?

***36.** The drawing shows two plane mirrors that intersect at an angle of 50°. An incident light ray reflects from one mirror and then the other. What is the angle θ between the incident and outgoing rays?



*37. In Figure 25.21*b* the head-up display is designed so that the distance between the digital readout device and virtual image 1 is 2.00 m. The magnification of virtual image 1 is 4.00. Find the focal length of the concave mirror. *(Hint: Remember that the image distance for virtual image 1 is a negative quantity.)*

*38. A candle is placed 15.0 cm in front of a convex mirror. When the convex mirror is replaced with a plane mirror, the image moves 7.0 cm farther away from the mirror. Find the focal length of the convex mirror.

*39. **ssm** An object is located 14.0 cm in front of a convex mirror, the image being 7.00 cm behind the mirror. A second object, twice as tall as the first one, is placed in front of the mirror, but at a different location. The image of this second object has the same height as the other image. How far in front of the mirror is the second object located?

**40. A spherical mirror is polished on both sides. When used as a convex mirror, the magnification is +1/4. What is the magnification when used as a concave mirror, the object remaining the same distance from the mirror?

**41. In the drawing for problem 8, a laser is fired from point *P* in the center of the open side of the square room. The laser is pointed at the mirrored wall on the right. At what angle of incidence must the light strike the right-hand wall, so that after being reflected, the light hits the left corner of the back wall?

CONCEPTS & CALCULATIONS
GROUP LEARNING PROBLEMS

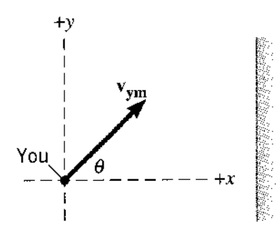
Note: Each of these problems consists of Concept Questions followed by a related quantitative Problem. They are designed for use by students working alone or in small learning groups. The Concept Questions involve little or no mathematics and are intended to stimulate group discussions. They focus on the concepts with which the problems deal. Recognizing the concepts is the essential initial step in any problem-solving technique.

42. Concept Questions (a) Suppose that you are walking toward a stationary plane mirror. Following the method discussed in Section 3.4, express your image's velocity $\mathbf{v}_{IY}$ relative to you in terms of the image's velocity $\mathbf{v}_{IM}$ relative to the mirror and the mirror's velocity $\mathbf{v}_{MY}$ relative to you. (b) How is the mirror's velocity $\mathbf{v}_{MY}$ relative to you related to your velocity $\mathbf{v}_{YM}$ relative to the mirror? Explain. (c) Consider both velocities $\mathbf{v}_{YM}$ and $\mathbf{v}_{IM}$. Do they have the same magnitudes and the same directions? Explain.

Problem When you walk perpendicularly toward a stationary plane mirror with a velocity of +0.90 m/s, what is the velocity of your image relative to you? The direction in which you walk is the positive direction.

43. Concept Questions (a) Suppose that you are walking toward a plane mirror as in the drawing. The view is from above. Following the method discussed in Section 3.4, express your image's velocity $\mathbf{v}_{IY}$ relative to you in terms of the image's velocity $\mathbf{v}_{IM}$ relative to the mirror and the mirror's velocity $\mathbf{v}_{MY}$ relative to you. (b) How is the mirror's velocity $\mathbf{v}_{MY}$ relative to you related to your velocity $\mathbf{v}_{YM}$ relative to the mirror? Explain. (c) Consider both velocities $\mathbf{v}_{YM}$ and $\mathbf{v}_{IM}$. Do they have the same x and y components? Explain.

Problem You walk at an angle of $\theta = 50.0°$ toward a plane mirror, as in the drawing. Your walking velocity has a magnitude of 0.90 m/s. What is the velocity of your image relative to you (magnitude and direction)?



Problem 43

44. Concept Questions (a) For an image that is in front of a mirror, is the image distance positive or negative? (b) Given the image distance, what additional information is needed to determine the focal length? Explain. (c) For an inverted image is the image height positive or negative? (d) Given the object and image heights and a statement as to whether the image is upright or inverted, what additional information is needed to determine the object distance?

Problem A small statue has a height of 3.5 cm and is placed in front of a concave mirror. The image of the statue is inverted, 1.5 cm tall, and is located 13 cm in front of the mirror. Find the focal length of the mirror.

45. Concept Questions These questions refer to Figure 25.22*a*. (a) As the object distance increases, does reflected ray 1 change? (b) As the object distance increases, does reflected ray 3 make a greater or smaller angle with respect to the principal axis? (c) Extending the reflected rays 1 and 3 behind the mirror allows us to locate the top of the image. As the object distance increases, does the image height increase or decrease?

Problem A convex mirror has a focal length of −27.0 cm. Find the magnification produced by the mirror when the object distance is 9.0 cm and 18.0 cm. Verify that your answers are consistent with your answers to the Concept Questions.

24. Suppose that a 21-year-old with normal vision (near point = 25 cm) is standing in front of a plane mirror. How close can he stand to the mirror and still see himself in focus? Explain.

25. ⚕ If we read for a long time, our eyes become "tired." When this happens, it helps to stop reading and look at a distant object. From the point of view of the ciliary muscle, why does this refresh the eyes?

26. To a swimmer under water, objects look blurred and out of focus. However, when the swimmer wears goggles that keep the water away from the eyes, the objects appear sharp and in focus. Why do goggles improve a swimmer's underwater vision?

27. ⚕ The refractive power of the lens of the eye is 15 diopters when surrounded by the aqueous and vitreous humors. If this lens is removed from the eye and surrounded by air, its refractive power increases to about 150 diopters. Why is the refractive power of the lens so much greater outside the eye?

28. The light shining through a full glass of wine forms an irregularly shaped bright spot on the table, but does not do so when the glass is empty. Explain.

29. Jupiter is the largest planet in our solar system. Yet, to the naked eye, it looks smaller than Venus. Why?

30. By means of a ray diagram, show that the eyes of a person wearing glasses appear to be (a) smaller when the glasses use diverging lenses to correct for nearsightedness and (b) larger when the glasses use converging lenses to correct for farsightedness.

31. Can a diverging lens be used as a magnifying glass? Justify your answer with a ray diagram.

32. Who benefits more from using a magnifying glass, a person whose near point is located 25 cm away from the eyes or a person whose near point is located 75 cm away from the eyes? Provide a reason for your answer.

33. Two lenses, whose focal lengths are 3.0 and 45 cm, are used to build a telescope. Which lens should be the objective? Why?

34. Two refracting telescopes have identical eyepieces, although one telescope is twice as long as the other. Which has the greater angular magnification? Provide a reason for your answer.

35. Suppose a well-designed optical instrument is composed of two converging lenses separated by 14 cm. The focal lengths of the lenses are 0.60 and 4.5 cm. Is the instrument a microscope or a telescope? Why?

36. It is often thought that virtual images are somehow less important than real images. To show that this is not true, identify which of the following instruments normally produce final images that are virtual: (a) a projector, (b) a camera, (c) a magnifying glass, (d) eyeglasses, (e) a compound microscope, and (f) an astronomical telescope.

37. Why does chromatic aberration occur in lenses, but not in mirrors?

PROBLEMS

Unless specified otherwise, use the values given in Table 26.1 for the refractive indices.

ssm Solution is in the Student Solutions Manual. www Solution is available on the World Wide Web at http://www.wiley.com/college/cutnell
⚕ This icon represents a biomedical application.

Section 26.1 The Index of Refraction

1. ssm What is the speed of light in benzene?

2. Find the ratio of the speed of light in diamond to the speed of light in ice.

3. The frequency of a light wave is the same when the light travels in ethyl alcohol as it is when it travels in carbon disulfide. Find the ratio of the wavelength of the light in ethyl alcohol to that in carbon disulfide.

4. Light has a wavelength of 340.0 nm and a frequency of 5.403×10^{14} Hz when traveling through a certain substance. What substance from Table 26.1 could this be?

5. ssm www A glass window ($n = 1.5$) has a thickness of 4.0×10^{-3} m. How long does it take light to pass perpendicularly through the plate?

6. The speed of light is 1.25 times as large in material A than in material B. Determine the ratio n_A/n_B of the refractive indices of these materials.

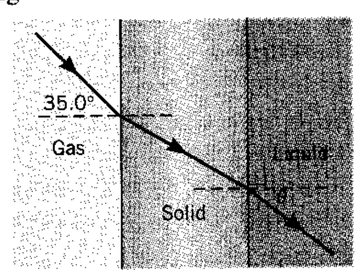
***7.** In a certain time, light travels 3.50 km in a vacuum. During the same time, light travels only 2.50 km in a liquid. What is the refractive index of the liquid?

***8.** A flat sheet of ice has a thickness of 2.0 cm. It is on top of a flat sheet of crystalline quartz that has a thickness of 1.1 cm. Light strikes the ice perpendicularly and travels through it and then through the quartz. In the time it takes the light to travel through the two sheets, how far (in cm) would it have traveled in a vacuum?

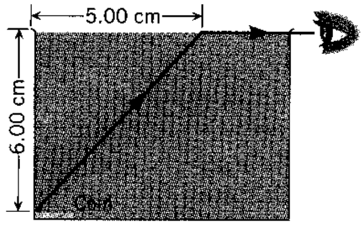
Section 26.2 Snell's Law and the Refraction of Light

9. ssm A beam of light is traveling in air and strikes a material. The angles of incidence and refraction are 63.0° and 47.0°, respectively. Obtain the speed of light in the material.

10. Refer to Conceptual Example 7 as an aid in understanding this problem. The drawing shows a ray of light traveling through a gas ($n = 1.00$), a solid ($n = 1.55$), and a liquid ($n = 1.55$). At what angle θ does the light enter the liquid?



11. ssm The drawing shows a coin resting on the bottom of a beaker filled with an unknown liquid. A ray of light from the coin travels to the surface of the liquid and is refracted as it enters into the air. A person sees the ray as it skims just above the surface of the liquid. How fast is the light traveling in the liquid?



12. As an aid in understanding this problem, refer to Conceptual Example 4. A swimmer, who is looking up from under the water, sees a diving board directly above at an apparent height of 4.0 m above the water. What is the actual height of the diving board?

13. A layer of oil (n = 1.45) floats on an unknown liquid. A ray of light shines from the oil into the unknown liquid. The angles of incidence and refraction are, respectively, 65.0° and 53.0°. What is the index of refraction of the unknown liquid?

14. Light in a vacuum is incident on a transparent glass slab. The angle of incidence is 35.0°. The slab is then immersed in a pool of liquid. When the angle of incidence for the light striking the slab is 20.3°, the angle of refraction for the light entering the slab is the same as when the slab was in a vacuum. What is the index of refraction of the liquid?

***15.** **ssm** **www** In Figure 26.7, suppose that the angle of incidence is θ_1 = 30.0°, the thickness of the glass pane is 6.00 mm, and the refractive index of the glass is n_2 = 1.52. Find the amount (in mm) by which the emergent ray is displaced relative to the incident ray.

16. A ray of sunlight hits a frozen lake at a 45° angle of incidence. At what angle of refraction does the ray penetrate (a) the ice and (b) the water beneath the ice?

***17.** Refer to Figure 26.5*a* and assume the observer is nearly above the submerged object. For this situation, derive the expression for the apparent depth: $d' = d(n_2/n_1)$, Equation 26.3. *(Hint: Use Snell's law of refraction and the fact that the angles of incidence and refraction are small, so tan $\theta \approx$ sin θ.)*

***18.** Review Conceptual Example 4 as background for this problem. A man in a boat is looking straight down at a fish in the water directly beneath him. The fish is looking straight up at the man. They are equidistant from the air/water interface. To the man, the fish appears to be 2.0 m beneath his eyes. To the fish, how far above its eyes does the man appear to be?

***19.** A silver medallion is sealed within a transparent block of plastic. An observer in air, viewing the medallion from directly above, sees the medallion at an apparent depth of 1.6 cm beneath the top surface of the block. How far below the top surface would the medallion appear if the observer (not wearing goggles) and the block were under water?

****20.** A beaker has a height of 30.0 cm. The lower half of the beaker is filled with water, and the upper half is filled with oil (n = 1.48). To a person looking down into the beaker from above, what is the apparent depth of the bottom?

****21.** **ssm** A small logo is embedded in a thick block of crown glass (n = 1.52), 3.20 cm beneath the top surface of the glass. The block is put under water, so there is 1.50 cm of water above the top surface of the block. The logo is viewed from directly above by an observer in air. How far beneath the top surface of the water does the logo appear to be?

****22.** The back wall of a home aquarium is a mirror that is 30.0 cm away from the front wall. The walls of the tank are negligibly thin. A fish is swimming midway between the front and back walls. (a) How far from the front wall does the fish seem to be located? (b) An image of the fish appears behind the mirror. How far does this image appear to be from the front wall of the aquarium? (c) Would the refractive index of the liquid have to be larger or smaller in order for the image of the fish to appear in *front* of the mirror, rather than behind it? Why?

Section 26.3 Total Internal Reflection

23. **ssm** One method of determining the refractive index of a transparent solid is to measure the critical angle when the solid is in air. If θ_c is found to be 40.5°, what is the index of refraction of the solid?

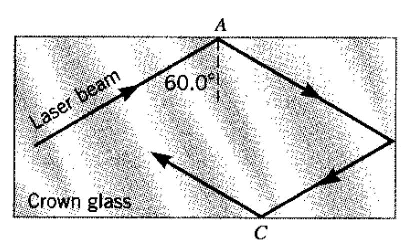
24. What is the critical angle for light emerging from carbon disulfide into air?

25. A ray of light is traveling in glass and strikes a glass/liquid interface. The angle of incidence is 58.0°, and the index of refraction of glass is n = 1.50. (a) What must be the index of refraction of the liquid such that the direction of the light entering the liquid is not changed? (b) What is the largest index of refraction that the liquid can have, such that none of the light is transmitted into the liquid and all of it is reflected back into the glass?

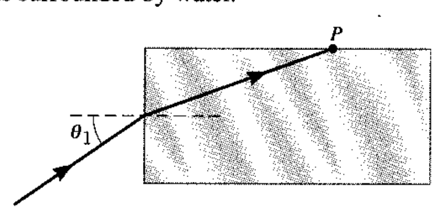
26. A point source of light is submerged 2.2 m below the surface of a lake and emits rays in all directions. On the surface of the lake, directly above the source, the area illuminated is a circle. What is the maximum radius that this circle could have?

27. **ssm** A person is sitting in a small boat in the ocean. A shark is swimming under water at a depth of 4.5 m. When the shark is beyond a certain distance (measured horizontally) from the boat, the shark cannot be seen. Assume that the person's eyes are very near the surface of the water and find that distance.

28. The drawing shows a crown glass slab with a rectangular cross section. As illustrated, a laser beam strikes the upper surface at an angle of 60.0°. After reflecting from the upper surface, the beam reflects from the side and bottom surfaces. (a) If the glass is surrounded by air, determine where part of the beam first exits the glass, at point A, B, or C. (b) Repeat part (a), assuming that the glass is surrounded by water.

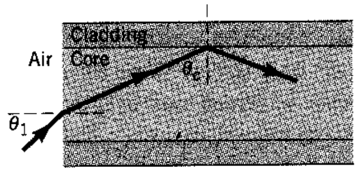


***29.** The drawing shows a crystalline quartz slab with a rectangular cross section. A ray of light strikes the slab at an incident angle of θ_1 =



34°, enters the quartz, and travels to point P. This slab is surrounded by a fluid with a refractive index n. What is the maximum value of n such that total internal reflection occurs at point P?

***30.** The drawing shows an optical fiber that consists of a core made of flint glass ($n_{\text{flint}} = 1.667$) surrounded by a cladding made of crown glass ($n_{\text{crown}} = 1.523$). A beam of light enters the fiber from air at an angle θ_1 with respect to the normal. What is θ_1 if the light strikes the core-cladding interface at the critical angle θ_c?



Section 26.4 Polarization and the Reflection and Refraction of Light

31. ssm Light is reflected from a glass coffee table. When the angle of incidence is 56.7°, the reflected light is completely polarized parallel to the surface of the glass. What is the index of refraction of the glass?

32. For light that originates within a liquid and strikes the liquid/air interface, the critical angle is 39°. What is Brewster's angle for this light?

33. At what angle of incidence is sunlight completely polarized upon being reflected from the surface of a lake (a) in the summer and (b) in the winter when the water is frozen?

34. Light is incident from air onto a beaker of carbon tetrachloride. If the reflected light is 100% polarized, what is the angle of refraction of the light that penetrates into the carbon tetrachloride?

35. ssm www When light strikes the surface between two materials from above, the Brewster angle is 65.0°. What is the Brewster angle when the light encounters the same surface from below?

***36.** When red light in a vacuum is incident at the Brewster angle on a certain type of glass, the angle of refraction is 29.9°. What are (a) the Brewster angle and (b) the index of refraction of the glass?

***37.** In Section 26.4 it is mentioned that the reflected and refracted rays are perpendicular to each other when light strikes the surface at the Brewster angle. This is equivalent to saying that the angle of reflection plus the angle of refraction is 90°. Using Snell's law and Brewster's law, prove that the angle of reflection plus the angle of refraction is 90°.

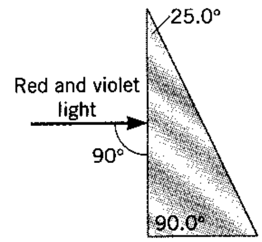
Section 26.5 The Dispersion of Light: Prisms and Rainbows

38. Yellow light ($n = 2.417$) strikes a diamond at a 45.0° angle of incidence and is refracted when it enters the diamond. Blue light ($n = 1.684$) strikes a piece of flint glass and has the same angle of refraction as does the yellow light in the diamond. What is the angle of incidence of the blue light?

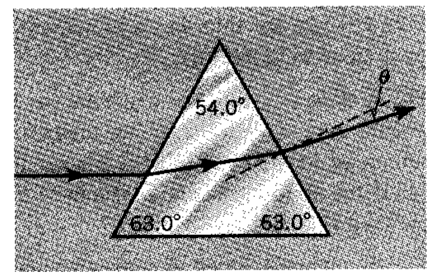
39. ssm A beam of sunlight encounters a plate of crown glass at a 45.00° angle of incidence. Using the data in Table 26.2, find the angle between the violet ray and the red ray in the glass.

40. A ray of sunlight is passing from diamond into crown glass; the angle of incidence is 35.00°. The indices of refraction for the blue and red components of the ray are: blue ($n_{\text{diamond}} = 2.444$, $n_{\text{crown glass}} = 1.531$), and red ($n_{\text{diamond}} = 2.410$, $n_{\text{crown glass}} = 1.520$). Determine the angle between the refracted blue and red rays in the crown glass.

41. Horizontal rays of red light (λ = 660 nm, in vacuum) and violet light (λ = 410 nm, in vacuum) are incident on the flint-glass prism shown in the drawing. The indices of refraction for the red and violet light are 1.662 and 1.698, respectively. What is the angle of refraction for each ray as it emerges from the prism?



***42.** Refer to Conceptual Example 7 as background material for this problem. The drawing shows a horizontal beam of light that is incident on an ice prism. The base of the prism is also horizontal. The prism ($n = 1.31$) is surrounded by oil whose index of refraction is 1.48. Determine the angle θ that the exiting light makes with the normal to the right face of the prism.



***43. ssm** This problem relates to Figure 26.18 which illustrates the dispersion of light by a prism. The prism is made from glass, and its cross section is an equilateral triangle. The indices of refraction for the red and violet light are 1.662 and 1.698, respectively. The angle of incidence for both the red and violet light is 60.0°. Find the angles of refraction at which the red and violet rays emerge into the air from the prism.

Section 26.6 Lenses, Section 26.7 The Formation of Images by Lenses, Section 26.8 The Thin-Lens Equation and the Magnification Equation

(Note: When drawing ray diagrams, be sure that the object height h_o is much smaller than the focal length f of the lens or mirror. This ensures that the rays are paraxial rays.)

44. When a diverging lens is held 13 cm above a line of print, as in Figure 26.29, the image is 5.0 cm beneath the lens. What is the focal length of the lens?

45. ssm A macroscopic (or macro) lens for a camera is usually a converging lens of normal focal length built into a lens barrel that can be adjusted to provide the additional lens-to-film distance needed when focusing at very close range. Suppose that a macro lens (f = 50.0 mm) has a maximum lens-to-film distance of 275 mm. How close can the object be located in front of the lens?

46. To focus a camera on objects at different distances, the converging lens is moved toward or away from the film, so a sharp image always falls on the film. A camera with a telephoto lens (f = 200.0 mm) is to be focused on an object located first at a distance of 3.5 m and then at 50.0 m. Over what distance must the lens be movable?

47. A diverging lens has a focal length of −25 cm. (a) Find the image distance when an object is placed 38 cm from the lens. (b) Is the image real or virtual?

48. A movie camera has a converging lens with a focal length of 85.0 mm. It takes a picture of a 145-cm tall person standing 16.0 m away. What is the height of the image on the film? Is the image upright or inverted relative to the object? Give your reasoning.

49. ssm An object is located 30.0 cm to the left of a converging lens whose focal length is 50.0 cm. (a) Draw a ray diagram to scale and from it determine the image distance and the magnification. (b) Use the thin-lens and magnification equations to verify your answers to part (a).

50. A slide projector has a converging lens whose focal length is 105.00 mm. (a) How far (in meters) from the lens must the screen be located if a slide is placed 108.00 mm from the lens? (b) If the slide measures 24.0 mm × 36.0 mm, what are the dimensions (in mm) of its image?

51. A camera is supplied with two interchangeable lenses, whose focal lengths are 35.0 and 150.0 mm. A woman whose height is 1.80 m stands 8.00 m in front of the camera. What is the height (including sign) of her image on the film, as produced by (a) the 35.0-mm lens and (b) the 150.0-mm lens?

52. The distance between an object and its image formed by a diverging lens is 6.0 cm. The focal length of the lens is −3.0 cm. Find (a) the image distance and (b) the object distance.

***53. ssm** An object is 18 cm in front of a diverging lens that has a focal length of −12 cm. How far in front of the lens should the object be placed so that the size of its image is reduced by a factor of 2.0?

***54.** When a converging lens is used in a camera (as in Figure 26.26*b*), the film must be placed at a distance of 0.210 m from the lens to record an image of an object that is 4.00 m from the lens. The same lens is then used in a projector (see Figure 26.27*b*), with the screen 0.500 m from the lens. How far from the projector lens should the film be placed?

***55. ssm www** The moon's diameter is 3.48×10^6 m, and its mean distance from the earth is 3.85×10^8 m. The moon is being photographed by a camera whose lens has a focal length of 50.0 mm. (a) Find the diameter of the moon's image on the slide film. (b) When the slide is projected onto a screen that is 15.0 m from the lens of the projector (f = 110.0 mm), what is the diameter of the moon's image on the screen?

***56.** From a distance of 72 m, a photographer uses a telephoto lens (f = 300.0 mm) to take a picture of a charging rhinoceros. How far from the rhinoceros would the photographer have to be to record an image of the same size using a lens whose focal length is 50.0 mm?

****57.** A converging lens (f = 25.0 cm) is used to project an image of an object onto a screen. The object and the screen are 125 cm apart, and between them the lens can be placed at either of two locations. Find the two object distances.

****58.** An object is 20.0 cm from a converging lens, and the image falls on a screen. When the object is moved 4.00 cm closer to the lens, the screen must be moved 2.70 cm farther away from the lens to register a sharp image. Determine the focal length of the lens.

Section 26.9 Lenses in Combination

59. ssm A converging lens (f = 12.0 cm) is located 30.0 cm to the left of a diverging lens (f = −6.00 cm). A postage stamp is placed 36.0 cm to the left of the converging lens. (a) Locate the final image of the stamp relative to the diverging lens. (b) Find the overall magnification. (c) Is the final image real or virtual? With respect to the original object, is the final image (d) upright or inverted, and is it (e) larger or smaller?

60. Two identical diverging lenses are separated by 16 cm. The focal length of each lens is −8.0 cm. An object is located 4.0 cm to the left of the lens that is on the left. Determine the final image distance relative to the lens on the right.

61. A converging lens has a focal length of 0.080 m. An object is located 0.040 m to the left of this lens. A second converging lens has the same focal length as the first one and is located 0.120 m to the right of it. Relative to the second lens, where is the final image located?

62. A converging lens (f_1 = 24.0 cm) is located 56.0 cm to the left of a diverging lens (f_2 = −28.0 cm). An object is placed to the left of the converging lens, and the final image produced by the two-lens combination lies 20.7 cm to the left of the diverging lens. How far is the object from the converging lens?

63. An object, 0.75 cm tall, is placed 12.0 cm to the left of a diverging lens (f = −8.00 cm). A converging lens is placed 8.00 cm to the right of the diverging lens. The final image is virtual and is 29.0 cm to the left of the diverging lens. Determine (a) the focal length of the converging lens and (b) the height of the final image.

***64.** A coin is located 20.0 cm to the left of a converging lens (f = 16.0 cm). A second, identical lens is placed to the right of the first lens, such that the image formed by the combination has the same size and orientation as the original coin. Find the separation between the lenses.

***65. ssm** An object is placed 20.0 cm to the left of a diverging lens (f = −8.00 cm). A concave mirror (f = 12.0 cm) is placed 30.0 cm to the right of the lens. (a) Find the final image distance, measured relative to the mirror. (b) Is the final image real or virtual? (c) Is the final image upright or inverted with respect to the original object?

****66.** Two converging lenses (f_1 = 9.00 cm and f_2 = 6.00 cm) are separated by 18.0 cm. The lens on the left has the longer focal length. An object stands 12.0 cm to the left of the left-hand lens in the combination. (a) Locate the final image relative to the lens on the right. (b) Obtain the overall magnification. (c) Is the final image real or virtual? With respect to the original object, is the final image (d) upright or inverted and is it (e) larger or smaller?

Section 26.10 The Human Eye

67. A farsighted person has a near point that is 48.0 cm from her eyes. She wears eyeglasses that are designed to enable her to read a newspaper held at a distance of 25.0 cm from her eyes. Find the focal length of the eyeglasses, assuming that they are worn (a) 2.0 cm from the eyes and (b) 3.0 cm from the eyes.

68. A woman can read the large print in a newspaper only when it is at a distance of 65 cm or more from her eyes. (a) Is she myopic or hyperopic? (b) What should be the refractive power of her glasses (worn 2.0 cm from the eyes), so she can read the newspaper at a distance of 25 cm from the eyes?

69. **ssm** A person has far points of 5.0 m from the right eye and 6.5 m from the left eye. Write a prescription for the refractive power of each corrective contact lens.

70. A student is reading a lecture written on a blackboard. The lenses in her eyes have a refractive power of 57.50 diopters, and the lens-to-retina distance is 1.750 cm. (a) How far (in meters) is the blackboard from her eyes? (b) If the writing on the blackboard is 5.00 cm high, what is the size of the image on her retina?

71. A nearsighted person cannot read a sign that is more than 5.2 m from his eyes. To deal with this problem, he wears contact lenses that do not correct his vision completely, but do allow him to read signs located up to distances of 12.0 m from his eyes. What is the focal length of the contacts?

72. A person holds a book 25 cm in front of the effective lens of her eye; the print in the book is 2.0 mm high. If the effective lens of the eye is located 1.7 cm from the retina, what is the size (including the sign) of the print image on the retina?

***73.** A nearsighted person wears contacts to correct for a far point that is only 3.62 m from his eyes. The near point of his unaided eyes is 25.0 cm from his eyes. If he does not remove the lenses when reading, how close can he hold a book and see it clearly?

****74.** Bill is farsighted and has a near point located 125 cm from his eyes. Anne is also farsighted, but her near point is 75.0 cm from her eyes. Both have glasses that correct their vision to a normal near point (25.0 cm from the eyes), and both wear the glasses 2.0 cm from the eyes. Relative to the eyes, what is the closest object that can be seen clearly (a) by Anne when she wears Bill's glasses and (b) by Bill when he wears Anne's glasses?

****75.** The far point of a nearsighted person is 6.0 m from her eyes, and she wears contacts that enable her to see distant objects clearly. A tree is 18.0 m away and 2.0 m high. (a) When she looks through the contacts at the tree, what is its image distance? (b) How high is the image formed by the contacts?

Section 26.11 Angular Magnification and the Magnifying Glass

76. A spectator, seated in the left field stands, is watching a 1.9-m-tall baseball player who is 75 m away. On a TV screen, located 3.0 m from a person watching the game at home, the same player has a 0.12-m image. Find the angular size of the player as seen by (a) the spectator watching the game live and (b) the TV viewer. (c) To whom does the player appear to be larger?

77. **ssm** A quarter (diameter = 2.4 cm) is held at arms length (70.0 cm). The sun has a diameter of 1.39×10^9 m and is 1.50×10^{11} m from the earth. What is the ratio of the angular size of the quarter to that of the sun?

78. An object has an angular size of 0.0150 rad when placed at the near point (21.0 cm) of an eye. When the eye views this object using a magnifying glass, the largest possible angular size of the image is 0.0380 rad. What is the focal length of the magnifying glass?

79. A magnifying glass is held next to the eye, above a magazine. The image formed by the magnifying glass is located at the near point of the eye. The near point is 0.30 m away from the eye, and the angular magnification is 3.4. Find the focal length of the magnifying glass.

80. The angular magnification of a magnifying glass ($f =$ 22 cm) used as in Figure 26.40*b* is 2.5. The person using it has a near point that is 36 cm from his eyes. What is the image distance for the object being examined?

***81.** **ssm** A person using a magnifying glass as in Figure 26.40*b* observes that for clear vision its maximum angular magnification is 1.25 times as large as its minimum angular magnification. Assuming that the person has a near point located 25 cm from her eye, what is the focal length of the magnifying glass?

****82.** A farsighted person can read printing as close as 25.0 cm when she wears contacts that have a focal length of 45.4 cm. One day, however, she forgets her contacts and uses a magnifying glass, as in Figure 26.40*b*. It has a maximum angular magnification of 7.50 for a young person with a normal near point of 25.0 cm. What is the maximum angular magnification that the magnifying glass can provide for her?

Section 26.12 The Compound Microscope

83. A microscope for viewing blood cells has an objective with a focal length of 0.50 cm and an eyepiece with a focal length of 2.5 cm. The distance between the objective and eyepiece is 14.0 cm. If a blood cell subtends an angle of 2.1×10^{-5} rad when viewed with the naked eye at a near point of 25.0 cm, what angle (magnitude only) does it subtend when viewed through the microscope?

84. The distance between the lenses in a microscope is 18 cm. The focal length of the objective is 1.5 cm. If the microscope is to provide an angular magnification of -83 when used by a person with a normal near point (25 cm from the eye), what must be the focal length of the eyepiece?

85. **ssm** A compound microscope has a barrel whose length is 16.0 cm and an eyepiece whose focal length is 1.4 cm. The viewer has a near point located 25 cm from his eyes. What focal length must the objective have so the angular magnification of the microscope is -320?

86. An anatomist is viewing heart muscle cells with a microscope that has two selectable objectives with refracting powers of

100 and 300 diopters. When she uses the 100-diopter objective, the image of a cell subtends an angle of 3×10^{-3} rad with the eye. What angle is subtended when she uses the 300-diopter objective?

***87.** The maximum angular magnification of a magnifying glass is 12.0 when a person uses it who has a near point that is 25.0 cm from his eyes. The same person finds that a microscope, using this magnifying glass as the eyepiece, has an angular magnification of −525. The separation between the eyepiece and the objective of the microscope is 23.0 cm. Obtain the focal length of the objective.

***88.** In a compound microscope, the focal length of the objective is 3.50 cm and that of the eyepiece is 6.50 cm. The distance between the lenses is 26.0 cm. (a) What is the angular magnification of the microscope if the person using it has a near point of 35.0 cm? (b) If, as normal, the first image lies just inside the focal point of the eyepiece (see Figure 26.33), how far is the object from the objective? (c) What is the magnification (not the angular magnification) of the objective?

Section 26.13 The Telescope

89. ssm An astronomical telescope has an angular magnification of −184 and uses an objective with a focal length of 48.0 cm. What is the focal length of the eyepiece?

90. An astronomical telescope for hobbyists has an angular magnification of −155. The eyepiece has a focal length of 5.00 mm. (a) Determine the focal length of the objective. (b) About how long is the telescope?

91. Mars subtends an angle of 8.0×10^{-5} rad at the unaided eye. An astronomical telescope has an eyepiece with a focal length of 0.032 m. When Mars is viewed using this telescope, it subtends an angle of 2.8×10^{-3} rad. Find the focal length of the telescope's objective lens.

92. A telescope has an objective and an eyepiece that have refractive powers of 1.25 diopters and 250 diopters, respectively. Find the angular magnification of the telescope.

93. ssm An amateur astronomer decides to build a telescope from a discarded pair of eyeglasses. One of the lenses has a refractive power of 11 diopters, while the other has a refractive power of 1.3 diopters. (a) Which lens should be the objective? (b) How far apart should the lenses be separated? (c) What is the angular magnification of the telescope?

***94.** The objective and eyepiece of an astronomical telescope are 1.25 m apart, and the eyepiece has a focal length of 5.0 cm. What is the angular magnification of the telescope?

***95.** The telescope at Yerkes Observatory in Wisconsin has an objective whose focal length is 19.4 m. Its eyepiece has a focal length of 10.0 cm. (a) What is the angular magnification of the telescope? (b) If the telescope is used to look at a lunar crater (diameter = 1500 m), what is the size of the first image, assuming the surface of the moon is 3.77×10^8 m from the surface of the earth? (c) How close does the crater appear to be when seen through the telescope?

****96.** An astronomical telescope is being used to examine a relatively close object that is only 114.00 m away from the objective of the telescope. The objective and eyepiece have focal lengths of 1.500 and 0.070 m, respectively. Noting that the expression $M \approx -f_o/f_e$ is no longer applicable because the object is so close, use the thin-lens and magnification equations to find the angular magnification of this telescope. *(Hint: See Figure 26.42 and note that the focal points F_o and F_e are so close together that the distance between them may be ignored.)*

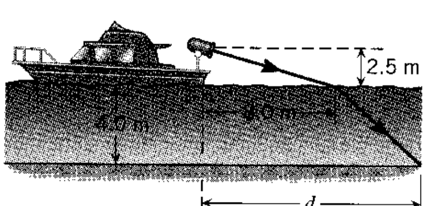
ADDITIONAL PROBLEMS

97. ssm An object is located 9.0 cm in front of a converging lens (f = 6.0 cm). Using an accurately drawn ray diagram, determine where the image is located.

98. An insect subtends an angle of only 4.0×10^{-3} rad at the unaided eye when placed at the near point. What is the angular size (magnitude only) when the insect is viewed through a microscope whose angular magnification has a magnitude of 160?

99. A glass block (n = 1.60) is immersed in a liquid. A ray of light within the glass hits a glass–liquid surface at a 65.0° angle of incidence. Some of the light enters the liquid. What is the smallest possible refractive index for the liquid?

100. A spotlight on a boat is 2.5 m above the water, and the light strikes the water at a point that is 8.0 m horizontally displaced from the spotlight (see the drawing). The depth of the water is 4.0 m. Determine the distance d, which locates the point where the light strikes the bottom.



101. ssm A nearsighted person has a far point located only 220 cm from his eyes. Determine the focal length of contact lenses that will enable him to see distant objects clearly.

102. Amber (n = 1.546) is a transparent brown-yellow fossil resin. An insect, trapped and preserved within the amber, appears to be 2.5 cm beneath the surface, when viewed directly from above. How far below the surface is the insect actually located?

103. A tourist takes a picture of a mountain 14 km away using a camera that has a lens with a focal length of 50 mm. She then takes a second picture when the mountain is only 5.0 km away. What is the ratio of the height of the mountain's image on the film for the second picture to its height on the film for the first picture?

104. A diverging lens has a focal length of −32 cm. An object is placed 19 cm in front of this lens. Calculate (a) the image distance and (b) the magnification. Is the image (c) real or virtual, (d) upright or inverted, and (e) enlarged or reduced in size?

105. ssm A light ray in air is incident on a water surface at a 43° angle of incidence. Find (a) the angle of reflection and (b) the angle of refraction.

106. A jeweler whose near point is 72 cm from his eye uses a magnifying glass as in Figure 26.40*b* to examine a watch. The watch is held 4.0 cm from the magnifying glass. Find the angular magnification of the magnifying glass.

107. ssm An optometrist prescribes contact lenses that have a focal length of 55.0 cm. (a) Are the lenses converging or diverging, and (b) is the person who wears them nearsighted or farsighted? (c) Where is the unaided near point of the person located, if the lenses are designed so that objects no closer than 35.0 cm can be seen clearly?

108. A ray of light traveling in material *A* strikes the interface between materials *A* and *B* at an angle of incidence of 72°. The angle of refraction is 56°. Find the ratio n_A/n_B of the refractive indices of the two materials.

109. A camper is trying to start a fire by focusing sunlight onto a piece of paper. The diameter of the sun is 1.39×10^9 m, and its mean distance from the earth is 1.50×10^{11} m. The camper is using a converging lens whose focal length is 10.0 cm. (a) What is the area of the sun's image on the paper? (b) If 0.530 W of sunlight pass through the lens, what is the intensity of the sunlight at the paper?

110. (a) For a diverging lens ($f = -20.0$ cm), construct a ray diagram to scale and find the image distance for an object that is 20.0 cm from the lens. (b) Determine the magnification of the lens from the diagram.

***111. ssm** An office copier uses a lens to place an image of a document onto a rotating drum. The copy is made from this image. (a) What kind of lens is used? If the document and its copy are to have the same size, but are inverted with respect to one another, (b) how far from the document is the lens located and (c) how far from the lens is the image located? Express your answers in terms of the focal length f of the lens.

***112.** A stamp collector is viewing a stamp with a magnifying glass held next to her eye. Her near point is 25 cm from her eye. (a) What is the refractive power of a magnifying glass that has an angular magnification of 6.0 when the image of the stamp is located at the near point? (b) What is the angular magnification when the image of the stamp is 45 cm from the eye?

***113. ssm** At age forty, a man requires contact lenses (f = 65.0 cm) to read a book held 25.0 cm from his eyes. At age forty-five, he finds that while wearing these contacts he must now hold a book 29.0 cm from his eyes. (a) By what distance has his near point *changed?* (b) What focal length lenses does he require at age forty-five to read a book at 25.0 cm?

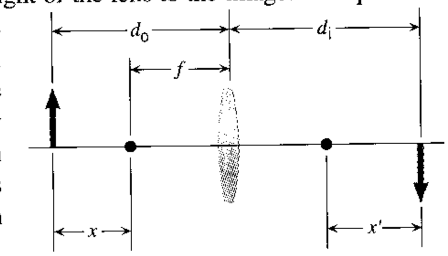
***114.** An object is in front of a converging lens ($f = 0.30$ m). The magnification of the lens is $m = 4.0$. (a) Relative to the lens, in what direction should the object be moved so that the magnification changes to $m = -4.0$? (b) Through what distance should the object be moved?

****115. ssm** The angular magnification of a telescope is 32 800 times as large when you look through the correct end of the telescope than when you look through the wrong end. What is the angular magnification of the telescope?

****116.** The equation

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

is called the *Gaussian* form of the thin-lens equation. The drawing shows the variables d_o, d_i, and f. The drawing also shows the distances x and x', which are, respectively, the distance from the object to the focal point on the left of the lens and the distance from the focal point on the right of the lens to the image. An equivalent form of the thin-lens equation, involving x, x', and f, is called the *Newtonian* form. Show that the Newtonian form of the thin-lens equation can be written as $xx' = f^2$.



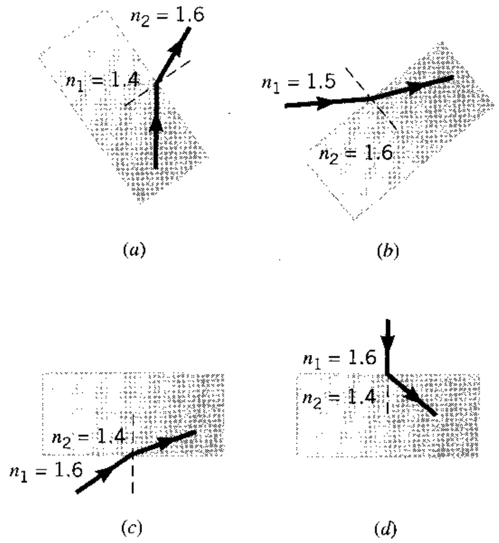
****117.** The contacts worn by a farsighted person allow her to see objects clearly that are as close as 25.0 cm, even though her uncorrected near point is 79.0 cm from her eyes. When she is looking at a poster, the contacts form an image of the poster at a distance of 217 cm from her eyes. (a) How far away is the poster actually located? (b) If the poster is 0.350 m tall, how tall is the image formed by the contacts?

CONCEPTS & CALCULATIONS
GROUP LEARNING PROBLEMS

Note: Each of these problems consists of Concept Questions followed by a related quantitative Problem. They are designed for use by students working alone or in small learning groups. The Concept Questions involve little or no mathematics and are intended to stimulate group discussions. They focus on the concepts with which the problems deal. Recognizing the concepts is the essential initial step in any problem-solving technique.

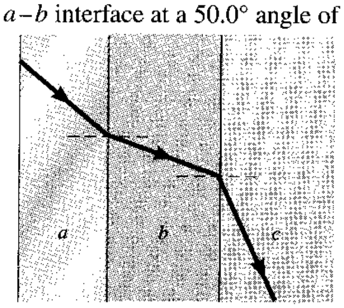
118. Concept Questions The drawing shows four different situations in which a light ray is traveling from one medium into another. Without doing any calculations, but taking note of the relative sizes of the angles of incidence and refraction, decide which situations (if any) show a refraction that is physically possible. Provide a reason as to why the refraction is possible or impossible.

Problem For the first three cases, the angle of incidence is 55°; for the fourth case, the angle of incidence is 0°. For each case, determine the actual angle of refraction. Check to be sure that your answers are consistent with your answers to the Concept Questions.



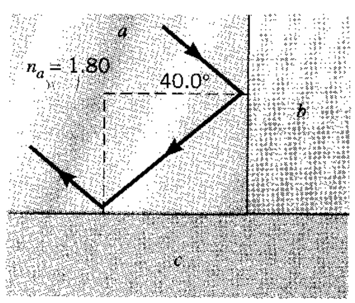
119. Concept Question The drawing shows a ray of light traveling through three materials whose surfaces are parallel to each other. The refracted rays (but not the reflected rays) are shown as the light passes through each material. Taking into account the relative sizes of the angles of incidence and refraction, rank the materials according to their indices of refraction, greatest first. Provide reasons for your ranking.

Problem A ray of light strikes the $a-b$ interface at a 50.0° angle of incidence. The index of refraction of material a is $n_a = 1.20$. The angles of refraction in materials b and c are, respectively, 45.0° and 56.7°. Find the indices of refraction in these two media. Verify that your answers are consistent with your answers to the Concept Question.



120. Concept Question The drawing shows three materials, a, b, and c. A ray of light strikes the $a-b$ interface at its critical angle. The reflected ray then strikes the $a-c$ interface at its critical angle. Rank the three materials according to their indices of refraction, largest first.

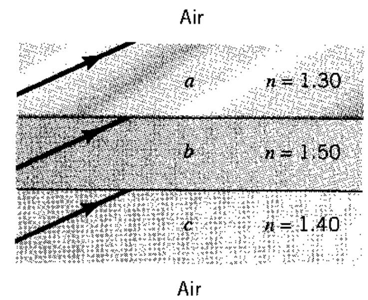
Problem A ray of light is incident at the $a-b$ interface with an angle of incidence equal to the critical angle, $\theta_c = 40.0°$. The index of refraction of material a is $n_a = 1.80$. Find the indices of refraction for the two other materials. Be sure your ranking of the indices is consistent with that determined in the Concept Question.



121. Concept Question The drawing shows three layers of different materials, with air above and below the layers. The interfaces between the layers are parallel. The index of refraction of each layer is given in the drawing. Identical rays of light are sent into the layers, and each ray zigzags through the layer, reflecting from the top and bottom surfaces. Fill in the table below, specifying a "yes" or "no" as to whether total internal reflection is possible from the top and bottom surfaces of each layer. Provide a reason for each of your answers.

	Is total internal reflection possible?	
Layer	Top surface of layer	Bottom surface of layer
a		
b		
c		

Problem For each layer, the ray of light has an angle of incidence of 75.0°. For the cases where total internal reflection is possible from either the top or bottom surface of a layer, determine the amount by which the angle of incidence exceeds the critical angle.

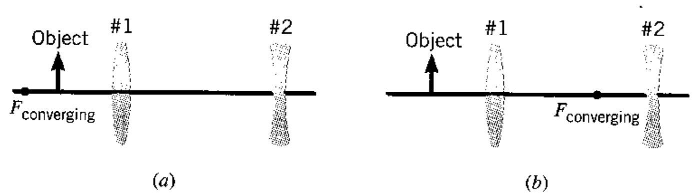


122. Concept Questions An object is placed to the left of a lens, and a real image is formed to the right of the lens. The image is inverted relative to the object and is one-half the size of the object. (a) What kind of lens, converging or diverging, is used to produce this image? (b) How is the height h_i of the image related to the height h_o of the object? Don't forget to take into account the fact that the image is inverted relative to the object. (c) What is the ratio d_i/d_o of the image distance to the object distance?

Problem For the situation described in the Concept Questions, the distance between the object and the image is 90.0 cm. (a) How far from the lens is the object? (b) What is the focal length of the lens?

123. Concept Question Two systems are formed from a converging lens and a diverging lens, as shown in parts a and b of the drawing. (The point labeled "F" is the focal point of the converging lens.) An object is placed inside the focal point of lens 1. Without doing any calculations, determine for each system whether the final image lies to the left or to the right of lens 2. Provide a reason for each answer.

Problem The focal lengths of the converging and diverging lenses are 15.00 and −20.0 cm, respectively. The distance between the lenses is 50.0 cm, and an object is placed 10.00 cm to the left of lens 1. Determine the final image distance for each system, measured with respect to lens 2. Check to be sure your answers are consistent with your answers to the Concept Question.



9. In Figure 27.14*b* there is a dark spot at the center of the pattern of Newton's rings. By considering the phase changes that occur when light reflects from the upper curved surface and the lower flat surface, account for the dark spot.

10. A thin film of a material is floating on water ($n = 1.33$). When the material has a refractive index of $n = 1.20$, the film looks bright in reflected light as its thickness approaches zero. But when the material has a refractive index of $n = 1.45$, the film looks black in reflected light as its thickness approaches zero. Explain these observations in terms of constructive and destructive interference and the phase changes that occur when light waves undergo reflection.

11. A transparent coating is deposited on a glass plate and has a refractive index that is *larger than that of the glass,* not smaller, as it is for a typical nonreflective coating. For a certain wavelength within the coating, the thickness of the coating is a quarter wavelength. The coating *enhances* the reflection of the light corresponding to this wavelength. Explain why, referring to Example 3 in the text to guide your thinking.

12. On most cameras one can select the *f*-number setting, or *f*-stop. The *f*-number gives the ratio of the focal length of the camera lens to the diameter of the aperture through which light enters the camera. If one wishes to resolve two closely spaced objects in a picture, should a small or a large *f*-number setting be used? Account for your answer.

13. Explain why a sound wave diffracts much more than a light wave does when the two pass through the same doorway.

14. Review Conceptual Example 8 before answering this question. A person is viewing one of Seurat's paintings that consists of dots of color. She is so close to the painting that the dots are distinguishable. Without moving, however, she can squint, which makes the painting take on a more normal appearance. In terms of the Rayleigh criterion, why does squinting make the painting look more normal?

15. Four light bulbs are arranged at the corners of a rectangle that is three times longer than it is wide. You look at this arrangement perpendicular to the plane of the rectangle. From very far away, your eyes cannot resolve the individual bulbs and you see a single "smear" of light. From close in, you see the individual bulbs. Between these two extremes, what do you see? Draw two pictures to illustrate the possibilities that exist, depending on how far away you are. Explain your drawings.

16. Suppose the pupil of your eye were elliptical instead of circular in shape, with the long axis of the ellipse oriented in the vertical direction. (a) Would the resolving power of your eye be the same in the horizontal and vertical directions? (b) In which direction would the resolving power be greatest? Justify your answers by discussing how the diffraction of light waves would differ in the two directions.

17. Suppose you were designing an eye and could select the size of the pupil and the wavelength of the electromagnetic waves to which the eye is sensitive. As far as the limitation created by diffraction is concerned, rank the following design choices in order of decreasing resolving power (greatest first): (a) large pupil and ultraviolet wavelengths, (b) small pupil and infrared wavelengths, and (c) small pupil and ultraviolet wavelengths. Justify your answer.

18. In our discussion of single-slit diffraction, we considered the ratio of the wavelength λ to the width W of the slit. We ignored the height of the slit, in effect assuming that the height was much larger than the width. Suppose the height and width were the same size, so that diffraction in both dimensions occurred. How would the diffraction pattern in Figure 27.19*b* be altered? Give your reasoning.

19. What would happen to the distance between the bright fringes produced by a diffraction grating if the entire interference apparatus (light source, grating, and screen) were immersed in water? Why?

PROBLEMS

ssm Solution is in the Student Solutions Manual. www Solution is available on the World Wide Web at http://www.wiley.com/college/cutnell
This icon represents a biomedical application.

Section 27.1 The Principle of Linear Superposition, Section 27.2 Young's Double-Slit Experiment

1. ssm The transmitting antenna for a radio station is 7.00 km from your house. The frequency of the electromagnetic wave broadcast by this station is 536 kHz. The station builds a second transmitting antenna that broadcasts an identical electromagnetic wave in phase with the original one. The new antenna is 8.12 km from your house. Does constructive or destructive interference occur at the receiving antenna of your radio? Show your calculations.

2. A Young's double-slit experiment is performed using light that has a wavelength of 630 nm. The separation between the slits is 5.3×10^{-5} m. Find the angles that locate the (a) first-, (b) second-, and (c) third-order bright fringes on the screen.

3. In a Young's double-slit experiment, the angle that locates the second dark fringe on either side of the central bright fringe is 5.4°. Find the ratio of the slit separation d to the wavelength λ of the light.

4. Two in-phase sources of waves are separated by a distance of 4.00 m. These sources produce identical waves that have a wavelength of 5.00 m. On the line between them, there are two places at which the same type of interference occurs. (a) Is it constructive or destructive interference, and (b) where are the places located?

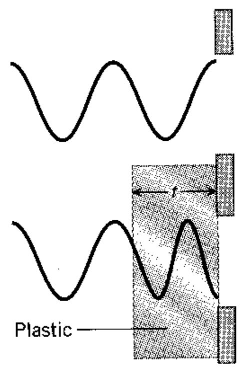
5. ssm In a Young's double-slit experiment, the angle that locates the second-order bright fringe is 2.0°. The slit separation is 3.8×10^{-5} m. What is the wavelength of the light?

***6.** Review Conceptual Example 2 before attempting this problem. Two slits are 0.158 mm apart. A mixture of red light (wavelength = 665 nm) and yellow-green light (wavelength = 565 nm) falls on the slits. A flat observation screen is located 2.24 m away. What is the distance on the screen between the third-order red fringe and the third-order yellow-green fringe?

***7.** In a Young's double-slit experiment the separation y between the first-order bright fringe and the central bright fringe on a flat screen is 0.0240 m, when the light has a wavelength of 475 nm. Assume that the angles that locate the fringes on the screen are small enough so that $\sin\theta \approx \tan\theta$. Find the separation y when the light has a wavelength of 611 nm.

****8.** In Young's experiment a mixture of orange light (611 nm) and blue light (471 nm) shines on the double slit. The centers of the first-order bright blue fringes lie at the outer edges of a screen that is located 0.500 m away from the slits. However, the first-order bright orange fringes fall off the screen. By how much and in which direction (toward or away from the slits) should the screen be moved, so that the centers of the first-order bright orange fringes just appear on the screen? It may be assumed that θ is small, so that $\sin\theta \approx \tan\theta$.

****9. ssm www** A sheet of plastic ($n = 1.60$) covers *one slit* of a double slit (see the drawing). When the double slit is illuminated by monochromatic light ($\lambda_{\text{vacuum}} = 586$ nm), the center of the screen appears dark rather than bright. What is the minimum thickness of the plastic?



Problem 9

Section 27.3 Thin-Film Interference

10. A layer of transparent plastic ($n = 1.61$) on glass ($n = 1.52$) looks dark when viewed in reflected light whose wavelength is 589 nm in vacuum. Find the two smallest possible nonzero values for the thickness of the layer.

11. ssm A nonreflective coating of magnesium fluoride ($n = 1.38$) covers the glass ($n = 1.52$) of a camera lens. Assuming that the coating prevents reflection of yellow-green light (wavelength in vacuum = 565 nm), determine the minimum nonzero thickness that the coating can have.

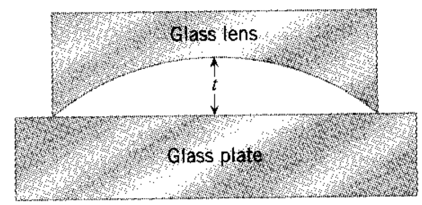
12. For background on this problem, review Conceptual Example 4. A mixture of yellow light (wavelength = 580 nm in vacuum) and violet light (wavelength = 410 nm in vacuum) falls perpendicularly on a film of gasoline that is floating on a puddle of water. For both wavelengths, the refractive index of gasoline is $n = 1.40$ and that of water is $n = 1.33$. What is the minimum nonzero thickness of the film in a spot that looks (a) yellow and (b) violet because of destructive interference?

13. Example 5(a) in the text deals with the air wedge formed between two plates of glass ($n = 1.52$). Repeat this example, assuming that the wedge of air is replaced by water ($n = 1.33$).

14. Review Conceptual Example 4 before beginning this problem. A soap film with different thicknesses at different places has an unknown refractive index n and air on both sides. In reflected light it looks multicolored. One region looks yellow because destructive interference has removed blue ($\lambda_{\text{vacuum}} = 469$ nm) from the reflected light, while another looks magenta because destructive interference has removed green ($\lambda_{\text{vacuum}} = 555$ nm). In these regions the film has the minimum nonzero thickness t required for the destructive interference to occur. Find the ratio $t_{\text{magenta}}/t_{\text{yellow}}$.

***15. ssm www** Orange light ($\lambda_{\text{vacuum}} = 611$ nm) shines on a soap film ($n = 1.33$) that has air on either side of it. The light strikes the film perpendicularly. What is the minimum thickness of the film for which constructive interference causes it to look bright in reflected light?

***16.** The drawing shows a cross section of a plano-concave lens resting on a flat glass plate. (A plano-concave lens has one surface that is a plane and the other that is concave spherical.) The thickness t is 1.37×10^{-5} m. The lens is illuminated with monochromatic light ($\lambda_{\text{vacuum}} = 550$ nm), and a series of concentric bright and dark rings is formed, much like Newton's rings. How many bright rings are there?



***17.** A film of oil lies on wet pavement. The refractive index of the oil exceeds that of the water. The film has the minimum nonzero thickness such that it appears dark due to destructive interference when viewed in red light (wavelength = 660 nm in vacuum). Assuming that the visible spectrum extends from 380 to 750 nm, what are the visible wavelength(s) (in vacuum) for which the film will appear bright due to constructive interference?

****18.** A uniform layer of water ($n = 1.33$) lies on a glass plate ($n = 1.52$). Light shines perpendicularly on the layer. Because of constructive interference, the layer looks maximally bright when the wavelength of the light is 432 nm in vacuum and *also* when it is 648 nm in vacuum. (a) Obtain the minimum thickness of the film. (b) Assuming that the film has the minimum thickness and that the visible spectrum extends from 380 to 750 nm, determine the visible wavelength(s) (in vacuum) for which the film appears completely dark.

Section 27.5 Diffraction

19. ssm A diffraction pattern forms when light passes through a single slit. The wavelength of the light is 675 nm. Determine the angle that locates the first dark fringe when the width of the slit is (a) 1.8×10^{-4} m and (b) 1.8×10^{-6} m.

20. A doorway is 0.91 m wide. (a) Obtain the angle that locates the first dark fringe in the Fraunhofer diffraction pattern formed when red light (wavelength = 660 nm) passes through the doorway. (b) Repeat part (a) for a 440-Hz sound wave (concert A), assuming that the speed of sound is 343 m/s.

21. A single slit has a width of 2.1×10^{-6} m and is used to form a diffraction pattern. Find the angle that locates the second dark fringe when the wavelength of the light is (a) 430 nm and (b) 660 nm.

22. The first dark fringe in the diffraction pattern of a single slit is located at an angle of $\theta_A = 34°$. With the same light, the first dark fringe formed with another single slit is at an angle of $\theta_B = 56°$. Find the ratio W_A/W_B of the widths of the two slits.

23. ssm www Light shines through a single slit whose width is 5.6×10^{-4} m. A diffraction pattern is formed on a flat screen located 4.0 m away. The distance between the middle of the central bright fringe and the first dark fringe is 3.5 mm. What is the wavelength of the light?

***24.** The width of a slit is 2.0×10^{-5} m. Light with a wavelength of 480 nm passes through this slit and falls on a screen that is located 0.50 m away. In the diffraction pattern, find the width of the bright fringe that is next to the central bright fringe.

***25. ssm** The central bright fringe in a single-slit diffraction pattern has a width that equals the distance between the screen and the slit. Find the ratio λ/W of the wavelength of the light to the width of the slit.

***26.** In a single-slit diffraction pattern on a flat screen, the central bright fringe is 1.2 cm wide when the slit width is 3.2×10^{-5} m. When the slit is replaced by a second slit, the wavelength of the light and the distance to the screen remaining unchanged, the central bright fringe broadens to a width of 1.9 cm. What is the width of the second slit? It may be assumed that θ is so small that $\sin\theta \approx \tan\theta$.

****27.** In a single-slit diffraction pattern, the central fringe is 450 times wider than the slit. The screen is 18 000 times farther from the slit than the slit is wide. What is the ratio λ/W, where λ is the wavelength of the light shining through the slit and W is the width of the slit? Assume that the angle that locates a dark fringe on the screen is small, so that $\sin\theta \approx \tan\theta$.

Section 27.6 Resolving Power

28. You are looking down at the earth from inside a jetliner flying at an altitude of 8690 m. The pupil of your eye has a diameter of 2.00 mm. Determine how far apart two cars must be on the ground if you are to have any hope of distinguishing between them in (a) red light (wavelength = 665 nm in vacuum) and (b) violet light (wavelength = 405 nm in vacuum).

29. It is claimed that some professional baseball players can see which way the ball is spinning as it travels toward home plate. One way to judge this claim is to estimate the distance at which a batter can first hope to resolve two points on opposite sides of a baseball, which has a diameter of 0.0738 m. (a) Estimate this distance, assuming that the pupil of the eye has a diameter of 2.0 mm and the wavelength of the light is 550 nm in vacuum. (b) Considering that the distance between the pitcher's mound and home plate is 18.4 m, can you rule out the claim based on your answer to part (a)?

30. Two asteroids are traveling close to each other through the solar system at a distance of 2.0×10^{10} m from earth. With light of wavelength 550 nm, they are just resolved by the Hubble Space Telescope, whose aperture has a diameter of 2.4 m. How far apart are the asteroids?

31. ssm The largest refracting telescope in the world is at the Yerkes Observatory in Williams Bay, Wisconsin. The objective of the telescope has a diameter of 1.02 m. Two objects are 3.75×10^4 m from the telescope. With light of wavelength 565 nm, how close can the objects be to each other so that they are just resolved by the telescope?

32. Astronomers have discovered a planetary system orbiting the star Upsilon Andromedae, which is at a distance of 4.2×10^{17} m from the earth. One planet is believed to be located at a distance of 1.2×10^{11} m from the star. Using visible light with a vacuum wavelength of 550 nm, what is the minimum necessary aperture diameter that a telescope must have so that it can resolve the planet and the star?

33. Review Conceptual Example 8 as background for this problem. In addition to the data given there, assume that the dots in the painting are separated by 1.5 mm and that the wavelength of the light is $\lambda_{vacuum} = 550$ nm. Find the distance at which the dots can just be resolved by (a) the eye and (b) the camera.

***34.** The pupil of an eagle's eye has a diameter of 6.0 mm. Two field mice are separated by 0.010 m. From a distance of 176 m, the eagle sees them as one unresolved object and dives toward them at a speed of 17 m/s. Assume that the eagle's eye detects light that has a wavelength of 550 nm in a vacuum. How much time passes until the eagle sees the mice as separate objects?

***35. ssm www** In an experiment, red light (wavelength = 694.3 nm) is sent to the moon. At the surface of the moon, which is 3.77×10^8 m away, the light strikes a reflector left there by astronauts. The reflected light returns to the earth, where it is detected. When it leaves the spotlight, the circular beam of light has a diameter of about 0.20 m, and diffraction causes the beam to spread as the light travels to the moon. In effect, the first circular dark fringe in the diffraction pattern defines the size of the central bright spot on the moon. Determine the diameter (not the radius) of the central bright spot on the moon.

****36.** Two concentric circles of light emit light whose wavelength is 555 nm. The larger circle has a radius of 4.0 cm, while the smaller circle has a radius of 1.0 cm. When taking a picture of these lighted circles, a camera admits light through an aperture whose diameter is 12.5 mm. What is the maximum distance at which the camera can (a) distinguish one circle from the other and (b) reveal that the inner circle is a circle of light rather than a solid disk of light?

Section 27.7 The Diffraction Grating, Section 27.8 Compact Discs, Digital Video Discs, and the Use of Interference

37. ssm The diffraction gratings discussed in the text are transmission gratings because light *passes through* them. There are also gratings in which the light *reflects from* the grating to form a pattern of fringes. Equation 27.7 also applies to a reflection grating with straight parallel lines when the incident light shines perpendicularly on the grating. The surface of a compact disc (CD) has a multicolored appearance because it acts like a reflection grating and spreads sunlight into its colors. The arms of the spiral track on the CD are separated by 1.1×10^{-6} m. Using Equation 27.7, estimate the angle that corresponds to the first-order maximum for a wavelength of (a) 660 nm (red) and (b) 410 nm (violet).

38. For a wavelength of 420 nm, a diffraction grating produces a bright fringe at an angle of 26°. For an unknown wavelength, the same grating produces a bright fringe at an angle of 41°. In both cases the bright fringes are of the same order m. What is the unknown wavelength?

39. A diffraction grating produces a first-order bright fringe that is 0.0894 m away from the central bright fringe on a flat screen. The separation between the slits of the grating is 4.17×10^{-6} m, and the distance between the grating and the screen is 0.625 m. What is the wavelength of the light shining on the grating?

40. When a grating is used with light that has a wavelength of 621 nm, a third-order maximum is formed at an angle of 18.0°. How many lines per centimeter does this grating have?

41. ssm The wavelength of the laser beam used in a compact disc player is 780 nm. Suppose that a diffraction grating produces first-order tracking beams that are 1.2 mm apart at a distance of 3.0 mm from the grating. Estimate the spacing between the slits of the grating.

***42.** The first-order maximum produced by a grating is located at an angle of $\theta = 16.0°$. What is the angle for the third-order maximum with the same light?

***43. ssm** Violet light (wavelength = 410 nm) and red light (wavelength = 660 nm) lie at opposite ends of the visible spectrum. (a) For each wavelength, find the angle θ that locates the first-order maximum produced by a grating with 3300 lines/cm. This grating converts a mixture of all colors between violet and red into a rainbow-like dispersion between the two angles. Repeat the calculation above for (b) the second-order maximum and (c) the third-order maximum. (d) From your results, decide whether there is an overlap between any of the "rainbows" and, if so, specify which orders overlap.

***44.** Three, and only three, bright fringes can be seen on either side of the central maximum when a grating is illuminated with light (λ = 510 nm). What is the maximum number of lines/cm for the grating?

****45.** Two gratings A and B have slit separations d_A and d_B, respectively. They are used with the same light and the same observation screen. When grating A is replaced with grating B, it is observed that the first-order maximum of A is exactly replaced by the second-order maximum of B. (a) Determine the ratio d_B/d_A of the spacings between the slits of the gratings. (b) Find the next two principal maxima of grating A and the principal maxima of B that exactly replace them when the gratings are switched. Identify these maxima by their order numbers.

ADDITIONAL PROBLEMS

46. A rock concert is being held in an open field. Two loudspeakers are separated by 7.00 m. As an aid in arranging the seating, a test is conducted in which both speakers vibrate in phase and produce an 80.0-Hz bass tone simultaneously. The speed of sound is 343 m/s. A reference line is marked out in front of the speakers, perpendicular to the midpoint of the line between the speakers. Relative to either side of this reference line, what is the smallest angle that locates the places where destructive interference occurs? People seated in these places would have trouble hearing the 80.0-Hz bass tone.

47. ssm A flat observation screen is placed at a distance of 4.5 m from a pair of slits. The separation on the screen between the central bright fringe and the first-order bright fringe is 0.037 m. The light illuminating the slits has a wavelength of 490 nm. Determine the slit separation.

48. A slit whose width is 4.30×10^{-5} m is located 1.32 m from a flat screen. Light shines through the slit and falls on the screen. Find the width of the central fringe of the diffraction pattern when the wavelength of the light is 635 nm.

49. A mixture of red light (λ_{vacuum} = 661 nm) and green light (λ_{vacuum} = 551 nm) shines perpendicularly on a soap film (n = 1.33) that has air on either side. What is the minimum nonzero thickness of the film, so that destructive interference causes it to look red in reflected light?

50. Two parallel slits are illuminated by light composed of two wavelengths, one of which is 645 nm. On a viewing screen, the light whose wavelength is known produces its third dark fringe at the same place where the light whose wavelength is unknown produces its fourth-order bright fringe. The fringes are counted relative to the central or zeroth-order bright fringe. What is the unknown wavelength?

51. ssm Late one night on a highway, a car speeds by you and fades into the distance. Under these conditions the pupils of your eyes have diameters of about 7.0 mm. The taillights of this car are separated by a distance of 1.2 m and emit red light (wavelength = 660 nm in vacuum). How far away from you is this car when its taillights appear to merge into a single spot of light because of the effects of diffraction?

***52.** Monochromatic light shines on a diffraction grating. When the light source and the grating are in air, the first-order maximum occurs at an angle of 33°. At what angle does the first-order maximum occur when the source and the grating are immersed in water (n = 1.33)?

***53.** You are using a microscope to examine a blood sample. Recall from Section 26.12 that the sample should be placed just outside the focal point of the objective lens of the microscope. (a) The specimen is being illuminated with light of wavelength λ and the diameter of the objective equals its focal length. Determine the closest distance between two blood cells that can just be resolved. Express your answer in terms of λ. (b) Based on your answer to (a), should you use light with a longer wavelength or a shorter wavelength if you wish to resolve two blood cells that are even closer together?

***54.** The separation between the slits of a grating is 2.2×10^{-6} m. This grating is used with light that contains all wavelengths between 410 and 660 nm. Rainbow-like spectra form on a screen 3.2 m away. How wide (in meters) is (a) the first-order spectrum and (b) the second-order spectrum?

***55. ssm** The same diffraction grating is used with two different wavelengths of light, λ_A and λ_B. The fourth-order principal maximum of light A exactly overlaps the third-order principal maximum of light B. Find the ratio λ_A/λ_B.

***56.** Review Conceptual Example 4 before attempting this problem. A film of gasoline ($n = 1.40$) floats on water ($n = 1.33$). Yellow light (wavelength = 580 nm in vacuum) shines perpendicularly on this film. (a) Determine the minimum nonzero thickness of the film, such that the film appears bright yellow due to constructive interference. (b) Repeat part (a), assuming that the gasoline film is on glass ($n = 1.52$) instead of water.

****57.** There are 5620 lines per centimeter in a grating that is used with light whose wavelength is 471 nm. A flat observation screen is located at a distance of 0.750 m from the grating. What is the minimum width that the screen must have so the *centers* of all the principal maxima formed on either side of the central maximum fall on the screen?

****58.** A piece of curved glass has a radius of curvature of 10.0 m and is used to form Newton's rings, as in Figure 27.14. Not counting the dark spot at the center of the pattern, there are one hundred dark fringes, the last one being at the outer edge of the curved piece of glass. The light being used has a wavelength of 654 nm in vacuum. What is the radius of the outermost dark ring in the pattern?

CONCEPTS & CALCULATIONS

GROUP LEARNING PROBLEMS

Note: Each of these problems consists of Concept Questions followed by a related quantitative Problem. They are designed for use by students working alone or in small learning groups. The Concept Questions involve little or no mathematics and are intended to stimulate group discussions. They focus on the concepts with which the problems deal. Recognizing the concepts is the essential initial step in any problem-solving technique.

59. Concept Questions (a) Point A is the midpoint of one of the sides of a square. On the side opposite this spot, two in-phase loudspeakers are located at adjacent corners, as in Figure 27.41. Standing at point A, you hear a loud sound because constructive interference occurs between the identical sound waves coming from the speakers. Why does constructive interference occur at point A? (b) As you walk along the side of the square toward either empty corner, the loudness diminishes gradually to nothing and then increases again until you hear a maximally loud sound at the corner. Explain these observations in terms of destructive and constructive interference. (c) The general condition that leads to constructive interference entails a number of possibilities for the variable m, which designates the order of the interference maxima. Which one of those possibilities, if any, applies at either empty corner of the square? Explain.

Problem The square referred to in the Concept Questions is 4.6 m on a side. Find the wavelength of the sound waves.

60. Concept Questions (a) The screen in Figure 27.8 has a fixed width and is centered on the midpoint between the two slits. Should the screen be moved to the left or to the right to ensure that the third-order bright fringe does *not* lie on the screen? (b) Do fewer fringes lie on the screen when the distance L between the double-slit and the screen is smaller or larger? Account for your answers.

Problem In a setup like that in Figure 27.8, a wavelength of 625 nm is used in a Young's double-slit experiment. The separation between the slits is $d = 1.4 \times 10^{-5}$ m. The total width of the screen is 0.20 m. In one version of the setup, the separation between the double slit and the screen is $L_A = 0.35$ m, while in another version it is $L_B = 0.50$ m. On one side of the central bright fringe, how many bright fringes lie on the screen in the two versions of the setup? Do not include the central bright fringe in your counting. Verify that your answer is consistent with your answers to the Concept Questions.

61. Concept Questions (a) What, if any, phase change occurs when light, traveling in air, reflects from the interface between the air and a soap film ($n = 1.33$)? (b) What, if any, phase change occurs when light, traveling in a soap film, reflects from the interface between the soap film and a glass plate ($n = 1.52$)? (c) Is the wavelength of the light in a soap film greater than, smaller than, or equal to the wavelength in a vacuum?

Problem A soap film ($n = 1.33$) is 465 nm thick and lies on a glass plate ($n = 1.52$). Sunlight, whose wavelengths (in vacuum) extend from 380 to 750 nm, travels through the air and strikes the film perpendicularly. For which wavelength(s) in this range does destructive interference cause the film to look dark in reflected light?

62. Concept Questions (a) In a single-slit diffraction pattern the width of the central bright fringe is defined by the location of the first dark fringe that lies on either side of it. For a given slit width, does the width of the central bright fringe increase, decrease, or remain the same as the wavelength of the light increases? (b) For a given wavelength, does the width of the central bright fringe increase, decrease, or remain the same as the slit width increases? (c) When both the wavelength and the slit width change, it is possible for the width of the central bright fringe to remain the same. What condition must be satisfied for this to happen? In each case, give your reasoning.

Problem A slit has a width of $W_1 = 2.3 \times 10^{-6}$ m. When light with a wavelength of $\lambda_1 = 510$ nm passes through this slit, the width of the central bright fringe on a flat observation screen has a certain value. Keeping the screen in the same place, this slit is replaced with a second slit (width W_2) and a wavelength of $\lambda_2 =$ 740 nm is used. The width of the central bright fringe on the screen is observed to be unchanged. Find W_2.

63. Concept Questions An inkjet color printer uses tiny dots of red, green, and blue ink to produce an image. At normal viewing distances, the eye does not resolve the individual dots, so that the image has a normal look. The angle θ_{min} is the minimum angle that two dots can subtend at the eye and still be resolved separately. (a) For which color does θ_{min} have the largest value? (b) For which color does θ_{min} have the smallest value? (c) Corresponding to each value of θ_{min}, there is a value for the separation distance s between the dots. How is θ_{min} related to s and the viewing distance L? (d) Assume that the dot separation on the printed page is the same for all colors and is chosen so that none of the colored dots can be seen as separate objects. Should the maximum allowable dot separation be s_{red}, s_{green}, or s_{blue}? For each answer, give your reasoning.

Problem The wavelengths for red, green, and blue are $\lambda_{red} =$ 660 nm, $\lambda_{green} = 550$ nm, and $\lambda_{blue} = 470$ nm. The diameter of the pupil through which light enters the eye is 2.0 mm. For a viewing distance of 0.40 m, find the maximum separation distance that the dots can have and not be resolved separately. Check to see that your answer is consistent with your answers to the Concept Questions.

64. Concept Questions (a) Two diffraction gratings are located at the same distance from observation screens. Light with the same wavelength λ is used for each. The principal maxima of grating A are observed to be closer together on the screen than the principal maxima of grating B. Which grating diffracts the light to a greater extent? (b) Which grating has the smaller slit separation d? (c) Which grating has the greater number of lines per meter? Justify each of your answers.

Problem The separation between adjacent principal maxima for grating A is 2.7 cm, while for grating B it is 3.2 cm. Grating A has 2000 lines per meter. How many lines per meter does grating B have? The diffraction angles are small enough that $\sin\theta \approx \tan\theta$. Be sure that your answer is consistent with your answers to the Concept Questions.