CHAPTER 20 | *ELECTRIC CIRCUITS*

PROBLEMS

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1. SSM ***REASONING*** Since current is defined as charge per unit time, the current used by the portable compact disc player is equal to the charge provided by the battery pack (180 C) divided by the time in which the charge is delivered (2.0 h).

SOLUTION The amount of current that the player uses in operation is determined from Equation 20.1:

$$I = \frac{\Delta q}{\Delta t} = \frac{180\ \text{C}}{2.0\ \text{h}} \underbrace{\left(\frac{1.0\ \text{h}}{3600\ \text{s}}\right)}_{\text{Converts hours to seconds}} = \boxed{0.025\ \text{A}}$$

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2. ***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

$$\Delta q = I\,\Delta t = (18\ \text{A})(2.0 \times 10^{-3}\ \text{s}) = \boxed{3.6 \times 10^{-2}\ \text{C}}$$

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

$$N = \frac{\Delta q}{e} = \frac{3.6 \times 10^{-2}\ \text{C}}{1.60 \times 10^{-19}\ \text{C}} = \boxed{2.3 \times 10^{17}}$$

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3. ***REASONING AND SOLUTION*** We know that $V = IR$. Therefore,

$$I = \frac{V}{R} = \frac{120\ \text{V}}{580\ \Omega} = \boxed{0.21\ \text{A}}$$

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4. ***REASONING AND SOLUTION*** Ohm's law gives

$$I = \frac{V}{R} = \frac{120\ \text{V}}{14\ \Omega} = \boxed{8.6\ \text{A}}$$

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

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

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6. ***REASONING AND SOLUTION*** First determine the total charge delivered to the battery using Equation 20.1:

$$\Delta q = I\Delta t = (6.0\ \text{A})(5.0\ \text{h})[(3600\ \text{s})/(1\ \text{h})] = 1.1 \times 10^5\ \text{C}$$

To find the energy delivered to the battery, multiply this charge by the energy per unit charge (i.e., the voltage) to get

$$\text{Energy} = (\Delta q)V = (1.1 \times 10^5\ \text{C})(12\ \text{V}) = \boxed{1.3 \times 10^6\ \text{J}}$$

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21. ***REASONING AND SOLUTION*** According to Equation 20.6, the power delivered to the battery to charge it is

$$P = IV = (19.0\ \text{A})(12.0\ \text{V}) = \boxed{228\ \text{W}}$$

22. ***REASONING AND SOLUTION***

a. According to Equation 20.6c, the resistance is

$$R = V^2/P = (12\ V)^2/(33\ W) = \boxed{4.4\ \Omega}$$

b. According to Equation 20.6a, the current is

$$I = P/V = (33\ W)/(12\ V) = \boxed{2.8\ A}$$

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23. SSM ***REASONING*** According to Equation 6.10b, the energy used is Energy = Pt, where P is the power and t is the time. According to Equation 20.6a, the power is $P = IV$, where I is the current and V is the voltage. Thus, Energy = IVt, and we apply this result first to the drier and then to the computer.

SOLUTION The energy used by the drier is

$$\text{Energy} = Pt = IVt = (16\ \text{A})(240\ \text{V})(45\ \text{min})\underbrace{\left(\frac{60\ \text{s}}{1.00\ \text{min}}\right)}_{\substack{\text{Converts minutes}\\ \text{to seconds}}} = 1.04\times10^{7}\ \text{J}$$

For the computer, we have

$$\text{Energy} = 1.04\times10^{7}\ \text{J} = IVt = (2.7\ \text{A})(120\ \text{V})t$$

Solving for t we find

$$t = \frac{1.04\times10^{7}\ \text{J}}{(2.7\ \text{A})(120\ \text{V})} = 3.21\times10^{4}\ \text{s} = \left(3.21\times10^{4}\ \text{s}\right)\left(\frac{1.00\ \text{h}}{3600\ \text{s}}\right) = \boxed{8.9\ \text{h}}$$

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24. ***REASONING*** The total cost of keeping all the TVs turned on is equal to the number of TVs times the cost to keep each one on. The cost for one TV is equal to the energy it consumes times the cost per unit of energy ($0.10 per kW·h). The energy that a single set uses is, according to Equation 6.10b, the power it consumes times the time of use.

SOLUTION The total cost is

$$\text{Total cost} = (110\ \text{million sets})(\text{Cost per set})$$

$$= (110\ \text{million sets})\left[\text{Energy (in kW}\cdot\text{h) used per set}\right]\left(\frac{\$0.10}{1\ \text{kW}\cdot\text{h}}\right)$$

The energy (in kW·h) used per set is the product of the power and the time, where the power is expressed in kilowatts and the time is in hours:

$$\text{Energy used per set} = Pt = (75\ \text{W})\left(\frac{1\ \text{kW}}{1000\ \text{W}}\right)(6.0\ \text{h}) \qquad (6.10\text{b})$$

The total cost of operating the TV sets is

$$\text{Total cost} = (110\ \text{million sets})\left[(75\ \text{W})\left(\frac{1\ \text{kW}}{1000\ \text{W}}\right)(6.0\ \text{h})\right]\left(\frac{\$0.10}{1\ \text{kW}\cdot\text{h}}\right) = \boxed{\$5.0\times 10^{6}}$$

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25. ***REASONING AND SOLUTION*** According to Equation 20.6a, we know $P = IV$, so that

$$I = P/V = (140\ \text{W})/(120\ \text{V}) = \boxed{1.2\ \text{A}}$$

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26. ***REASONING AND SOLUTION*** The power delivered is P = VI so

a. $$P_{bd} = VI_{bd} = (120\ \text{V})(11\ \text{A}) = \boxed{1300\ \text{W}}$$

b. $$P_{vc} = VI_{vc} = (120\ \text{V})(4.0\ \text{A}) = \boxed{480\ \text{W}}$$

c. The energy is E = Pt so,

$$E_{bd}/E_{vc} = (P_{bd}t_{bd})/(P_{vc}t_{vc}) = (1300\ \text{W})(15\ \text{min})/[(480\ \text{W})(30.0\ \text{min})] = \boxed{1.4}$$

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39. 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 as $V = IR_S$.

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

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

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40. ***REASONING*** Since the two resistors are connected in series, they are equivalent to a single equivalent resistance that is the sum of the two resistances, according to Equation 20.16. Ohm's law (Equation 20.2) can be applied with this equivalent resistance to give the battery voltage.

SOLUTION According to Ohm's law, we find

$$V = IR_s = I(R_1 + R_2) = (0.12\ \text{A})(47\ \Omega + 28\ \Omega) = \boxed{9.0\ \text{V}}$$

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41. ***REASONING AND SOLUTION*** The equivalent resistance of the circuit is

$$R_s = R_1 + R_2 = 36.0\ \Omega + 18.0\ \Omega = 54.0\ \Omega$$

Ohm's law for the circuit gives $I = V/R_s = (15.0\ \text{V})/(54.0\ \Omega) = 0.278\ \text{A}$

a. Ohm's law for R_1 gives $V_1 = (0.278\ \text{A})(36.0\ \Omega) = \boxed{10.0\ \text{V}}$

b. Ohm's law for R_2 gives $V_2 = (0.278\ \text{A})(18.0\ \Omega) = \boxed{5.00\ \text{V}}$

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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

$$R = \frac{120.0\text{ V} - V_\text{L}}{P / V_\text{L}}$$

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

$$R = \frac{120.0\text{ V} - 25\text{ V}}{(60.0\text{ W})/(25\text{ V})} = \boxed{4.0 \times 10^1\ \Omega}$$

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43. SSM ***REASONING*** Using Ohm's law (Equation 20.2) we can write an expression for the voltage across the original circuit as $V = I_0 R_0$. 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 $I_0 R_0 = I(R + R_0)$. This expression can be solved for R_0.

SOLUTION Solving for R_0, we have $I_0 R_0 - I R_0 = IR$ or $R_0 (I_0 - I) = IR$; therefore,

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

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48. ***REASONING AND SOLUTION*** The rule for combining parallel resistors is

$$\frac{1}{R_P}=\frac{1}{R_1}+\frac{1}{R_2}$$

which gives

$$\frac{1}{R_2}=\frac{1}{R_P}-\frac{1}{R_1}=\frac{1}{115\,\Omega}-\frac{1}{155\,\Omega} \quad \text{or} \quad \boxed{R_2=446\,\Omega}$$

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49. SSM ***REASONING AND SOLUTION*** Since the circuit elements are in parallel, the equivalent resistance can be obtained directly from Equation 20.17:

$$\frac{1}{R_P}=\frac{1}{R_1}+\frac{1}{R_2}=\frac{1}{16\,\Omega}+\frac{1}{8.0\,\Omega} \quad \text{or} \quad \boxed{R_P=5.3\,\Omega}$$

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50. ***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

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

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51. 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

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

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

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

while the power consumed by the 64.0-Ω resistor is

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

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

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52. ***REASONING AND SOLUTION*** Each piece has a resistance of 1/3 R. Then

$$1/R_p = 1/(1/3\text{ R}) + 1/(1/3\text{ R}) + 1/(1/3\text{ R}) = 9/R \qquad \text{or} \qquad R_p = \boxed{R/9}$$

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53. ***REASONING*** The total power is given by Equation 20.15c as $\overline{P} = V_{\text{rms}}^2 / R_p$, where R_p is the equivalent parallel resistance of the heater and the lamp. Since the total power and the rms voltage are known, we can use this expression to obtain the equivalent parallel resistance. This equivalent resistance is related to the individual resistances of the heater

and the lamp via Equation 20.17, which is $R_p^{-1} = R_{heater}^{-1} + R_{lamp}^{-1}$. Since R_{heater} is given, R_{lamp} can be found once R_p is known.

SOLUTION According to Equation 20.15c, the equivalent parallel resistance is

$$R_p = \frac{V_{rms}^2}{\overline{P}}$$

Using this result in Equation 20.17 gives

$$\frac{1}{R_p} = \frac{1}{V_{rms}^2 / \overline{P}} = \frac{1}{R_{heater}} + \frac{1}{R_{lamp}}$$

Rearranging this expression shows that

$$\frac{1}{R_{lamp}} = \frac{\overline{P}}{V_{rms}^2} - \frac{1}{R_{heater}} = \frac{84\ \text{W}}{(120\ \text{V})^2} - \frac{1}{6.0 \times 10^2\ \Omega} = 4.2 \times 10^{-3}\ \Omega^{-1}$$

Therefore,

$$R_{lamp} = \frac{1}{4.2 \times 10^{-3}\ \Omega^{-1}} = \boxed{240\ \Omega}$$

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54. ***REASONING*** The electric heater and the toaster are connected in parallel with the voltage source, so each receives the same voltage as the source. The rms-current through the toaster is given by Equation 20.14, $I_{rms} = V_{rms}/R$, where V_{rms} is the rms-voltage across the toaster and R is its resistance. The total power supplied to the heater and toaster is given by Equation 20.15c as $\overline{P} = V_{rms}^2 / R_p$, where R_p is the equivalent resistance of the parallel circuit.

SOLUTION

a. The voltage across the heater is the same as that of the generator, $V_{rms} = \boxed{120.0\ \text{V}}$.

b. The current through the toaster is

$$I_{rms} = \frac{V_{rms}}{R_{toaster}} = \frac{120.0\ \text{V}}{17.0\ \Omega} = \boxed{7.06\ \text{A}} \qquad (20.14)$$

c. The average power supplied to the heater and toaster is $\overline{P} = V_{rms}^2 / R_p$. The equivalent resistance can be obtained from Equation 20.17:

$$\frac{1}{R_p} = \frac{1}{R_{heater}} + \frac{1}{R_{toaster}}$$

The average power becomes

$$\bar{P} = \frac{V_{rms}^2}{R_p} = V_{rms}^2 \left(\frac{1}{R_{heater}} + \frac{1}{R_{toaster}} \right) = (120.0\ \text{V})^2 \left(\frac{1}{9.60\ \Omega} + \frac{1}{17.0\ \Omega} \right) = \boxed{2350\ \text{W}}$$

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55. SSM ***REASONING*** The equivalent resistance of the three devices in parallel is R_p, and we can find the value of R_p by using our knowledge of the total power consumption of the circuit; the value of R_p can be found from Equation 20.6c, $P = V^2 / R_p$. Ohm's law (Equation 20.2, $V = IR$) can then be used to find the current through the circuit.

SOLUTION

a. The total power used by the circuit is P = 1650 W + 1090 W +1250 W = 3990 W. The equivalent resistance of the circuit is

$$R_p = \frac{V^2}{P} = \frac{(120\ \text{V})^2}{3990\ \text{W}} = \boxed{3.6\ \Omega}$$

b. The total current through the circuit is

$$I = \frac{V}{R_p} = \frac{120\ \text{V}}{3.6\ \Omega} = \boxed{33\ \text{A}}$$

This current is larger than the rating of the circuit breaker; therefore, the **breaker will open**.

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58. ***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 $R_{\text{coffee}} + R_{\text{pan}}$. 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 $R_{\text{p}}^{-1} = (R_{\text{coffee}} + R_{\text{pan}})^{-1} + R_{\text{bread}}^{-1}$.

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

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

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59. SSM ***REASONING*** We will analyze the combination in parts. The 65 and 85-Ω resistors are in parallel. This parallel combination is in series with the 63-Ω resistor.

SOLUTION The equivalent resistance for the parallel combination of the 65 and 85-Ω resistors can be determined as follows, using Equation 20.17:

$$\frac{1}{R_{\text{p}}} = \frac{1}{65\,\Omega} + \frac{1}{85\,\Omega} = 0.027\,\Omega^{-1} \quad \text{or} \quad R_{\text{p}} = \frac{1}{0.027\,\Omega^{-1}} = 37\,\Omega$$

This equivalent resistance is in series with the 63-Ω resistance, the two giving the following total resistance between points *A* and *B*, according to Equation 20.16:

$$R_{\text{s}} = R_{AB} = 63\,\Omega + 37\,\Omega = \boxed{1.0 \times 10^{2}\,\Omega}$$

63. ***REASONING AND SOLUTION*** The resistors in the small network have an equivalent resistance

$$\frac{1}{R_p} = \frac{1}{2.0\ \Omega + 1.0\ \Omega} + \frac{1}{5.0\ \Omega + 1.0\ \Omega} \qquad \text{or} \qquad R_p = 2.0\ \Omega$$

This resistance is in series with the 4.0-Ω resistor so the equivalent resistance of the circuit is R = 6.0 Ω. Therefore, Ohm's law gives the total current in the circuit to be

$$I = V/R = (12\ V)/(6.0\ \Omega) = 2.0\ A$$

This current, upon entering the parallel branch, will split in the ratios of 3:9 and 6:9, with the largest current entering the smallest resistance path. The 5.0-Ω resistor then has a current of

$$I = (3/9)(2.0\ A)$$

The power dissipated in this resistor is

$$P = [(3/9)(2.0\ A)]^2(5.0\ \Omega) = \boxed{2.2\ W}$$

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64. ***REASONING*** The power P delivered to the circuit is, according to Equation 20.6c, $P = V^2 / R_{12345}$, where V is the voltage of the battery and R_{12345} is the equivalent resistance of the five-resistor circuit. The voltage and power are known, so that the equivalent resistance can be calculated. We will use our knowledge of resistors wired in series and parallel to evaluate R_{12345} in terms of the resistance R of each resistor. In this manner we will find the value for R.

SOLUTION First we note that all the resistors are equal, so $R_1 = R_2 = R_3 = R_4 = R_5 = R$. We can find the equivalent resistance R_{12345} as follows. The resistors R_3 and R_4 are in series, so the equivalent resistance R_{34} of these two is $R_{34} = R_3 + R_4 = 2R$. The resistors R_2, R_{34}, and R_5 are in parallel, and the reciprocal of the equivalent resistance R_{2345} is

$$\frac{1}{R_{2345}} = \frac{1}{R_2} + \frac{1}{R_{34}} + \frac{1}{R_5} = \frac{1}{R} + \frac{1}{2R} + \frac{1}{R} = \frac{5}{2R}$$

so $R_{2345} = 2R/5$. The resistor R_1 is in series with R_{2345}, and the equivalent resistance of this combination is the equivalent resistance of the circuit. Thus, we have

$$R_{12345} = R_1 + R_{2345} = R + \frac{2R}{5} = \frac{7R}{5}$$

The power delivered to the circuit is

$$P = \frac{V^2}{R_{12345}} = \frac{V^2}{\left(\frac{7R}{5}\right)}$$

Solving for the resistance R, we find that

$$R = \frac{5V^2}{7P} = \frac{5(45\ \text{V})^2}{7(58\ \text{W})} = \boxed{25\ \Omega}$$

78. ***REASONING AND SOLUTION***

Let the current through the 20.0 Ω be I_1 and flow to the right.

Let the current through the 10.0 Ω be I_2 and flow up.

Let the current through the 5.0 Ω be I_3 and flow to the right.

Applying the loop rule to the left loop gives

$$20.0\,I_1 - 10.0\,I_2 = 0$$

and to the right loop

$$10.0\,I_2 + 5.0\,I_3 = 30.0$$

The junction rule applied to the upper junction gives

$$I_1 + I_2 - I_3 = 0$$

A simultaneous solution of the above gives $I_2 = \boxed{1.71\ \text{A}}$.

Since the answer is positive, the current flows in the assumed direction. That is, $\boxed{\text{from the bottom to the top}}$.