CHAPTER 20 | *CIRCUITS*

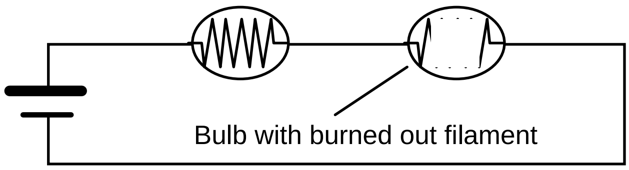
CONCEPTUAL QUESTIONS

Cutnell & Johnson 7E

2. When an incandescent light bulb is turned on, the tungsten filament becomes white hot. The temperature coefficient of resistivity for tungsten is a positive number. What happens to the power delivered to the bulb as the filament heats up? Does the power increase, remain the same, or decrease? Justify your answer.

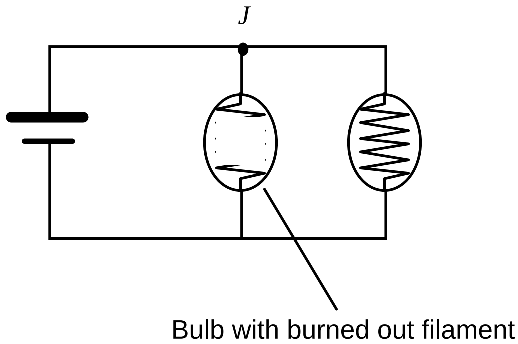
2. ***REASONING AND SOLUTION*** When an incandescent light bulb is turned on, the tungsten filament becomes white hot. Since the voltage is constant, the power delivered to the light bulb is given by Equation 20.6c: $P = V^2 / R$. From Equation 20.5, $R = R_0[1+\alpha(T-T_0)]$, where α is the temperature coefficient of resistivity and is a positive number. Thus, as the filament temperature increases, the resistance of the wire increases, and as the filament heats up, the power delivered to the bulb decreases.

11. ***REASONING AND SOLUTION*** A car has two headlights. The filament of one burns out. However, the other headlight stays on. We can immediately conclude that the bulbs are *not* connected in series. The figure below shows the series arrangement of two such bulbs.



When the bulbs are connected in series, charges must flow through the filaments of *both* lights in order to have a complete circuit. Since the filament of the second bulb is burned out, charges will not be able to flow around the circuit, and neither headlight will stay on.

On the other hand, if the bulbs are connected in parallel, as shown at the right, the current will split at the junction *J*. Charges will be able to flow through the branch of the circuit that contains the good bulb, and that headlight will stay on. Notice that the order of the bulbs does not matter in either case. The results are the same.



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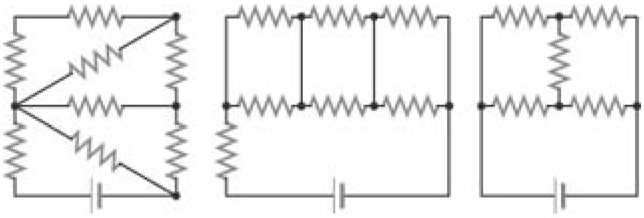
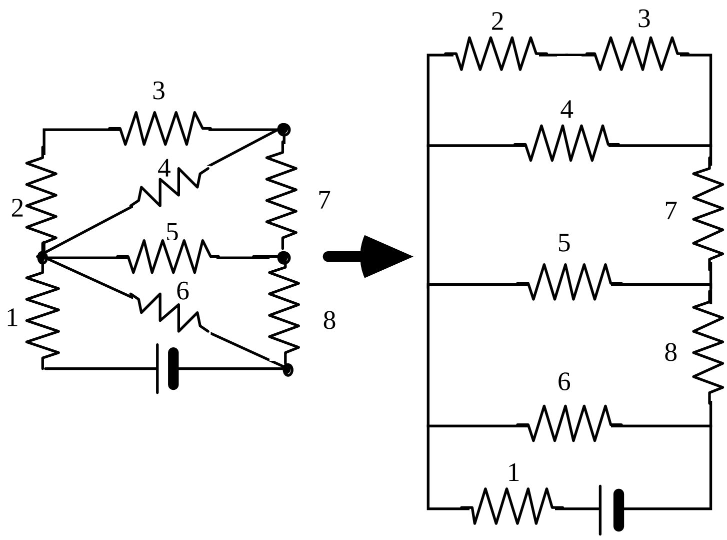
12. In one of the circuits in the drawing, none of the resistors is in series or in parallel. Which is it? Explain.



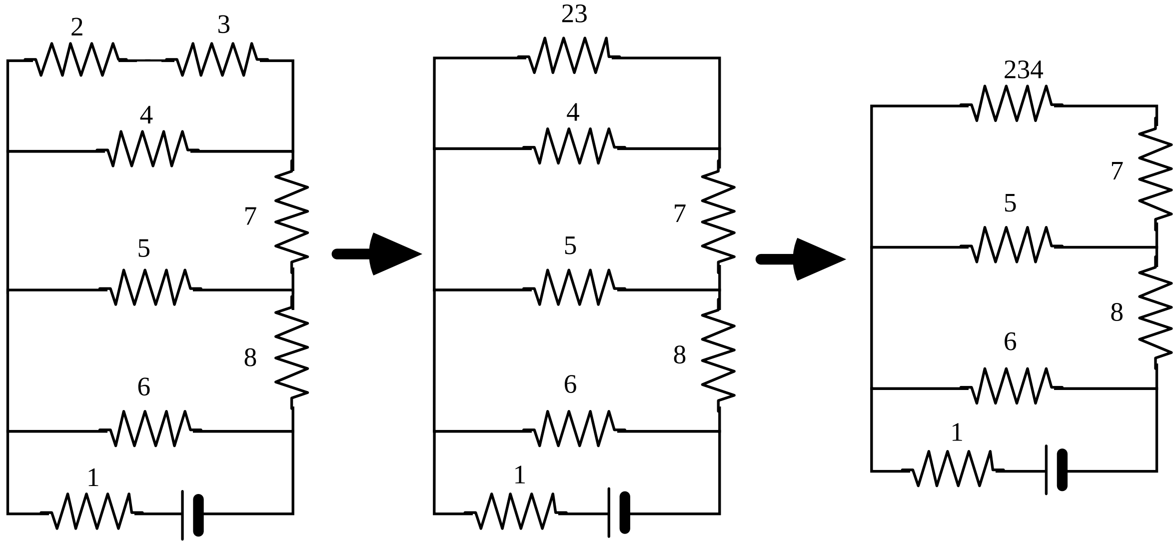
(a) (b) (c)

12. ***REASONING AND SOLUTION*** When two or more circuit elements are connected in series, they are connected such that the same electric current flows through each element. When two or more circuit elements are connected in parallel, they are connected such that the same voltage is applied across each element.

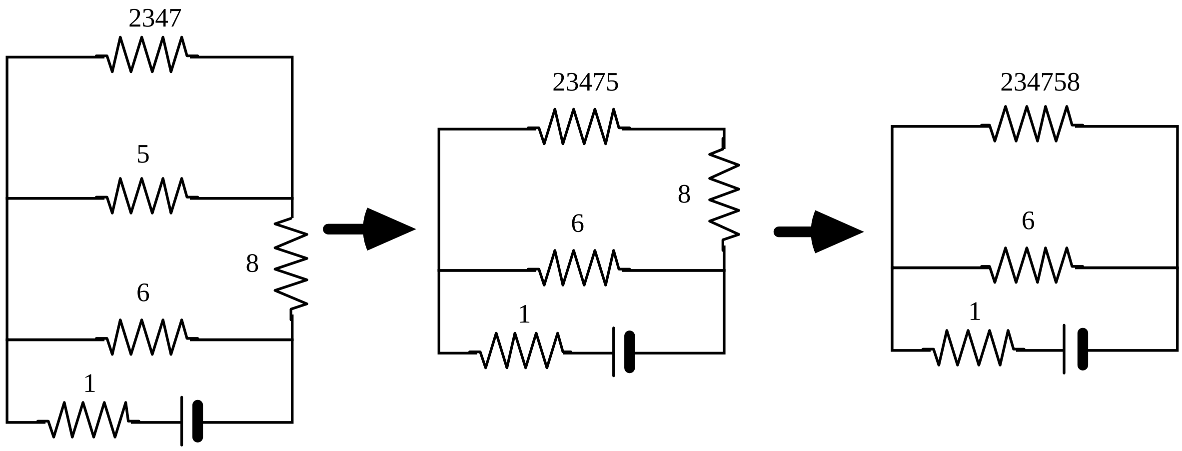
The circuit in Figure (*a*) can be shown to be a combination of series and parallel arrangements of resistors. The circuit can be redrawn as shown in the following drawing.



We can see in the redrawn figure that the current through resistors 2 and 3 is the same; therefore, resistors 2 and 3 are in series and can be represented by an equivalent resistance 23 as shown in the following drawing.

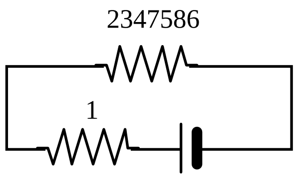


The voltage across resistance 23 and resistor 4 is the same, so these two resistances are in parallel; they can be represented by an equivalent resistance 234. The current through resistance 234 is the same as that through resistor 7, so resistance 234 is in series with resistor 7; they can be represented by an equivalent resistance 2347 as shown in the following figure.

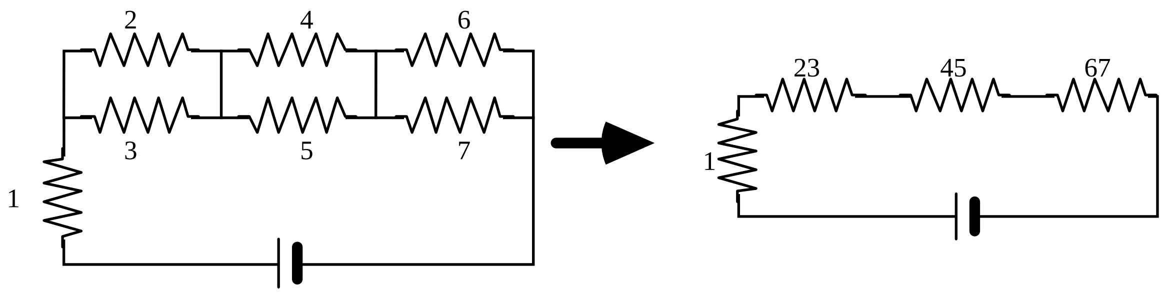


The voltage across 2347 is the same as that across resistor 5; therefore, resistance 2347 is in parallel with resistor 5. They can be represented by an equivalent resistance 23475. Similarly, resistance 23475 is in series with resistor 8, giving an equivalent resistance 234758. Resistance 234758 is in parallel with resistor 6, giving an equivalent resistance 2347586.

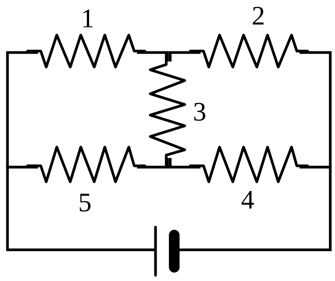
Finally, the current through resistor 1 and resistance 2347586 is the same, so they are in series as shown at the right.



The circuit in Figure (*b*) can also be shown to be a combination of series and parallel arrangements of resistors. Since both ends of resistors 2 and 3 are connected, the voltage across resistors 2 and 3 is the same. The same statement can be made for resistors 4 and 5, and resistors 6 and 7. Therefore, resistor 2 is in parallel with the resistor 3 to give an equivalent resistance labeled 23. Resistor 4 is in parallel with resistor 5 to give an equivalent resistance 45, and resistor 6 is in parallel with resistor 7 to give an equivalent resistance 67. From the right-hand portion of the drawing below, it is clear that the resistances 23, 45, and 67 are in series with resistor 1.



The drawing at the right shows the circuit in Figure (*c*). No such simplifying arguments can be made for this circuit. No two resistors carry the same current; thus, no two of the resistors are in series. Furthermore, no two resistors have the same voltage applied across them; thus, no two of the resistors are in parallel. Circuit (*c*) contains resistors that are neither in series nor in parallel.



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

16***. REASONING AND SOLUTION*** Since both particles are released from rest, their initial kinetic energies are zero. They both have electric potential energy by virtue of their respective positions in the electric field between the plates. Since the particles are oppositely charged, they move in opposite directions toward opposite plates of the capacitor. As they move toward the plates, the particles gain kinetic energy and lose potential energy. Using $(\text{EPE})_0$ and $(\text{EPE})_\text{f}$ to denote the initial and final electric potential energies of the particle, respectively, we find from energy conservation that

$$(\text{EPE})_0 = \tfrac{1}{2} m_\text{particle} v_\text{f}^2 + (\text{EPE})_\text{f}$$

The final speed of each particle is given by

$$v_\text{f} = \sqrt{\frac{2\left[(\text{EPE})_0 - (\text{EPE})_\text{f}\right]}{m_\text{particle}}}$$

Since both particles travel through the same distance between the plates of the capacitor, the change in the electric potential energy is the same for both particles. Since the mass of the electron is smaller than the mass of the proton, the final speed of the electron will be greater than that of the proton. Therefore, the electron travels faster than the proton as the particles move toward the respective plates. The electron, therefore, strikes the capacitor plate first.

CHAPTER 20 | *CIRCUITS*

Samples of solutions to Problems from chapter 20 Cutnell & Johnson 7E

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

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

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

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

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

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

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

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

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

13. ***REASONING*** The resistance of a metal wire of length L, cross-sectional area A and resistivity ρ is given by Equation 20.3: $R = \rho L / A$. Solving for A, we have $A = \rho L / R$. We can use this expression to find the ratio of the cross-sectional area of the aluminum wire to that of the copper wire.

SOLUTION Forming the ratio of the areas and using resistivity values from Table 20.1, we have

$$\frac{A_{\text{aluminum}}}{A_{\text{copper}}}=\frac{\rho_{\text{aluminum}}L/R}{\rho_{\text{copper}}L/R}=\frac{\rho_{\text{aluminum}}}{\rho_{\text{copper}}}=\frac{2.82\times10^{-8}\ \Omega\cdot\text{m}}{1.72\times10^{-8}\ \Omega\cdot\text{m}}=\boxed{1.64}$$

---

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

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

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

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

c. The energy is $E = Pt$ so,

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

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

38. ***REASONING AND SOLUTION*** The energy Q_1 that is released when the water cools from an initial temperature T to a final temperature of 0.0 °C is given by Equation 12.4 as $Q_1 = cm(T - 0.0\ °\text{C})$. The energy Q_2 released when the water turns into ice at 0.0 °C is $Q_2 = mL_f$, where L_f is the latent heat of fusion for water. Since power P is energy divided by time, the power produced is

$$P=\frac{Q_1+Q_2}{t}=\frac{cm(T-0.0\ °C)+mL_f}{t}$$

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

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

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

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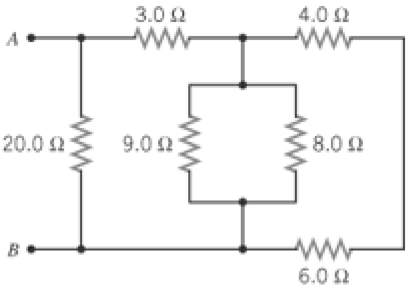
61. ssm Determine the equivalent resistance between the points *A* and *B* for the group of resistors in the drawing.



61. ***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 $\boxed{4.6\ \Omega}$.

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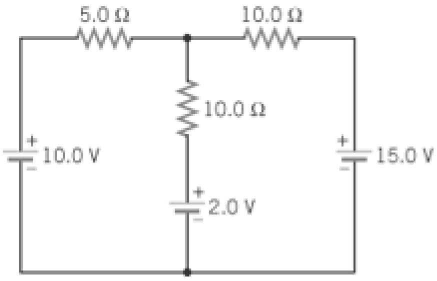
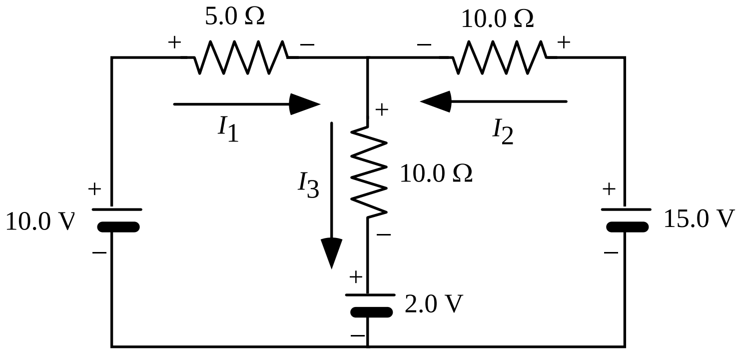
77. Determine the voltage across the 5.0 - Ω resistor in the drawing. Which end of the resistor is at the higher potential?



77. ***REASONING*** We begin by labeling the currents in the three resistors. The drawing below shows the directions chosen for these currents. The directions are arbitrary, and if any of them is incorrect, then the analysis will show that the corresponding value for the current is negative.



We then mark the resistors with the plus and minus signs that serve as an aid in identifying the potential drops and rises for the loop rule, recalling that conventional current is always directed from a higher potential (+) toward a lower potential (–). Thus, given the directions chosen for I_1, I_2, and I_3, the plus and minus signs *must* be those shown in the drawing. We can now use Kirchhoff's rules to find the voltage across the 5.0-Ω resistor.

SOLUTION Applying the loop rule to the left loop (and suppressing units for onvenience) gives

$$5.0\,I_1 + 10.0\,I_3 + 2.0 = 10.0 \qquad (1)$$

Similarly, for the right loop,

$$10.0\,I_2 + 10.0\,I_3 + 2.0 = 15.0 \qquad (2)$$

If we apply the junction rule to the upper junction, we obtain

$$I_1 + I_2 = I_3 \qquad (3)$$

Subtracting Equation (2) from Equation (1) gives

$$5.0I_1 - 10.0I_2 = -5.0 \qquad (4)$$

We now multiply Equation (3) by 10 and add the result to Equation (2); the result is

$$10.0I_1 + 20.0I_2 = 13.0 \qquad (5)$$

If we then multiply Equation (4) by 2 and add the result to Equation (5), we obtain $20.0 I_1 = 3.0$, or solving for I_1, we obtain $I_1 = 0.15$ A. The fact that I_1 is positive means that the current in the drawing has the correct direction. The voltage across the 5.0-Ω resistor can be found from Ohm's law:

$$V = (0.15\text{ A})(5.0\ \Omega) = \boxed{0.75\text{ V}}$$

Current flows from the higher potential to the lower potential, and the current through the 5.0-Ω flows from left to right, so the $\boxed{\text{left end of the resistor}}$ is at the higher potential.

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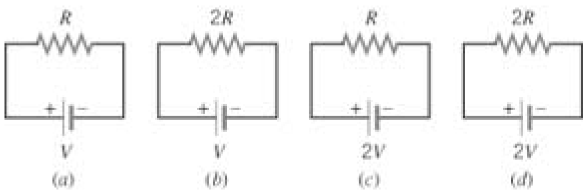
118. Concept Questions Each of the four circuits in the drawing consists of a single resistor whose resistance is either *R* or 2*R*, and a single battery whose voltage is either *V* or 2*V*. Rank the circuits according to (a) the power and (b) the current delivered to the resistor, largest to smallest.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

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



118. ***CONCEPT QUESTIONS***

a. The power delivered to a resistor is given by Equation 20.6c as $P = V^2/R$, where *V* is the voltage and *R* is the resistance. Because of the dependence of the power on V^2, doubling the voltage has a greater effect in increasing the power than halving the resistance. The table shows the power for each circuit, given in terms of these variables:

	Power	Rank
a	$P = \dfrac{V^2}{R}$	3
b	$P = \dfrac{V^2}{2R}$	4
c	$P = \dfrac{(2V)^2}{R} = \dfrac{4V^2}{R}$	1
d	$P = \dfrac{(2V)^2}{2R} = \dfrac{2V^2}{R}$	2

b. The current is given by Equation 20.2 as $I = V/R$. Note that the current, unlike the power, depends linearly on the voltage. Therefore, either doubling the voltage or halving the resistance has the same effect on the current. The table shows the current for the four circuits:

	Current	Rank
a	$I = \dfrac{V}{R}$	2
b	$I = \dfrac{V}{2R}$	3
c	$I = \dfrac{2V}{R}$	1
d	$I = \dfrac{2V}{2R} = \dfrac{V}{R}$	2

SOLUTION

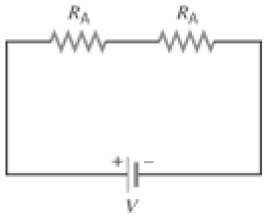
a. Using the results from part (a) and the values of $V = 12.0$ V and $R = 6.00\ \Omega$, the power dissipated in each resistor is

	Power	Rank
a	$P = \dfrac{V^2}{R} = \dfrac{(12.0\text{ V})^2}{6.00\ \Omega} = \boxed{24.0\text{ W}}$	3
b	$P = \dfrac{V^2}{2R} = \dfrac{(12.0\text{ V})^2}{2(6.00\ \Omega)} = \boxed{12.0\text{ W}}$	4
c	$P = \dfrac{4V^2}{R} = \dfrac{4(12.0\text{ V})^2}{(6.00\ \Omega)} = \boxed{96.0\text{ W}}$	1
d	$P = \dfrac{2V^2}{R} = \dfrac{2(12.0\text{ V})^2}{(6.00\ \Omega)} = \boxed{48.0\text{ W}}$	2

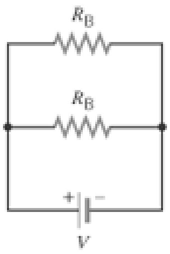
b. Using the results from part (b) and the values of $V = 12.0$ V and $R = 6.00\ \Omega$, the current in each circuit is

	Current	Rank
a	$I = \dfrac{V}{R} = \dfrac{12.0\text{ V}}{6.00\ \Omega} = \boxed{2.00\text{ A}}$	2
b	$I = \dfrac{V}{2R} = \dfrac{12.0\text{ V}}{2(6.00\ \Omega)} = \boxed{1.00\text{ A}}$	3
c	$I = \dfrac{2V}{R} = \dfrac{2(12.0\text{ V})}{6.00\ \Omega} = \boxed{4.00\text{ A}}$	1
d	$I = \dfrac{2V}{2R} = \dfrac{2(12.0\text{ V})}{2(6.00\ \Omega)} = \boxed{2.00\text{ A}}$	2

123. Concept Questions The drawing shows two circuits, and the same battery is used in each. The two resistances R_A in circuit A are the same, and the two resistances R_B in circuit B are the same. (a) How is the total power delivered by the battery related to the equivalent resistance connected between the battery terminals and to the battery voltage? (b) When two resistors are connected in series, is the equivalent resistance of the combination greater than, smaller than, or equal to the resistance of either resistor alone? (c) When two resistors are connected in parallel, is the equivalent resistance of the combination greater than, smaller than, or equal to the resistance of either resistor alone? (d) The same total power is delivered by the battery in circuits A and B. Is R_B greater than, smaller than, or equal to R_A?



Circuit A



Circuit B

Problem Knowing that the same total power is delivered in each case, find the ratio R_B/R_A for the circuits in the drawing. Verify that your answer is consistent with your answer to Concept Question (d).

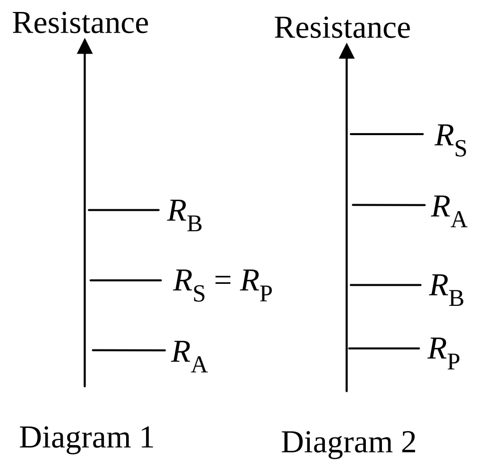
123. ***CONCEPT QUESTIONS***

a. The total power P delivered by the battery is related to the equivalent resistance R_{eq} connected between the battery terminals and to the battery voltage V according to Equation 20.6c: $P = V^2 / R_{eq}$.

b. When two resistors are connected in series, the equivalent resistance R_S of the combination is greater than the resistance of either resistor alone. This can be seen directly from $R_S = R_1 + R_2$ (Equation 20.16).

c. When two resistors are connected in parallel, the equivalent resistance R_P of the combination is smaller than the resistance of either resistor alone. This can be seen directly by substituting values in $R_P^{-1} = R_1^{-1} + R_2^{-1}$ (Equation 20.17) or by reviewing the discussion in Section 20.7 concerning the water flow analogy for electric current in a circuit.

d. Since the total power delivered by the battery is $P = V^2 / R_{\text{eq}}$ and since the power and the battery voltage are the same in both cases, it follows that the equivalent resistances are also the same. But the parallel combination has an equivalent resistance R_P that is smaller than R_B, whereas the series combination has an equivalent resistance R_S that is greater than R_A. This means that R_B must be greater than R_A, as Diagram 1 at the right shows. If R_A were greater than R_B, as in Diagram 2, the equivalent resistances R_S and R_P would not be equal.



SOLUTION As discussed in our answer to Concept Question (d), the equivalent resistances in circuits A and B are equal. According to Equations 20.16 and 20.17, the series and parallel equivalent resistances are

$$R_\text{S} = R_\text{A} + R_\text{A} = 2R_\text{A}$$

$$\frac{1}{R_\text{P}} = \frac{1}{R_\text{B}} + \frac{1}{R_\text{B}} \quad \text{or} \quad R_\text{P} = \tfrac{1}{2} R_\text{B}$$

Setting the equivalent resistances equal gives

$$2R_\text{A} = \tfrac{1}{2} R_\text{B} \quad \text{or} \quad \frac{R_\text{B}}{R_\text{A}} = \boxed{4}$$

As expected, R_B is greater than R_A.