5.A: Current and Resistance (Answers)

Check Your Understanding

9.1. The time for 1.00 C of charge to flow would be $\Delta t = \frac{\Delta Q}{I} = \frac{1.00C}{0.300 \times 10^{-3} C/s} = 3.33 \times 10^{3} s$, slightly less than an hour. This is quite different from the 5.55 ms for the truck battery. The calculator takes a very small amount of energy to operate, unlike the truck's starter motor. There are several reasons that vehicles use batteries and not solar cells. Aside from the obvious fact that a light source to run the solar cells for a car or truck is not always available, the large amount of current needed to start the engine cannot easily be supplied by present-day solar cells. Solar cells can possibly be used to charge the batteries. Charging the battery requires a small amount of energy when compared to the energy required to run the engine and the other accessories such as the heater and air conditioner. Present day solar-powered cars are powered by solar panels, which may power an electric motor, instead of an internal combustion engine.

9.2. The total current needed by all the appliances in the living room (a few lamps, a television, and your laptop) draw less current and require less power than the refrigerator.

9.3. The diameter of the 14-gauge wire is smaller than the diameter of the 12-gauge wire. Since the drift velocity is inversely proportional to the cross-sectional area, the drift velocity in the 14-gauge wire is larger than the drift velocity in the 12-gauge wire carrying the same current. The number of electrons per cubic meter will remain constant.

9.4. The current density in a conducting wire increases due to an increase in current. The drift velocity is inversely proportional to the current ($v_d = \frac{I}{nqA}$), so the drift velocity would decrease.

9.5. Silver, gold, and aluminum are all used for making wires. All four materials have a high conductivity, silver having the highest. All four can easily be drawn into wires and have a high tensile strength, though not as high as copper. The obvious disadvantage of gold and silver is the cost, but silver and gold wires are used for special applications, such as speaker wires. Gold does not oxidize, making better connections between components. Aluminum wires do have their drawbacks. Aluminum has a higher resistivity than copper, so a larger diameter is needed to match the resistance per length of copper wires, but aluminum is cheaper than copper, so this is not a major drawback. Aluminum wires do not have as high of a ductility and tensile strength as copper, but the ductility and tensile strength is within acceptable levels. There are a few concerns that must be addressed in using aluminum and care must be used when making connections. Aluminum has a higher rate of thermal expansion than copper, which can lead to loose connections and a possible fire hazard. The oxidation of aluminum does not conduct and can cause problems. Special techniques must be used when using aluminum wires and components, such as electrical outlets, must be designed to accept aluminum wires.

9.6. The foil pattern stretches as the backing stretches, and the foil tracks become longer and thinner. Since the resistance is calculated as $R = \rho \frac{L}{A}$, the resistance increases as the foil tracks are stretched. When the temperature changes, so does the resistivity of the foil tracks, changing the resistance. One way to combat this is to use two strain gauges, one used as a reference and the other used to measure the strain. The two strain gauges are kept at a constant temperature

9.7. The longer the length, the smaller the resistance. The greater the resistivity, the higher the resistance. The larger the difference between the outer radius and the inner radius, that is, the greater the ratio between the two, the greater the resistance. If you are attempting to maximize the resistance, the choice of the values for these variables will depend on the application. For example, if the cable must be flexible, the choice of materials may be limited.

9.8. Yes, Ohm's law is still valid. At every point in time the current is equal to I(t)=V(t)/RI(t)=V(t)/R, so the current is also a function of time, $I(t) = \frac{V_{max}}{R} sin(2\pi f t)$.

9.9. Even though electric motors are highly efficient 10–20% of the power consumed is wasted, not being used for doing useful work. Most of the 10–20% of the power lost is transferred into heat dissipated by the copper wires used to make the coils of the motor. This heat adds to the heat of the environment and adds to the demand on power plants providing the power. The demand on the power plant can lead to increased greenhouse gases, particularly if the power plant uses coal or gas as fuel.

9.10. No, the efficiency is a very important consideration of the light bulbs, but there are many other considerations. As mentioned above, the cost of the bulbs and the life span of the bulbs are important considerations. For example, CFL bulbs contain mercury, a neurotoxin, and must be disposed of as hazardous waste. When replacing incandescent bulbs that are being controlled by a dimmer switch with LED, the dimmer switch may need to be replaced. The dimmer switches for LED lights are comparably priced to the incandescent light switches, but this is an initial cost which should be considered. The spectrum of light should also be considered, but there is a broad range of color temperatures available, so you should be able to find one that fits your needs. None of these considerations mentioned are meant to discourage the use of LED or CFL light bulbs, but they are considerations.

Conceptual Questions

1. If a wire is carrying a current, charges enter the wire from the voltage source's positive terminal and leave at the negative terminal, so the total charge remains zero while the current flows through it.

3. Using one hand will reduce the possibility of "completing the circuit" and having current run through your body, especially current running through your heart.

5. Even though the electrons collide with atoms and other electrons in the wire, they travel from the negative terminal to the positive terminal, so they drift in one direction. Gas molecules travel in completely random directions.

7. In the early years of light bulbs, the bulbs are partially evacuated to reduce the amount of heat conducted through the air to the glass envelope. Dissipating the heat would cool the filament, increasing the amount of energy needed to produce light from the filament. It also protects the glass from the heat produced from the hot filament. If the glass heats, it expands, and as it cools, it contacts. This expansion and contraction could cause the glass to become brittle and crack, reducing the life of the bulbs. Many bulbs are now partially filled with an inert gas. It is also useful to remove the oxygen to reduce the possibility of the filament actually burning. When the original filaments were replaced with more efficient tungsten filaments, atoms from the tungsten would evaporate off the filament at such high temperatures. The atoms collide with the atoms of the inert gas and land back on the filament.

9. In carbon, resistivity increases with the amount of impurities, meaning fewer free charges. In silicon and germanium, impurities decrease resistivity, meaning more free electrons.

11. Copper has a lower resistivity than aluminum, so if length is the same, copper must have the smaller diameter.

13. Device B shows a linear relationship and the device is ohmic.

15. Although the conductors have a low resistance, the lines from the power company can be kilometers long. Using a high voltage reduces the current that is required to supply the power demand and that reduces line losses.

17. The resistor would overheat, possibly to the point of causing the resistor to burn. Fuses are commonly added to circuits to prevent such accidents.

19. Very low temperatures necessitate refrigeration. Some materials require liquid nitrogen to cool them below their critical temperatures. Other materials may need liquid helium, which is even more costly.

Problems

21. a. $v = 4.38 \times 10^5 \frac{m}{s}$;

b. $\Delta q = 5.00 \times 10^{-3} C$,no. of protons=$3.13 \times 10^{16}$

23. $I = \frac{\Delta Q}{\Delta t}$, $\Delta Q = 12.00C$, no. of electrons=7.46×10^{19}

25. $I(t) = 0.016 \frac{C}{s^4} t^3 - 0.001 \frac{C}{s}$ $I(3.00s) = 0.431A$

27. $I(t) = -I_{max} sin(\omega t + \phi)$

29. $|J| = 15.92 A/m^2$

31. $I = 3.98 \times 10^{-5} A$

33. a. $|J| = 7.60 \times 10^5 \frac{A}{m^2}$;

b. $v_d = 5.60 \times 10^{-5} \frac{m}{s}$

35. $R = 6.750 k\Omega$

37. $R = 0.10\Omega$

39. $R = \rho \frac{L}{A}$; $L = 3cm$

41. $\frac{R_{Al}/L_{Al}}{R_{Cu}/L_{Cu}} = \frac{\rho_{Al}\frac{1}{\pi(\frac{D_{Al}}{2})^2}}{\rho_{Cu}\frac{1}{\pi(\frac{D_{Cu}}{2})^2}} = \frac{\rho_{Al}}{\rho_{Cu}}(\frac{D_{Cu}}{D_{Al}})^2 = 1, \frac{D_{Al}}{D_{Cu}} = \sqrt{\frac{\rho_{AI}}{\rho_{Cu}}}$

43. a. $R = R_0(1 + \alpha \Delta T), 2 = 1 + \alpha \Delta T, \Delta T = 256.4^\circ C, T = 276.4^\circ C$;

b. Under normal conditions, no it should not occur.

45. $R = R_0(1 + \alpha \Delta T) \;\; \alpha = 0.006^\circ C^{-1}$, iron

47. a. $R = \rho \frac{L}{A}, \rho = 2.44 \times 10^{-} 8 \Omega \cdot m$, gold; $R = \rho \frac{L}{A}(1 + \alpha \Delta T)$

b. $R = 2.44 \times 10^{-8} \Omega \cdot m(\frac{25m}{\pi(\frac{0.100 \times 10^{-3} m}{2})^2})(1 + 0.0034^\circ C^{-1}(150^\circ C - 20^\circ C))R = 112\Omega$

49. $R_{Fe} = 0.525\Omega, R_{Cu} = 0.500\Omega, \alpha_{Fe} = 0.0065^\circ C^{-1}, \alpha_{Cu} = 0.0039^\circ C^{-1}, R_{Fe} = R_{Cu}, R_{0Fe}(1 + \alpha_{Fe}(T - T_0))$
$= R_{0Cu}(1 + \alpha_{Cu}(T - T_0)), \frac{R_{0Fe}}{R_{0Cu}}(1 + \alpha_{Fe}(T - T_0)) = 1 + \alpha_{Cu}(T - T_0), T = 2.91^\circ C$

51. $R_{min} = 2.375 \times 10^5 \Omega, I_{min} = 12.63 \mu A$

$R_{max} = 2.625 \times 10^5 \Omega, I_{max} = 11.43 \mu A$

53. $R = 100\Omega$

55. a. $I = 2mA$;

b. $P = 0.04mW$;

c. $P = 0.04mW$;

d. It is converted into heat.

57. $P = \frac{V^2}{R}, R = 40\Omega, A = 2.08mm^2, \rho = 100 \times 10^{-8} \Omega \cdot m, R = \rho \frac{L}{A}, L = 83m$

59. $I = 0.14A, V = 14V$

61. a. $I \approx 3.00A + \frac{100W}{110V} + \frac{60W}{110V} + \frac{3.00W}{110V} = 4.48A$

$P = 493W$

$R = 9.91\Omega$,

$P_{loss} = 200.W$

b. $P = 493W$

$I = 0.0045A$

$R = 9.91\Omega$

$P_{loss} = 201 \mu W$

63. $R_{copper} = 23.77\Omega\, P = 2.377 \times 10^5 W$

65. $R = R_0(1 + \alpha(T - T_0)$

$0.82R_0 = R_0(1 + \alpha(T - T_0)), 0.82 = 1 - 0.06(T - 37^\circ C), T = 40^\circ C$

67. a. $R_{Au} = R_{Ag}, \rho_{Au}\frac{L_{Au}}{A_{Au}} = \rho_{Ag}\frac{L_{Ag}}{A_{Ag}}, L_{Ag} = 1.53m$;

b. $R_{Au,20^\circ C} = 0.0074\Omega, R_{Au,100^\circ C} = 0.0094\Omega, R_{Ag,100^\circ C} = 0.0096\Omega$

Additional Problems

69. $dR = \frac{\rho}{2\pi rL}dr$

$R = \frac{\rho}{2\pi L}ln\frac{r_o}{r_i}$

$R = 2.21 \times 10^{11}\Omega$

71. a. $R_0 = 0.003\Omega$;

b. $T_c = 37.0^\circ C\; R = 0.00302\Omega$

73. $\rho = 5.00 \times 10^{-8}\Omega \cdot m$

75. $\rho = 1.71 \times 10^{-8}\Omega \cdot m$

77. $a. V = 6000V$;

b. $V = 60V$

79. $P = \frac{W}{t}, W = 8.64J$

Challenge Problems

81. $V = 7.09cm^3\; n = 8.49 \times 10^{28}\frac{electrons}{m^2}\;\; v_d = 7.00 \times 10^{-5}\frac{m}{s}$

83. a. $v = 4.38 \times 10^7 m/s$;

b. $v = 5.81 \times 10^{13}\,\frac{protons}{m^3}$;

c. 1.25 $\frac{electrons}{m^3}$

85. $E = 75kJ$

87. a. $P = 52W\; R = 36\Omega$;

b. $V = 43.54V$

89. a. $R = \frac{\rho}{2\pi L}ln(\frac{R_0}{R_i})$;

b. $R = 2.5m\Omega$

91. a. $I = 0.870A$;

b. $\#\text{electrons} = 2.54 \times 10^{23}$

c. $R = 132\Omega$;

d. $q = 4.68 \times 10^6 J$

93. $P = 1045W, P = \frac{V^2}{R}, R = 12.27\Omega$

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