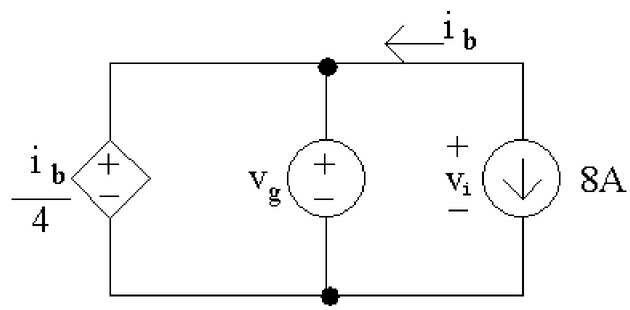
2

Circuit Elements

Assessment Problems

AP 2.1



[a] To find v_g write a KVL equation clockwise around the left loop, starting below the dependent source:

$$-\frac{i_b}{4} + v_g = 0 \qquad \text{so} \qquad v_g = \frac{i_b}{4}$$

To find i_b write a KCL equation at the upper right node. Sum the currents leaving the node:

$$i_b + 8\,\text{A} = 0 \qquad \text{so} \qquad i_b = -8\,\text{A}$$

Thus,

$$v_g = \frac{-8}{4} = -2\,\text{V}$$

[b] To find the power associated with the 8 A source, we need to find the voltage drop across the source, v_i. To do this, write a KVL equation clockwise around the left loop, starting below the voltage source:

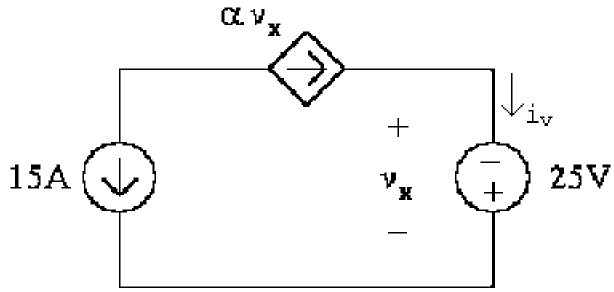
$$-v_g + v_i = 0 \qquad \text{so} \qquad v_i = v_g = -2\,\text{V}$$

Using the passive sign convention,

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

Thus the current source generated 16 W of power.

AP 2.2



[a] Note from the circuit that $v_x = -25$ V. To find α write a KCL equation at the top left node, summing the currents leaving:

$$15\,\mathrm{A} + \alpha v_x = 0$$

Substituting for v_x,

$$15\,\mathrm{A} + \alpha(-25\,\mathrm{V}) = 0 \qquad \text{so} \qquad \alpha(25\,\mathrm{V}) = 15\,\mathrm{A}$$

Thus $\qquad \alpha = \dfrac{15\,\mathrm{A}}{25\,\mathrm{V}} = 0.6$ A/V

[b] To find the power associated with the voltage source we need to know the current, i_v. To find this current, write a KCL equation at the top left node, summing the currents leaving the node:

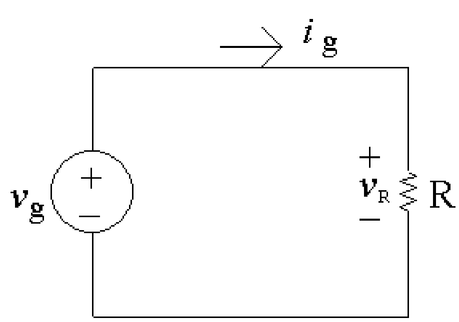
$$-\alpha v_x + i_v = 0 \qquad \text{so} \qquad i_v = \alpha v_x = (0.6)(-25) = -15\,\mathrm{A}$$

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] A KVL equation gives

$$-v_g + v_R = 0 \qquad \text{so} \qquad v_R = v_g = 1\,\mathrm{kV}$$

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:

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

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

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

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:

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

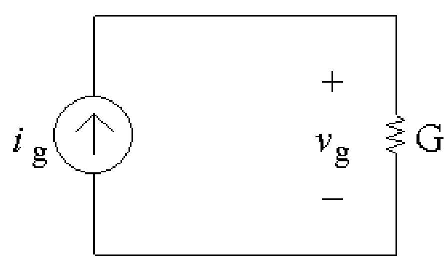
Solving for i_g,

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

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 throught the conductance G is i_g, flowing from top to bottom (from KCL), and the voltage drop across the current source is v_g, positive at the top (from KVL). 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:

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

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

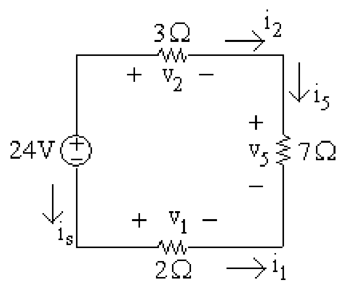
[c] We can find the voltage from the power and the conductance, and then use the voltage value in Ohm's law to find the current:

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

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 $i_5 = 24/12 = 2\,\text{A}$

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

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

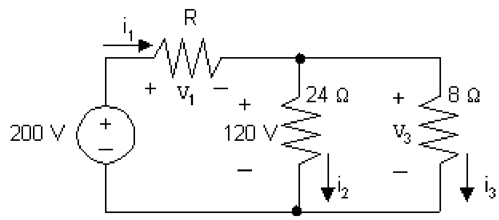
[d] $v_5 = 7i_5 = 7(2) = 14\,\text{V}$

[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:

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

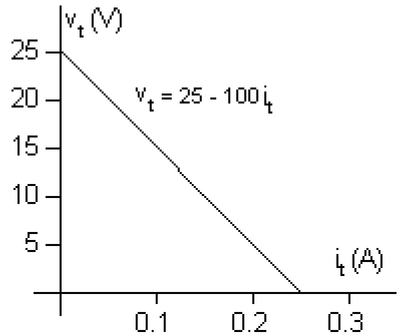
Write a KVL equation clockwise around the left loop, starting below the voltage source:

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

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:

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

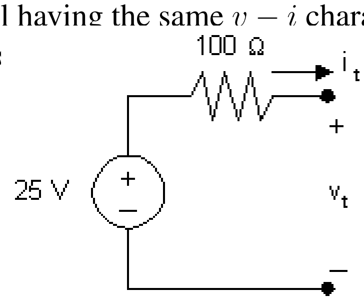
AP 2.7 **[a]** Plotting a graph



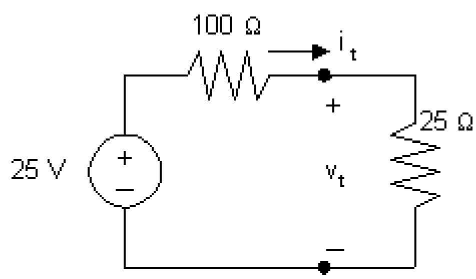
Note that when $i_t = 0$, $v_t = 25$ V; therefore the voltage source must be 25 V. Since the plot is a straight line, its slope can be used to calculate the value of resistance:

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

A circuit model having the same $v - i$ characteristic is a 25 V source in series with a 100Ω re



[b] Draw the circuit 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:

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

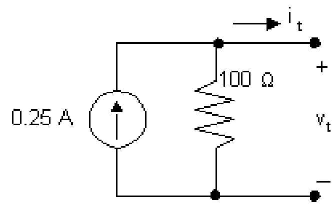
Thus, the power delivered to the $25\,\Omega$ resistor is

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

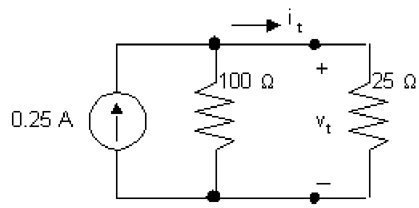
AP 2.8 **[a]** From the graph in Assessment Problem 2.7(a), we see that when $v_t = 0$, $i_t = 0.25$ A. Therefore the current source must be 0.25 A. Since the plot is a straight line, its slope can be used to calculate the value of resistance:

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

A circuit model having the same $v - i$ characteristic is a 0.25 A current source in parallel with a 100Ω 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.

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

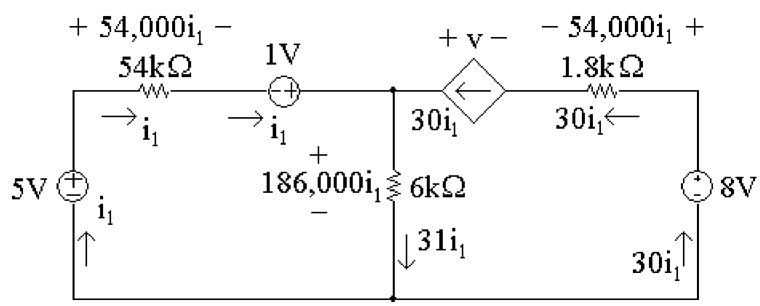
$$p_{25} = \frac{v_t^2}{25} = 1\,\text{W}.$$

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:

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

Solving for i_1

$$54{,}000 i_1 + 189{,}000 i_1 = 6\,\mathrm{V} \qquad \text{so} \qquad 240{,}000 i_1 = 6\,\mathrm{V}$$

Thus,

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

[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:

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

Thus,

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

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

Element	**Current (μA)**	**Voltage (V)**	**Power Equation**	**Power (μW)**
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:

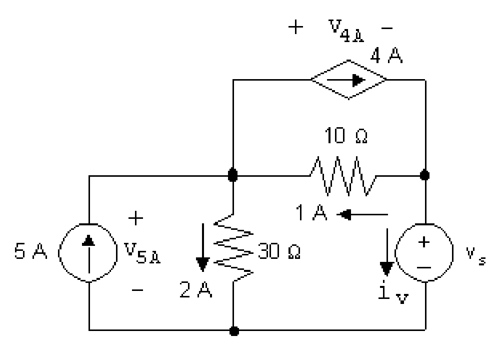
$$33.75\,\mu\text{W} + 3603.75\,\mu\text{W} + 1500\,\mu\text{W} + 1012.5\,\mu\text{W} = 6150\,\mu\text{W}$$

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 $10\,\Omega$ 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 $10\,\Omega$ 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 $3\,\text{A}$, flowing top to bottom. The power associated with this source is

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

Thus, $210\,\text{W}$ 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 $300\,\text{W}$ 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

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

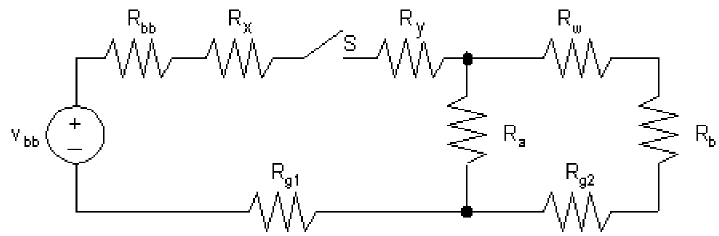
This source thus delivers $40\,\text{W}$ of power to the circuit.

[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



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_{a}	=	resistance of lamp A
R_{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 2.2 Since we know the device is a resistor, we can use Ohm's law to calculate the resistance. From Fig. P2.2(a),

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

Using the values in the table of Fig. P2.2(b),

$$R = \frac{-160}{-0.02} = \frac{-80}{-0.01} = \frac{80}{0.01} = \frac{160}{0.02} = \frac{240}{0.03} = 8\text{k}\Omega$$

P 2.3 The resistor value is the ratio of the power to the square of the current:

$$\frac{500}{1^2} = \frac{2000}{2^2} = \frac{4500}{3^2} = \frac{8000}{4^2} = \frac{12{,}500}{5^2} = \frac{18{,}000}{6^2} = 500\,\Omega$$

P 2.4 Since we know the device is a resistor, we can use the power equation. From Fig. P2.4(a),

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

Using the values in the table of Fig. P2.4(b)

$$R = \frac{(-8)^2}{3.2} = \frac{(-4)^2}{0.8} = \frac{(4)^2}{0.8} = \frac{(8)^2}{3.2} = \frac{(12)^2}{7.2} = \frac{(16)^2}{12.8} = 20\,\Omega$$

P 2.5 **[a]** Yes, independent voltage sources can carry whatever current is required by the connection; independent current source can support any voltage required by the connection.

[b] 18 V source: absorbing

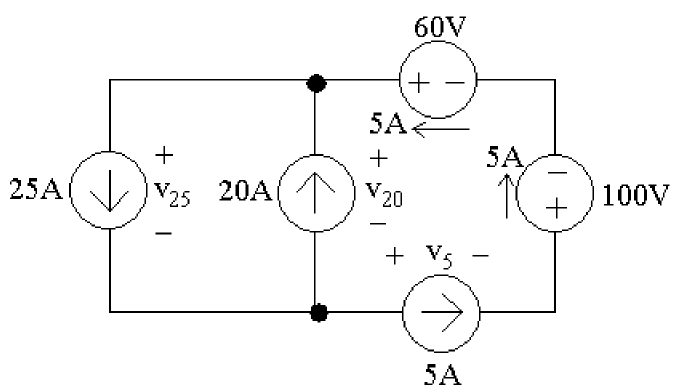
5 mA source: delivering

7 V source: absorbing

[c]
$$P_{18\text{V}} = (5 \times 10^{-3})(18) = 90 \text{ mW} \quad \text{(abs)}$$
$$P_{5\text{mA}} = -(5 \times 10^{-3})(25) = -125 \text{ mW} \quad \text{(del)}$$
$$P_{7\text{V}} = (5 \times 10^{-3})(7) = 35 \text{ mW} \quad \text{(abs)}$$
$$\sum P_{\text{abs}} = \sum P_{\text{del}} = 125 \text{ mW}$$

[d] Yes; 18 V source is delivering, the 5 mA source is absorbing, and the 7 V source is absorbing
$$P_{18\text{V}} = -(5 \times 10^{-3})(18) = -90 \text{ mW} \quad \text{(del)}$$
$$P_{5\text{mA}} = (5 \times 10^{-3})(11) = 55 \text{ mW} \quad \text{(abs)}$$
$$P_{7\text{V}} = (5 \times 10^{-3})(7) = 35 \text{ mW} \quad \text{(abs)}$$
$$\sum P_{\text{abs}} = \sum P_{\text{del}} = 90 \text{ mW}$$

P 2.6



Write the two KCL equations, summing the currents leaving the node:

KCL, top node: $25\text{A} - 20\text{A} - 5\text{A} = 0\text{A}$

KCL, bottom node: $-25\text{A} + 20\text{A} + 5\text{A} = 0\text{A}$

Write the three KVL equations, summing the voltages in a clockwise direction:

KVL, left loop: $-v_{25} + v_{20} = 0$

KVL, right loop: $60\text{V} - 100\text{V} - v_5 - v_{20} = 0$

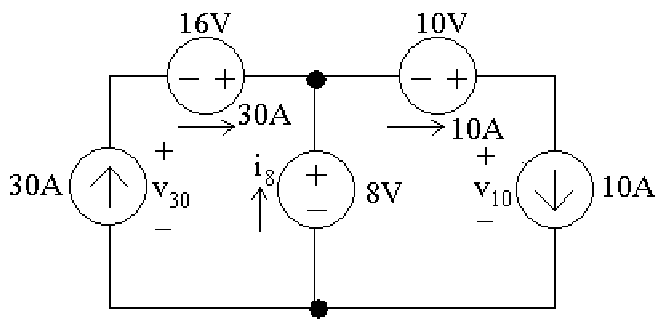
KVL, outer loop: $60\text{V} - 100\text{V} - v_5 - v_{25} = 0$

Note that since v_5, v_{20}, and v_{25} are not specified, we can choose values that satisfy the equations. For example, let $v_5 = -80\text{V}$, $v_{20} = 40\text{V}$, and $v_{25} = 40\text{V}$. There are many other voltage values that will satisfy the equations, too.
Thus, the interconnection is valid because it does not violate Kirchhoff's laws. We can now calculate the power developed by the two voltage sources:

$$p_{\text{v-sources}} = p_{60} + p_{100} = -(60)(5) + (100)(5) = 200\,\text{W}.$$

Since the power is positive, the sources are absorbing 200 W of power, or developing −200 W of power.

P 2.7



Write the two KCL equations, summing the currents leaving the node:

KCL, top node: $-30\text{A} - i_8 + 10\text{A} = 0\text{A}$

KCL, bottom node: $30\text{A} + i_8 - 10\text{A} = 0\text{A}$

Note that the value $i_8 = -20\text{A}$ satisfies these two equations.
Write the three KVL equations, summing the voltages in a clockwise direction:

KVL, left loop: $-v_{30} - 16\text{V} + 8\text{V} = 0$

KVL, right loop: $-10\text{V} + v_{10} - 8\text{V} = 0$

KVL, outer loop: $-16\text{V} - 10\text{V} + v_{10} - v_{30} = 0$

Note that $v_{30} = -8\text{V}$ and $v_{10} = 18\text{V}$ satisfy the three KVL equations.
The interconnection is valid, since neither of Kirchhoff's laws is violated. We use the values of i_8, v_{30} and v_{10} stated above to calculate the power associated with each source:

$p_{30\text{A}} = -(30)(-8) = 240\,\text{W}$ $\quad$ $p_{16\text{V}} = -(30)(16) = -480\,\text{W}$

$p_{8\text{V}} = -(-20)(8) = 160\,\text{W}$ $\qquad$ $p_{10\text{V}} = -(10)(10) = -100\,\text{W}$

$p_{10\text{A}} = (10)(18) = 180\,\text{W}$

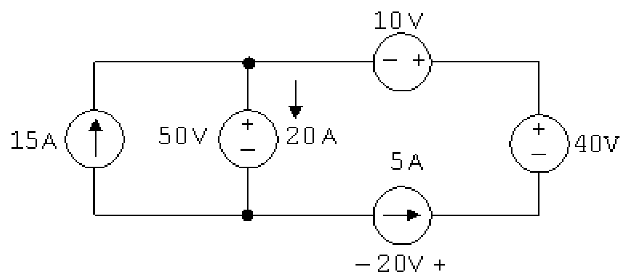
$\sum P_{\text{abs}} = \sum P_{\text{del}} = 580\,\text{W}$

Power developed by the current sources:

$p_{i-\text{sources}} = p_{30\text{A}} + p_{10\text{A}} = 240 + 180 = 420\,\text{W}$

Since power is positive, the sources are absorbing 420 W of power, or developing -420 W of power.

P 2.8 The interconnect is valid since it does not violate Kirchhoff's laws.



$-10 + 40 + v_{5\text{A}} - 50 = 0 \qquad \text{so} \qquad v_{5\text{A}} = 20\,\text{V} \qquad \text{(KVL)}$

$15 + 5 + i_{50\text{V}} = 0 \qquad \text{so} \qquad i_{50\text{V}} = -20\,\text{A} \qquad \text{(KCL)}$

$p_{15\text{A}} = -(15)(50) = -750\,\text{W}$ $\qquad$ $p_{50\text{V}} = (20)(50) = 1000\,\text{W}$

$p_{5\text{A}} = -(5)(20) = -100\,\text{W}$ $\qquad$ $p_{10\text{V}} = (5)(10) = 50\,\text{W}$

$p_{40\text{V}} = -(5)(40) = -200\,\text{W}$

$\sum P_{\text{dev}} = \sum P_{\text{abs}} = 1050\,\text{W}$

P 2.9 First there is no violation of Kirchhoff's laws, hence the interconnection is valid. Kirchhoff's voltage law requires

$-20 + 60 + v_1 - v_2 = 0 \qquad \text{so} \qquad v_1 - v_2 = -40\,\text{V}$

The conservation of energy law requires

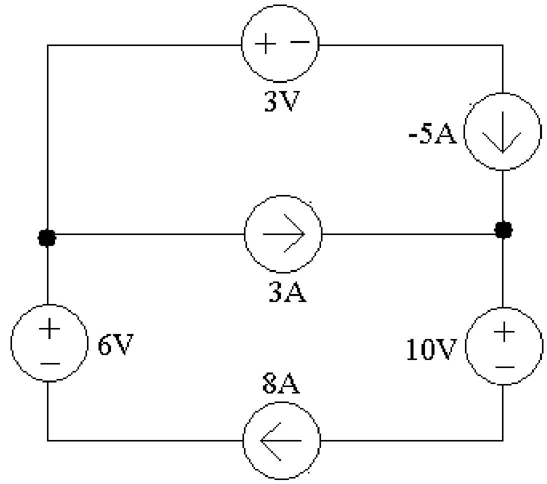
$$-(5\times10^{-3})v_2 - (15\times10^{-3})v_2 - (20\times10^{-3})(20) + (20\times10^{-3})(60) + (20\times10^{-3})v_1 = 0$$

or

$v_1 - v_2 = -40\,\text{V}$

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

P 2.10

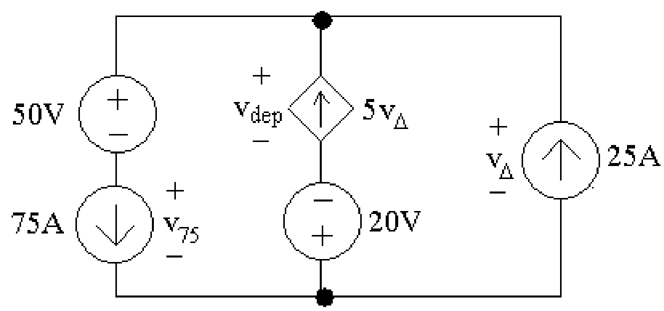


The interconnection is invalid because KCL is violated at the right-hand node. Summing the currents leaving,

$$-(-5\text{A}) - 3\text{A} + 8\text{A} = 10\text{A} \neq 0$$

Note that KCL is also violated at the left-hand node.

P 2.11



Write the two KCL equations, summing the currents leaving the node:

KCL, top node: $75\text{A} - 5v_\Delta - 25\text{A} = 0\text{A}$

KCL, bottom node: $-75\text{A} + 5v_\Delta + 25\text{A} = 0\text{A}$

To satisfy KCL, note that $v_\Delta = 10$ V.

Write the three KVL equations, summing the voltages in a clockwise direction:

KVL, left loop: $-v_{75} - 50\text{V} + v_{\text{dep}} - 20\text{V} = 0$

KVL, right loop: $20\text{V} - v_{\text{dep}} + v_\Delta = 0$

KVL, outer loop: $-v_{75} - 50\text{V} + v_\Delta = 0$

Substitute the value $v_\Delta = 10$ V into the second KVL equation and find $v_{\rm dep} = 30$ V. Substitute the value $v_\Delta = 10$ V into the third equation and find $v_{75} = -40$ V. These values satisfy the first equation.
Thus, the interconnection is valid because it does not violate Kirchhoff's laws.
Use the values for v_Δ, v_{75}, and $v_{\rm dep}$ above to calculate the total power developed in the circuit:

$$p_{\rm 50V} = (75)(50) = 3750\,{\rm W} \qquad p_{\rm 75A} = (75)(-40) = -3000\,{\rm W}$$

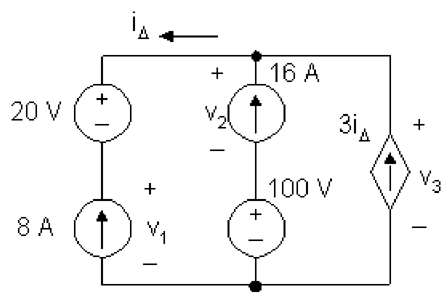
$$p_{\rm 20V} = [5(10)](20) = 1000\,{\rm W} \qquad p_{\rm ds} = -(50)(30) = -1500\,{\rm W}$$

$$p_{\rm 25A} = -(25)(10) = -250\,{\rm W}$$

$$\sum P_{\rm dev} = 3750 + 1000 = 4750\,{\rm W} = \sum P_{\rm abs}$$

P 2.12 **[a]** Yes, Kirchhoff's laws are not violated. (Note that $i_\Delta = -8$ A.)

[b] No, because the voltages across the independent and dependent current sources are indeterminate. For example, define v_1, v_2, and v_3 as shown:



Kirchhoff's voltage law requires

$$v_1 + 20 = v_3$$

$$v_2 + 100 = v_3$$

Conservation of energy requires

$$-8(20) - 8v_1 - 16v_2 - 16(100) + 24v_3 = 0$$

or

$$v_1 + 2v_2 - 3v_3 = -220$$

Now arbitrarily select a value of v_3 and show the conservation of energy will be satisfied. Examples:
If $v_3 = 200$ V then $v_1 = 180$ V and $v_2 = 100$ V. Then

$$180 + 200 - 600 = -220 \text{ (CHECKS)}$$

If $v_3 = -100$ V, then $v_1 = -120$ V and $v_2 = -200$ V. Then

$$-120 - 400 + 300 = -220 \text{ (CHECKS)}$$

P 2.13 First, $10v_a = 5$ V, so $v_a = 0.5$ V
KVL for the outer loop: $5 - 20 + v_{9\text{A}} = 0$ so $v_{9\text{A}} = 15\,\text{V}$
KVL for the right loop: $5 - 0.5 + v_g = 0$ so $v_g = -4.5\,\text{V}$
KCL at the top node: $9 + 6 + i_{\text{ds}} = 9$ so $i_{\text{ds}} = -15\,\text{A}$
Thus,

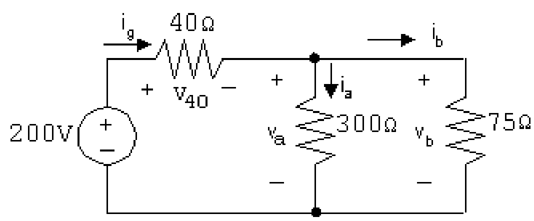
$p_{9\text{A}} = -(9)(15) = -135\,\text{W}$ $\qquad$ $p_{20\text{V}} = (9)(20) = 180\,\text{W}$

$p_{v_g} = -(6)(-4.5) = 27\,\text{W}$ $\qquad$ $p_{6\text{A}} = (6)(0.5) = 3\,\text{W}$

$p_{\text{ds}} = -(15)(5) = -75\,\text{W}$

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

P 2.14



[a] Write a KVL equation clockwise aroud the right loop, starting below the $300\,\Omega$ resistor:

$-v_a + v_b = -0$ so $v_a = v_b$

Using Ohm's law,

$v_a = 300i_a$ and $v_b = 75i_b$

Substituting,

$300i_a = 75i_b$ so $i_b = 4i_a$

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

$-i_g + i_a + i_b = 0$ so $i_g = i_a + i_b = i_a + 4i_a = 5i_a$

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

$-200\,\text{V} + v_{40} + v_a = 0$

From Ohm's law,

$v_{40} = 40i_g$ and $v_a = 300i_a$

Substituting,

$$-200\,\text{V} + 40i_g + 300i_a = 0$$

Subsituting for i_g:

$$-200\,\text{V} + 40(5i_a) + 300i_a = -200\,\text{V} + 200i_a + 300i_a = -200\,\text{V} + 500i_a = 0$$

Thus,

$$500i_a = 200\,\text{V} \qquad \text{so} \qquad i_a = \frac{200\,\text{V}}{500} = 0.4\,\text{A}$$

[b] From part (a), $i_b = 4i_a = 4(0.4\,\text{A}) = 1.6\,\text{A}$.

[c] From the circuit, $v_o = 75\,\Omega(i_b) = 75\,\Omega(1.6\,\text{A}) = 120\,\text{V}$.

[d] Use the formula $p_R = Ri_R^2$ to calculate the power absorbed by each resistor:

$$p_{40\Omega} = i_g^2(40\,\Omega) = (5i_a)^2(40\,\Omega) = [5(0.4)]^2(40\,\Omega) = (2)^2(40\,\Omega) = 160\,\text{W}$$

$$p_{300\Omega} = i_{\text{a}}^2(300\,\Omega) = (0.4)^2(300\,\Omega) = 48\,\text{W}$$

$$p_{75\Omega} = i_{\text{b}}^2(75\,\Omega) = (4i_a)^2(75\,\Omega) = [4(0.4)]^2(75\,\Omega) = (1.6)^2(75\,\Omega) = 192\,\text{W}$$

[e] Using the passive sign convention,

$$p_{\text{source}} = -(200\,\text{V})i_g = -(200\,\text{V})(5i_a) = -(200\,\text{V})[5(0.4\,\text{A})]$$
$$= -(200\,\text{V})(2\,\text{A}) = -400\,\text{W}$$

Thus the voltage source delivers 400 W of power to the circuit. Check:

$$\sum P_{\text{dis}} = 160 + 48 + 192 = 400\,\text{W}$$

$$\sum P_{\text{del}} = 400\,\text{W}$$

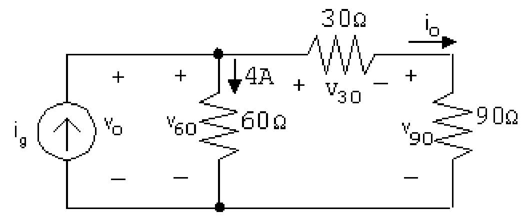
P 2.15 **[a]**

$$\begin{aligned} v_o &= 8i_{\text{a}} + 14i_{\text{a}} + 18i_{\text{a}} = 40(20) = 800\ \text{V} \\ 800 &= 10i_o \\ i_o &= 800/10 = 80\ \text{A} \end{aligned}$$

[b] $i_g = i_{\text{a}} + i_o = 20 + 80 = 100$ A

[c] $p_g(\text{delivered}) = (100)(800) = 80{,}000$ W $= 80$ kW

P 2.16



[a] Write a KVL equation clockwise around the right loop:

$$-v_{60} + v_{30} + v_{90} = 0$$

From Ohm's law,

$$v_{60} = (60\,\Omega)(4\,\text{A}) = 240\,\text{V}, \qquad v_{30} = 30i_o, \qquad v_{90} = 90i_o$$

Substituting,

$$-240\,\text{V} + 30i_o + 90i_o = 0 \qquad \text{so} \qquad 120i_o = 240\,\text{V}$$

$$\text{Thus} \qquad i_o = \frac{240\,\text{V}}{120} = 2\,\text{A}$$

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

$$-i_g + 4\,\text{A} + i_o = 0 \qquad \text{so} \qquad i_g = 4\,\text{A} + 2\,\text{A} = 6\,\text{A}$$

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

$$-v_o + v_{60} = 0 \qquad \text{so} \qquad v_o = v_{60} = 240\,\text{V}$$

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

$$p_{\text{source}} = -v_o i_g = -(240\,\text{V})(6\,\text{A}) = -1440\,\text{W}$$

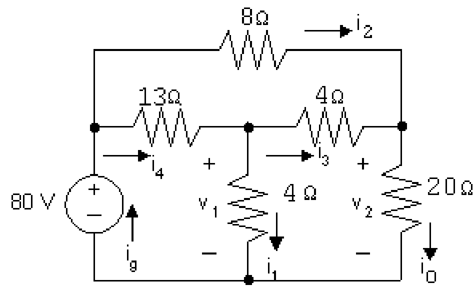
$$p_{60\Omega} = 4^2(60) = 960\,\text{W}$$

$$p_{30\Omega} = 30i_o^2 = (30)2^2 = 120\,\text{W}$$

$$p_{90\Omega} = 90i_o^2 = (90)2^2 = 360\,\text{W}$$

$$\sum P_{\text{dev}} = 1440\,\text{W} \qquad \sum P_{\text{abs}} = 960 + 120 + 360 = 1440\,\text{W}$$

P 2.17 **[a]**



$v_2 = 2(20) = 40$ V
$v_{8\Omega} = 80 - 40 = 40$ V
$i_2 = 40\,\text{V}/8\,\Omega = 5\,\text{A}$
$i_3 = i_o - i_2 = 2 - 5 = -3$ A
$v_{4\Omega} = (-3)(4) = -12$ V
$v_1 = 4i_3 + v_2 = -12 + 40 = 28$ V
$i_1 = 28\,\text{V}/4\,\Omega = 7$ A

[b] $i_4 = i_1 + i_3 = 7 - 3 = 4$ A

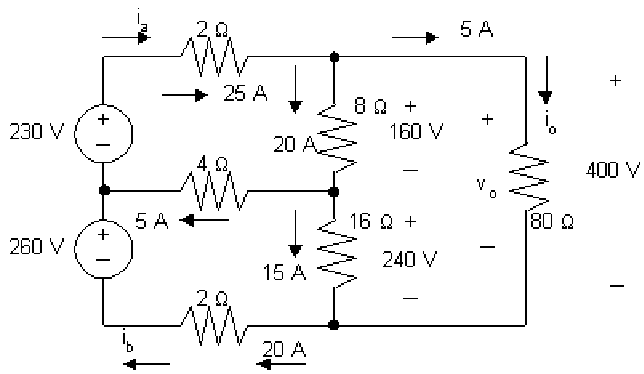
$$p_{13\Omega} = 4^2(13) = 208 \text{ W}$$
$$p_{8\Omega} = (5)^2(8) = 200 \text{ W}$$
$$p_{4\Omega} = 7^2(4) = 196 \text{ W}$$
$$p_{4\Omega} = (-3)^2(4) = 36 \text{ W}$$
$$p_{20\Omega} = 2^2(20) = 80 \text{ W}$$

[c] $\sum P_{\text{dis}} = 208 + 200 + 196 + 36 + 80 = 720\,\text{W}$

$i_g = i_4 + i_2 = 4 + 5 = 9\,\text{A}$

$P_{\text{dev}} = (9)(80) = 720\,\text{W}$

P 2.18 **[a]**



$$v_o = 20(8) + 16(15) = 400 \text{ V}$$
$$i_o = 400/80 = 5 \text{ A}$$
$$i_\text{a} = 25 \text{ A}$$

P_{230} (supplied) $= (230)(25) = 5750\,\text{W}$

$i_\text{b} = 5 + 15 = 20\,\text{A}$

P_{260} (supplied) $= (260)(20) = 5200\,\text{W}$

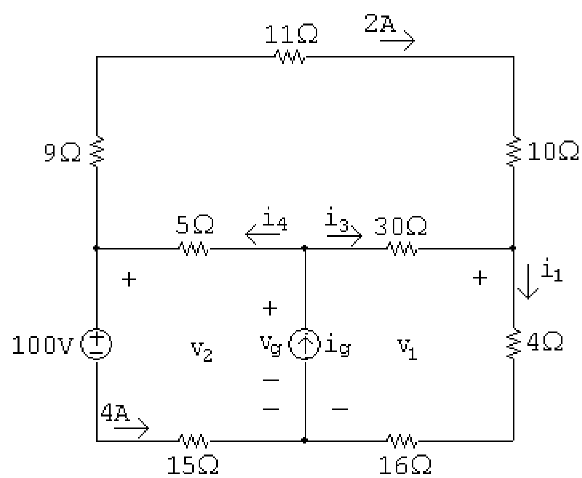
[b] $\sum P_\text{dis} = (25)^2(2) + (20)^2(8) + (5)^2(4) + (15)^2 16 + (20)^2 2 + (5)^2(80)$

$= 1250 + 3200 + 100 + 3600 + 800 + 2000 = 10{,}950$ W

$\sum P_\text{sup} = 5750 + 5200 = 10{,}950$ W

Therefore, $\sum P_\text{dis} = \sum P_\text{sup} = 10{,}950$ W

P 2.19 **[a]**



$v_2 = 100 + 4(15) = 160\,\text{V}; \qquad v_1 = 160 - 30(2) = 100\,\text{V}$

$i_1 = \dfrac{v_1}{20} = \dfrac{100}{20} = 5\,\text{A}; \qquad i_3 = i_1 - 2 = 5 - 2 = 3\,\text{A}$

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

$v_g - 5i_4 = v_2$ so $5i_4 = v_g - v_2 = 190 - 160 = 30\,\text{V}$

Thus $i_4 = \dfrac{30}{5} = 6\,\text{A}$

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

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

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

$p_{10\,\Omega} = (10)(2)^2 = 40\,\text{W};$ $p_{30\,\Omega} = (30)(3)^2 = 270\,\text{W}$

$p_{5\,\Omega} = (5)(6)^2 = 180\,\text{W};$ $p_{4\,\Omega} = (4)(5)^2 = 100\,\text{W}$

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

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

[d] Sum the power dissipated by the resistors:

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

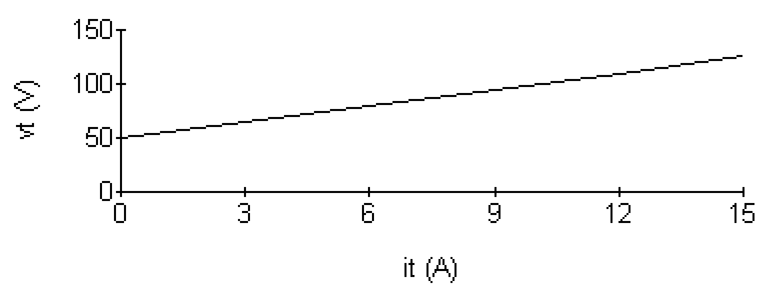
The power associated with the sources is

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

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

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

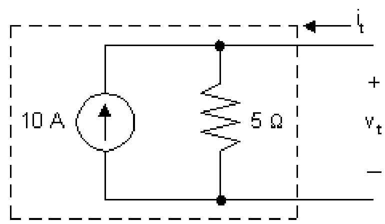
P 2.20 **[a]** Plot tl



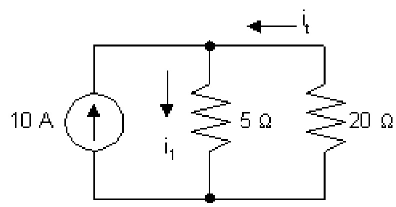
From the plot:

$$R = \frac{\Delta v}{\Delta i} = \frac{(125 - 50)}{(15 - 0)} = 5\,\Omega$$

When $i_t = 0$, $v_t = 50$ V; therefore the ideal current source has a current of 10 A



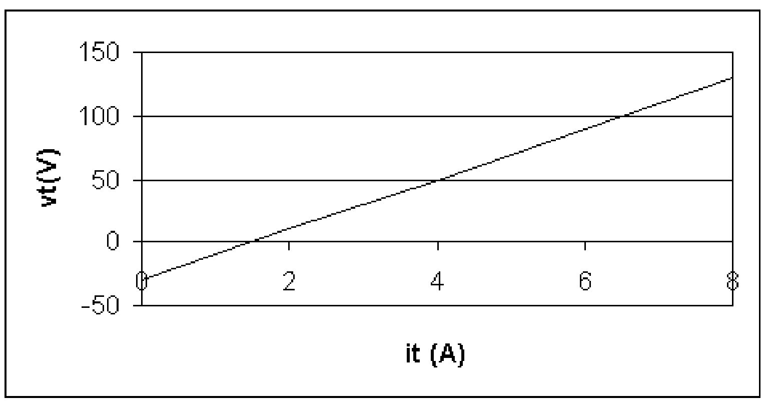
[b]



$10 + i_t = i_1$ and $5i_1 = -20i_t$

Therefore, $10 + i_t = -4i_t$ so $i_t = -2$ A

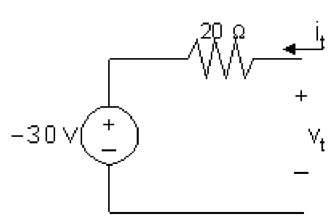
P 2.21 **[a]** Plot the v—i characteristic:



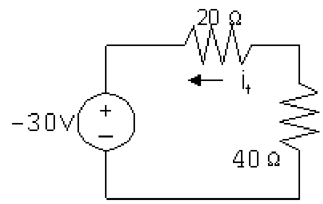
From the plot:

$$R = \frac{\Delta v}{\Delta i} = \frac{130 - (-30)}{8 - 0} = 20\,\Omega$$

When $i_t = 0$, $v_t = -30$ V; therefore the ideal voltage source has a voltage of -30 V. Thus the device can be modeled as a -30 V source in series with a $20\,\Omega$ resistor, as shown below:



[b] We attach a $40\,\Omega$ resistor to the device model developed in part (a):



Write a KVL equation clockwise around the circuit, using Ohm's law to express the voltage drop across the resistors in terms of the current i_t through the resistors:

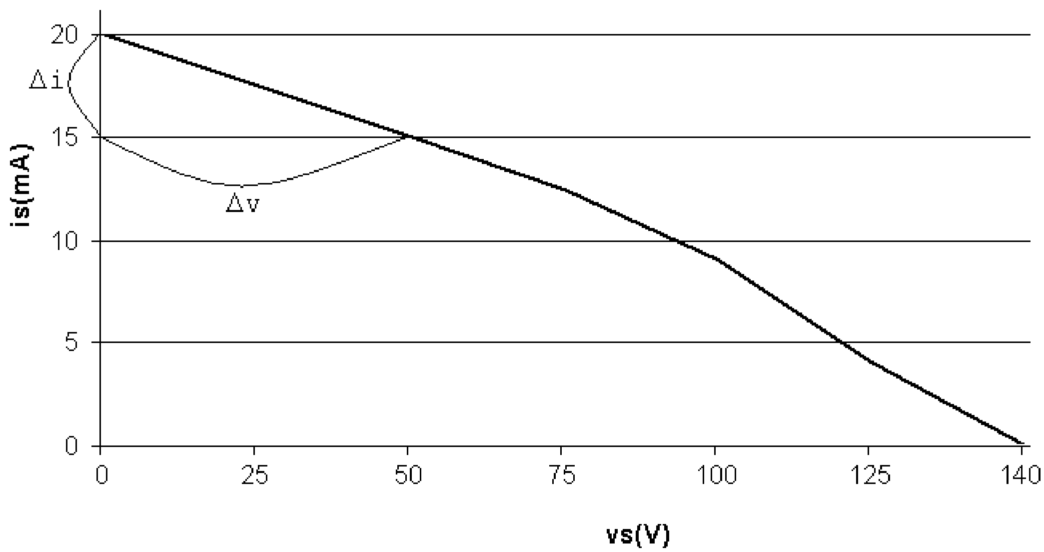
$$-(-30\,\text{V}) - 20i_t - 40i_t = 0 \qquad \text{so} \qquad -60i_t = -30\,\text{V}$$

Thus $\quad i_t = \dfrac{-30\,\text{V}}{-60} = +0.5\,\text{A}$

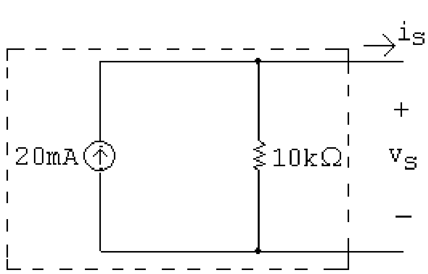
Now calculate the power dissipated by the resistor:

$$p_{40\,\Omega} = 40i_t^2 = (40)(0.5)^2 = 10\,\text{W}$$

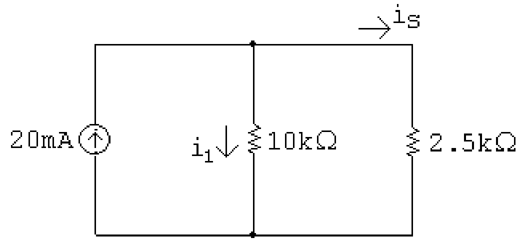
P 2.22 **[a]**



[b] $\Delta v = 50\,\text{V}; \qquad \Delta i = 5\,\text{mA}; \qquad R = \dfrac{\Delta v}{\Delta i} = \dfrac{50\,\text{V}}{5\,\text{mA}} = 10\,\text{k}\Omega$



[c]



$$10{,}000 i_1 = 2500 i_s \qquad \text{so} \qquad i_1 = 0.25 i_s$$

$$0.02 = i_1 + i_s = 0.25 i_s + i_s = 1.25 i_s$$

$$\text{Thus,} \qquad i_s = \frac{0.02}{1.25} = 0.016\,\text{A} = 16\,\text{mA}$$

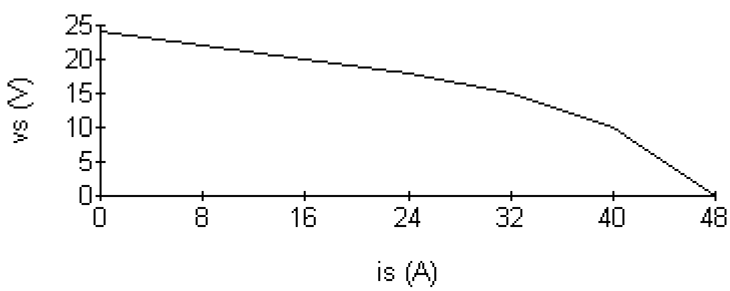
[d] Predicted open circuit voltage:

$$v_{\text{oc}} = v_s = (0.02)(10{,}000) = 200\,\text{V}$$

[e] From the table, the actual open circuit voltage is 140 V.

[f] This is a practical current source and is not a linear device.

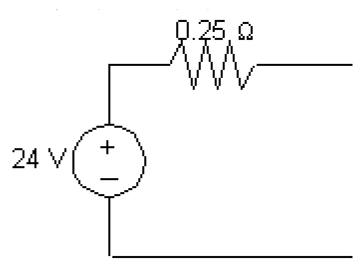
P 2.23 **[a]** Begin



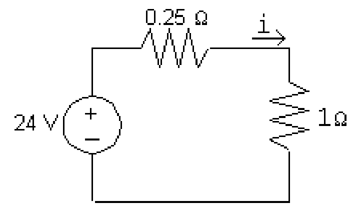
[b] Since the plot is linear for $0 \leq i_s \leq 24$ A amd since $R = \Delta v/\Delta i$, we can calculate R from the plotted values as follows:

$$R = \frac{\Delta v}{\Delta i} = \frac{24 - 18}{24 - 0} = \frac{6}{24} = 0.25\,\Omega$$

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 $0 \leq i_s \leq 24$



[c] The circuit is shown below:

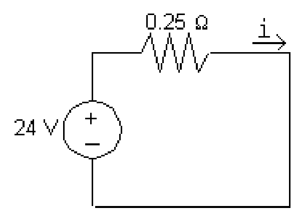


Write a KVL equation in the clockwise direction, starting below the voltage source. Use Ohm's law to express the voltage drop across the resistors in terms of the current i:

$$-24\,\mathrm{V} + 0.25i + 1i = 0 \qquad \text{so} \qquad 1.25i = 24\,\mathrm{V}$$

Thus, $\quad i = \dfrac{24\,\mathrm{V}}{1.25\,\Omega} = 19.2\,\mathrm{A}$

[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:

$$-24\,\mathrm{V} + 0.25i = 0 \qquad \text{so} \qquad 0.25i = 24\,\mathrm{V}$$

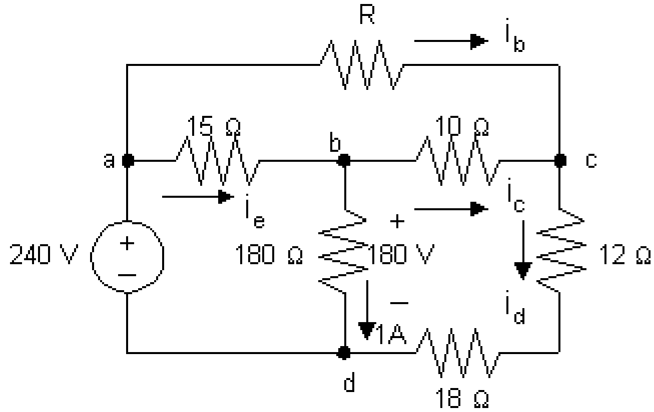
Thus, $\quad i = \dfrac{24\,\mathrm{V}}{0.25\,\Omega} = 96\,\mathrm{A}$

[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,

$i_{sc} = 48\,\mathrm{A}$ (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 2.24



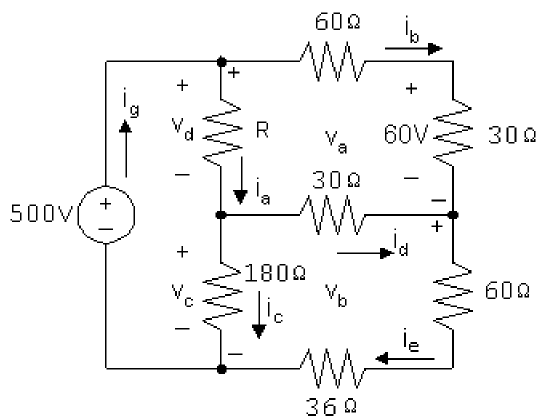
$v_{\rm ab} = 240 - 180 = 60\,\text{V};$ therefore, $i_{\rm e} = 60/15 = 4\,\text{A}$
$i_{\rm c} = i_{\rm e} - 1 = 4 - 1 = 3\,\text{A};$ therefore, $v_{\rm bc} = 10 i_{\rm c} = 30\,\text{V}$
$v_{\rm cd} = 180 - v_{\rm bc} = 180 - 30 = 150\,\text{V};$
therefore, $i_{\rm d} = v_{\rm cd}/(12+18) = 150/30 = 5\,\text{A}$
$i_{\rm b} = i_{\rm d} - i_{\rm c} = 5 - 3 = 2\,\text{A}$
$v_{\rm ac} = v_{\rm ab} + v_{\rm bc} = 60 + 30 = 90\,\text{V}$
$R = v_{\rm ac}/i_{\rm b} = 90/2 = 45\,\Omega$

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

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

$\sum P_{\rm dis} =$ $1(180) + 4(45) + 9(10) + 25(12) + 25(18) + 16(15) = 1440$ W (CHECKS)

P 2.25 **[a]**



$i_b = 60\,\text{V}/30\,\Omega = 2\,\text{A}$
$v_a = (30 + 60)(2) = 180\,\text{V}$
$-500 + v_a + v_b = 0$ so $v_b = 500 - v_a = 500 - 180 = 320\,\text{V}$
$i_e = v_b/(60+36) = 320/96 = (10/3)\,\text{A}$
$i_d = i_e - i_b = (10/3) - 2 = (4/3)\,\text{A}$
$v_c = 30 i_d + v_b = 40 + 320 = 360\,\text{V}$
$i_c = v_c/180 = 360/180 = 2\,\text{A}$
$v_d = 500 - v_c = 500 - 360 = 140\,\text{V}$
$i_a = i_d + i_c = 4/3 + 2 = (10/3)\,\text{A}$
$R = v_d/i_a = 140/(10/3) = 42\,\Omega$

[b] $i_g = i_a + i_b = (10/3) + 2 = (16/3)$ A
p_g (supplied) $= (500)(16/3) = 2666.67$ W

P 2.26 **[a]** Start with the $22.5\,\Omega$ resistor. Since the voltage drop across this resistor is 90 V, we can use Ohm's law to calculate the current:

$$i_{22.5\,\Omega} = \frac{90\,\mathrm{V}}{22.5\,\Omega} = 4\,\mathrm{A}$$

Next we can calculate the voltage drop across the $15\,\Omega$ resistor by writing a KVL equation around the outer loop of the circuit:

$$-240\,\mathrm{V} + 90\,\mathrm{V} + v_{15\,\Omega} = 0 \qquad \text{so} \qquad v_{15\,\Omega} = 240 - 90 = 150\,\mathrm{V}$$

Now that we know the voltage drop across the $15\,\Omega$ resistor, we can use Ohm's law to find the current in this resistor:

$$i_{15\,\Omega} = \frac{150\,\mathrm{V}}{15\,\Omega} = 10\,\mathrm{A}$$

Write a KCL equation at the middle right node to find the current through the $5\,\Omega$ resistor. Sum the currents entering:

$$4\,\mathrm{A} - 10\,\mathrm{A} + i_{5\,\Omega} = 0 \qquad \text{so} \qquad i_{5\,\Omega} = 10\,\mathrm{A} - 4\,\mathrm{A} = 6\,\mathrm{A}$$

Write a KVL equation clockwise around the upper right loop, starting below the $4\,\Omega$ resistor. Use Ohm's law to express the voltage drop across the resistors in terms of the current through the resistors:

$$-v_{4\,\Omega} + 90\,\mathrm{V} + (5\,\Omega)(-6\,\mathrm{A}) = 0 \qquad \text{so} \qquad v_{4\,\Omega} = 90\,\mathrm{V} - 30\,\mathrm{V} = 60\,\mathrm{V}$$

Using Ohm's law we can find the current through the $4\,\Omega$ resistor:

$$i_{4\,\Omega} = \frac{60\,\mathrm{V}}{4\,\Omega} = 15\,\mathrm{A}$$

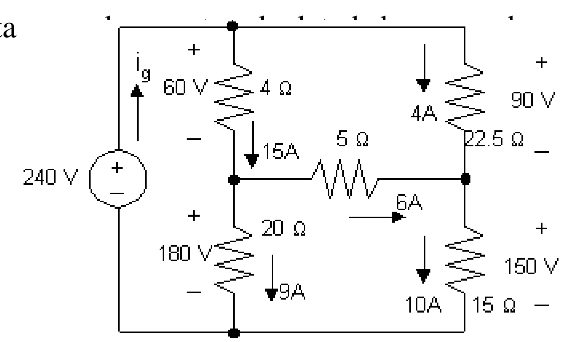
Write a KCL equation at the middle node. Sum the currents entering:

$$15\,\mathrm{A} - 6\,\mathrm{A} - i_{20\,\Omega} = 0 \qquad \text{so} \qquad i_{20\,\Omega} = 15\,\mathrm{A} - 6\,\mathrm{A} = 9\,\mathrm{A}$$

Use Ohm's law to calculate the voltage drop across the $20\,\Omega$ resistor:

$$v_{20\,\Omega} = (20\,\Omega)(9\,\mathrm{A}) = 180\,\mathrm{V}$$

All of the volta n in the figure below:



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

$$p_{4\Omega} = (4)(15)^2 = 900\,\mathrm{W} \qquad p_{20\Omega} = (20)(9)^2 = 1620\,\mathrm{W}$$

$$p_{5\Omega} = (5)(6)^2 = 180\,\mathrm{W} \qquad p_{22.5\Omega} = (22.5)(4)^2 = 360\,\mathrm{W}$$

$$p_{15\Omega} = (15)(10)^2 = 1500\,\mathrm{W}$$

[b] We can calculate the current in the voltage source, i_g by writing a KCL equation at the top middle node:

$$i_g = 15\,\text{A} + 4\,\text{A} = 19\,\text{A}$$

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

$$p_g = -240(19) = -4560\,\text{W} \qquad \text{thus} \qquad p_g\,\text{(supplied)} = 4560\,\text{W}$$

[c] $\sum P_{\text{dis}} = 900 + 1620 + 180 + 360 + 1500 = 4560\,\text{W}$

Therefore,

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

P 2.27 $i_E - i_B - i_C = 0$

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

$$i_2 = -i_B + i_1$$

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

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

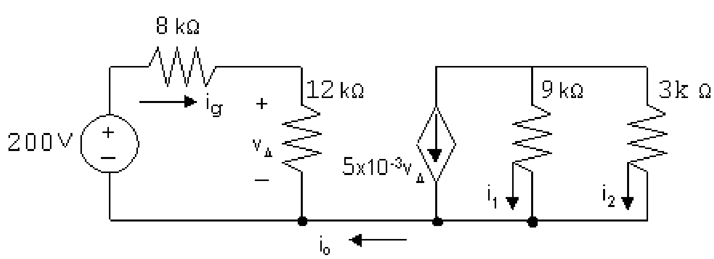
$$V_o + i_E R_E + i_B R_2 - \frac{V_{CC} + i_B R_2}{R_1 + R_2} R_2 = 0$$

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

[b]



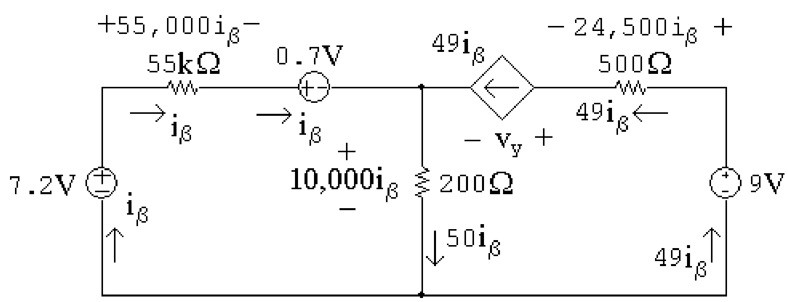
$$-200 + 8000 i_g + 12{,}000 i_g = 0 \qquad \text{so} \qquad i_g = 200/20{,}000 = 10\text{ mA}$$
$$v_\Delta = (12\times10^3)(10\times10^{-3}) = 120\text{ V}$$
$$5\times10^{-3}v_\Delta = 0.6\,\text{A}$$
$$9000 i_1 = 3000 i_2 \qquad \text{so} \qquad i_2 = 3i_1$$
$$0.6 + i_1 + i_2 = 0 \qquad \text{so} \qquad 0.6 + i_1 + 3i_1 = 0 \qquad \text{thus} \qquad i_1 = -0.15\text{ A}$$

[c] $i_2 = 3i_1 = -0.45$ A

P 2.29 First note that we know the current through all elements in the circuit except the $200\,\Omega$ resistor (the current in the three elements to the left of the $200\,\Omega$ resistor is i_β; the current in the three elements to the right of the $200\,\Omega$ resistor is $49i_\beta$). To find the current in the $200\,\Omega$ resistor, write a KCL equation at the top node:

$$i_\beta + 49i_\beta = i_{200\,\Omega} = 50i_\beta$$

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



[a] To find i_β, write a KVL equation around the left-hand loop, summing voltages in a clockwise direction starting below the 7.2V source:

$$-7.2\,\text{V} + 55{,}000i_1 + 0.7\,\text{V} + 10{,}000i_\beta = 0$$

Solving for i_β

$$55{,}000i_\beta + 10{,}000i_\beta = 6.5\,\text{V} \qquad \text{so} \qquad 65{,}000i_\beta = 6.5\,\text{V}$$

Thus,

$$i_\beta = \frac{6.5}{65{,}000} = 100\,\mu\text{A}$$

Now that we have the value of i_β, 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:

$$-v_y - 24{,}500i_\beta + 9\,\text{V} - 10{,}000i_\beta = 0$$

Thus,

$$v_y = 9\,\text{V} - 34{,}500i_\beta = 9\,\text{V} - 34{,}500(100 \times 10^{-6}) = 9\,\text{V} - 3.45\,\text{V} = 5.55\,\text{V}$$

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

Element	**Current (μA)**	**Voltage (V)**	**Power Equation**	**Power (μW)**
$7.2\,\text{V}$	100	7.2	$p = -vi$	-720
$55\,\text{k}\Omega$	100	5.5	$p = Ri^2$	550
$0.7\,\text{V}$	100	0.7	$p = vi$	70
$200\,\Omega$	5000	1	$p = Ri^2$	5000
Dep. source	4900	5.55	$p = vi$	27,195
$500\,\Omega$	4900	2.45	$p = Ri^2$	12,005
$9\,\text{V}$	4900	9	$p = -vi$	$-44{,}100$

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

$$-720\,\mu\text{W} + -44{,}100\,\mu\text{W} = -44{,}820\,\mu\text{W}$$

Thus, the total power generated in the circuit is $44{,}820\,\mu$W. The total power absorbed in the circuit is the sum of the positive power values in the power table:

$$550\,\mu\text{W} + 70\,\mu\text{W} + 5000\,\mu\text{W} + 27{,}195\,\mu\text{W} + 12{,}005\,\mu\text{W} = 44{,}820\,\mu\text{W}$$

Thus, the total power absorbed in the circuit is $44{,}820\,\mu$W and the power in the circuit balances.

P 2.30 **[a]** $12 - 2i_\sigma = 5i_\Delta$

$$5i_\Delta = 8i_\sigma + 2i_\sigma = 10i_\sigma$$

Therefore, $12 - 2i_\sigma = 10i_\sigma$, so $i_\sigma = 1\,\text{A}$

$$5i_\Delta = 10i_\sigma = 10; \text{ so } i_\Delta = 2\,\text{A}$$

$$v_o = 2i_\sigma = 2\,\text{V}$$

[b] i_g = current out of the positive terminal of the 12 V source
v_d = voltage drop across the $8i_\Delta$ source

$$i_g = i_\Delta + i_\sigma + 8i_\Delta = 9i_\Delta + i_\sigma = 19\,\text{A}$$

$$v_d = 2 + 8 = 10\,\text{V}$$

$$\begin{aligned}
\sum P_{\text{gen}} &= 12i_g + 8i_\Delta(8) = 12(19) + 8(2)(8) = 356 \text{ W} \\
\sum P_{\text{diss}} &= 2i_\sigma i_g + 5i_\Delta^2 + 8i_\sigma(i_\sigma + 8i_\Delta) + 2i_\sigma^2 + 8i_\Delta v_d \\
&= 2(1)(19) + 5(2)^2 + 8(1)(17) + 2(1)^2 + 8(2)(10) \\
&= 356 \text{ W; Therefore,} \\
\sum P_{\text{gen}} &= \sum P_{\text{diss}} = 356 \text{ W}
\end{aligned}$$

P 2.31 $40i_2 + \frac{5}{40} + \frac{5}{10} = 0 \qquad \text{so} \qquad i_2 = -15.625\,\text{mA}$

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

$25i_1 + \frac{-1.25}{20} + (-15.625 \times 10^{-3}) = 0 \qquad \text{so} \qquad i_1 = 3.125\,\text{mA}$

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

Therefore, $\quad v_g = 1\,\text{V}$

P 2.32 $\frac{V_{CC}R_2}{R_1 + R_2} = \frac{(10)(60 \times 10^3)}{100 \times 10^3} = 6\text{V}$

$$\frac{R_1R_2}{R_1 + R_2} = \frac{(40 \times 10^3)(60 \times 10^3)}{100 \times 10^3} = 24\ \text{k}\Omega$$

$$i_B = \frac{6 - 0.6}{24 \times 10^3 + 50(120)} = \frac{5.4}{(24 + 6) \times 10^3} = 0.18\ \text{mA}$$

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

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

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

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

$$i_2 = \frac{v_{bd}}{R_2} = \frac{1.68}{60} \times 10^{-3} = 28\,\mu\text{A}$$

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

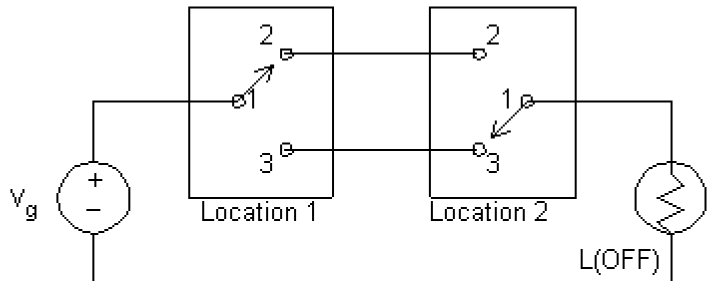
$v_{\text{ab}} = (40 \times 10^3)(208 \times 10^{-6}) = 8.32\text{V}$

$i_{CC} = i_C + i_1 = 8.82\ \text{mA} + 208\,\mu\text{A} = 9.028\ \text{mA}$

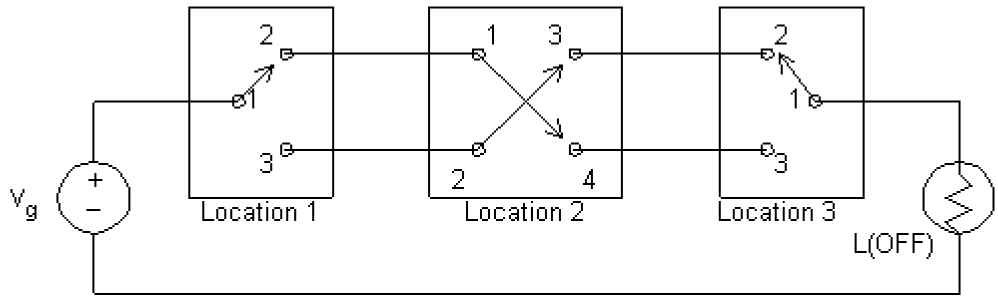
$v_{13} + (8.82 \times 10^{-3})(750) + 1.08 = 10$

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

P 2.33 **[a]**



[b]

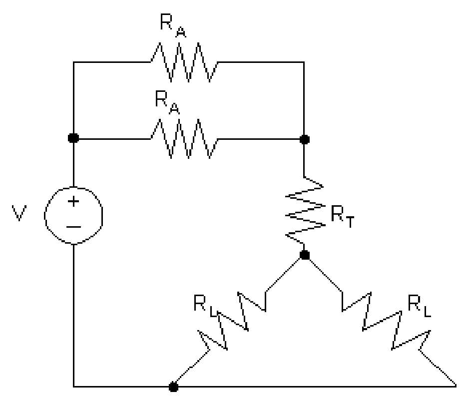


P 2.34 From the simplified circuit model, using Ohm's law and KVL:

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

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.

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] $$\left(\frac{dT}{dt}\right)_{\rm arm} = \frac{2.39\times10^{-4}p_{\rm arm}}{4} = 35.36\times10^{-4}\,^\circ\ \text{C/s}$$

$$t_{\rm arm} = \frac{5}{35.36}\times10^4 = 1414.23\ \text{s or } 23.57\ \text{min}$$

$$\left(\frac{dT}{dt}\right)_{\rm leg} = \frac{2.39\times10^{-4}}{10}P_{\rm leg} = 7.07\times10^{-4\circ}\ \text{C/s}$$

$$t_{\rm leg} = \frac{5\times10^4}{7.07} = 7{,}071.13\ \text{s or } 117.85\ \text{min}$$

$$\left(\frac{dT}{dt}\right)_{\rm trunk} = \frac{2.39\times10^{-4}(7.4)}{25} = 0.71\times10^{-4}\,^\circ\ \text{C/s}$$

$$t_{\rm trunk} = \frac{5\times10^4}{0.71} = 70{,}677.37\ \text{s or } 1{,}177.96\ \text{min}$$

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

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

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

$$v_{\rm min} = (800)(50)\times10^{-3} = 40\,\text{V}$$

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

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

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

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