What causes the action potential to travel along the axon? The action potential occurs at the point of stimulation, as shown in Fig. 18–31a. The membrane momentarily is positive on the inside and negative on the outside at this point. Nearby charges are attracted toward this region, as shown in Fig. 18–31b. The potential in these adjacent regions then drops, causing an action potential there. Thus, as the membrane returns to normal at the original point, nearby it experiences an action potential, so the action potential moves down the axon (Figs. 18–31c and d).

You may wonder if the number of ions that pass through the membrane would significantly alter the concentrations. The answer is no; and we can show why (and again show the power and usefulness of physics) by treating the axon as a capacitor as we do in Search and Learn Problem 6 (the concentration changes by less than 1 part in 10^4).

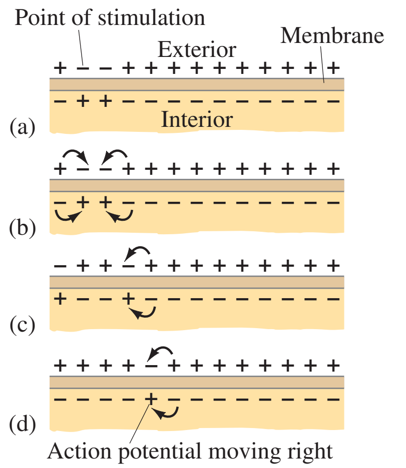

FIGURE 18–31 Propagation of action potential along axon membrane.

Summary

An electric **battery** serves as a source of nearly constant potential difference by transforming chemical energy into electric energy. A simple battery consists of two electrodes made of different metals immersed in a solution or paste known as an electrolyte.

Electric current, I, refers to the rate of flow of electric charge and is measured in **amperes** (A): 1 A equals a flow of 1 C/s past a given point.

The direction of **conventional current** is that of positive charge flow. In a wire, it is actually negatively charged electrons that move, so they flow in a direction opposite to the conventional current. A positive charge flow in one direction is almost always equivalent to a negative charge flow in the opposite direction. Positive conventional current always flows from a high potential to a low potential.

The **resistance** R of a device is defined by the relation

$$V = IR, \tag{18–2}$$

where I is the current in the device when a potential difference V is applied across it. For materials such as metals, R is a constant independent of V (thus $I \propto V$), a result known as **Ohm's law**. Thus, the current I coming from a battery of voltage V depends on the resistance R of the circuit connected to it.

Voltage is applied *across* a device or between the ends of a wire. Current passes *through* a wire or device. Resistance is a property *of* the wire or device.

The unit of resistance is the **ohm** (Ω), where $1\,\Omega = 1\,\text{V/A}$. See Table 18–3.

TABLE 18–3 Summary of Units

Current	$1\text{ A} = 1\text{ C/s}$
Potential difference	$1\text{ V} = 1\text{ J/C}$
Power	$1\text{ W} = 1\text{ J/s}$
Resistance	$1\,\Omega = 1\text{ V/A}$

The resistance R of a wire is inversely proportional to its cross-sectional area A, and directly proportional to its length ℓ and to a property of the material called its resistivity:

$$R = \frac{\rho\ell}{A}. \tag{18–3}$$

The **resistivity**, ρ, increases with temperature for metals, but for semiconductors it may decrease.

The rate at which energy is transformed in a resistance R from electric to other forms of energy (such as heat and light) is equal to the product of current and voltage. That is, the **power** transformed, measured in watts, is given by

$$P = IV, \tag{18–5}$$

which for resistors can be written as

$$P = I^2R = \frac{V^2}{R}. \tag{18–6}$$

The SI unit of power is the **watt** ($1\text{ W} = 1\text{ J/s}$).

The total electric energy transformed in any device equals the product of the power and the time during which the device is operated. In SI units, energy is given in joules ($1\text{ J} = 1\text{ W}\cdot\text{s}$), but electric companies use a larger unit, the **kilowatt-hour** ($1\text{ kWh} = 3.6 \times 10^6\text{ J}$).

Electric current can be **direct current** (**dc**), in which the current is steady in one direction; or it can be **alternating current** (**ac**), in which the current reverses direction at a particular frequency f, typically 60 Hz. Alternating currents are typically sinusoidal in time,

$$I = I_0 \sin \omega t, \tag{18–7b}$$

where $\omega = 2\pi f$, and are produced by an alternating voltage.

The **rms** values of sinusoidally alternating currents and voltages are given by

$$I_{\text{rms}} = \frac{I_0}{\sqrt{2}} \quad \text{and} \quad V_{\text{rms}} = \frac{V_0}{\sqrt{2}}, \tag{18–8}$$

respectively, where I_0 and V_0 are the **peak** values. The power relationship, $P = IV = I^2R = V^2/R$, is valid for the average power in alternating currents when the rms values of V and I are used.

[*The current in a wire, at the microscopic level, is considered to be a slow **drift velocity** of electrons, $\vec{\mathbf{v}}_{\text{d}}$. The current I is given by

$$I = neAv_{\text{d}}, \tag{18–10}$$

where n is the number of free electrons per unit volume, e is the magnitude of the charge on an electron, and A is the cross-sectional area of the wire.]

[*At very low temperatures certain materials become **superconducting**, which means their electrical resistance becomes zero.]

[*The human nervous system operates via electrical conduction: when a nerve "fires," an electrical signal travels as a voltage pulse known as an **action potential**.]

Questions

1. When an electric cell is connected to a circuit, electrons flow away from the negative terminal in the circuit. But within the cell, electrons flow *to* the negative terminal. Explain.
2. When a flashlight is operated, what is being used up: battery current, battery voltage, battery energy, battery power, or battery resistance? Explain.
3. What quantity is measured by a battery rating given in ampere-hours $(A \cdot h)$? Explain.
4. Can a copper wire and an aluminum wire of the same length have the same resistance? Explain.
5. One terminal of a car battery is said to be connected to "ground." Since it is not really connected to the ground, what is meant by this expression?
6. The equation $P = V^2/R$ indicates that the power dissipated in a resistor decreases if the resistance is increased, whereas the equation $P = I^2R$ implies the opposite. Is there a contradiction here? Explain.
7. What happens when a lightbulb burns out?
8. If the resistance of a small immersion heater (to heat water for tea or soup, Fig. 18–32) was increased, would it speed up or slow down the heating process? Explain.

FIGURE 18–32 Question 8.

9. If a rectangular solid made of carbon has sides of lengths a, $2a$, and $3a$, to which faces would you connect the wires from a battery so as to obtain (*a*) the least resistance, (*b*) the greatest resistance?
10. Explain why lightbulbs almost always burn out just as they are turned on and not after they have been on for some time.
11. Which draws more current, a 100-W lightbulb or a 75-W bulb? Which has the higher resistance?
12. Electric power is transferred over large distances at very high voltages. Explain how the high voltage reduces power losses in the transmission lines.
13. A 15-A fuse blows out repeatedly. Why is it dangerous to replace this fuse with a 25-A fuse?
14. When electric lights are operated on low-frequency ac (say, 5 Hz), they flicker noticeably. Why?
15. Driven by ac power, the same electrons pass back and forth through your reading lamp over and over again. Explain why the light stays lit instead of going out after the first pass of electrons.
16. The heating element in a toaster is made of Nichrome wire. Immediately after the toaster is turned on, is the current magnitude (I_{rms}) in the wire increasing, decreasing, or staying constant? Explain.
17. Is current used up in a resistor? Explain.
18. Why is it more dangerous to turn on an electric appliance when you are standing outside in bare feet than when you are inside wearing shoes with thick soles?

*19. Compare the drift velocities and electric currents in two wires that are geometrically identical and the density of atoms is similar, but the number of free electrons per atom in the material of one wire is twice that in the other.

*20. A voltage V is connected across a wire of length ℓ and radius r. How is the electron drift speed affected if (*a*) ℓ is doubled, (*b*) r is doubled, (*c*) V is doubled, assuming in each case that other quantities stay the same?

MisConceptual Questions

1. When connected to a battery, a lightbulb glows brightly. If the battery is reversed and reconnected to the bulb, the bulb will glow
   (*a*) brighter.
   (*b*) dimmer.
   (*c*) with the same brightness.
   (*d*) not at all.
2. When a battery is connected to a lightbulb properly, current flows through the lightbulb and makes it glow. How much current flows through the battery compared with the lightbulb?
   (*a*) More.
   (*b*) Less.
   (*c*) The same amount.
   (*d*) No current flows through the battery.
3. Which of the following statements about Ohm's law is true?
   (*a*) Ohm's law relates the current through a wire to the voltage across the wire.
   (*b*) Ohm's law holds for all materials.
   (*c*) Any material that obeys Ohm's law does so independently of temperature.
   (*d*) Ohm's law is a fundamental law of physics.
   (*e*) Ohm's law is valid for superconductors.
4. Electrons carry energy from a battery to a lightbulb. What happens to the electrons when they reach the lightbulb?
   (*a*) The electrons are used up.
   (*b*) The electrons stay in the lightbulb.
   (*c*) The electrons are emitted as light.
   (*d*) Fewer electrons leave the bulb than enter it.
   (*e*) None of the above.
5. Where in the circuit of Fig. 18–33 is the current the largest, (*a*), (*b*), (*c*), or (*d*)? Or (*e*) it is the same at all points?

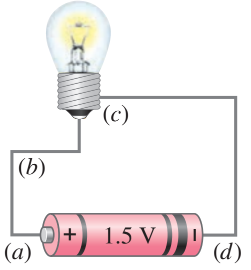

FIGURE 18–33 MisConceptual Question 5.

6. When you double the *voltage* across a certain material or device, you observe that the *current* increases by a factor of 3. What can you conclude?
   (*a*) Ohm's law is obeyed, because the current increases when V increases.
   (*b*) Ohm's law is not obeyed in this case.
   (*c*) This situation has nothing to do with Ohm's law.

7. When current flows through a resistor,
   (*a*) some of the charge is used up by the resistor.
   (*b*) some of the current is used up by the resistor.
   (*c*) Both (*a*) and (*b*) are true.
   (*d*) Neither (*a*) nor (*b*) is true.

8. The unit kilowatt-hour is a measure of
   (*a*) the rate at which energy is transformed.
   (*b*) power.
   (*c*) an amount of energy.
   (*d*) the amount of power used per second.

9. Why might a circuit breaker open if you plug too many electrical devices into a single circuit?
   (*a*) The voltage becomes too high.
   (*b*) The current becomes too high.
   (*c*) The resistance becomes too high.
   (*d*) A circuit breaker will not "trip" no matter how many electrical devices you plug into the circuit.

10. Nothing happens when birds land on a power line, yet we are warned not to touch a power line with a ladder. What is the difference?
    (*a*) Birds have extremely high internal resistance compared to humans.
    (*b*) There is little to no voltage drop between a bird's two feet, but there is a significant voltage drop between the top of a ladder touching a power line and the bottom of the ladder on the ground.
    (*c*) Dangerous current comes from the ground only.
    (*d*) Most birds don't understand the situation.

11. When a light switch is turned on, the light comes on immediately because
    (*a*) the electrons coming from the power source move through the initially empty wires very fast.
    (*b*) the electrons already in the wire are instantly "pushed" by a voltage difference.
    (*c*) the lightbulb may be old with low resistance. It would take longer if the bulb were new and had high resistance.
    (*d*) the electricity bill is paid. The electric company can make it take longer when the bill is unpaid.

For assigned homework and other learning materials, go to the MasteringPhysics website.

Problems

18–2 and 18–3 Electric Current, Resistance, Ohm's Law

(*Note*: The charge on one electron is 1.60×10^{-19} C.)

1. (I) A current of 1.60 A flows in a wire. How many electrons are flowing past any point in the wire per second?

2. (I) A service station charges a battery using a current of 6.7 A for 5.0 h. How much charge passes through the battery?

3. (I) What is the current in amperes if 1200 Na^+ ions flow across a cell membrane in 3.1 μs? The charge on the sodium is the same as on an electron, but positive.

4. (I) What is the resistance of a toaster if 120 V produces a current of 4.6 A?

5. (I) What voltage will produce 0.25 A of current through a 4800-Ω resistor?

6. (I) How many coulombs are there in a 75 ampere-hour car battery?

7. (II) (*a*) What is the current in the element of an electric clothes dryer with a resistance of 8.6 Ω when it is connected to 240 V? (*b*) How much charge passes through the element in 50 min? (Assume direct current.)

8. (II) A bird stands on a dc electric transmission line carrying 4100 A (Fig. 18–34). The line has 2.5×10^{-5} Ω resistance per meter, and the bird's feet are 4.0 cm apart. What is the potential difference between the bird's feet?

FIGURE 18–34 Problem 8.

9. (II) A hair dryer draws 13.5 A when plugged into a 120-V line. (*a*) What is its resistance? (*b*) How much charge passes through it in 15 min? (Assume direct current.)

10. (II) A 4.5-V battery is connected to a bulb whose resistance is 1.3 Ω. How many electrons leave the battery per minute?

11. (II) An electric device draws 5.60 A at 240 V. (*a*) If the voltage drops by 15%, what will be the current, assuming nothing else changes? (*b*) If the resistance of the device were reduced by 15%, what current would be drawn at 240 V?

18–4 Resistivity

12. (I) What is the diameter of a 1.00-m length of tungsten wire whose resistance is 0.32 Ω?

13. (I) What is the resistance of a 5.4-m length of copper wire 1.5 mm in diameter?

14. (II) Calculate the ratio of the resistance of 10.0 m of aluminum wire 2.2 mm in diameter, to 24.0 m of copper wire 1.8 mm in diameter.

15. (II) Can a 2.2-mm-diameter copper wire have the same resistance as a tungsten wire of the same length? Give numerical details.

16. (II) A certain copper wire has a resistance of 15.0 Ω. At what point along its length must the wire be cut so that the resistance of one piece is 4.0 times the resistance of the other? What is the resistance of each piece?

17. (II) Compute the voltage drop along a 21-m length of household no. 14 copper wire (used in 15-A circuits). The wire has diameter 1.628 mm and carries a 12-A current.

18. (II) Two aluminum wires have the same resistance. If one has twice the length of the other, what is the ratio of the diameter of the longer wire to the diameter of the shorter wire?

19. (II) A rectangular solid made of carbon has sides of lengths 1.0 cm, 2.0 cm, and 4.0 cm, lying along the x, y, and z axes, respectively (Fig. 18–35). Determine the resistance for current that passes through the solid in (a) the x direction, (b) the y direction, and (c) the z direction. Assume the resistivity is $\rho = 3.0 \times 10^{-5}\,\Omega\cdot\text{m}$.

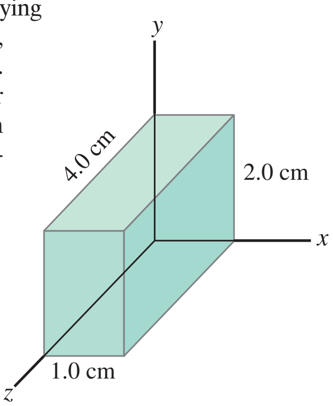

FIGURE 18–35 Problem 19.

20. (II) A length of wire is cut in half and the two lengths are wrapped together side by side to make a thicker wire. How does the resistance of this new combination compare to the resistance of the original wire?

21. (II) How much would you have to raise the temperature of a copper wire (originally at 20°C) to increase its resistance by 12%?

22. (II) Determine at what temperature aluminum will have the same resistivity as tungsten does at 20°C.

23. (II) A 100-W lightbulb has a resistance of about 12 Ω when cold (20°C) and 140 Ω when on (hot). Estimate the temperature of the filament when hot assuming an average temperature coefficient of resistivity $\alpha = 0.0045\,(\text{C}°)^{-1}$.

24. (III) A length of aluminum wire is connected to a precision 10.00-V power supply, and a current of 0.4212 A is precisely measured at 23.5°C. The wire is placed in a new environment of unknown temperature where the measured current is 0.3818 A. What is the unknown temperature?

25. (III) For some applications, it is important that the value of a resistance not change with temperature. For example, suppose you made a 3.20-kΩ resistor from a carbon resistor and a Nichrome wire-wound resistor connected together so the total resistance is the sum of their separate resistances. What value should each of these resistors have (at 0°C) so that the combination is temperature independent?

18–5 and 18–6 Electric Power

26. (I) What is the maximum power consumption of a 3.0-V portable CD player that draws a maximum of 240 mA of current?

27. (I) The heating element of an electric oven is designed to produce 3.3 kW of heat when connected to a 240-V source. What must be the resistance of the element?

28. (I) What is the maximum voltage that can be applied across a 3.9-kΩ resistor rated at $\frac{1}{4}$ watt?

29. (I) (a) Determine the resistance of, and current through, a 75-W lightbulb connected to its proper source voltage of 110 V. (b) Repeat for a 250-W bulb.

30. (I) An electric car has a battery that can hold 16 kWh of energy (approximately 6×10^7 J). If the battery is designed to operate at 340 V, how many coulombs of charge would need to leave the battery at 340 V and return at 0 V to equal the stored energy of the battery?

31. (I) An electric car uses a 45-kW (160-hp) motor. If the battery pack is designed for 340 V, what current would the motor need to draw from the battery? Neglect any energy losses in getting energy from the battery to the motor.

32. (II) A 120-V hair dryer has two settings: 950 W and 1450 W. (a) At which setting do you guess the resistance to be higher? After making a guess, determine the resistance at (b) the lower setting, and (c) the higher setting.

33. (II) A 12-V battery causes a current of 0.60 A through a resistor. (a) What is its resistance, and (b) how many joules of energy does the battery lose in a minute?

34. (II) A 120-V fish-tank heater is rated at 130 W. Calculate (a) the current through the heater when it is operating, and (b) its resistance.

35. (II) How many kWh of energy does a 550-W toaster use in the morning if it is in operation for a total of 5.0 min? At a cost of 9.0 cents/kWh, estimate how much this would add to your monthly electric energy bill if you made toast four mornings per week.

36. (II) At $0.095/kWh, what does it cost to leave a 25-W porch light on day and night for a year?

37. (II) What is the total amount of energy stored in a 12-V, 65 A·h car battery when it is fully charged?

38. (II) An ordinary flashlight uses two D-cell 1.5-V batteries connected in series to provide 3.0 V across the bulb, as in Fig. 18–4b (Fig. 18–36). The bulb draws 380 mA when turned on. (a) Calculate the resistance of the bulb and the power dissipated. (b) By what factor would the power increase if four D-cells in series (total 6.0 V) were used with the same bulb? (Neglect heating effects of the filament.) Why shouldn't you try this?

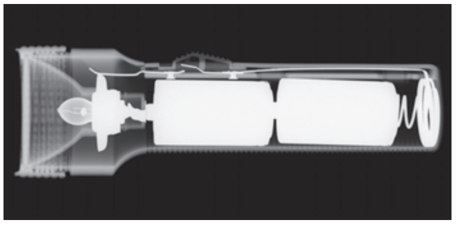

FIGURE 18–36 Problem 38 (X-ray of a flashlight).

39. (II) How many 75-W lightbulbs, connected to 120 V as in Fig. 18–20, can be used without blowing a 15-A fuse?

40. (II) An extension cord made of two wires of diameter 0.129 cm (no. 16 copper wire) and of length 2.7 m (9 ft) is connected to an electric heater which draws 18.0 A on a 120-V line. How much power is dissipated in the cord?

41. (II) You want to design a portable electric blanket that runs on a 1.5-V battery. If you use a 0.50-mm-diameter copper wire as the heating element, how long should the wire be if you want to generate 18 W of heating power? What happens if you accidentally connect the blanket to a 9.0-V battery?

42. (II) A power station delivers 750 kW of power at 12,000 V to a factory through wires with total resistance 3.0 Ω. How much less power is wasted if the electricity is delivered at 50,000 V rather than 12,000 V?

43. (III) A small immersion heater can be used in a car to heat a cup of water for coffee or tea. If the heater can heat 120 mL of water from 25°C to 95°C in 8.0 min, (*a*) approximately how much current does it draw from the car's 12-V battery, and (*b*) what is its resistance? Assume the manufacturer's claim of 85% efficiency.

18–7 Alternating Current

44. (I) Calculate the peak current in a 2.7-kΩ resistor connected to a 220-V rms ac source.

45. (I) An ac voltage, whose peak value is 180 V, is across a 310-Ω resistor. What are the rms and peak currents in the resistor?

46. (II) Estimate the resistance of the 120-V_{rms} circuits in your house as seen by the power company, when (*a*) everything electrical is unplugged, and (*b*) two 75-W lightbulbs are on.

47. (II) The peak value of an alternating current in a 1500-W device is 6.4 A. What is the rms voltage across it?

48. (II) An 1800-W arc welder is connected to a 660-V_{rms} ac line. Calculate (*a*) the peak voltage and (*b*) the peak current.

49. (II) Each channel of a stereo receiver is capable of an average power output of 100 W into an 8-Ω loudspeaker (see Fig. 18–14). What are the rms voltage and the rms current fed to the speaker (*a*) at the maximum power of 100 W, and (*b*) at 1.0 W when the volume is turned down?

50. (II) Determine (*a*) the maximum instantaneous power dissipated by a 2.2-hp pump connected to a 240-V_{rms} ac power source, and (*b*) the maximum current passing through the pump.

*18–8 Microscopic View of Electric Current

*51. (II) A 0.65-mm-diameter copper wire carries a tiny dc current of 2.7 μA. Estimate the electron drift velocity.

*52. (II) A 4.80-m length of 2.0-mm-diameter wire carries a 750-mA dc current when 22.0 mV is applied to its ends. If the drift velocity is 1.7×10^{-5} m/s, determine (*a*) the resistance R of the wire, (*b*) the resistivity ρ, and (*c*) the number n of free electrons per unit volume.

*53. (III) At a point high in the Earth's atmosphere, He^{2+} ions in a concentration of $2.4 \times 10^{12}/m^3$ are moving due north at a speed of 2.0×10^6 m/s. Also, a $7.0 \times 10^{11}/m^3$ concentration of O_2^- ions is moving due south at a speed of 6.2×10^6 m/s. Determine the magnitude and direction of the net current passing through unit area (A/m^2).

*18–10 Nerve Conduction

*54. (I) What is the magnitude of the electric field across an axon membrane 1.0×10^{-8} m thick if the resting potential is −70 mV?

*55. (II) A neuron is stimulated with an electric pulse. The action potential is detected at a point 3.70 cm down the axon 0.0052 s later. When the action potential is detected 7.20 cm from the point of stimulation, the time required is 0.0063 s. What is the speed of the electric pulse along the axon? (Why are two measurements needed instead of only one?)

*56. (III) During an action potential, Na^+ ions move into the cell at a rate of about 3×10^{-7} mol/m²·s. How much power must be produced by the "active Na^+ pumping" system to produce this flow against a +30-mV potential difference? Assume that the axon is 10 cm long and 20 μm in diameter.

General Problems

57. A person accidentally leaves a car with the lights on. If each of the two headlights uses 40 W and each of the two taillights 6 W, for a total of 92 W, how long will a fresh 12-V battery last if it is rated at 75 A·h? Assume the full 12 V appears across each bulb.

58. What is the average current drawn by a 1.0-hp 120-V motor? (1 hp = 746 W.)

59. The **conductance** G of an object is defined as the reciprocal of the resistance R; that is, $G = 1/R$. The unit of conductance is a *mho* (= ohm^{-1}), which is also called the *siemens* (S). What is the conductance (in siemens) of an object that draws 440 mA of current at 3.0 V?

60. The heating element of a 110-V, 1500-W heater is 3.8 m long. If it is made of iron, what must its diameter be?

61. (*a*) A particular household uses a 2.2-kW heater 2.0 h/day ("on" time), four 100-W lightbulbs 6.0 h/day, a 3.0-kW electric stove element for a total of 1.0 h/day, and miscellaneous power amounting to 2.0 kWh/day. If electricity costs $0.115 per kWh, what will be their monthly bill (30 d)? (*b*) How much coal (which produces 7500 kcal/kg) must be burned by a 35%-efficient power plant to provide the yearly needs of this household?

62. A small city requires about 15 MW of power. Suppose that instead of using high-voltage lines to supply the power, the power is delivered at 120 V. Assuming a two-wire line of 0.50-cm-diameter copper wire, estimate the cost of the energy lost to heat per hour per meter. Assume the cost of electricity is about 12 cents per kWh.

63. A 1600-W hair dryer is designed for 117 V. (*a*) What will be the percentage change in power output if the voltage drops to 105 V? Assume no change in resistance. (*b*) How would the actual change in resistivity with temperature affect your answer?

64. The wiring in a house must be thick enough so it does not become so hot as to start a fire. What diameter must a copper wire be if it is to carry a maximum current of 35 A and produce no more than 1.5 W of heat per meter of length?

65. Determine the resistance of the tungsten filament in a 75-W 120-V incandescent lightbulb (*a*) at its operating temperature of about 2800 K, (*b*) at room temperature.

66. Suppose a current is given by the equation $I = 1.40 \sin 210t$, where I is in amperes and t in seconds. (*a*) What is the frequency? (*b*) What is the rms value of the current? (*c*) If this is the current through a 24.0-Ω resistor, write the equation that describes the voltage as a function of time.

67. A microwave oven running at 65% efficiency delivers 950 W to the interior. Find (*a*) the power drawn from the source, and (*b*) the current drawn. Assume a source voltage of 120 V.

68. A 1.00-Ω wire is stretched uniformly to 1.50 times its original length. What is its resistance now?

69. 220 V is applied to two different conductors made of the same material. One conductor is twice as long and twice the diameter of the second. What is the ratio of the power transformed in the first relative to the second?

70. An electric power plant can produce electricity at a fixed power P, but the plant operator is free to choose the voltage V at which it is produced. This electricity is carried as an electric current I through a transmission line (resistance R) from the plant to the user, where it provides the user with electric power P'. (*a*) Show that the reduction in power $\Delta P = P - P'$ due to transmission losses is given by $\Delta P = P^2R/V^2$. (*b*) In order to reduce power losses during transmission, should the operator choose V to be as large or as small as possible?

71. A proposed electric vehicle makes use of storage batteries as its source of energy. It is powered by 24 batteries, each 12 V, 95 A·h. Assume that the car is driven on level roads at an average speed of 45 km/h, and the average friction force is 440 N. Assume 100% efficiency and neglect energy used for acceleration. No energy is consumed when the vehicle is stopped, since the engine doesn't need to idle. (*a*) Determine the horsepower required. (*b*) After approximately how many kilometers must the batteries be recharged?

72. A fish-tank heater is rated at 95 W when connected to 120 V. The heating element is a coil of Nichrome wire. When uncoiled, the wire has a total length of 3.5 m. What is the diameter of the wire?

73. A 100-W, 120-V lightbulb has a resistance of 12 Ω when cold (20°C) and 140 Ω when on (hot). Calculate its power consumption (*a*) at the instant it is turned on, and (*b*) after a few moments when it is hot.

74. In an automobile, the system voltage varies from about 12 V when the car is off to about 13.8 V when the car is on and the charging system is in operation, a difference of 15%. By what percentage does the power delivered to the headlights vary as the voltage changes from 12 V to 13.8 V? Assume the headlight resistance remains constant.

75. A tungsten filament used in a flashlight bulb operates at 0.20 A and 3.0 V. If its resistance at 20°C is 1.5 Ω, what is the temperature of the filament when the flashlight is on?

76. An air conditioner draws 18 A at 220-V ac. The connecting cord is copper wire with a diameter of 1.628 mm. (*a*) How much power does the air conditioner draw? (*b*) If the length of the cord (containing two wires) is 3.5 m, how much power is dissipated in the wiring? (*c*) If no. 12 wire, with a diameter of 2.053 mm, was used instead, how much power would be dissipated in the wiring? (*d*) Assuming that the air conditioner is run 12 h per day, how much money per month (30 days) would be saved by using no. 12 wire? Assume that the cost of electricity is 12 cents per kWh.

77. An electric wheelchair is designed to run on a single 12-V battery rated to provide 100 ampere-hours (100 A·h). (*a*) How much energy is stored in this battery? (*b*) If the wheelchair experiences an average total retarding force (mainly friction) of 210 N, how far can the wheelchair travel on one charge?

78. If a wire of resistance R is stretched uniformly so that its length doubles, by what factor does the power dissipated in the wire change, assuming it remains hooked up to the same voltage source? Assume the wire's volume and density remain constant.

79. Copper wire of diameter 0.259 cm is used to connect a set of appliances at 120 V, which draw 1450 W of power total. (*a*) What power is wasted in 25.0 m of this wire? (*b*) What is your answer if wire of diameter 0.412 cm is used?

80. Battery-powered electricity is very expensive compared with that available from a wall outlet. Estimate the cost per kWh of (*a*) an alkaline D-cell (cost $1.70) and (*b*) an alkaline AA-cell (cost $1.25). These batteries can provide a continuous current of 25 mA for 820 h and 120 h, respectively, at 1.5 V. (*c*) Compare to the cost of a normal 120-V ac house source at $0.10/kWh.

81. A copper pipe has an inside diameter of 3.00 cm and an outside diameter of 5.00 cm (Fig. 18–37). What is the resistance of a 10.0-m length of this pipe?

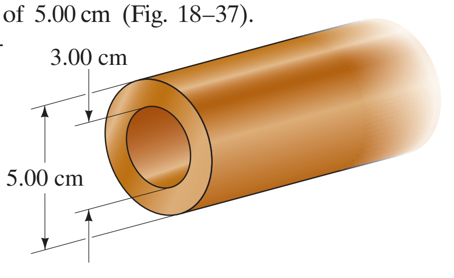

FIGURE 18–37 Problem 81.

***82.** The Tevatron accelerator at Fermilab (Illinois) is designed to carry an 11-mA beam of protons ($q = 1.6 \times 10^{-19}$ C) traveling at very nearly the speed of light (3.0×10^8 m/s) around a ring 6300 m in circumference. How many protons are in the beam?

Search and Learn

1. Why is Ohm's law less of a law than Newton's laws?
2. A traditional incandescent lamp filament may have been lit to a temperature of 2700 K. A contemporary halogen incandescent lamp filament may be at around 2900 K. (*a*) Estimate the percent improvement of the halogen bulb over the traditional one. [*Hint*: See Section 14–8.] (*b*) To produce the same amount of light as a traditional 100-W bulb, estimate what wattage a halogen bulb should use.
3. You find a small cylindrical resistor that measures 9.00 mm in length and 2.15 mm in diameter, and it has a color code of red, yellow, brown, and gold. What is the resistor made of primarily?
4. Small changes in the length of an object can be measured using a **strain gauge** sensor, which is a wire that when undeformed has length ℓ_0, cross-sectional area A_0, and resistance R_0. This sensor is rigidly affixed to the object's surface, aligning its length in the direction in which length changes are to be measured. As the object deforms, the length of the wire sensor changes by $\Delta\ell$, and the resulting change ΔR in the sensor's resistance is measured. Assuming that as the solid wire is deformed to a length ℓ, its density and volume remain constant (only approximately valid), show that the strain $(= \Delta\ell/\ell_0)$ of the wire sensor, and thus of the object to which it is attached, is approximately $\Delta R/2R_0$. [See Sections 18–4 and 9–5.]
5. Household wiring has sometimes used aluminium instead of copper. (*a*) Using Table 18–1, find the ratio of the resistance of a copper wire to that of an aluminum wire of the same length and diameter. (*b*) Typical copper wire used for home wiring in the U.S. has a diameter of 1.63 mm. What is the resistance of 125 m of this wire? (*c*) What would be the resistance of the same wire if it were made of aluminum? (*d*) How much power would be dissipated in each wire if it carried 18 A of current? (*e*) What should be the diameter of the aluminum wire for it to have the same resistance as the copper wire? (*f*) In Section 18–4, a statement is made about the resistance of copper and aluminum wires of the same weight. Using Table 10–1 for the densities of copper and aluminum, find the resistance of an aluminum wire of the same mass and length as the copper wire in part (*b*). Is the statement true?

*6. **Capacitance of an axon.** (*a*) Do an order-of-magnitude estimate for the capacitance of an axon 10 cm long of radius 10 μm. The thickness of the membrane is about 10^{-8} m, and the dielectric constant is about 3. (*b*) By what factor does the concentration (number of ions per volume) of Na^+ ions in the cell change as a result of one action potential?

ANSWERS TO EXERCISES

A: 1.6×10^{-13} A.
B: 3600 C.
C: 240 Ω.
D: (*b*), (*c*).
E: (*c*).
F: 110 m.
G: (*d*).
H: 370,000 kg, or about 5000 people.
I: (*e*) 40.