CHAPTER 20 | ELECTRIC CIRCUITS

PROBLEMS

1. ***REASONING*** The current I is defined in Equation 20.1 as the amount of charge Δq per unit of time Δt that flows in a wire. Therefore, the amount of charge is the product of the current and the time interval. The number of electrons is equal to the charge that flows divided by the magnitude of the charge on an electron.

SOLUTION
a. The amount of charge that flows is

$$\Delta q = I\,\Delta t = (18\text{ A})\left(2.0\times10^{-3}\text{ s}\right) = \boxed{3.6\times10^{-2}\text{ C}}$$

b. The number of electrons N is equal to the amount of charge divided by e, the magnitude of the charge on an electron.

$$N = \frac{\Delta q}{e} = \frac{3.6\times10^{-2}\text{ C}}{1.60\times10^{-19}\text{ C}} = \boxed{2.3\times10^{17}}$$

2. ***REASONING*** We are given the average current I and its duration Δt. We will employ $I = \dfrac{\Delta q}{\Delta t}$ (Equation 20.1) to determine the amount Δq of charge delivered to the ground by the lightning flash.

SOLUTION Solving $I = \dfrac{\Delta q}{\Delta t}$ (Equation 20.1) for Δq, we obtain

$$\Delta q = I\Delta t = \left(1.26\times10^{3}\text{ A}\right)(0.138\text{ s}) = \boxed{174\text{ C}}$$

3. SSM ***REASONING*** Electric current is the amount of charge flowing per unit time (see Equation 20.1). Thus, the amount of charge is the current times the time. Furthermore, the potential difference is the difference in electric potential energy per unit charge (see Equation 19.4), so that, once the amount of charge has been calculated, we can determine the energy by multiplying the potential difference by the charge.

SOLUTION
a. According to Equation 20.1, the current I is the amount of charge Δq divided by the time Δt, or $I = \Delta q/\Delta t$. Therefore, the additional charge that passes through the machine in normal mode versus standby mode is

$$q_{\text{additional}} = \underbrace{I_{\text{normal}}\Delta t}_{\Delta q\text{ in normal mode}} - \underbrace{I_{\text{standby}}\Delta t}_{\Delta q\text{ in standby mode}} = \left(I_{\text{normal}} - I_{\text{standby}}\right)\Delta t$$

$$= (0.110\text{ A} - 0.067\text{ A})(60.0\text{ s}) = \boxed{2.6\text{ C}}$$

b. According to Equation 19.4, the potential difference ΔV is the difference $\Delta(\text{EPE})$ in the electric potential energy divided by the charge $q_{\text{additional}}$, or $\Delta V = \Delta(\text{EPE})/q_{\text{additional}}$. As a result, the additional energy used in the normal mode as compared to the standby mode is

$$\Delta(\text{EPE}) = q_{\text{additional}}\Delta V = (2.6\text{ C})(120\text{ V}) = \boxed{310\text{ J}}$$

4. ***REASONING***
a. According to Ohm's law, the current is equal to the voltage between the cell walls divided by the resistance.

b. The number of Na^+ ions that flow through the cell wall is the total charge that flows divided by the charge of each ion. The total charge is equal to the current multiplied by the time.

SOLUTION
a. The current is

$$I = \frac{V}{R} = \frac{75\times10^{-3}\text{ V}}{5.0\times10^{9}\ \Omega} = \boxed{1.5\times10^{-11}\text{ A}} \tag{20.2}$$

b. The number of Na^+ ions is the total charge Δq that flows divided by the charge $+e$ on each ion, or $\Delta q/e$. The charge is the product of the current I and the time Δt, according to Equation 20.1, so that

$$\text{Number of Na}^+\text{ ions} = \frac{\Delta q}{e} = \frac{I\Delta t}{e} = \frac{\left(1.5\times10^{-11}\text{ A}\right)(0.50\text{ s})}{1.60\times10^{-19}\text{ C}} = \boxed{4.7\times10^{7}}$$

5. ***REASONING AND SOLUTION*** Ohm's law (Equation 20.2, $V = IR$) gives the result directly

$$I = \frac{V}{R} = \frac{240\text{ V}}{11\ \Omega} = \boxed{22\text{ A}}$$

6. ***REASONING*** Voltage is a measure of energy per unit charge (joules per coulomb). Therefore, when an amount Δq of charge passes through the toaster and there is a potential difference across the toaster equal to the voltage V of the outlet, the energy that the charge delivers to the toaster is given by

$$\text{Energy} = V\,\Delta q \tag{1}$$

The charge Δq that flows through the toaster in a time Δt depends upon the magnitude I of the electric current according to $I = \frac{\Delta q}{\Delta t}$ (Equation 20.1). Therefore, we have that

$$\Delta q = I\Delta t \tag{2}$$

We will employ Ohm's law, $I = \frac{V}{R}$ (Equation 20.2), to calculate the current in the toaster in terms of the voltage V of the outlet and the resistance R of the toaster.

SOLUTION Substituting Equation (2) into Equation (1) yields

$$\text{Energy} = V\,\Delta q = VI\Delta t \tag{3}$$

Substituting $I = \frac{V}{R}$ (Equation 20.2) into equation (3), we find that

$$\text{Energy} = VI\Delta t = V\left(\frac{V}{R}\right)\Delta t = \frac{V^2}{R}\Delta t = \frac{(120\text{ V})^2}{14\ \Omega}(60.0\text{ s}) = \boxed{6.2\times10^4\text{ J}}$$

---

7. ***REASONING*** According to Ohm's law, the resistance is the voltage of the battery divided by the current that the battery delivers. The current is the charge divided by the time during which it flows, as stated in Equation 20.1. We know the time, but are not given the charge directly. However, we can determine the charge from the energy delivered to the resistor, because this energy comes from the battery, and the potential difference between the battery terminals is the difference in electric potential energy per unit charge, according to Equation 19.4. Thus, a 9.0-V battery supplies 9.0 J of energy to each coulomb of charge passing through it. To calculate the charge, then, we need only divide the energy from the battery by the 9.0 V potential difference.

SOLUTION Ohm's law indicates that the resistance R is the voltage V of the battery divided by the current I, or $R = V/I$. According to Equation 20.1, the current I is the amount of charge Δq divided by the time Δt, or $I = \Delta q/\Delta t$. Using these two equations, we have

$$R = \frac{V}{I} = \frac{V}{\Delta q/\Delta t} = \frac{V\Delta t}{\Delta q}$$

According to Equation 19.4, the potential difference ΔV is the difference $\Delta(\text{EPE})$ in the electric potential energy divided by the charge Δq, or $\Delta V = \frac{\Delta(\text{EPE})}{\Delta q}$. However, it is customary to denote the potential difference across a battery by V, rather than ΔV, so $V = \frac{\Delta(\text{EPE})}{\Delta q}$. Solving this expression for the charge gives $\Delta q = \frac{\Delta(\text{EPE})}{V}$. Using this result in the expression for the resistance, we find that

$$R = \frac{V\Delta t}{\Delta q} = \frac{V\Delta t}{\Delta(\text{EPE})/V} = \frac{V^2\Delta t}{\Delta(\text{EPE})} = \frac{(9.0\text{ V})^2(6\times3600\text{ s})}{1.1\times10^5\text{ J}} = \boxed{16\ \Omega}$$

---

8. ***REASONING AND SOLUTION***

a. The total charge that can be delivered is

$$\Delta q = (220\text{ A}\cdot\text{h})\left(\frac{3600\text{ s}}{1\text{ h}}\right) = \boxed{7.9\times10^5\text{ C}}$$

b. The maximum current is

$$I = \frac{220\text{ A}\cdot\text{h}}{(38\text{ min})\left(\frac{1\text{ h}}{60\text{ min}}\right)} = \boxed{350\text{ A}}$$

---

9. SSM ***REASONING*** The number N of protons that strike the target is equal to the amount of electric charge Δq striking the target divided by the charge e of a proton, $N = (\Delta q)/e$. From Equation 20.1, the amount of charge is equal to the product of the current I and the time Δt. We can combine these two relations to find the number of protons that strike the target in 15 seconds.

The heat Q that must be supplied to change the temperature of the aluminum sample of mass m by an amount ΔT is given by Equation 12.4 as $Q = cm\Delta T$, where c is the specific heat capacity of aluminum. The heat is provided by the kinetic energy of the protons and is equal to the number of protons that strike the target times the kinetic energy per proton. Using this reasoning, we can find the change in temperature of the block for the 15 second-time interval.

SOLUTION

a. The number N of protons that strike the target is

$$N = \frac{\Delta q}{e} = \frac{I\,\Delta t}{e} = \frac{(0.50\times10^{-6}\text{ A})(15\text{ s})}{1.6\times10^{-19}\text{ C}} = \boxed{4.7\times10^{13}}$$

The power produced by an electric heater is, according to Equation 20.6a, $P = IV$. Substituting this expression for P into the equation above and solving for the current I, we get

$$I = \frac{cm(T - 0.0\ °C) + mL_f}{tV}$$

$$I = \frac{(4186\ \text{J/kg}\cdot\text{C°})(660\ \text{kg})(10.0\ \text{C°}) + (660\ \text{kg})(33.5\times10^4\ \text{J/kg})}{(9.0\ \text{h})\left(\frac{3600\ \text{s}}{\text{h}}\right)(240\ \text{V})} = \boxed{32\ \text{A}}$$

---

41. SSM **_REASONING_** Using Ohm's law (Equation 20.2) we can write an expression for the voltage across the original circuit as $V = I_0R_0$. When the additional resistor R is inserted in series, assuming that the battery remains the same, the voltage across the new combination is given by $V = I(R + R_0)$. Since V is the same in both cases, we can write $I_0R_0 = I(R + R_0)$. This expression can be solved for R_0.

SOLUTION Solving for R_0, we have

$$I_0R_0 - IR_0 = IR \quad \text{or} \quad R_0(I_0 - I) = IR$$

Therefore, we find that

$$R_0 = \frac{IR}{I_0 - I} = \frac{(12.0\ \text{A})(8.00\ \Omega)}{15.0\ \text{A}-12.0\ \text{A}} = \boxed{32\ \Omega}$$

---

42. **_REASONING_** According to Equation 20.2, the resistance R of the resistor is equal to the voltage V_R across it divided by the current I, or $R = V_R/I$. Since the resistor, the lamp, and the voltage source are in series, the voltage across the resistor is $V_R = 120.0\ \text{V} - V_L$, where V_L is the voltage across the lamp. Thus, the resistance is

$$R = \frac{120.0\ \text{V} - V_L}{I}$$

Since V_L is known, we need only determine the current in the circuit. Since we know the voltage V_L across the lamp and the power P dissipated by it, we can use Equation 20.6a to find the current: $I = P/V_L$. The resistance can be written as

$$R = \frac{120.0\ \text{V} - V_L}{\dfrac{P}{V_L}}$$

SOLUTION Substituting the known values for V_L and P into the equation above, the resistance is

$$R = \frac{120.0\ \text{V} - 25\ \text{V}}{\dfrac{60.0\ \text{W}}{25\ \text{V}}} = \boxed{4.0\times10^1\ \Omega}$$

---

43. SSM **_REASONING_** The equivalent series resistance R_s is the sum of the resistances of the three resistors. The potential difference V can be determined from Ohm's law according to $V = IR_s$.

SOLUTION
a. The equivalent resistance is

$$R_s = 25\ \Omega + 45\ \Omega + 75\ \Omega = \boxed{145\ \Omega}$$

b. The potential difference across the three resistors is

$$V = IR_s = (0.51\ \text{A})(145\ \Omega) = \boxed{74\ \text{V}}$$

---

44. **_REASONING_** Ohm's law relates the resistance R of either resistor to the current I in it and the voltage V across it:

$$R = \frac{V}{I} \tag{20.2}$$

Because the two resistors are in series, they must have the same current I. We will, therefore, apply Equation 20.2 to the 86-Ω resistor to determine the current I. Following that, we will use Equation 20.2 again, to obtain the potential difference across the 67-Ω resistor.

SOLUTION Let $R_1 = 86\ \Omega$ be the resistance of the first resistor, which has a potential difference of $V_1 = 27\ \text{V}$ across it. The current I in this resistor, from Equation 20.2, is

$$I = \frac{V_1}{R_1} \tag{1}$$

53. ***REASONING*** When the switch is open, no current goes to the resistor R_2. Current exists only in R_1, so it is the equivalent resistance. When the switch is closed, current is sent to both resistors. Since they are wired in parallel, we can use Equation 20.17 to find the equivalent resistance. Whether the switch is open or closed, the power P delivered to the circuit can be found from the relation $P = V^2/R$ (Equation 20.6c), where V is the battery voltage and R is the equivalent resistance.

SOLUTION
a. When the switch is open, there is current only in resistor R_1. Thus, the equivalent resistance is $R_1 = \boxed{65.0\ \Omega}$.

b. When the switch is closed, there is current in both resistors and, furthermore, they are wired in parallel. The equivalent resistance is

$$\frac{1}{R_P} = \frac{1}{R_1} + \frac{1}{R_2} = \frac{1}{65.0\ \Omega} + \frac{1}{96.0\ \Omega} \quad \text{or} \quad R_P = \boxed{38.8\ \Omega} \qquad (20.17)$$

c. When the switch is open, the power delivered to the circuit by the battery is given by $P = V^2/R_1$, since the only resistance in the circuit is R_1. Thus, the power is

$$P = \frac{V^2}{R_1} = \frac{(9.00\ \text{V})^2}{65.0\ \Omega} = \boxed{1.25\ \text{W}} \qquad (20.6)$$

d. When the switch is closed, the power delivered to the circuit is $P = V^2/R_P$, where R_P is the equivalent resistance of the two resistors wired in parallel:

$$P = \frac{V^2}{R_P} = \frac{(9.00\ \text{V})^2}{38.8\ \Omega} = \boxed{2.09\ \text{W}} \qquad (20.6)$$

---

54. ***REASONING AND SOLUTION*** The power P dissipated in a resistance R is given by Equation 20.6c as $P = V^2/R$. The resistance R_{50} of the 50.0-W filament is

$$R_{50} = \frac{V^2}{P} = \frac{(120.0\ \text{V})^2}{50.0\ \text{W}} = \boxed{288\ \Omega}$$

The resistance R_{100} of the 100.0-W filament is

$$R_{100} = \frac{V^2}{P} = \frac{(120.0\ \text{V})^2}{100.0\ \text{W}} = \boxed{144\ \Omega}$$

---

55. SSM ***REASONING*** Since the resistors are connected in parallel, the voltage across each one is the same and can be calculated from Ohm's Law (Equation 20.2: $V = IR$). Once the voltage across each resistor is known, Ohm's law can again be used to find the current in the second resistor. The total power consumed by the parallel combination can be found calculating the power consumed by each resistor from Equation 20.6b: $P = I^2R$. Then, the total power consumed is the sum of the power consumed by each resistor.

SOLUTION Using data for the second resistor, the voltage across the resistors is equal to

$$V = IR = (3.00\ \text{A})(64.0\ \Omega) = 192\ \text{V}$$

a. The current through the 42.0-Ω resistor is

$$I = \frac{V}{R} = \frac{192\ \text{V}}{42.0\ \Omega} = \boxed{4.57\ \text{A}}$$

b. The power consumed by the 42.0-Ω resistor is

$$P = I^2R = (4.57\ \text{A})^2(42.0\ \Omega) = 877\ \text{W}$$

while the power consumed by the 64.0-Ω resistor is

$$P = I^2R = (3.00\ \text{A})^2(64.0\ \Omega) = 576\ \text{W}$$

Therefore the total power consumed by the two resistors is $877\ \text{W} + 576\ \text{W} = \boxed{1450\ \text{W}}$.

---

56. ***REASONING***
a. The two identical resistors, each with a resistance R, are connected in parallel across the battery, so the potential difference across each resistor is V, the potential difference provided by the battery. The power P supplied to each resistor, then, is $P = \frac{V^2}{R}$ (Equation 20.6c). The total power supplied by the battery is twice this amount.

b. According to Equation 20.6c, the resistor which is heated until its resistance is $2R$ consumes only half as much power as it did initially. Because the resistance of the other resistor does not change, it consumes the same power as before. The battery supplies less power, therefore, than it did initially. We will use Equation 20.6c to determine the final power supplied.

$$R_{ac} = R_{ab} + R_{bc} = R + \tfrac{1}{2}R = \tfrac{3}{2}R$$

Thus, we see that $R_{ac} > R_{ab} > R_{bc}$.

SOLUTION Since the resistance is $R = 10.0\ \Omega$, the equivalent resistances are:

$$R_{ab} = R = \boxed{10.0\ \Omega}$$

$$R_{bc} = \tfrac{1}{2}R = \boxed{5.00\ \Omega}$$

$$R_{ac} = \tfrac{3}{2}R = \boxed{15.0\ \Omega}$$

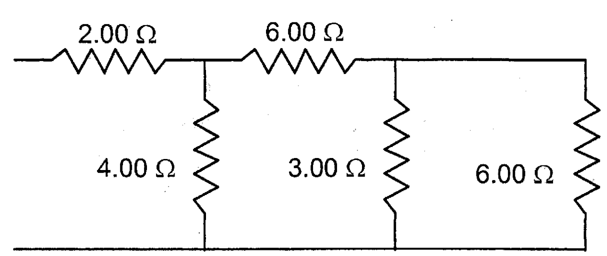
63. SSM ***REASONING*** To find the current, we will use Ohm's law, together with the proper equivalent resistance. The coffee maker and frying pan are in series, so their equivalent resistance is given by Equation 20.16 as $R_{coffee} + R_{pan}$. This total resistance is in parallel with the resistance of the bread maker, so the equivalent resistance of the parallel combination can be obtained from Equation 20.17 as $R_p^{-1} = (R_{coffee} + R_{pan})^{-1} + R_{bread}^{-1}$.

SOLUTION Using Ohm's law and the expression developed above for R_p^{-1}, we find

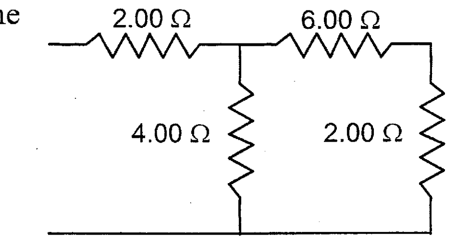
$$I = \frac{V}{R_p} = V\left(\frac{1}{R_{coffee} + R_{pan}} + \frac{1}{R_{bread}}\right) = (120\ \text{V})\left(\frac{1}{14\ \Omega + 16\ \Omega} + \frac{1}{23\ \Omega}\right) = \boxed{9.2\ \text{A}}$$

64. ***REASONING*** We will approach this problem in parts. The resistors that are in series will be combined according to Equation 20.16, and the resistors that are in parallel will be combined according to Equation 20.17.

SOLUTION The 1.00 Ω, 2.00 Ω and 3.00 Ω resistors are in series with an equivalent resistance of $R_S = 6.00\ \Omega$.



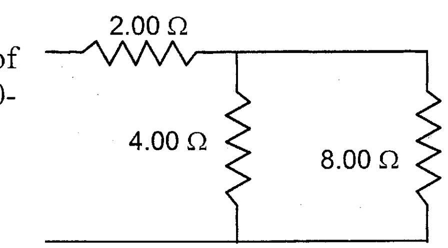
This equivalent resistor of 6.00 O is in parallel with the 3.00-Ω resistor, so



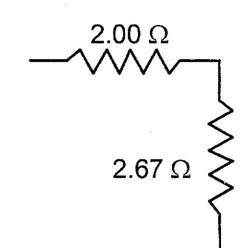
$$\frac{1}{R_P} = \frac{1}{6.00\ \Omega} + \frac{1}{3.00\ \Omega}$$

$$R_P = 2.00\ \Omega$$

This new equivalent resistor of 2.00 O is in series with the 6.00-Ω resistor, so $R_S' = 8.00\ \Omega$.



R_S' is in parallel with the 4.00-Ω resistor, so



$$\frac{1}{R_P'} = \frac{1}{8.00\ \Omega} + \frac{1}{4.00\ \Omega}$$

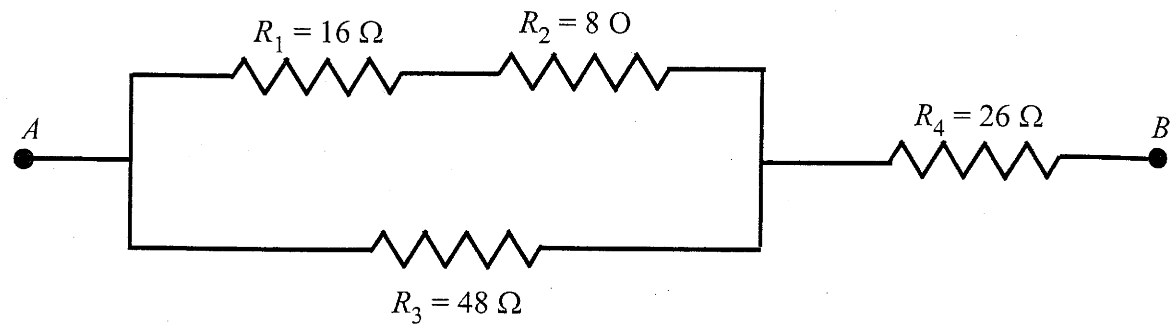
$$R_P' = 2.67\ \Omega$$

Finally, R_P' is in series with the 2.00-Ω, so the total equivalent resistance is $\boxed{4.67\ \text{O}}$.

65. SSM ***REASONING*** When two or more resistors are in series, the equivalent resistance is given by Equation 20.16: $R_s = R_1 + R_2 + R_3 + \ldots$. Likewise, when resistors are in parallel, the expression to be solved to find the equivalent resistance is given by Equation 20.17: $\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots$. We will successively apply these to the individual resistors in the figure in the text beginning with the resistors on the right side of the figure.

SOLUTION Since the 4.0-Ω and the 6.0-Ω resistors are in series, the equivalent resistance of the combination of those two resistors is 10.0 Ω. The 9.0-Ω and 8.0-Ω resistors are in parallel; their equivalent resistance is 4.24 Ω. The equivalent resistances of the parallel combination (9.0 Ω and 8.0 Ω) and the series combination (4.0 Ω and the 6.0 Ω) are in parallel; therefore, their equivalent resistance is 2.98 Ω. The 2.98-Ω combination is in series with the 3.0-Ω resistor, so that equivalent resistance is 5.98 Ω. Finally, the 5.98-Ω combination and the 20.0-Ω resistor are in parallel, so the equivalent resistance between the points A and B is $\boxed{4.6\ \Omega}$.

66. ***REASONING*** The two resistors R_1 and R_2 are wired in series, so we can determine their equivalent resistance R_{12}. The resistor R_3 is wired in parallel with the equivalent resistance R_{12}, so the equivalent resistance R_{123} can be found. Finally, the resistor R_4 is wired in series with the equivalent resistance R_{123}. With these observations, we can evaluate the equivalent resistance between the points A and B.



SOLUTION Since R_1 and R_2 are wired in series, the equivalent resistance R_{12} is

$$R_{12} = R_1 + R_2 = 16\ \Omega + 8\ \Omega = 24\ \Omega \qquad (20.16)$$

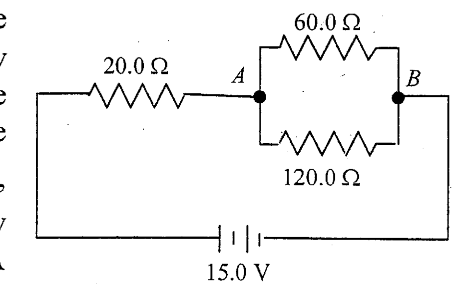
The resistor R_3 is wired in parallel with the equivalent resistor R_{12}, so the equivalent resistance R_{123} of this combination is

$$\frac{1}{R_{123}} = \frac{1}{R_3} + \frac{1}{R_{12}} = \frac{1}{48\ \Omega} + \frac{1}{24\ \Omega} \quad \text{or} \quad R_{123} = 16\ \Omega \qquad (20.17)$$

The resistance R_4 is in series with the equivalent resistance R_{123}, so the equivalent resistance R_{AB} between the points A and B is

$$R_{AB} = R_4 + R_{123} = 26\ \Omega + 16\ \Omega = \boxed{42\ \Omega}$$

67. ***REASONING*** The circuit diagram is shown at the right. We can find the current in the 120.0-Ω resistor by using Ohm's law, provided that we can obtain a value for V_{AB}, the voltage between points A and B in the diagram. To find V_{AB}, we will also apply Ohm's law, this time by multiplying the current from the battery times R_{AB}, the equivalent parallel resistance between A and B. The current from the battery can be obtained by applying Ohm's law again, now to the entire circuit and using the total equivalent resistance of the series combination of the 20.0-Ω resistor and R_{AB}. Once the current in the 120.0-Ω resistor is found, the power delivered to it can be obtained from Equation 20.6b, $P = I^2R$.



SOLUTION

a. According to Ohm's law, the current in the 120.0-Ω resistor is $I_{120} = V_{AB}/(120.0\ \Omega)$. To find V_{AB}, we note that the equivalent parallel resistance between points A and B can be obtained from Equation 20.17 as follows:

$$\frac{1}{R_{AB}} = \frac{1}{60.0\ \Omega} + \frac{1}{120.0\ \Omega} \quad \text{or} \quad R_{AB} = 40.0\ \Omega$$

This resistance of 40.0 Ω is in series with the 20.0-Ω resistance, so that according to Equation 20.16, the total equivalent resistance connected across the battery is 40.0 Ω + 20.0 Ω = 60.0 Ω. Applying Ohm's law to the entire circuit, we can see that the current from the battery is

$$I = \frac{15.0\ \text{V}}{60.0\ \Omega} = 0.250\ \text{A}$$

Again applying Ohm's law, this time to the resistance R_{AB}, we find that

$$V_{AB} = (0.250\ \text{A})R_{AB} = (0.250\ \text{A})(40.0\ \Omega) = 10.0\ \text{V}$$

Finally, we can see that the current in the 120.0-Ω resistor is

$$I_{120} = \frac{V_{AB}}{120\ \Omega} = \frac{10.0\ \text{V}}{120\ \Omega} = \boxed{8.33 \times 10^{-2}\ \text{A}}$$

b. The power delivered to the 120.0-Ω resistor is given by Equation 20.6b as

$$P = I_{120}^2 R = \left(8.33 \times 10^{-2}\ \text{A}\right)^2 (120.0\ \Omega) = \boxed{0.833\ \text{W}}$$

SOLUTION When all the resistors are connected in series, the equivalent resistance is the sum of all three resistors and the equivalent resistance is $\boxed{6.00\ \Omega}$. When all three are in parallel, we have from Equation 20.17, the equivalent resistance is $\boxed{0.545\ \Omega}$.

We can also connect two of the resistors in parallel and connect the parallel combination in series with the third resistor. When the 1.00 and 2.00-Ω resistors are connected in parallel and the 3.00-Ω resistor is connected in series with the parallel combination, the equivalent resistance is $\boxed{3.67\ \Omega}$. When the 1.00 and 3.00-Ω resistors are connected in parallel and the 2.00-Ω resistor is connected in series with the parallel combination, the equivalent resistance is $\boxed{2.75\ \Omega}$. When the 2.00 and 3.00-Ω resistors are connected in parallel and the 1.00-Ω resistor is connected in series with the parallel combination, the equivalent resistance is $\boxed{2.20\ \Omega}$.

We can also connect two of the resistors in series and put the third resistor in parallel with the series combination. When the 1.00 and 2.00-Ω resistors are connected in series and the 3.00-Ω resistor is connected in parallel with the series combination, the equivalent resistance is $\boxed{1.50\ \Omega}$. When the 1.00 and 3.00-Ω resistors are connected in series and the 2.00-Ω resistor is connected in parallel with the series combination, the equivalent resistance is $\boxed{1.33\ \Omega}$. Finally, when the 2.00 and 3.00-Ω resistors are connected in series and the 1.00-Ω resistor is connected in parallel with the series combination, the equivalent resistance is $\boxed{0.833\ \Omega}$.

---

70. ***REASONING*** The power P dissipated in each resistance R is given by Equation 20.6b as $P = I^2R$, where I is the current. This means that we need to determine the current in each resistor in order to calculate the power. The current in R_1 is the same as the current in the equivalent resistance for the circuit. Since R_2 and R_3 are in parallel and equal, the current in R_1 splits into two equal parts at the junction A in the circuit.

SOLUTION To determine the equivalent resistance of the circuit, we note that the parallel combination of R_2 and R_3 is in series with R_1. The equivalent resistance of the parallel combination can be obtained from Equation 20.17 as follows:

$$\frac{1}{R_\text{P}} = \frac{1}{576\ \Omega} + \frac{1}{576\ \Omega} \quad \text{or} \quad R_\text{P} = 288\ \Omega$$

This 288-O resistance is in series with R_1, so that the equivalent resistance of the circuit is given by Equation 20.16 as

$$R_\text{eq} = 576\ \Omega + 288\ \Omega = 864\ \Omega$$

To find the current from the battery we use Ohm's law:

$$I = \frac{V}{R_\text{eq}} = \frac{120.0\ \text{V}}{864\ \Omega} = 0.139\ \text{A}$$

Since this is the current in R_1, Equation 20.6b gives the power dissipated in R_1 as

$$P_1 = I_1^2 R_1 = (0.139\ \text{A})^2 (576\ \Omega) = \boxed{11.1\ \text{W}}$$

R_2 and R_3 are in parallel and equal, so that the current in R_1 splits into two equal parts at the junction A. As a result, there is a current of $\frac{1}{2}(0.139\ \text{A})$ in R_2 and in R_3. Again using Equation 20.6b, we find that the power dissipated in each of these two resistors is

$$P_2 = I_2^2 R_2 = \left[\tfrac{1}{2}(0.139\ \text{A})\right]^2 (576\ \Omega) = \boxed{2.78\ \text{W}}$$

$$P_3 = I_3^2 R_3 = \left[\tfrac{1}{2}(0.139\ \text{A})\right]^2 (576\ \Omega) = \boxed{2.78\ \text{W}}$$

---

71. SSM WWW ***REASONING*** Since we know that the current in the 8.00-Ω resistor is 0.500 A, we can use Ohm's law ($V = IR$) to find the voltage across the 8.00-Ω resistor. The 8.00-Ω resistor and the 16.0-Ω resistor are in parallel; therefore, the voltages across them are equal. Thus, we can also use Ohm's law to find the current through the 16.0-Ω resistor. The currents that flow through the 8.00-Ω and the 16.0-Ω resistors combine to give the total current that flows through the 20.0-Ω resistor. Similar reasoning can be used to find the current through the 9.00-Ω resistor.

SOLUTION

a. The voltage across the 8.00-Ω resistor is $V_8 = (0.500\ \text{A})(8.00\ \Omega) = 4.00\ \text{V}$. Since this is also the voltage that is across the 16.0-Ω resistor, we find that the current through the 16.0-Ω resistor is $I_{16} = (4.00\ \text{V})/(16.0\Omega) = 0.250\ \text{A}$. Therefore, the total current that flows through the 20.0-Ω resistor is

$$I_{20} = 0.500\ \text{A} + 0.250\ \text{A} = \boxed{0.750\ \text{A}}$$

b. The 8.00-Ω and the 16.0-Ω resistors are in parallel, so their equivalent resistance can be obtained from Equation 20.17, $\frac{1}{R_\text{p}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots$, and is equal to 5.33 Ω. Therefore, the equivalent resistance of the upper branch of the circuit is $R_\text{upper} = 5.33\ \Omega + 20.0\ \Omega = 25.3\ \Omega$, since the 5.33-Ω resistance is in series with the 20.0-Ω resistance. Using Ohm's law, we find that the voltage across the upper branch must be $V = (0.750\text{ A})(25.3\ \Omega) = 19.0\text{ V}$. Since the lower branch is in parallel with the upper branch, the voltage across both branches must be the same. Therefore, the current through the 9.00-Ω resistor is, from Ohm's law,

$$I_9 = \frac{V_{\text{lower}}}{R_9} = \frac{19.0\text{ V}}{9.00\ \Omega} = \boxed{2.11\text{ A}}$$

---

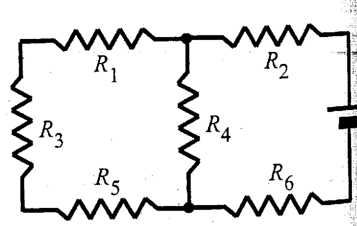
72. ***REASONING*** The resistance R of each of the identical resistors determines the equivalent resistance R_{eq} of the entire circuit, both in its initial form (six resistors) and in its final form (five resistors). We will calculate the initial and final equivalent circuit resistances by replacing groups of resistors that are connected either in series or parallel. The resistances of the replacement resistors are found either from $R_{\text{S}} = R_1 + R_2 + R_3 + \cdots$ (Equation 20.16) for resistors connected in series, or from $\frac{1}{R_{\text{P}}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \cdots$ (Equation 20.17), for resistors connected in parallel.

Once the equivalent resistance R_{eq} of the circuit is determined, the current I supplied by the battery (voltage = V) is found from $I = \frac{V}{R_{\text{eq}}}$ (Equation 20.2). We are given the *decrease* ΔI in the battery current, which is equal to the final current I_{f} minus the initial current I_0:

$$\Delta I = I_{\text{f}} - I_0 = -1.9\text{ A} \tag{1}$$

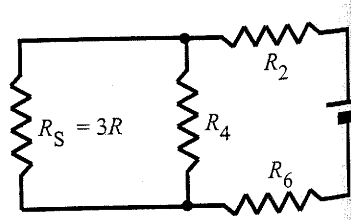
The algebraic sign of ΔI is negative because the final current is smaller than the initial current.

SOLUTION Beginning with the circuit in its initial form, we see that resistors 1, 3, and 5 are connected in series (see the drawing). These three resistors, according to Equation 20.16, may be replaced with a single resistor R_{S} that has three times the resistance R of a single resistor:



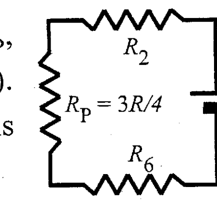
$$R_{\text{S}} = 3R$$

The resistor R_{S} is connected in parallel with the resistor R_4 (see the drawing), so these two resistors may be replaced by an equivalent resistor R_{P} found from Equation 20.17:



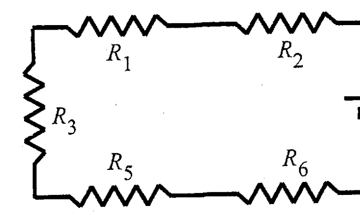
$$R_{\text{P}} = \left(\frac{1}{R_{\text{P}}}\right)^{-1} = \left(\frac{1}{R_S} + \frac{1}{R_4}\right)^{-1} = \left(\frac{1}{3R} + \frac{1}{R}\right)^{-1} = \left(\frac{1}{3R} + \frac{3}{3R}\right)^{-1} = \left(\frac{4}{3R}\right)^{-1} = \frac{3R}{4}$$

After making this replacement, the three remaining resistors (R_2, R_{P}, and R_6) are connected in series across the battery (see the drawing). The initial equivalent resistance $R_{\text{eq,0}}$ of the entire circuit, then, is found from Equation 20.16:



$$\text{R}_{\text{eq,0}} = R_{\text{P}} + R_2 + R_4 = \frac{3R}{4} + 2R = \frac{11R}{4} \tag{2}$$

Next, we consider the circuit after the resistor R_4 has been removed. The remaining five resistors are connected in series (see the drawing). From Equation 20.16, then, the final equivalent resistance $R_{\text{eq,f}}$ of the entire circuit is five times the resistance R of a single resistor:



$$\text{R}_{\text{eq,f}} = 5R \tag{3}$$

From $I = \frac{V}{R_{\text{eq}}}$ (Equation 20.2), the initial and final battery currents are

$$I_0 = \frac{V}{R_{\text{eq,0}}} \quad \text{and} \quad I_{\text{f}} = \frac{V}{R_{\text{eq,f}}} \tag{4}$$

Substituting Equations (2), (3), and (4) into Equation (1), we obtain

$$\Delta I = I_{\text{f}} - I_0 = \frac{V}{R_{\text{eq,f}}} - \frac{V}{R_{\text{eq,0}}} = \frac{V}{5R} - \frac{V}{\left(\frac{11R}{4}\right)} = \frac{V}{R}\left(\frac{1}{5} - \frac{4}{11}\right) = -\frac{9V}{55R} \tag{5}$$

Solving Equation (5) for R yields

$$R = -\frac{9V}{55\Delta I} = -\frac{9(35\text{ V})}{55(-1.9\text{ A})} = \boxed{3.0\ \Omega}$$

---

73. SSM ***REASONING*** The terminal voltage of the battery is given by $V_{\text{terminal}} = \text{Emf} - Ir$, where r is the internal resistance of the battery. Since the terminal voltage is observed to be one-half of the emf of the battery, we have $V_{\text{terminal}} = \text{Emf}/2$ and $I = \text{Emf}/(2r)$. From Ohm's law, the equivalent resistance of the circuit is $R = \text{emf}/I = 2r$. We can also find the equivalent resistance of the circuit by considering that the identical bulbs are in parallel across the battery terminals, so that the equivalent resistance of the N bulbs is found from