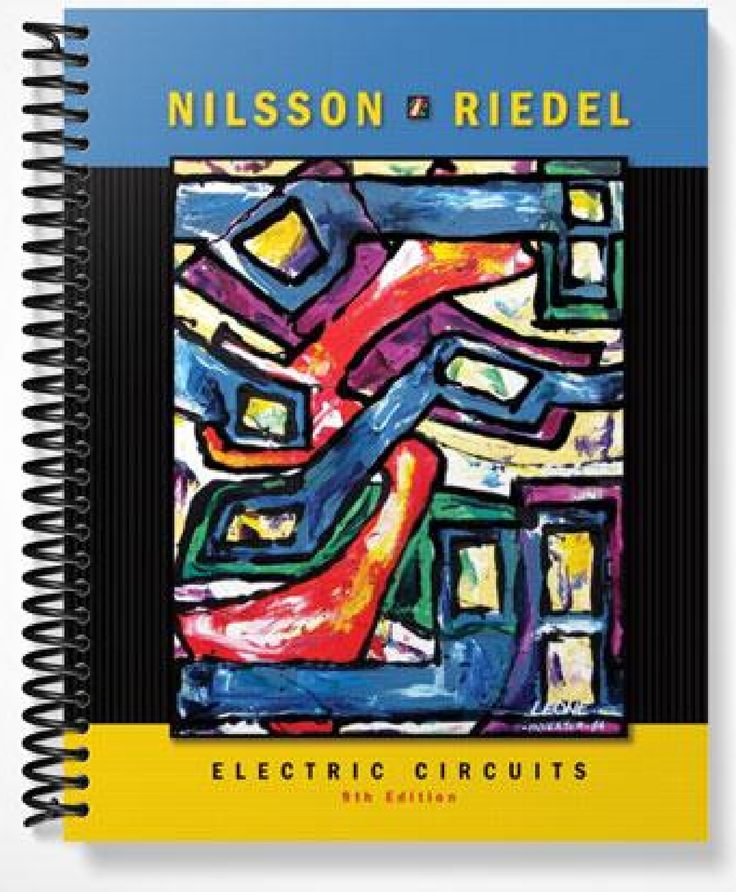
# SOLUTIONS MANUAL

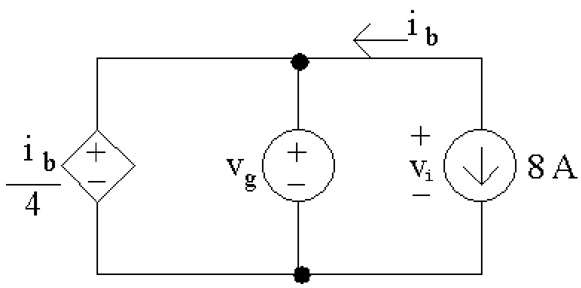


# 2

# Circuit Elements

## Assessment Problems

AP 2.1




[a] Note that the current $i_\mathrm{b}$ is in the same circuit branch as the 8 A current source; however, $i_\mathrm{b}$ is defined in the opposite direction of the current source. Therefore,

$$i_\mathrm{b} = -8\,\mathrm{A}$$

Next, note that the dependent voltage source and the independent voltage source are in parallel with the same polarity. Therefore, their voltages are equal, and

$$v_\mathrm{g} = \frac{i_\mathrm{b}}{4} = \frac{-8}{4} = -2\,\mathrm{V}$$

[b] To find the power associated with the 8 A source, we need to find the voltage drop across the source, $v_i$. Note that the two independent sources are in parallel, and that the voltages $v_\mathrm{g}$ and $v_1$ have the same polarities, so these voltages are equal:

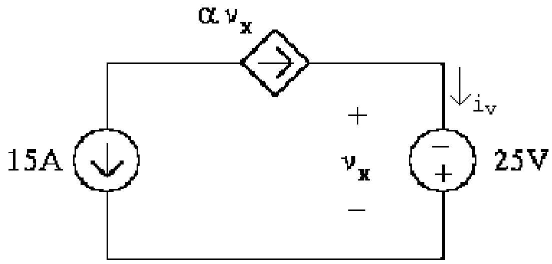
$$v_i = v_g = -2\,\mathrm{V}$$

Using the passive sign convention,

$$p_s = (8\,\mathrm{A})(v_i) = (8\,\mathrm{A})(-2\,\mathrm{V}) = -16\,\mathrm{W}$$

Thus the current source generated 16 W of power.

AP 2.2




[a] Note from the circuit that $v_x = -25$ V. To find $\alpha$ note that the two current sources are in the same branch of the circuit but their currents flow in opposite directions. Therefore

$$\alpha v_x = -15\,\mathrm{A}$$

Solve the above equation for $\alpha$ and substitute for $v_x$,

$$\alpha = \frac{-15\,\mathrm{A}}{v_x} = \frac{-15\,\mathrm{A}}{-25\,\mathrm{V}} = 0.6\ \mathrm{A/V}$$

[b] To find the power associated with the voltage source we need to know the current, $i_v$. Note that this current is in the same branch of the circuit as the dependent current source and these two currents flow in the same direction. Therefore, the current $i_v$ is the same as the current of the dependent source:

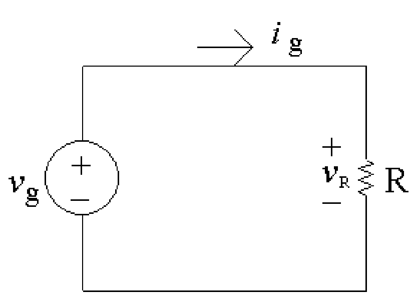
$$i_v = \alpha v_x = (0.6)(-25) = -15\,\mathrm{A}$$

Using the passive sign convention,

$$p_s = -(i_v)(25\,\mathrm{V}) = -(-15\,\mathrm{A})(25\,\mathrm{V}) = 375\,\mathrm{W}.$$

Thus the voltage source dissipates 375 W.

AP 2.3




[a] The resistor and the voltage source are in parallel and the resistor voltage and the voltage source have the same polarities. Therefore these two voltages are the same:

$$v_R = v_g = 1\,\mathrm{kV}$$

Note from the circuit that the current through the resistor is $i_g = 5$ mA. Use Ohm's law to calculate the value of the resistor:

$$R = \frac{v_R}{i_g} = \frac{1\,\text{kV}}{5\,\text{mA}} = 200\,\text{k}\Omega$$

Using the passive sign convention to calculate the power in the resistor,

$$p_R = (v_R)(i_g) = (1\,\text{kV})(5\,\text{mA}) = 5\,\text{W}$$

The resistor is dissipating 5 W of power.

[b] Note from part (a) the $v_R = v_g$ and $i_R = i_g$. The power delivered by the source is thus

$$p_{\text{source}} = -v_g i_g \qquad \text{so} \qquad v_g = -\frac{p_{\text{source}}}{i_g} = -\frac{-3\,\text{W}}{75\,\text{mA}} = 40\,\text{V}$$

Since we now have the value of both the voltage and the current for the resistor, we can use Ohm's law to calculate the resistor value:

$$R = \frac{v_g}{i_g} = \frac{40\,\text{V}}{75\,\text{mA}} = 533.33\,\Omega$$

The power absorbed by the resistor must equal the power generated by the source. Thus,

$$p_R = -p_{\text{source}} = -(-3\,\text{W}) = 3\,\text{W}$$

[c] Again, note the $i_R = i_g$. The power dissipated by the resistor can be determined from the resistor's current:

$$p_R = R(i_R)^2 = R(i_g)^2$$

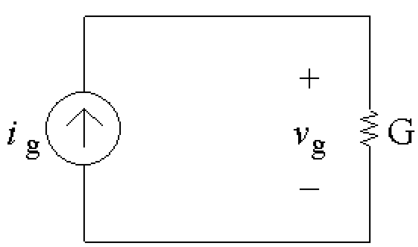
Solving for $i_g$,

$$i_g^2 = \frac{p_r}{R} = \frac{480\,\text{mW}}{300\,\Omega} = 0.0016 \qquad \text{so} \qquad i_g = \sqrt{0.0016} = 0.04\,\text{A} = 40\,\text{mA}$$

Then, since $v_R = v_g$

$$v_R = Ri_R = Ri_g = (300\,\Omega)(40\,\text{mA}) = 12\,\text{V} \qquad \text{so} \qquad v_g = 12\,\text{V}$$

AP 2.4




[a] Note from the circuit that the current through the conductance $G$ is $i_g$, flowing from top to bottom, because the current source and the conductance are in the same branch of the circuit so must have the same

current. The voltage drop across the current source is $v_g$, positive at the top, because the current source and the conductance are also in parallel so must have the same voltage. From a version of Ohm's law,

$$v_g = \frac{i_g}{G} = \frac{0.5\,\text{A}}{50\,\text{mS}} = 10\,\text{V}$$

Now that we know the voltage drop across the current source, we can find the power delivered by this source:

$$p_{\text{source}} = -v_g i_g = -(10)(0.5) = -5\,\text{W}$$

Thus the current source delivers 5 W to the circuit.

[b] We can find the value of the conductance using the power, and the value of the current using Ohm's law and the conductance value:

$$p_g = Gv_g^2 \qquad \text{so} \qquad G = \frac{p_g}{v_g^2} = \frac{9}{15^2} = 0.04\,\text{S} = 40\,\text{mS}$$

$$i_g = Gv_g = (40\,\text{mS})(15\,\text{V}) = 0.6\,\text{A}$$

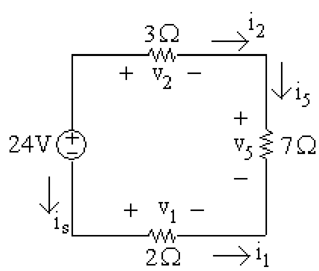
[c] We can find the voltage from the power and the conductance, and then use the voltage value in Ohm's law to find the current:

$$p_g = Gv_g^2 \qquad \text{so} \qquad v_g^2 = \frac{p_g}{G} = \frac{8\,\text{W}}{200\,\mu\text{S}} = 40{,}000$$

Thus $\quad v_g = \sqrt{40{,}000} = 200\,\text{V}$

$$i_g = Gv_g = (200\,\mu\text{S})(200\,\text{V}) = 0.04\,\text{A} = 40\,\text{mA}$$

AP 2.5 **[a]** Redraw the circuit with all of the voltages and currents labeled for every circuit element.




Write a KVL equation clockwise around the circuit, starting below the voltage source:

$$-24\,\text{V} + v_2 + v_5 - v_1 = 0$$

Next, use Ohm's law to calculate the three unknown voltages from the three currents:

$$v_2 = 3i_2; \qquad v_5 = 7i_5; \qquad v_1 = 2i_1$$

A KCL equation at the upper right node gives $i_2 = i_5$; a KCL equation at the bottom right node gives $i_5 = -i_1$; a KCL equation at the upper left node gives $i_s = -i_2$. Now replace the currents $i_1$ and $i_2$ in the Ohm's law equations with $i_5$:

$$v_2 = 3i_2 = 3i_5; \qquad v_5 = 7i_5; \qquad v_1 = 2i_1 = -2i_5$$

Now substitute these expressions for the three voltages into the first equation:

$$24 = v_2 + v_5 - v_1 = 3i_5 + 7i_5 - (-2i_5) = 12i_5$$

Therefore $i_5 = 24/12 = 2$ A

[**b**] $v_1 = -2i_5 = -2(2) = -4\,\text{V}$

[**c**] $v_2 = 3i_5 = 3(2) = 6\,\text{V}$

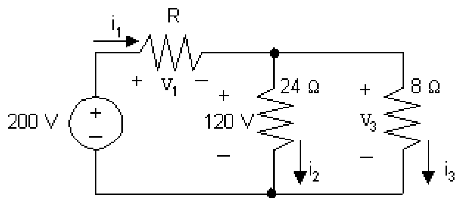
[**d**] $v_5 = 7i_5 = 7(2) = 14\,\text{V}$

[**e**] A KCL equation at the lower left node gives $i_s = i_1$. Since $i_1 = -i_5$, $i_s = -2\,\text{A}$. We can now compute the power associated with the voltage source:

$$p_{24} = (24)i_s = (24)(-2) = -48\,\text{W}$$

Therefore 24 V source is delivering 48 W.

AP 2.6 Redraw the circuit labeling all voltages and currents:




We can find the value of the unknown resistor if we can find the value of its voltage and its current. To start, write a KVL equation clockwise around the right loop, starting below the $24\,\Omega$ resistor:

$$-120\,\text{V} + v_3 = 0$$

Use Ohm's law to calculate the voltage across the $8\,\Omega$ resistor in terms of its current:

$$v_3 = 8i_3$$

Substitute the expression for $v_3$ into the first equation:

$$-120\,\text{V} + 8i_3 = 0 \qquad \text{so} \qquad i_3 = \frac{120}{8} = 15\,\text{A}$$

Also use Ohm's law to calculate the value of the current through the $24\,\Omega$ resistor:

$$i_2 = \frac{120\,\text{V}}{24\,\Omega} = 5\,\text{A}$$

Now write a KCL equation at the top middle node, summing the currents leaving:

$$-i_1 + i_2 + i_3 = 0 \qquad \text{so} \qquad i_1 = i_2 + i_3 = 5 + 15 = 20\,\text{A}$$

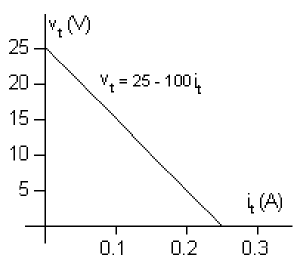
Write a KVL equation clockwise around the left loop, starting below the voltage source:

$$-200\,\text{V} + v_1 + 120\,\text{V} = 0 \qquad \text{so} \qquad v_1 = 200 - 120 = 80\,\text{V}$$

Now that we know the values of both the voltage and the current for the unknown resistor, we can use Ohm's law to calculate the resistance:

$$\text{R} = \frac{v_1}{i_1} = \frac{80}{20} = 4\,\Omega$$

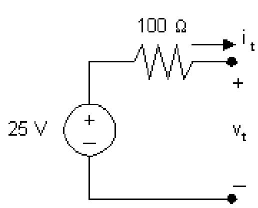
AP 2.7 **[a]** Plotting a graph of $v_t$ versus $i_t$ gives



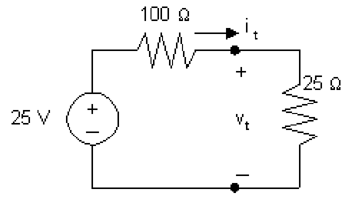

Note that when $i_t = 0$, $v_t = 25$ V; therefore the voltage source must be 25 V. Since the plot is a straight line, its slope can be used to calculate the value of resistance:

$$R = \frac{\Delta v}{\Delta i} = \frac{25 - 0}{0.25 - 0} = \frac{25}{0.25} = 100\,\Omega$$

A circuit model having the same $v - i$ characteristic is a 25 V source in series with a $100\Omega$ resistor, as shown below:



**[b]** Draw the circuit model from part (a) and attach a $25\,\Omega$ resistor:




To find the power delivered to the $25\,\Omega$ resistor we must calculate the current through the $25\,\Omega$ resistor. Do this by first using KCL to recognize that the current in each of the components is $i_t$, flowing in a clockwise direction. Write a KVL equation in the clockwise direction, starting below the voltage source, and using Ohm's law to express the voltage drop across the resistors in the direction of the current $i_t$ flowing through the resistors:

$$-25\,\text{V} + 100i_t + 25i_t = 0 \qquad \text{so} \qquad 125i_t = 25 \qquad \text{so} \qquad i_t = \frac{25}{125} = 0.2\,\text{A}$$

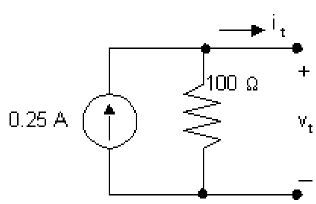
Thus, the power delivered to the $25\,\Omega$ resistor is

$$p_{25} = (25)i_t^2 = (25)(0.2)^2 = 1\,\text{W}.$$

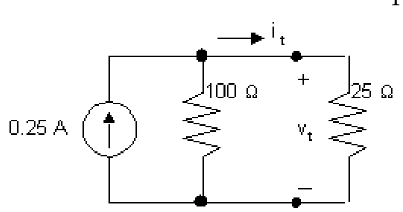
AP 2.8 **[a]** From the graph in Assessment Problem 2.7(a), we see that when $v_t = 0$, $i_t = 0.25\,\text{A}$. Therefore the current source must be 0.25 A. Since the plot is a straight line, its slope can be used to calculate the value of resistance:

$$R = \frac{\Delta v}{\Delta i} = \frac{25 - 0}{0.25 - 0} = \frac{25}{0.25} = 100\,\Omega$$

A circuit model having the same $v - i$ characteristic is a 0.25 A current source in parallel with a $100\Omega$ resistor, as shown below:




**[b]** Draw the circuit model from part (a) and attach a $25\,\Omega$ resistor:




Note that by writing a KVL equation around the right loop we see that the voltage drop across both resistors is $v_t$. Write a KCL equation at the top center node, summing the currents leaving the node. Use Ohm's law to specify the currents through the resistors in terms of the voltage drop across the resistors and the value of the resistors.

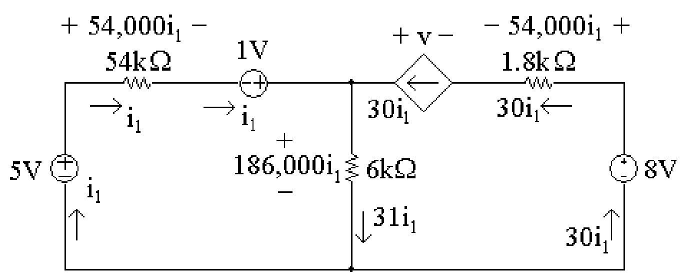
$$-0.25 + \frac{v_t}{100} + \frac{v_t}{25} = 0, \qquad \text{so} \qquad 5v_t = 25, \qquad \text{thus} \qquad v_t = 5\,\text{V}$$

$$p_{25} = \frac{v_t^2}{25} = 1\,\text{W}.$$

AP 2.9 First note that we know the current through all elements in the circuit except the 6 kΩ resistor (the current in the three elements to the left of the 6 kΩ resistor is $i_1$; the current in the three elements to the right of the 6 kΩ resistor is $30i_1$). To find the current in the 6 kΩ resistor, write a KCL equation at the top node:

$$i_1 + 30i_1 = i_{6\text{k}} = 31i_1$$

We can then use Ohm's law to find the voltages across each resistor in terms of $i_1$. The results are shown in the figure below:




**[a]** To find $i_1$, write a KVL equation around the left-hand loop, summing voltages in a clockwise direction starting below the 5V source:

$$-5\,\text{V} + 54{,}000i_1 - 1\,\text{V} + 186{,}000i_1 = 0$$

Solving for $i_1$

$$54{,}000i_1 + 186{,}000i_1 = 6\,\text{V} \qquad \text{so} \qquad 240{,}000i_1 = 6\,\text{V}$$

Thus,

$$i_1 = \frac{6}{240{,}000} = 25\,\mu\text{A}$$

**[b]** Now that we have the value of $i_1$, we can calculate the voltage for each component except the dependent source. Then we can write a KVL equation for the right-hand loop to find the voltage $v$ of the dependent source. Sum the voltages in the clockwise direction, starting to the left of the dependent source:

$$+v - 54{,}000i_1 + 8\,\text{V} - 186{,}000i_1 = 0$$

Thus,

$$v = 240{,}000i_1 - 8\,\text{V} = 240{,}000(25 \times 10^{-6}) - 8\,\text{V} = 6\,\text{V} - 8\,\text{V} = -2\,\text{V}$$

We now know the values of voltage and current for every circuit element.

Let's construct a power table:

| **Element** | **Current ($\mu$A)** | **Voltage (V)** | **Power Equation** | **Power ($\mu$W)** |
|---|---|---|---|---|
| 5 V | 25 | 5 | $p = -vi$ | −125 |
| 54 kΩ | 25 | 1.35 | $p = Ri^2$ | 33.75 |
| 1 V | 25 | 1 | $p = -vi$ | −25 |
| 6 kΩ | 775 | 4.65 | $p = Ri^2$ | 3603.75 |
| Dep. source | 750 | −2 | $p = -vi$ | 1500 |
| 1.8 kΩ | 750 | 1.35 | $p = Ri^2$ | 1012.5 |
| 8 V | 750 | 8 | $p = -vi$ | −6000 |

[**c**] The total power generated in the circuit is the sum of the negative power values in the power table:

$$-125\,\mu\text{W} + -25\,\mu\text{W} + -6000\,\mu\text{W} = -6150\,\mu\text{W}$$

Thus, the total power generated in the circuit is 6150 $\mu$W.

[**d**] The total power absorbed in the circuit is the sum of the positive power values in the power table:

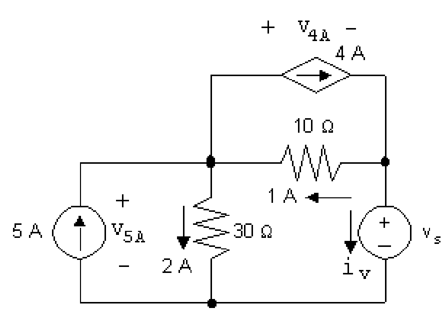
$$33.75\,\mu\text{W} + 3603.75\,\mu\text{W} + 1500\,\mu\text{W} + 1012.5\,\mu\text{W} = 6150\,\mu\text{W}$$

Thus, the total power absorbed in the circuit is 6150 $\mu$W.

AP 2.10 Given that $i_\phi = 2$ A, we know the current in the dependent source is $2i_\phi = 4$ A. We can write a KCL equation at the left node to find the current in the 10 Ω resistor. Summing the currents leaving the node,

$$-5\,\text{A} + 2\,\text{A} + 4\,\text{A} + i_{10\Omega} = 0 \qquad \text{so} \qquad i_{10\Omega} = 5\,\text{A} - 2\,\text{A} - 4\,\text{A} = -1\,\text{A}$$

Thus, the current in the 10 Ω resistor is 1 A, flowing right to left, as seen in the circuit below.



**[a]** To find $v_s$, write a KVL equation, summing the voltages counter-clockwise around the lower right loop. Start below the voltage source.

$$-v_s + (1\,\text{A})(10\,\Omega) + (2\,\text{A})(30\,\Omega) = 0 \qquad \text{so} \qquad v_s = 10\,\text{V} + 60\,\text{V} = 70\,\text{V}$$

**[b]** The current in the voltage source can be found by writing a KCL equation at the right-hand node. Sum the currents leaving the node

$$-4\,\text{A} + 1\,\text{A} + i_v = 0 \qquad \text{so} \qquad i_v = 4\,\text{A} - 1\,\text{A} = 3\,\text{A}$$

The current in the voltage source is 3 A, flowing top to bottom. The power associated with this source is

$$p = vi = (70\,\text{V})(3\,\text{A}) = 210\,\text{W}$$

Thus, 210 W are absorbed by the voltage source.

**[c]** The voltage drop across the independent current source can be found by writing a KVL equation around the left loop in a clockwise direction:

$$-v_{5A} + (2\,\text{A})(30\,\Omega) = 0 \qquad \text{so} \qquad v_{5A} = 60\,\text{V}$$

The power associated with this source is

$$p = -v_{5A}i = -(60\,\text{V})(5\,\text{A}) = -300\,\text{W}$$

This source thus delivers 300 W of power to the circuit.

**[d]** The voltage across the controlled current source can be found by writing a KVL equation around the upper right loop in a clockwise direction:

$$+v_{4A} + (10\,\Omega)(1\,\text{A}) = 0 \qquad \text{so} \qquad v_{4A} = -10\,\text{V}$$

The power associated with this source is

$$p = v_{4A}i = (-10\,\text{V})(4\,\text{A}) = -40\,\text{W}$$

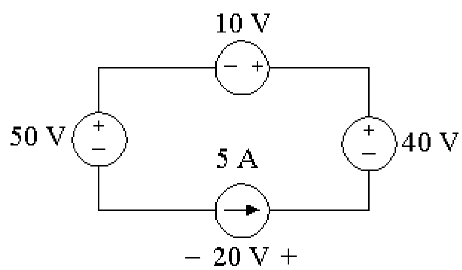
This source thus delivers 40 W of power to the circuit.

**[e]** The total power dissipated by the resistors is given by

$$(i_{30\Omega})^2(30\,\Omega) + (i_{10\Omega})^2(10\,\Omega) = (2)^2(30\,\Omega) + (1)^2(10\,\Omega) = 120 + 10 = 130\,\text{W}$$

# Problems

P 2.1 The interconnect is valid since the voltage sources can all carry 5 A of current supplied by the current source, and the current source can carry the voltage drop required by the interconnection. Note that the branch containing the 10 V, 40 V, and 5 A sources must have the same voltage drop as the branch containing the 50 V source, so the 5 A current source must have a voltage drop of 20 V, positive at the right. The voltages and currents are summarize in the circuit below:




$$P_{50\text{V}} = (50)(5) = 250 \text{ W} \quad \text{(abs)}$$
$$P_{10\text{V}} = (10)(5) = 50 \text{ W} \quad \text{(abs)}$$
$$P_{40\text{V}} = -(40)(5) = -200 \text{ W} \quad \text{(dev)}$$
$$P_{5\text{A}} = -(20)(5) = -100 \text{ W} \quad \text{(dev)}$$
$$\sum P_{\text{dev}} = 300 \text{ W}$$

P 2.2 The interconnection is not valid. Note that the 10 V and 20 V sources are both connected between the same two nodes in the circuit. If the interconnection was valid, these two voltage sources would supply the same voltage drop between these two nodes, which they do not.

P 2.3 [**a**] Yes, independent voltage sources can carry the 5 A current required by the connection; independent current source can support any voltage required by the connection, in this case 5 V, positive at the bottom.

[**b**] 20 V source: absorbing

15 V source: developing (delivering)

5 A source: developing (delivering)

[**c**]
$$P_{20\text{V}} = (20)(5) = 100 \text{ W} \quad \text{(abs)}$$
$$P_{15\text{V}} = -(15)(5) = -75 \text{ W} \quad \text{(dev/del)}$$
$$P_{5\text{A}} = -(5)(5) = -25 \text{ W} \quad \text{(dev/del)}$$
$$\sum P_{\text{abs}} = \sum P_{\text{del}} = 100 \text{ W}$$

[**d**] The interconnection is valid, but in this circuit the voltage drop across the 5 A current source is 35 V, positive at the top; 20 V source is developing (delivering), the 15 V source is developing (delivering), and the 5 A source is absorbing:

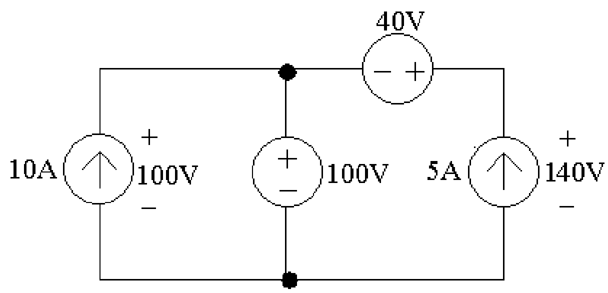
$$P_{20\text{V}} = -(20)(5) = -100 \text{ W} \quad \text{(dev/del)}$$

$$P_{15\text{V}} = -(15)(5) = -75 \text{ W} \quad \text{(dev/del)}$$

$$P_{5\text{A}} = (35)(5) = 175 \text{ W} \quad \text{(abs)}$$

$$\sum P_{\text{abs}} = \sum P_{\text{del}} = 175 \text{ W}$$

P 2.4 The interconnection is valid. The 10 A current source has a voltage drop of 100 V, positive at the top, because the 100 V source supplies its voltage drop across a pair of terminals shared by the 10 A current source. The right hand branch of the circuit must also have a voltage drop of 100 V from the left terminal of the 40 V source to the bottom terminal of the 5 A current source, because this branch shares the same terminals as the 100 V source. This means that the voltage drop across the 5 A current source is 140 V, positive at the top. Also, the two voltage sources can carry the current required of the interconnection. This is summarized in the figure below:



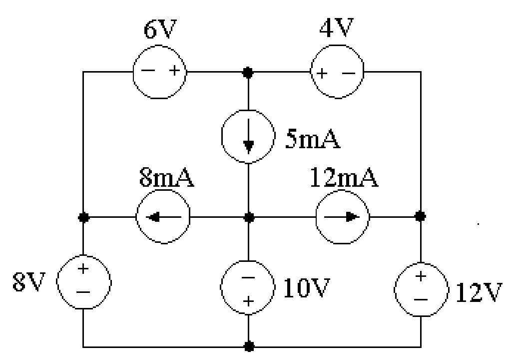

From the values of voltage and current in the figure, the power supplied by the current sources is calculated as follows:

$$P_{10\text{A}} = -(100)(10) = -1000 \text{ W} \quad \text{(1000 W supplied)}$$

$$P_{5\text{A}} = -(140)(5) = -700 \text{ W} \quad \text{(700 W supplied)}$$

$$\sum P_{\text{dev}} = 1700 \text{ W}$$

P 2.5



The interconnection is invalid. The voltage drop between the top terminal and the bottom terminal on the left hand side is due to the 6 V and 8 V sources, giving a total voltage drop between these terminals of 14 V. But the voltage drop between the top terminal and the bottom terminal on the right hand side is due to the 4 V and 12 V sources, giving a total voltage drop between these two terminals of 16 V. The voltage drop between any two terminals in a valid circuit must be the same, so the interconnection is invalid.

P 2.6 The interconnection is valid, since the voltage sources can carry the 20 mA current supplied by the current source, and the current sources can carry whatever voltage drop is required by the interconnection. In particular, note the the voltage drop across the three sources in the right hand branch must be the same as the voltage drop across the 15 mA current source in the middle branch, since the middle and right hand branches are connected between the same two terminals. In particular, this means that

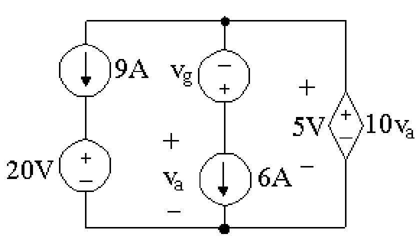
$v_1$(the voltage drop across the middle branch)

$$= -20\text{V} + 60\text{V} - v_2$$

Hence any combination of $v_1$ and $v_2$ such that $v_1 + v_2 = 40\,\text{V}$ is a valid solution.

P 2.7 The interconnection is invalid. In the middle branch, the value of the current $i_\Delta$ must be −25 A, since the 25 A current source supplies current in this branch in the direction opposite the direction of the current $i_\Delta$. Therefore, the voltage supplied by the dependent voltage source in the left hand branch is $6(-25) = -150$ V. This gives a voltage drop from the top terminal to the bottom terminal in the left hand branch of $50 - (-150) = 200$ V. But the voltage drop between these same terminals in the right hand branch is 250 V, due to the voltage source in that branch. Therefore, the interconnection is invalid.

P 2.8




First, $10v_a = 5$ V, so $v_a = 0.5$ V. Then recognize that each of the three branches is connected between the same two nodes, so each of these branches must have the same voltage drop. The voltage drop across the middle branch is 5 V, and since $v_a = 0.5$ V, $v_g = 0.5 - 5 = -4.5$ V. Also, the voltage drop across the left branch is 5 V, so $20 + v_{9A} = 5$ V, and $v_{9A} = -15$ V, where $v_{9A}$ is positive at the top. Note that the current through the 20 V source must be 9 A, flowing from top to bottom, and the current through the $v_g$ is 6 A flowing from top to bottom. Let's find the power associated with the left and middle branches:

$p_{9A} = (9)(-15) = -135\,\text{W}$
$p_{20V} = (9)(20) = 180\,\text{W}$
$p_{v_g} = -(6)(-4.5) = 27\,\text{W}$
$p_{6A} = (6)(0.5) = 3\,\text{W}$

Since there is only one component left, we can find the total power:

$p_{\text{total}} = -135 + 180 + 27 + 3 + p_{\text{ds}} = 75 + p_{\text{ds}} = 0$

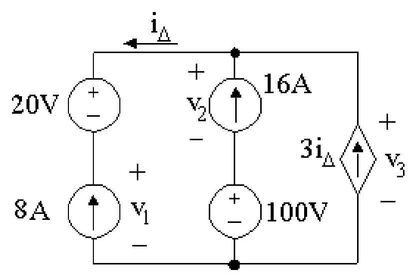
so $p_{\text{ds}}$ must equal $-75$ W.

Therefore,

$$\sum P_{\text{dev}} = \sum P_{\text{abs}} = 210\,\text{W}$$

P 2.9 **[a]** Yes, each of the voltage sources can carry the current required by the interconnection, and each of the current sources can carry the voltage drop required by the interconnection. (Note that $i_\Delta = -8$ A.)

**[b]** No, because the voltage drop between the top terminal and the bottom terminal cannot be determined. For example, define $v_1$, $v_2$, and $v_3$ as shown:

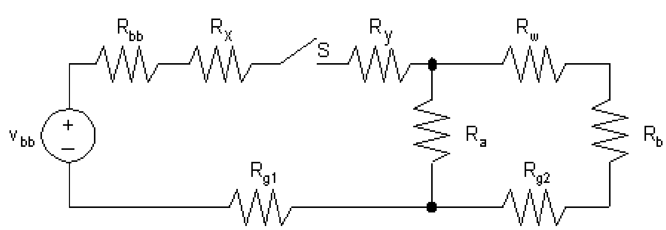



The voltage drop across the left branch, the center branch, and the right branch must be the same, since these branches are connected at the same two terminals. This requires that

$$20 + v_1 = v_2 + 100 = v_3$$

But this equation has three unknown voltages, so the individual voltages cannot be determined, and thus the power of the sources cannot be determined.

P 2.10 **[a]**



[b] $V_{bb}$ = no-load voltage of battery

$R_{bb}$ = internal resistance of battery

$R_x$ = resistance of wire between battery and switch

$R_y$ = resistance of wire between switch and lamp A

$R_{\rm a}$ = resistance of lamp A

$R_{\rm b}$ = resistance of lamp B

$R_w$ = resistance of wire between lamp A and lamp B

$R_{g1}$ = resistance of frame between battery and lamp A

$R_{g2}$ = resistance of frame between lamp A and lamp B

$S$ = switch

P 2.11 Since we know the device is a resistor, we can use Ohm's law to calculate the resistance. From Fig. P2.11(a),

$$v = Ri \qquad \text{so} \qquad R = \frac{v}{i}$$

Using the values in the table of Fig. P2.11(b),

$$R = \frac{-108}{-0.004} = \frac{-54}{-0.002} = \frac{54}{0.002} = \frac{108}{0.004} = \frac{162}{0.006} = 27\,\text{k}\Omega$$

Note that this value is found in Appendix H.

P 2.12 The resistor value is the ratio of the power to the square of the current: $R = \frac{p}{i^2}$. Using the values for power and current in Fig. P2.12(b),

$$\frac{5.5 \times 10^{-3}}{(50 \times 10^{-6})^2} = \frac{22 \times 10^{-3}}{(100 \times 10^{-6})^2} = \frac{49.5 \times 10^{-3}}{(150 \times 10^{-6})^2} = \frac{88 \times 10^{-3}}{(200 \times 10^{-6})^2}$$

$$= \frac{137.5 \times 10^{-3}}{(250 \times 10^{-6})^2} = \frac{198 \times 10^{-3}}{(300 \times 10^{-6})^2} = 2.2\ \text{M}\Omega$$

Note that this is a value from Appendix H.

P 2.13 Since we know the device is a resistor, we can use the power equation. From Fig. P2.13(a),

$$p = vi = \frac{v^2}{R} \qquad \text{so} \qquad R = \frac{v^2}{p}$$

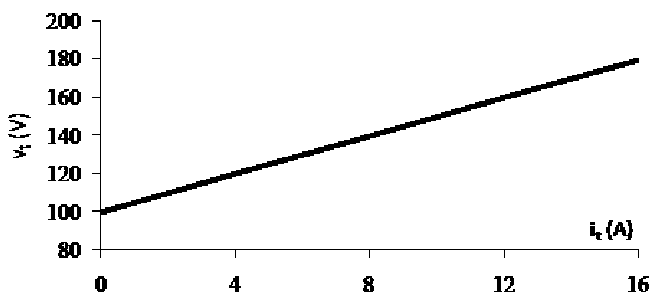
Using the values in the table of Fig. P2.13(b)

$$R = \frac{(-10)^2}{17.86 \times 10^{-3}} = \frac{(-5)^2}{4.46 \times 10^{-3}} = \frac{(5)^2}{4.46 \times 10^{-3}} = \frac{(10)^2}{17.86 \times 10^{-3}}$$

$$= \frac{(15)^2}{40.18 \times 10^{-3}} = \frac{(20)^2}{71.43 \times 10^{-3}} \approx 5.6\,\text{k}\Omega$$

Note that this value is found in Appendix H.

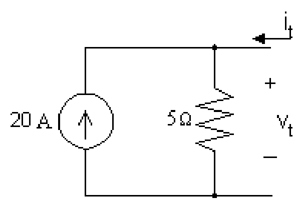
P 2.14 **[a]** Plot the $v$—$i$ characteristic:



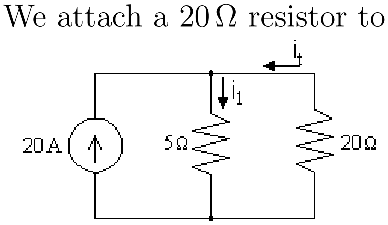

From the plot:

$$R = \frac{\Delta v}{\Delta i} = \frac{(180-100)}{(16-0)} = 5\,\Omega$$

When $i_t = 0$, $v_t = 100$ V; therefore the ideal current source must have a current of $100/5 = 20$ A




**[b]** We attach a $20\,\Omega$ resistor to the device model developed in part (a):




Write a KCL equation at the top node:

$20 + i_t = i_1$

Write a KVL equation for the right loop, in the direction of the two currents, using Ohm's law:

$5i_1 + 20i_t = 0$

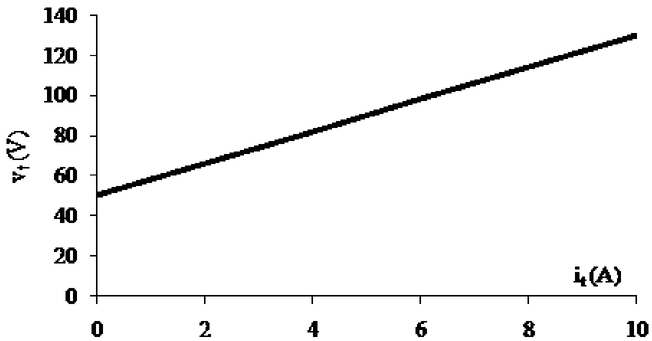
Combining the two equations and solving,

$5(20 + i_t) + 20i_t = 0 \qquad \text{so} \qquad 25i_t = -100; \qquad \text{thus} \qquad i_t = -4\,\text{A}$

Now calculate the power dissipated by the resistor:

$p_{20\,\Omega} = 20i_t^2 = 20(-4)^2 = 320\,\text{W}$

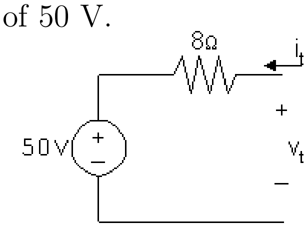
P 2.15 **[a]** Plot the $v - i$ characteristic



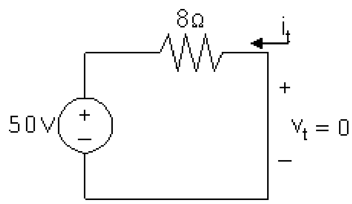

From the plot:

$$R = \frac{\Delta v}{\Delta i} = \frac{(130 - 50)}{(10 - 0)} = 8\,\Omega$$

When $i_t = 0$, $v_t = 50$ V; therefore the ideal voltage source has a voltage of 50 V.



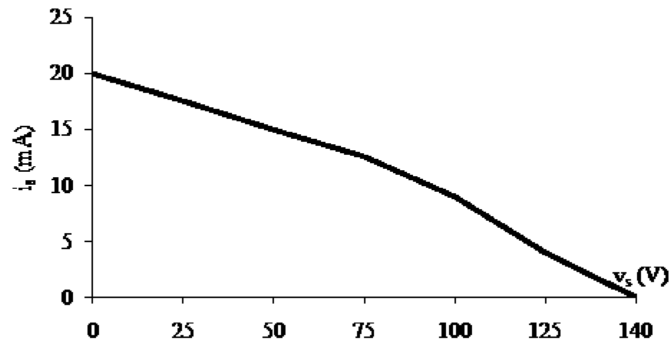

**[b]**



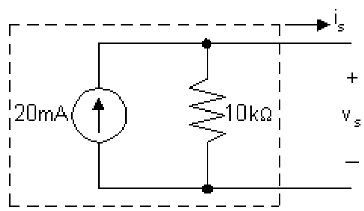

When $v_t = 0$, $\qquad i_t = \dfrac{-50}{8} = -6.25\text{A}$

Note that this result can also be obtained by extrapolating the $v - i$ characteristic to $v_t = 0$.

P 2.16 [a]

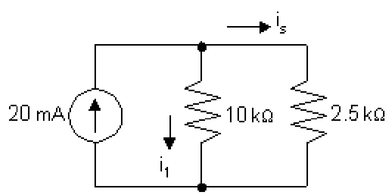



[b] $\Delta v = 25\text{V}; \quad \Delta i = 2.5 \text{ mA}; \quad R = \dfrac{\Delta v}{\Delta i} = 10 \text{ k}\Omega$




[c] $10{,}000 i_1 = 2500 i_s, \qquad i_1 = 0.25 i_s$

$0.02 = i_1 + i_s = 1.25 i_s, \qquad i_s = 16 \text{ mA}$

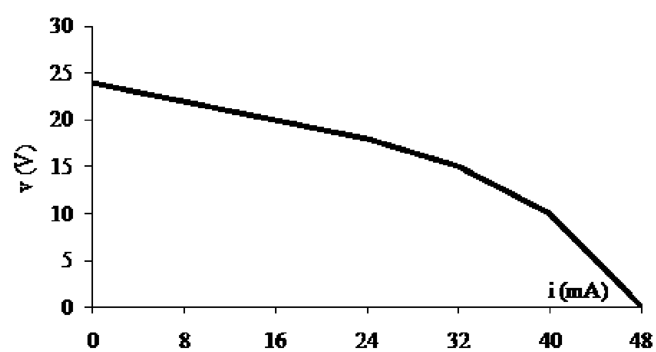



[d] $v_s(\text{open circuit}) = (20 \times 10^{-3})(10 \times 10^3) = 200 \text{ V}$

[e] The open circuit voltage can be found in the table of values (or from the plot) as the value of the voltage $v_s$ when the current $i_s = 0$. Thus, $v_s(\text{open circuit}) = 140$ V (from the table)

[f] Linear model cannot predict the nonlinear behavior of the practical current source.

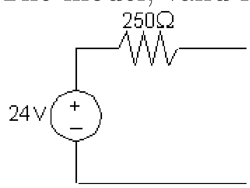
P 2.17 [a] Begin by constructing a plot of voltage versus current:



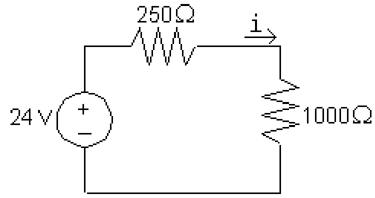
**[b]** Since the plot is linear for $0 \leq i_s \leq 24$ mA amd since $R = \Delta v/\Delta i$, we can calculate $R$ from the plotted values as follows:

$$R = \frac{\Delta v}{\Delta i} = \frac{24 - 18}{0.024 - 0} = \frac{6}{0.024} = 250\,\Omega$$

We can determine the value of the ideal voltage source by considering the value of $v_s$ when $i_s = 0$. When there is no current, there is no voltage drop across the resistor, so all of the voltage drop at the output is due to the voltage source. Thus the value of the voltage source must be 24 V. The model, valid for $0 \leq i_s \leq 24$ mA, is shown below:




**[c]** The circuit is shown below:

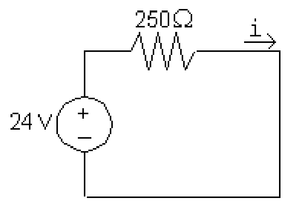



Write a KVL equation in the clockwise direction, starting below the voltage source. Use Ohm's law to express the voltage drop across the resistors in terms of the current $i$:

$$-24\,\text{V} + 250i + 1000i = 0 \qquad \text{so} \qquad 1250i = 24\,\text{V}$$

$$\text{Thus,} \qquad i = \frac{24\,\text{V}}{1250\,\Omega} = 19.2\,\text{mA}$$

**[d]** The circuit is shown below:




Write a KVL equation in the clockwise direction, starting below the voltage source. Use Ohm's law to express the voltage drop across the resistors in terms of the current $i$:

$$-24\,\text{V} + 250i = 0 \qquad \text{so} \qquad 250i = 24\,\text{V}$$

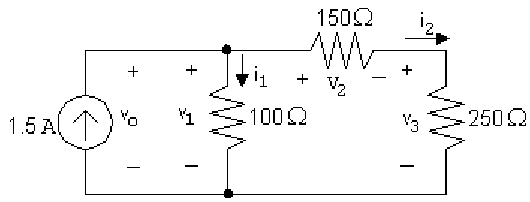
$$\text{Thus,} \qquad i = \frac{24\,\text{V}}{250\,\Omega} = 96\,\text{mA}$$

[e] The short circuit current can be found in the table of values (or from the plot) as the value of the current $i_s$ when the voltage $v_s = 0$. Thus,

$$i_{sc} = 48\,\text{mA} \qquad \text{(from table)}$$

[f] The plot of voltage versus current constructed in part (a) is not linear (it is piecewise linear, but not linear for all values of $i_s$). Since the proposed circuit model is a linear model, it cannot be used to predict the nonlinear behavior exhibited by the plotted data.

P 2.18




[a] Write a KCL equation at the top node:

$$-1.5 + i_1 + i_2 = 0 \qquad \text{so} \qquad i_1 + i_2 = 1.5$$

Write a KVL equation around the right loop:

$$-v_1 + v_2 + v_3 = 0$$

From Ohm's law,

$$v_1 = 100i_1, \qquad v_2 = 150i_2, \qquad v_3 = 250i_2$$

Substituting,

$$-100i_1 + 150i_2 + 250i_2 = 0 \qquad \text{so} \qquad -100i_1 + 400i_2 = 0$$

Solving the two equations for $i_1$ and $i_2$ simultaneously,

$$i_1 = 1.2\,\text{A} \qquad \text{and} \qquad i_2 = 0.3\,\text{A}$$

[b] Write a KVL equation clockwise around the left loop:

$$-v_o + v_1 = 0 \qquad \text{but} \qquad v_1 = 100i_1 = 100(1.2) = 120\,\text{V}$$

$$\text{So} \qquad v_o = v_1 = 120\,\text{V}$$

[c] Calculate power using $p = vi$ for the source and $p = Ri^2$ for the resistors:

$$p_{\text{source}} = -v_o(1.5) = -(120)(1.5) = -180\,\text{W}$$

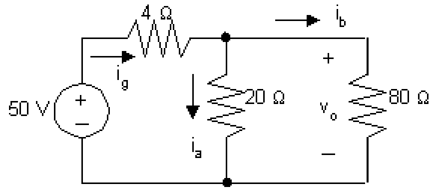
$$p_{100\Omega} = 1.2^2(100) = 144\,\text{W}$$

$$p_{150\Omega} = 0.3^2(150) = 13.5\,\text{W}$$

$$p_{250\Omega} = 0.3^2(250) = 22.5\,\text{W}$$

$$\sum P_{\text{dev}} = 180\,\text{W} \qquad \sum P_{\text{abs}} = 144 + 13.5 + 22.5 = 180\,\text{W}$$

P 2.19 [**a**]




$$\begin{aligned} 20i_{\rm a} &= 80i_{\rm b} \qquad i_g = i_{\rm a} + i_{\rm b} = 5i_{\rm b} \\ i_{\rm a} &= 4i_{\rm b} \\ 50 &= 4i_g + 80i_{\rm b} = 20i_{\rm b} + 80i_{\rm b} = 100i_{\rm b} \\ i_{\rm b} &= 0.5 \text{ A, therefore, } i_{\rm a} = 2 \text{ A} \quad \text{and} \quad i_g = 2.5 \text{ A} \end{aligned}$$

[**b**] $i_{\rm b} = 0.5$ A

[**c**] $v_o = 80i_{\rm b} = 40$ V

[**d**]
$$\begin{aligned} p_{4\Omega} &= i_g^2(4) = 6.25(4) = 25 \text{ W} \\ p_{20\Omega} &= i_{\rm a}^2(20) = (4)(20) = 80 \text{ W} \\ p_{80\Omega} &= i_{\rm b}^2(80) = 0.25(80) = 20 \text{ W} \end{aligned}$$

[**e**] $p_{50\rm V}$ (delivered) $= 50i_g = 125$ W

Check:

$$\sum P_{\rm dis} = 25 + 80 + 20 = 125\,\text{W}$$

$$\sum P_{\rm del} = 125\,\text{W}$$

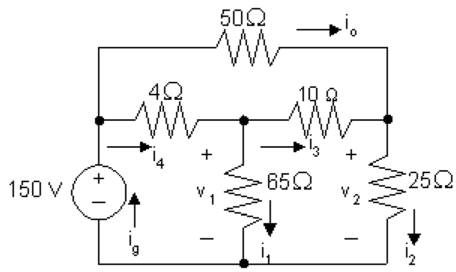
P 2.20 [**a**] Use KVL for the right loop to calculate the voltage drop across the right-hand branch $v_o$. This is also the voltage drop across the middle branch, so once $v_o$ is known, use Ohm's law to calculate $i_o$:

$$\begin{aligned} v_o &= 1000i_{\rm a} + 4000i_{\rm a} + 3000i_{\rm a} = 8000i_{\rm a} = 8000(0.002) = 16 \text{ V} \\ 16 &= 2000i_o \\ i_o &= \frac{16}{2000} = 8 \text{ mA} \end{aligned}$$

[**b**] KCL at the top node: $i_g = i_{\rm a} + i_o = 0.002 + 0.008 = 0.010 \text{ A} = 10$ mA.

[**c**] The voltage drop across the source is $v_0$, seen by writing a KVL equation for the left loop. Thus,
$p_g = -v_o i_{\rm g} = -(16)(0.01) = -0.160 \text{ W} = -160$ mW.
Thus the source delivers 160 mW.

P 2.21 [**a**]




$$v_2 = 150 - 50(1) = 100\text{V}$$

$$i_2 = \frac{v_2}{25} = 4\text{A}$$

$$i_3 + 1 = i_2, \qquad i_3 = 4 - 1 = 3\text{A}$$

$$v_1 = 10i_3 + 25i_2 = 10(3) + 25(4) = 130\text{V}$$

$$i_1 = \frac{v_1}{65} = \frac{130}{65} = 2\text{A}$$

Note also that

$$i_4 = i_1 + i_3 = 2 + 3 = 5\,\text{A}$$

$$i_g = i_4 + i_o = 5 + 1 = 6\,\text{A}$$

[**b**]

$$p_{4\Omega} = 5^2(4) = 100\ \text{W}$$

$$p_{50\Omega} = 1^2(50) = 50\ \text{W}$$

$$p_{65\Omega} = 2^2(65) = 260\ \text{W}$$

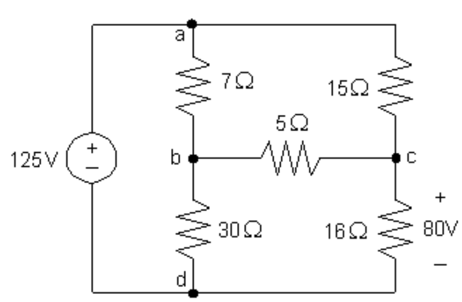
$$p_{10\Omega} = 3^2(10) = 90\ \text{W}$$

$$p_{25\Omega} = 4^2(25) = 400\ \text{W}$$

[**c**] $\sum P_{\text{dis}} = 100 + 50 + 260 + 90 + 400 = 900\,\text{W}$

$$P_{\text{dev}} = 150i_g = 150(6) = 900\,\text{W}$$

P 2.22 [**a**]




$$i_{\text{cd}} = 80/16 = 5\,\text{A}$$

$v_{\rm ac} = 125 - 80 = 45 \quad \text{so} \quad i_{\rm ac} = 45/15 = 3\,\text{A}$

$i_{\rm ac} + i_{\rm bc} = i_{\rm cd} \quad \text{so} \quad i_{\rm bc} = 5 - 3 = 2\,\text{A}$

$v_{\rm ab} = 15i_{\rm ac} - 5i_{\rm bc} = 15(3) - 5(2) = 35\,\text{V} \quad \text{so} \quad i_{\rm ab} = 35/7 = 5\,\text{A}$

$i_{\rm bd} = i_{\rm ab} - i_{\rm bc} = 5 - 2 = 3\,\text{A}$

Calculate the power dissipated by the resistors using the equation $p_R = Ri_R^2$:

$p_{7\Omega} = (7)(5)^2 = 175\,\text{W} \qquad p_{30\Omega} = (30)(3)^2 = 270\,\text{W}$

$p_{15\Omega} = (15)(3)^2 = 135\,\text{W} \qquad p_{16\Omega} = (16)(5)^2 = 400\,\text{W}$

$p_{5\Omega} = (5)(2)^2 = 20\,\text{W}$

**[b]** Calculate the current through the voltage source:

$i_{\rm ad} = -i_{\rm ab} - i_{\rm ac} = -5 - 3 = -8\,\text{A}$

Now that we have both the voltage and the current for the source, we can calculate the power supplied by the source:

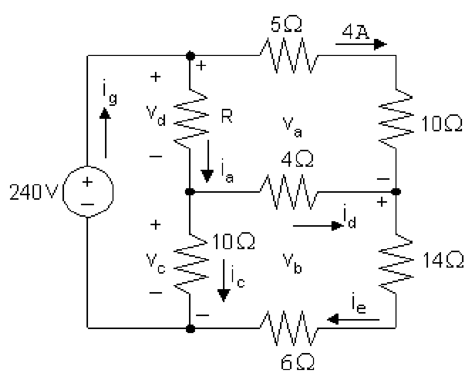
$p_g = 125(-8) = -1000\,\text{W} \quad \text{thus} \quad p_g\ \text{(supplied)} = 1000\,\text{W}$

**[c]** $\sum P_{\rm dis} = 175 + 270 + 135 + 400 + 20 = 1000\,\text{W}$

Therefore,

$\sum P_{\rm supp} = \sum P_{\rm dis}$

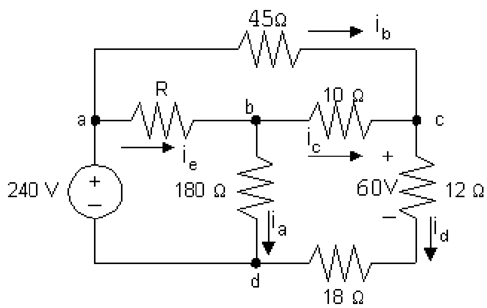
P 2.23 **[a]**




$v_a = (5 + 10)(4) = 60\,\text{V}$
$-240 + v_a + v_b = 0 \quad \text{so} \quad v_b = 240 - v_a = 240 - 60 = 180\,\text{V}$
$i_e = v_b/(14 + 6) = 180/20 = 9\,\text{A}$
$i_d = i_e - 4 = 9 - 4 = 5\,\text{A}$
$v_c = 4i_d + v_b = 4(5) + 180 = 200\,\text{V}$
$i_c = v_c/10 = 200/10 = 20\,\text{A}$
$v_d = 240 - v_c = 240 - 200 = 40\,\text{V}$
$i_a = i_d + i_c = 5 + 20 = 25\,\text{A}$
$R = v_d/i_a = 40/25 = 1.6\,\Omega$

[**b**] $i_g = i_a + 4 = 25 + 4 = 29$ A
$p_g$ (supplied) $= (240)(29) = 6960$ W

P 2.24



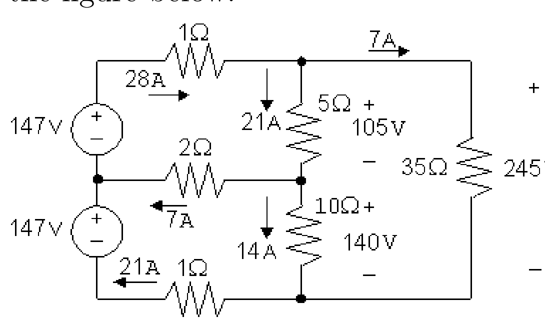

$i_{\rm d} = 60/12 = 5\,\text{A};$ therefore, $v_{\rm cd} = 60 + 18(5) = 150\,\text{V}$
$-240 + v_{\rm ac} + v_{\rm cd} = 0;$ therefore, $v_{\rm ac} = 240 - 150 = 90\,\text{V}$
$i_{\rm b} = v_{\rm ac}/45 = 90/45 = 2\,\text{A};$ therefore, $i_{\rm c} = i_{\rm d} - i_{\rm b} = 5 - 2 = 3\,\text{A}$
$v_{\rm bd} = 10i_{\rm c} + v_{\rm cd} = 10(3) + 150 = 180\,\text{V};$
therefore, $i_{\rm a} = v_{\rm bd}/180 = 180/180 = 1\,\text{A}$
$i_{\rm e} = i_{\rm a} + i_{\rm c} = 1 + 3 = 4\,\text{A}$
$-240 + v_{\rm ab} + v_{\rm bd} = 0$ therefore, $v_{\rm ab} = 240 - 180 = 60\,\text{V}$
$R = v_{\rm ab}/i_{\rm e} = 60/4 = 15\,\Omega$

CHECK: $i_g = i_{\rm b} + i_{\rm e} = 2 + 4 = 6$ A

$p_{\rm dev} = (240)(6) = 1440$ W

$$\sum P_{\rm dis} = 1^2(180) + 4^2(15) + 3^2(10) + 5^2(12) + 5^2(18) + 2^2(45)$$
$$= 1440 \text{ W (CHECKS)}$$

P 2.25 [**a**] Start by calculating the voltage drops due to the currents $i_1$ and $i_2$. Then use KVL to calculate the voltage drop across and $35\,\Omega$ resistor, and Ohm's law to find the current in the $35\,\Omega$ resistor. Finally, KCL at each of the middle three nodes yields the currents in the two sources and the current in the middle $2\,\Omega$ resistor. These calculations are summarized in the figure below:



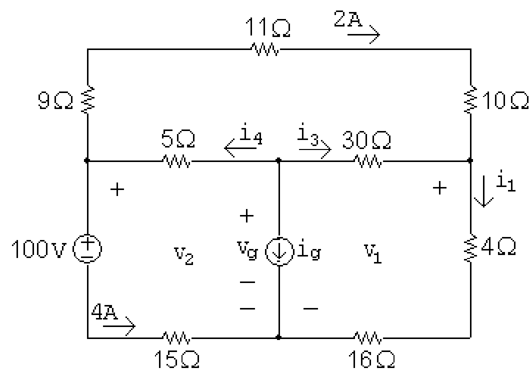

$$p_{147(\text{top})} = -(147)(28) = -4116 \text{ W}$$
$$p_{147(\text{bottom})} = -(147)(21) = -3087 \text{ W}$$

[b]

$$\sum P_{\text{dis}} = (28)^2(1) + (7)^2(2) + (21)^2(1) + (21)^2(5) + (14)^2(10) + (7)^2(35)$$
$$= 784 + 98 + 441 + 2205 + 1960 + 1715 = 7203 \text{ W}$$
$$\sum P_{\text{sup}} = 4116 + 3087 = 7203 \text{ W}$$

Therefore, $\sum P_{\text{dis}} = \sum P_{\text{sup}} = 7203$ W

P 2.26 [a]




$v_2 = 100 + 4(15) = 160\,\text{V}$; $\quad v_1 = 160 - (9 + 11 + 10)(2) = 100\,\text{V}$

$i_1 = \dfrac{v_1}{4 + 16} = \dfrac{100}{20} = 5\,\text{A}$; $\quad i_3 = i_1 - 2 = 5 - 2 = 3\,\text{A}$

$v_g = v_1 + 30i_3 = 100 + 30(3) = 190\,\text{V}$

$i_4 = 2 + 4 = 6\,\text{A}$

$i_g = -i_4 - i_3 = -6 - 3 = -9\,\text{A}$

[b] Calculate power using the formula $p = Ri^2$:

$p_{9\,\Omega} = (9)(2)^2 = 36\,\text{W}$; $\quad p_{11\,\Omega} = (11)(2)^2 = 44\,\text{W}$

$p_{10\,\Omega} = (10)(2)^2 = 40\,\text{W}$; $\quad p_{5\,\Omega} = (5)(6)^2 = 180\,\text{W}$

$p_{30\,\Omega} = (30)(3)^2 = 270\,\text{W}$; $\quad p_{4\,\Omega} = (4)(5)^2 = 100\,\text{W}$

$p_{16\,\Omega} = (16)(5)^2 = 400\,\text{W}$; $\quad p_{15\,\Omega} = (15)(4)^2 = 240\,\text{W}$

[c] $v_g = 190\,\text{V}$

[d] Sum the power dissipated by the resistors:

$\sum p_{\text{diss}} = 36 + 44 + 40 + 180 + 270 + 100 + 400 + 240 = 1310\,\text{W}$

The power associated with the sources is

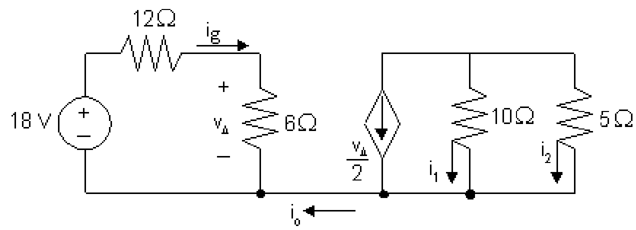
$p_{\text{volt-source}} = (100)(4) = 400\,\text{W}$

$p_{\text{curr-source}} = v_g i_g = (190)(-9) = -1710\,\text{W}$

Thus the total power dissipated is $1310 + 400 = 1710$ W and the total power developed is 1710 W, so the power balances.

P 2.27 **[a]** $i_o = 0$ because no current can exist in a single conductor connecting two parts of a circuit.

**[b]**




$18 = (12+6)i_g \qquad i_g = 1$ A

$v_\Delta = 6i_g = 6$V $\qquad v_\Delta/2 = 3$ A

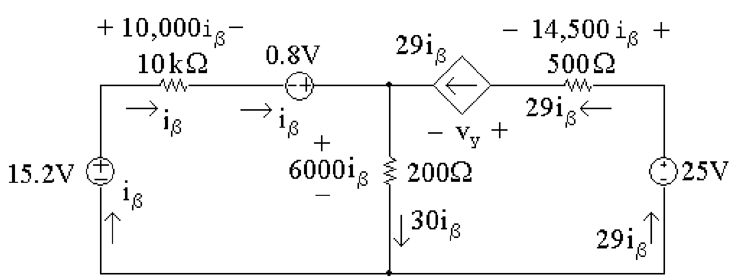
$10i_1 = 5i_2$, so $i_1 + 2i_1 = -3$ A; therefore, $i_1 = -1$ A

**[c]** $i_2 = 2i_1 = -2$ A.

P 2.28 First note that we know the current through all elements in the circuit except the 200 Ω resistor (the current in the three elements to the left of the 200 Ω resistor is $i_\beta$; the current in the three elements to the right of the 200 Ω resistor is $29i_\beta$). To find the current in the 200 Ω resistor, write a KCL equation at the top node:

$$i_\beta + 29i_\beta = i_{200\,\Omega} = 30i_\beta$$

We can then use Ohm's law to find the voltages across each resistor in terms of $i_\beta$. The results are shown in the figure below:




**[a]** To find $i_\beta$, write a KVL equation around the left-hand loop, summing voltages in a clockwise direction starting below the 15.2V source:

$$-15.2\,\text{V} + 10{,}000i_1 - 0.8\,\text{V} + 6000i_\beta = 0$$

Solving for $i_\beta$

$$10{,}000i_\beta + 6000i_\beta = 16\,\text{V} \qquad \text{so} \qquad 16{,}000i_\beta = 16\,\text{V}$$

Thus,

$$i_\beta = \frac{16}{16{,}000} = 1\,\text{mA}$$

Now that we have the value of $i_\beta$, we can calculate the voltage for each component except the dependent source. Then we can write a KVL equation for the right-hand loop to find the voltage $v_y$ of the dependent source. Sum the voltages in the clockwise direction, starting to the left of the dependent source:

$$-v_y - 14{,}500 i_\beta + 25\,\text{V} - 6000 i_\beta = 0$$

Thus,

$$v_y = 25\,\text{V} - 20{,}500 i_\beta = 25\,\text{V} - 20{,}500(10^{-3}) = 25\,\text{V} - 20.5\,\text{V} = 4.5\,\text{V}$$

[**b**] We now know the values of voltage and current for every circuit element. Let's construct a power table:

| **Element** | **Current (mA)** | **Voltage (V)** | **Power Equation** | **Power (mW)** |
|---|---|---|---|---|
| 15.2 V | 1 | 15.2 | $p = -vi$ | −15.2 |
| 10 kΩ | 1 | 10 | $p = Ri^2$ | 10 |
| 0.8 V | 1 | 0.8 | $p = -vi$ | −0.8 |
| 200 Ω | 30 | 6 | $p = Ri^2$ | 180 |
| Dep. source | 29 | 4.5 | $p = vi$ | 130.5 |
| 500 Ω | 29 | 14.5 | $p = Ri^2$ | 420.5 |
| 25 V | 29 | 25 | $p = -vi$ | −725 |

The total power generated in the circuit is the sum of the negative power values in the power table:

$$-15.2\,\text{mW} + -0.8\,\text{mW} + -725\,\text{mW} = -741\,\text{mW}$$

Thus, the total power generated in the circuit is 741 mW. The total power absorbed in the circuit is the sum of the positive power values in the power table:

$$10\,\text{mW} + 180\,\text{mW} + 130.5\,\text{mW} + 420.5\,\text{mW} = 741\,\text{mW}$$

Thus, the total power absorbed in the circuit is 741 mW and the power in the circuit balances.

P 2.29 $40i_2 + \frac{5}{40} + \frac{5}{10} = 0; \quad i_2 = -15.625\ \text{mA}$

$$v_1 = 80i_2 = -1.25\ \text{V}$$

$$25i_1 + \frac{(-1.25)}{20} + (-0.015625) = 0; \quad i_1 = 3.125 \text{ mA}$$

$$v_g = 60i_1 + 260i_1 = 320i_1$$

Therefore, $v_g = 1$ V.

P 2.30 **[a]** $-50 - 20i_\sigma + 18i_\Delta = 0$

$$-18i_\Delta + 5i_\sigma + 40i_\sigma = 0 \quad \text{so} \quad 18i_\Delta = 45i_\sigma$$

$$\text{Therefore,} \quad -50 - 20i_\sigma + 45i_\sigma = 0, \quad \text{so} \quad i_\sigma = 2\,\text{A}$$

$$18i_\Delta = 45i_\sigma = 90; \text{ so } i_\Delta = 5\,\text{A}$$

$$v_o = 40i_\sigma = 80\,\text{V}$$

**[b]** $i_g$ = current out of the positive terminal of the 50 V source
$v_{\text{d}}$ = voltage drop across the $8i_\Delta$ source

$$i_g = i_\Delta + i_\sigma + 8i_\Delta = 9i_\Delta + i_\sigma = 47\,\text{A}$$

$$v_d = 80 - 20 = 60\,\text{V}$$

$$\begin{aligned}
\sum P_{\text{gen}} &= 50i_g + 20i_\sigma i_g = 50(47) + 20(2)(47) = 4230 \text{ W} \\
\sum P_{\text{diss}} &= 18i_\Delta^2 + 5i_\sigma(i_g - i_\Delta) + 40i_\sigma^2 + 8i_\Delta v_d + 8i_\Delta(20) \\
&= (18)(25) + 10(47 - 5) + 4(40) + 40(60) + 40(20) \\
&= 4230 \text{ W; Therefore,} \\
\sum P_{\text{gen}} &= \sum P_{\text{diss}} = 4230 \text{ W}
\end{aligned}$$

P 2.31 $i_E - i_B - i_C = 0$

$$i_C = \beta i_B \qquad \text{therefore } i_E = (1 + \beta)i_B$$

$$i_2 = -i_B + i_1$$

$$V_o + i_E R_E - (i_1 - i_B)R_2 = 0$$

$$-i_1 R_1 + V_{CC} - (i_1 - i_B)R_2 = 0 \quad \text{or} \quad i_1 = \frac{V_{CC} + i_B R_2}{R_1 + R_2}$$

$$V_o + i_E R_E + i_B R_2 - \frac{V_{CC} + i_B R_2}{R_1 + R_2} R_2 = 0$$

Now replace $i_E$ by $(1 + \beta)i_B$ and solve for $i_B$. Thus

$$i_B = \frac{[V_{CC} R_2/(R_1 + R_2)] - V_o}{(1 + \beta)R_E + R_1 R_2/(R_1 + R_2)}$$

P 2.32 Here is Equation 2.25:

$$i_{\text{B}} = \frac{(V_{\text{CC}}R_2)/(R_1 + R_2) - V_0}{(R_1R_2)/(R_1 + R_2) + (1 + \beta)R_{\text{E}}}$$

$$\frac{V_{CC}R_2}{R_1 + R_2} = \frac{(10)(60{,}000)}{100{,}000} = 6\text{V}$$

$$\frac{R_1R_2}{R_1 + R_2} = \frac{(40{,}000)(60{,}000)}{100{,}000} = 24\ \text{k}\Omega$$

$$i_B = \frac{6 - 0.6}{24{,}000 + 50(120)} = \frac{5.4}{30{,}000} = 0.18\ \text{mA}$$

$$i_C = \beta i_B = (49)(0.18) = 8.82\ \text{mA}$$

$$i_E = i_C + i_B = 8.82 + 0.18 = 9\ \text{mA}$$

$$v_{3d} = (0.009)(120) = 1.08\text{V}$$

$$v_{bd} = V_o + v_{3d} = 1.68\text{V}$$

$$i_2 = \frac{v_{bd}}{R_2} = \frac{1.68}{60{,}000} = 28\,\mu\text{A}$$

$$i_1 = i_2 + i_B = 28 + 180 = 208\,\mu\text{A}$$

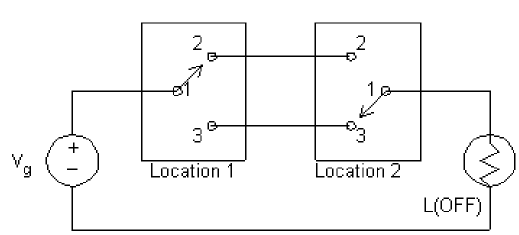
$$v_{\text{ab}} = 40{,}000(208 \times 10^{-6}) = 8.32\,\text{V}$$

$$i_{CC} = i_C + i_1 = 8.82 + 0.208 = 9.028\ \text{mA}$$

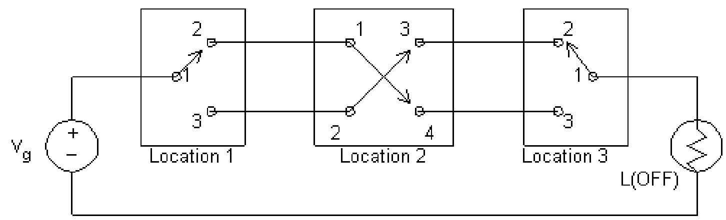
$$v_{13} + (8.82 \times 10^{-3})(750) + 1.08 = 10\ \text{V}$$

$$v_{13} = 2.305\,\text{V}$$

P 2.33 [**a**]



[**b**]




P 2.34 [**a**] From the simplified circuit model, using Ohm's law and KVL:

$$400i + 50i + 200i - 250 = 0 \qquad \text{so} \qquad i = 250/650 = 385 \text{ mA}$$

This current is nearly enough to stop the heart, according to Table 2.1, so a warning sign should be posted at the 250 V source.

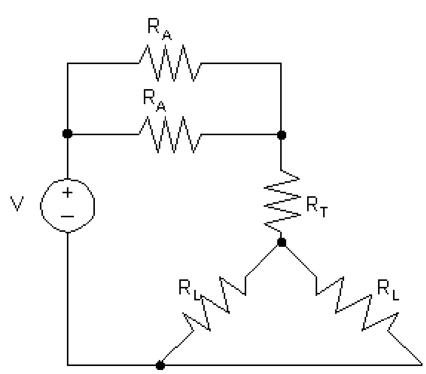
[**b**] The closest value from Appendix H to 400 Ω is 390 Ω; the closest value from Appendix H to 50 Ω is 47 Ω. There are two possibilites for replacing the 200 Ω resistor with a value from Appendix H – 180 Ω and 220 Ω. We calculate the resulting current for each of these possibilities, and determine which current is closest to 385 mA:

$$390i + 47i + 180i - 250 = 0 \qquad \text{so} \qquad i = 250/617 = 405.2 \text{ mA}$$

$$390i + 47i + 220i - 250 = 0 \qquad \text{so} \qquad i = 250/657 = 380.5 \text{ mA}$$

Therefore, choose the 220 Ω resistor to replace the 200 Ω resistor in the model.

P 2.35




P 2.36 [**a**] $p = i^2R$

$$p_{\text{arm}} = \left(\frac{250}{650}\right)^2 (400) = 59.17\,\text{W}$$

$$p_{\text{leg}} = \left(\frac{250}{650}\right)^2 (200) = 29.59\,\text{W}$$

$$p_{\text{trunk}} = \left(\frac{250}{650}\right)^2 (50) = 7.40\,\text{W}$$

**[b]** $$\left(\frac{dT}{dt}\right)_{\text{arm}} = \frac{2.39 \times 10^{-4} p_{\text{arm}}}{4} = 35.36 \times 10^{-4}\,^\circ\ \text{C/s}$$

$$t_{\text{arm}} = \frac{5}{35.36} \times 10^4 = 1414.23 \text{ s or } 23.57 \text{ min}$$

$$\left(\frac{dT}{dt}\right)_{\text{leg}} = \frac{2.39 \times 10^{-4}}{10} P_{\text{leg}} = 7.07 \times 10^{-4\circ}\ \text{C/s}$$

$$t_{\text{leg}} = \frac{5 \times 10^4}{7.07} = 7{,}071.13 \text{ s or } 117.85 \text{ min}$$

$$\left(\frac{dT}{dt}\right)_{\text{trunk}} = \frac{2.39 \times 10^{-4}(7.4)}{25} = 0.707 \times 10^{-4}\,^\circ\ \text{C/s}$$

$$t_{\text{trunk}} = \frac{5 \times 10^4}{0.707} = 70{,}711.30 \text{ s or } 1{,}178.52 \text{ min}$$

**[c]** They are all much greater than a few minutes.

P 2.37 **[a]** $R_{\text{arms}} = 400 + 400 = 800\,\Omega$

$$i_{\text{letgo}} = 50 \text{ mA (minimum)}$$

$$v_{\text{min}} = (800)(50) \times 10^{-3} = 40\,\text{V}$$

**[b]** No, 12/800 = 15 mA. Note this current is sufficient to give a perceptible shock.

P 2.38 $R_{\text{space}} = 1\ \text{M}\Omega$

$$i_{\text{space}} = 3 \text{ mA}$$

$$v = i_{\text{space}} R_{\text{space}} = 3000\,\text{V}.$$