Chapter 3: Resistive Network Analysis – Instructor Notes

Chapter 3 presents the principal topics in the analysis of resistive (DC) circuits. The presentation of node voltage and mesh current analysis is supported by several solved examples and drill exercises, with emphasis placed on developing consistent solution methods, and on reinforcing the use of a systematic approach. The aim of this style of presentation, which is perhaps more detailed than usual in a textbook written for a non-majors audience, is to develop good habits early on, with the hope that the orderly approach presented in Chapter 3 may facilitate the discussion of AC and transient analysis in Chapters 4 and 5. *Make The Connection* sidebars (pp. 83-85) introduce analogies between electrical and thermal circuit elements. These analogies are to be encountered again in Chapter 5. A brief discussion of the principle of superposition precedes the discussion of Thèvenin and Norton equivalent circuits. Again, the presentation is rich in examples and drill exercises, because the concept of equivalent circuits will be heavily exploited in the analysis of AC and transient circuits in later chapters. The *Focus on Methodology* boxes (p. 84 – Node Analysis; p. 94 – Mesh Analysis; pp. 111, 115, 119 – Equivalent Circuits) provide the student with a systematic approach to the solution of all basic network analysis problems.

Following a brief discussion of maximum power transfer, the chapter closes with a section on nonlinear circuit elements and load-line analysis. This section can be easily skipped in a survey course, and may be picked up later, in conjunction with Chapter 9, if the instructor wishes to devote some attention to load-line analysis of diode circuits. Finally, **those instructors who are used to introducing the op-amp as a circuit element, will find that sections 8.1 and 8.2 can be covered together with Chapter 3, and that a good complement of homework problems and exercises devoted to the analysis of the op-amp as a circuit element is provided in Chapter 8.** Modularity is a recurrent feature of this book, and we shall draw attention to it throughout these *Instructor Notes*.

The homework problems present a graded variety of circuit problems. Since the aim of this chapter is to teach solution techniques, there are relatively few problems devoted to applications. We should call the instructor's attention to the following end-of-chapter problems: 3.30 on the Wheatstone bridge; 3.33 and 3.34 on fuses; 3.35-3.37 on electrical power distribution systems; 3.76-83 on various nonlinear resistance devices. The 5th Edition of this book includes 19 new problems; some of the 4th Edition problems were removed, increasing the end-of-chapter problem count from 66 to 83.

Learning Objectives for Chapter 3

1. Compute the solution of circuits containing linear resistors and independent and dependent sources using *node analysis*.
2. Compute the solution of circuits containing linear resistors and independent and dependent sources using *mesh analysis*.
3. Apply the *principle of superposition* to linear circuits containing independent sources.
4. Compute *Thévenin and Norton equivalent circuits* for networks containing linear resistors and independent and dependent sources.
5. Use equivalent circuits ideas to compute the *maximum power transfer* between a source and a load.
6. Use the concept of equivalent circuit to determine voltage, current and power for nonlinear loads using *load-line analysis* and analytical methods.

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Sections 3.1, 3.2, 3.3, 3.4: Nodal and Mesh Analysis

Focus on Methodology: Node Voltage Analysis Method

1. Select a reference node(usually ground). This node usually has most elements tied to it. All other nodes will be referenced to this node.
2. Define the remaining n–1 node voltages as the independent or dependent variables. Each of the m voltage sources in the circuit will be associated with a dependent variable. If a node is not connected to a voltage source, then its voltage is treated as an independent variable.
3. Apply KCL at each node labeled as an independent variable, expressing each current in terms of the adjacent node voltages.
4. Solve the linear system of n–1–m unknowns.

Focus on Methodology: Mesh Current Analysis Method

1. Define each mesh current consistently. Unknown mesh currents will be always defined in the clockwise direction; known mesh currents (i.e., when a current source is present) will always be defined in the direction of the current source.
2. In a circuit with n meshes and m current sources, n–m independent equations will result. The unknown mesh currents are the n–m independent variables.
3. Apply KVL to each mesh containing an unknown mesh current, expressing each voltage in terms of one or more mesh currents..
4. Solve the linear system of n–m unknowns.

Problem 3.1

Note: the rightmost top resistor missing a value should be 1 Ω.

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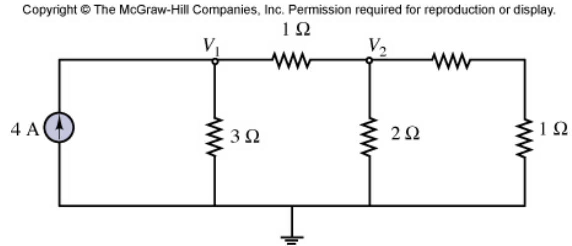

Solution:

Known quantities:
Circuit shown in Figure P3.1

Find:
Voltages v_1 and v_2.

Analysis:

Applying KCL at each of the two nodes, we obtain the following equations:

$$\frac{V_1}{3} + \frac{V_1 - V_2}{1} - 4 = 0$$

$$\frac{V_2}{2} + \frac{V_2}{2} + \frac{V_2 - V_1}{1} = 0$$

Rearranging the equations,

$$\frac{4}{3}V_1 - V_2 = 4$$

$$-V_1 + 2V_2 = 0$$

Solving the equations,

$$V_1 = 4.8\ V \text{ and } V_2 = 2.4\ V$$

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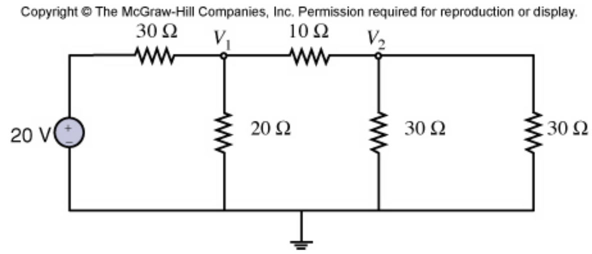
Problem 3.2

Solution:



Known quantities:
Circuit shown in Figure P3.2

Find:
Voltages v_1 and v_2.

Analysis:

Applying KCL at each node, we obtain:

$$\frac{v_1 - 20}{30} + \frac{v_1}{20} + \frac{v_1 - v_2}{10} = 0$$

$$\frac{v_2}{30} + \frac{v_2}{30} + \frac{v_2 - v_1}{10} = 0$$

Rearranging the equations,

$$5.5v_1 - 3v_2 = 20$$

$$-3v_1 + 5v_2 = 0$$

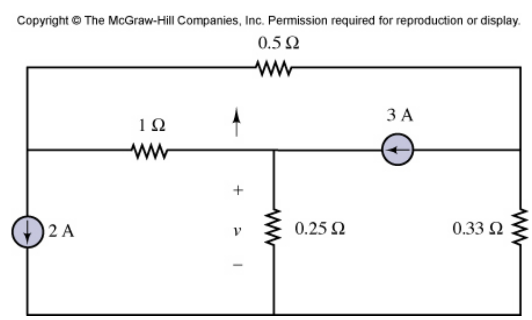
Solving the two equations,

$$v_1 = 5.41 \text{ V} \text{ and } v_2 = 3.24 \text{ V}$$

Problem 3.3

Note: ignore the "floating" arrow pointing up in the top mesh.

Solution:



Known quantities:
Circuit shown in Figure P3.3

Find:
Voltages across the resistance.

Analysis:

At node 1:

$$\frac{v_1 - v_2}{1} + \frac{v_1 - v_3}{0.5} = -2$$

At node 2:

$$\frac{v_2 - v_1}{1} + \frac{v_2}{0.25} = 3$$

At node 3:

$$\frac{v_3 - v_1}{0.25} + \frac{v_3}{0.33} = -3$$

Solving for v_2, we find $v_2 = 0.34\text{V}$ and, therefore, $v = 0.34\text{V}$.

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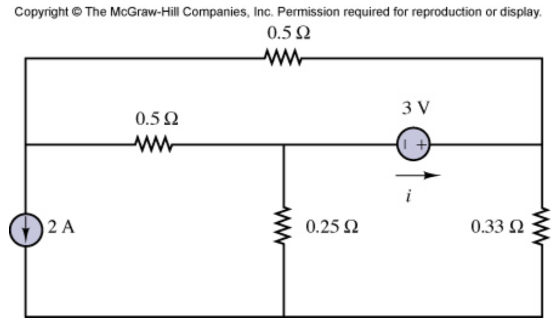
Problem 3.4

Solution:

Known quantities:
Circuit shown in Figure P3.4

Find:
Current through the voltage source.

Analysis:



At node 1:

$$\frac{v_1 - v_2}{0.5} + \frac{v_1 - v_3}{0.5} = -2 \qquad (1)$$

At node 2:

$$\frac{v_2 - v_1}{0.5} + \frac{v_2}{0.25} + i = 0 \qquad (2)$$

At node 3:

$$\frac{v_3 - v_1}{0.5} + \frac{v_3}{0.33} - i = 0 \qquad (3)$$

Further, we know that $v_3 = v_2 + 3$. Now we can eliminate either v_2 or v_3 from the equations, and be left with three equations in three unknowns:

$$\frac{v_1 - v_2}{0.5} + \frac{v_1 - (v_2 + 3)}{0.5} = -2 \qquad (1)$$

$$\frac{v_2 - v_1}{0.5} + \frac{v_2}{0.25} + i = 0 \qquad (2)$$

$$\frac{(v_2 + 3) - v_1}{0.5} + \frac{(v_2 + 3)}{0.33} - i = 0 \qquad (3)$$

Solving the three equations we compute

$$i = 8.286\text{A}$$

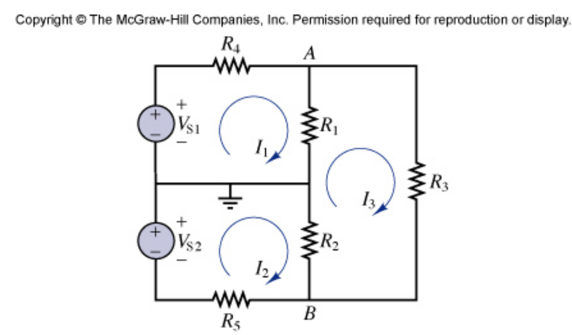
Problem 3.5

Solution:

Known quantities:
Circuit shown in Figure P3.5 with mesh currents: $I_1 = 5$ A, $I_2 = 3$ A, $I_3 =$ 7 A.

Find:
The branch currents through:

a) R_1,
b) R_2,
c) R_3.



Analysis:
a) Assume a direction for the current through R_1 (e.g., from node A to node B). Then summing currents at node A:

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KCL: $-I_1 + I_{R1} + I_3 = 0$

$I_{R1} = I_1 - I_3 = -2 \text{ A}$

This can also be done by inspection noting that the assumed direction of the current through R_1 and the direction of I_1 are the same.

b) Assume a direction for the current through R_2 (e.g., from node B to node A). Then summing currents at node B:

KCL: $I_2 + I_{R2} - I_3 = 0$

$I_{R2} = I_3 - I_2 = 4 \text{ A}$

This can also be done by inspection noting that the assumed direction of the current through R_2 and the direction of I_3 are the same.

c) Only one mesh current flows through R_3. If the current through R_3 is assumed to flow in the same direction, then:

$I_{R1} = I_3 = 7 \text{ A}$.

Problem 3.6

Solution:

Known quantities:

Circuit shown in Figure P3.5 with source and node voltages: $V_{S1} = V_{S2} = 110\ V$, $V_A = 103\ V$, $V_B = -107\ V$.

Find:

The voltage across each of the five resistors.

Analysis:

Assume a polarity for the voltages across R_1 and R_2 (e.g., from ground to node A, and from node B to ground). R_1 is connected between node A and ground; therefore, the voltage across R_1 is equal to this node voltage. R_2 is connected between node B and ground; therefore, the voltage across R_2 is equal to the negative of this voltage.

$V_{R1} = V_A = 103 \text{ V}, \quad V_{R2} = -V_B = +107 \text{ V}$

The two node voltages are with respect to the ground which is given.
Assume a polarity for the voltage across R_3 (e.g., from node B to node A). Then:
KVL: $V_A + V_{R3} + V_B = 0$

$V_{R3} = V_A - V_B = 210 \text{ V}$

Assume polarities for the voltages across R_4 and R_5 (e.g., from node A to ground , and from ground to node B):

KVL: $-V_{S1} + V_{R4} + V_A = 0$ *KVL*: $-V_{S2} - V_B - V_{R5} = 0$

$V_{R4} = V_{S1} - V_A = 7 \text{ V}$ $V_{R5} = -V_{S2} - V_B = -3 \text{ V}$

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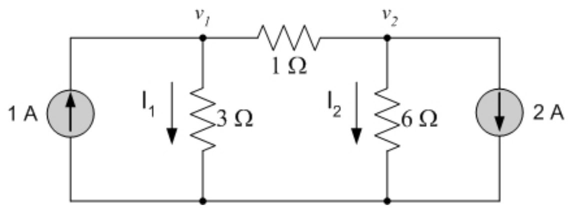
Problem 3.7

Solution:

Known quantities:
Circuit shown in Figure P3.7 with known source currents and resistances, $R_1 = 3\ \Omega, R_2 = 1\ \Omega, R_3 = 6\ \Omega$.

Find:
The currents I_1, I_2 using node voltage analysis.

Analysis:



At node 1:

$$\left(\frac{v_1 - v_2}{3}\right) + \frac{v_2}{1} = 1$$

At node 2:

$$\frac{v_2 - v_1}{1} + \frac{v_2}{6} = -2$$

Solving, we find that: $v_1 = -1.5$ V, $v_2 = -3$ V

Then, $i_1 = \frac{v_1}{3} = -0.5$ A, $i_2 = \frac{v_2}{6} = -0.5$ A

Problem 3.8

Solution:

Known quantities:
Circuit shown in Figure P3.7 with known source currents and resistances, $R_1 = 3\Omega, R_2 = 1\Omega, R_3 = 6\Omega$.

Find:
The currents I_1, I_2 using mesh analysis.

Analysis:

At mesh (a):

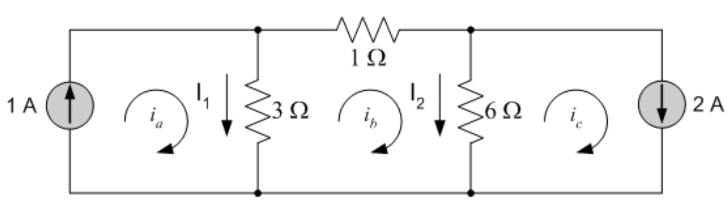
$i_a = 1$ A

At mesh (b):

$3\ (i_b - i_a) + i_b + 6\ (i_b - i_c) = 0$

At mesh (c):

$i_c = 2$ A



Solving, we find that:

$i_b = 1.5$ A

Then,

$i_1 = (i_a - i_b) = -0.5$ A

$i_2 = (i_b - i_c) = -0.5$ A

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Problem 3.9

Solution:

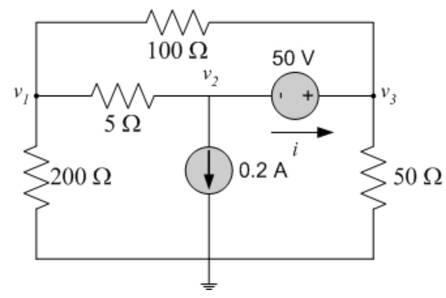
Known quantities:

Circuit shown in Figure P3.9 with resistance values, current and voltage source values.

Find:

The current, i, through the voltage source using node voltage analysis.

Analysis:



At node 1:

$$\frac{v_1}{200}+\frac{v_1-v_2}{5}+\frac{v_1-v_3}{100}=0$$

At node 2:

$$\frac{v_2-v_1}{5}+i+0.2=0$$

At node 3:

$$-i+\frac{v_3-v_1}{100}+\frac{v_3}{50}=0$$

For the voltage source we have:

$$v_3-v_2=50\text{ V}$$

Solving the system, we obtain:

$v_1=-45.53$ V, $v_2=-48.69$ V, $v_3=1.31$ V and, finally, $i=491$ mA.

Problem 3.10

Solution:

Known quantities:

The current source value, the voltage source value and the resistance values for the circuit shown in Figure P3.10.

Find:

The three node voltages indicated in Figure P3.10 using node voltage analysis.

Analysis:

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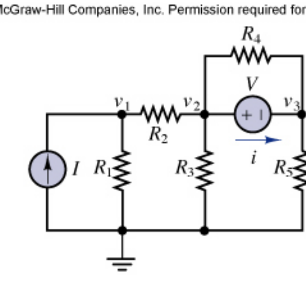

At node 1:

$$\frac{v_1}{200}+\frac{v_1-v_2}{75}=0.2\text{ A}$$

At node 2:

$$\frac{v_2-v_1}{75}+\frac{v_2}{25}+\frac{v_2-v_3}{50}+i=0$$

At node 3:

$$-i+\frac{v_3-v_2}{50}+\frac{v_3}{100}=0$$

For the voltage source we have: $v_3+10=v_2$

Solving the system, we obtain:

$v_1=14.24$ V, $v_2=4.58$V, $v_3=-5.42$ V and, finally, $i=-254$ mA.

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Problem 3.11

Solution:

Known quantities:
The voltage source value, 3 V, and the five resistance values, indicated in Figure P3.11.

Find:
The current, i, drawn from the independent voltage source using node voltage analysis.

Analysis:

At node 1:

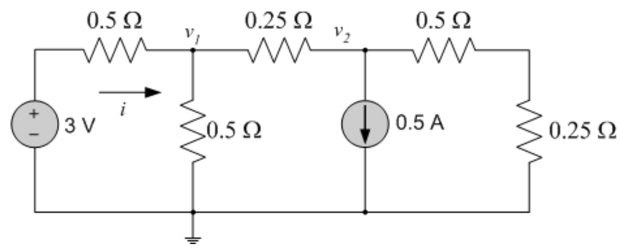
$$\frac{v_1 - 3}{0.5} + \frac{v_1}{0.5} + \frac{v_1 - v_2}{0.25} = 0$$

At node 2:

$$\frac{v_2 - v_1}{0.25} + \frac{v_2}{0.75} + 0.5 = 0$$

Solving the system, we obtain:
$v_1 = 1.125 \text{ V}$, $v_2 = 0.75 \text{ V}$

Therefore, $i = \dfrac{3 - v_1}{0.5} = 3.75 \text{ A}$.



Problem 3.12

Solution:

Known quantities:
Circuit shown in Figure P3.12.

Find:
Power delivered to the load resistance.

Analysis:

KCL at node 1:

$$\frac{V_1}{R_I} + \frac{V_1 - V_s - V_2}{R_V} = 0.5$$

Or $3V_1 - V_2 = 6$ (Eq. 1)

KCL at node 2:

$$\frac{V_1 - V_s - V_2}{R_V} = \frac{V_2}{R_1 \| (R_2 + R_L)}$$

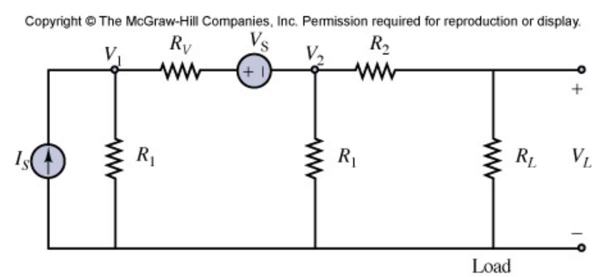
Or $14V_2 - 4V_1 = -16$ (Eq. 2)

substitute Eq. 1 into Eq. 2 $V_2 = -0.6316$

and by voltage divider:

$$V_L = \left(\frac{R_L}{R_2 + R_L}\right) V_2 = -0.316 \text{V}$$

$$P_L = \frac{V_L^2}{R_L} = 25 \text{ mW}$$



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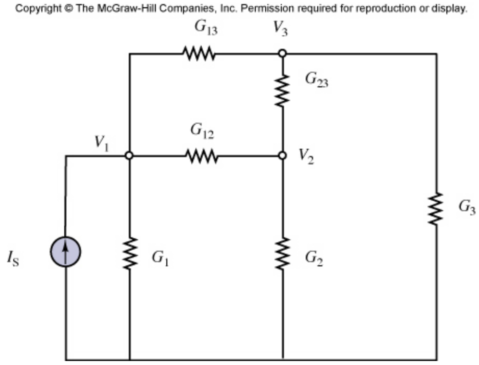
Problem 3.13

Solution:

Known quantities:
Circuit shown in Figure P3.13.



Find:
a) Voltages
b) Write down the equations in matrix form.

Analysis:

a) Using conductances, apply KCL at node 1:

$$(G_1 + G_{12} + G_{13})V_1 - G_{12}V_2 - G_{13}V_3 = I_s$$

Then apply KCL at node 2:

$$-G_{12}V_1 + (G_2 + G_{12} + G_{23})V_2 - G_{23}V_3 = 0$$

and at node 3:

$$-G_{13}V_1 - G_{23}V_2 + (G_3 + G_{13} + G_{23})V_3 = 0$$

Rewriting in the form

$$[G][V]=[I]$$

we have

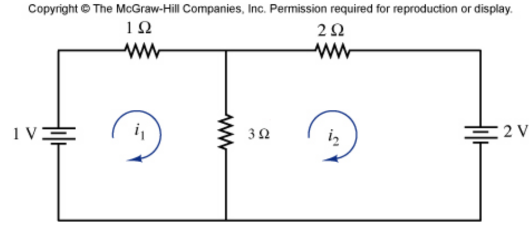
$$\begin{bmatrix} G_1 + G_{12} + G_{13} & -G_{12} & -G_{13} \\ -G_{12} & G_2 + G_{12} + G_{23} & -G_{23} \\ -G_{13} & -G_{23} & G_3 + G_{13} + G_{23} \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \\ V_3 \end{bmatrix} = \begin{bmatrix} I_S \\ 0 \\ 0 \end{bmatrix}$$

b) The result is identical to that obtained in part a).

Problem 3.14

Solution:

Circuit shown in Figure P3.14.



Find:
Current i_1 and i_2.

Analysis:

For mesh #1:

$$i_1(1+3)+i_2(-3)=1$$

For mesh #2:

$$i_1(-3)+i_2(3+2)=-2$$

Solving,

$$i_1 = -0.091\text{A}$$
$$i_2 = -0.455\text{A}$$

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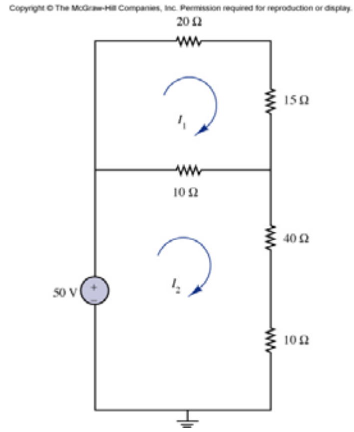
Problem 3.15



Solution:

Circuit shown in Figure P3.15.

Find:

Current i_1 and i_2 and voltage across the resistance 10Ω .

Analysis:

Mesh #1 $\quad (20+15+10)I_1 \text{ -}10I_2 = 0$

Mesh #2 $\quad (10+40+10)I_2 \text{ -}10I_1 = 50$

Therefore,

$I_1 = 0.1923$ A and $I_2 = 0.865$ A ,

$v_{10\Omega} = 10(i_2 - i_1) = 6.727$ V

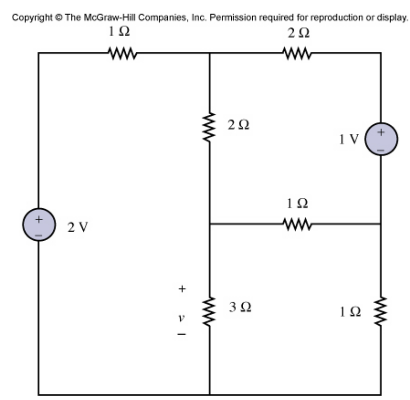
Problem 3.16

Solution:

Circuit shown in Figure P3.16.

Find:

Voltage across the 3Ω resistance.



Analysis:

Meshes 1, 2 and 3 are clockwise from the left

For mesh #1:

$$i_1(1+2+3)+i_2(-2)+i_3(-3)=2$$

For mesh #2:

$$i_1(-2)+i_2(2+2+1)+i_3(-1)=-1$$

For mesh #3:

$$i_1(-3)+i_2(-1)+i_3(3+1+1)=0$$

Solving,

$$i_1 = 0.5224 \text{ A}$$
$$i_2 = 0.0746 \text{ A}$$
$$i_3 = 0.3284 \text{ A}$$

and $\quad v = 3(i_1 - i_3) = 3(0.194) = 0.5821$ V

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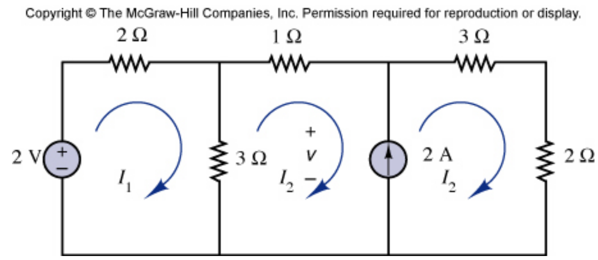
Problem 3.17

Note: the right-most mesh current should be labeled I_3, not I_2.

Solution:

Mesh #1 (on the left-hand side)

$$2 - 2I_1 - 3(I_1 - I_2) = 0$$



If we treat mesh #2 (middle) and mesh #3 (on the right-hand side) as a single loop containing the four resistors (but not the current source), we can write

$$-1I_2 - 3I_3 - 2I_3 - 3(I_2 - I_1) = 0$$

From the current source:

$$I_3 - I_2 = 2$$

Solving the system of equations:

I_1 = - 0.333 A I_2 = - 1.222 A I_3 = 0.778 A

Problem 3.18

Solution:

Circuit shown in Figure P3.18.

Find:

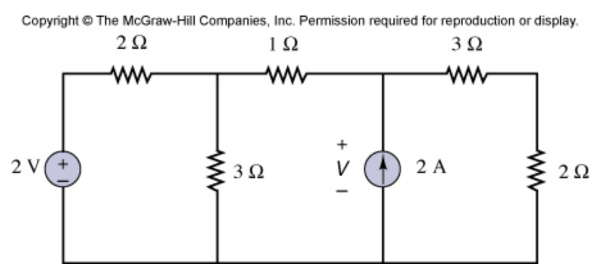
Voltage across the current source.

Analysis:

Meshes 1, 2 and 3 go from left to right.

For mesh #1:

$$i_1(2+3) + i_2(-3) + i_3(0) = 2$$



For meshes #2 and #3:

$$i_1(-3) + i_2(1+3) + i_3(3+2) = 0$$

For the current source:

$$i_1(0) + i_2(1) + i_3(-1) = -2$$

Solving,

$$i_3 = 0.778\text{A}$$

and $v = i_3(3+2) = 3.89\text{V}$

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Problem 3.19

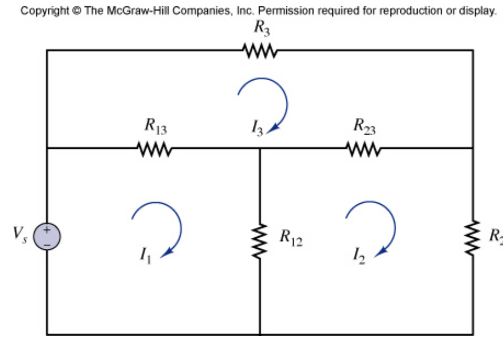
Solution:

Circuit shown in Figure P3.19.

Find:

Mesh equation in matrix form.

Analysis:



a) $$\begin{bmatrix} R_{12}+R_{13} & -R_{12} & -R_{13} \\ -R_{12} & R_{12}+R_2+R_{23} & -R_{23} \\ -R_{13} & -R_{23} & R_3+R_{13}+R_{23} \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \\ I_3 \end{bmatrix} = \begin{bmatrix} V_S \\ 0 \\ 0 \end{bmatrix}$$

b) same result as a).

Problem 3.20

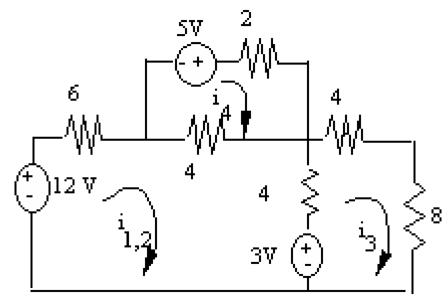
Solution:

Circuit shown in Figure P3.20.

Find:

Mesh equation in matrix form and solve for currents.

Analysis:



after source transformation, we can have the equivalent circuit shown in the right hand side. We can write down the following matrix

$$\begin{bmatrix} 6+4+4 & -4 & -4 \\ -4 & 4+4+8 & 0 \\ -4 & 0 & 2+4 \end{bmatrix} \begin{bmatrix} I_{1,2} \\ I_3 \\ I_4 \end{bmatrix} = \begin{bmatrix} 12-3 \\ 3 \\ 5 \end{bmatrix}$$

Solve the equation, we can have

$I_{1,2} = 1.2661\,\text{A} = I_2$

$I_3 = 0.5040\,\text{A}$

$I_4 = 1.6774\,\text{A}$

$I_1 = 2\text{A}$

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Problem 3.21

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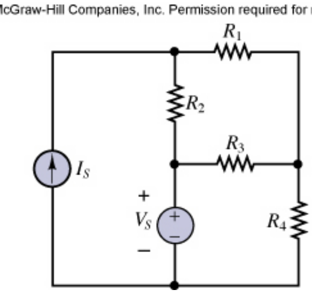

Solution:

Known quantities:

Circuit of Figure P3.21 with voltage source, V_S , current source, I_S, and all resistances**.**

Find:

a. The node equations required to determine the node voltages.
b. The matrix solution for each node voltage in terms of the known parameters.

Analysis:

a) Specify the nodes (e.g., A on the upper left corner of the circuit in Figure P3.10, and B on the right corner). Choose one node as the reference or ground node. If possible, ground one of the sources in the circuit. Note that this is possible here. When using KCL, assume all unknown current flow out of the node. The direction of the current supplied by the current source is specified and must flow into node A.

$$KCL: \quad -I_S + \frac{V_a - V_S}{R_2} + \frac{V_a - V_b}{R_1} = 0$$
$$V_a\left(\frac{1}{R_2} + \frac{1}{R_1}\right) + V_b\left(-\frac{1}{R_1}\right) = I_S + \frac{V_S}{R_2}$$

$$KCL: \quad \frac{V_b - V_a}{R_1} + \frac{V_b - V_S}{R_3} + \frac{V_b - 0}{R_4} = 0$$
$$V_a\left(-\frac{1}{R_1}\right) + V_b\left(\frac{1}{R_1} + \frac{1}{R_3} + \frac{1}{R_4}\right) = \frac{V_S}{R_3}$$

b) Matrix solution:

$$V_a = \frac{\begin{vmatrix} I_S + \frac{V_S}{R_2} & -\frac{1}{R_1} \\ \frac{V_S}{R_3} & \frac{1}{R_1} + \frac{1}{R_3} + \frac{1}{R_4} \end{vmatrix}}{\begin{vmatrix} \frac{1}{R_1} + \frac{1}{R_2} & -\frac{1}{R_1} \\ -\frac{1}{R_1} & \frac{1}{R_1} + \frac{1}{R_3} + \frac{1}{R_4} \end{vmatrix}} = \frac{\left(I_S + \frac{V_S}{R_2}\right)\left(\frac{1}{R_1} + \frac{1}{R_3} + \frac{1}{R_4}\right) - \left(\frac{V_S}{R_3}\right)\left(-\frac{1}{R_1}\right)}{\left(\frac{1}{R_1} + \frac{1}{R_2}\right)\left(\frac{1}{R_1} + \frac{1}{R_3} + \frac{1}{R_4}\right) - \left(-\frac{1}{R_1}\right)\left(-\frac{1}{R_1}\right)}$$

$$V_b = \frac{\begin{vmatrix} \frac{1}{R_1} + \frac{1}{R_2} & I_S + \frac{V_S}{R_2} \\ -\frac{1}{R_1} & \frac{V_S}{R_3} \end{vmatrix}}{\begin{vmatrix} \frac{1}{R_1} + \frac{1}{R_2} & -\frac{1}{R_1} \\ -\frac{1}{R_1} & \frac{1}{R_1} + \frac{1}{R_3} + \frac{1}{R_4} \end{vmatrix}} = \frac{\left(\frac{1}{R_1} + \frac{1}{R_2}\right)\left(\frac{V_S}{R_3}\right) - \left(-\frac{1}{R_1}\right)\left(I_S + \frac{V_S}{R_2}\right)}{\left(\frac{1}{R_1} + \frac{1}{R_2}\right)\left(\frac{1}{R_1} + \frac{1}{R_3} + \frac{1}{R_4}\right) - \left(-\frac{1}{R_1}\right)\left(-\frac{1}{R_1}\right)}$$

Notes:
1. The denominators are the same for both solutions.
2. The main diagonal of a matrix is the one that goes to the right and down.
3. The denominator matrix is the "conductance" matrix and has certain properties:
a) The elements on the main diagonal [i(row) = j(column)] include all the conductance connected to node i=j.
b) The off-diagonal elements are all negative.
c) The off-diagonal elements are all symmetric, i.e., the i j-th element = j i-th element. This is true only because there are no controlled (dependent) sources in this circuit.
d) The off-diagonal elements include all the conductance connected between node i [row] and node j [column].

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Problem 3.22

Solution:

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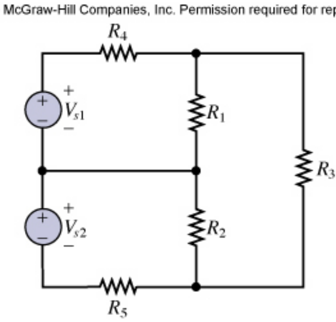

Known quantities:

Circuit shown in Figure P3.22

$V_{S1} = V_{S2} = 110 \text{ V}$

$R_1 = 500 \text{ m}\Omega \quad R_2 = 167 \text{ m}\Omega$

$R_3 = 700 \text{ m}\Omega$

$R_4 = 200 \text{ m}\Omega \quad R_5 = 333 \text{ m}\Omega$

Find:

a. The most efficient way to solve for the voltage across R_3. Prove your case.

b. The voltage across R_3.

Analysis:

a) There are 3 meshes and 3 mesh currents requiring the solution of 3 simultaneous equations. Only one of these mesh currents is required to determine, using Ohm's Law, the voltage across R_3.

In the terminal (or node) between the two voltage sources is made the ground (or reference) node, then three node voltages are known (the ground or reference voltage and the two source voltages). This leaves only two unknown node voltages (the voltages across R_1, V_{R1}, and across R_2, V_{R2}). Both these voltages are required to determine, using KVL, the voltage across R_3, V_{R3}.

A difficult choice. Choose node analysis due to the smaller number of unknowns. Specify the nodes. Choose one node as the ground node. In KCL, assume unknown currents flow out.

b)

$$KCL: \quad \frac{V_{R1}-V_{S1}}{R_4}+\frac{V_{R1}-0}{R_1}+\frac{V_{R1}-V_{R2}}{R_3}=0 \qquad KCL: \quad \frac{V_{R2}-(-V_{S2})}{R_5}+\frac{V_{R2}-0}{R_2}+\frac{V_{R2}-V_{R1}}{R_3}=0$$

$$V_{R1}\left(\frac{1}{R_1}+\frac{1}{R_3}+\frac{1}{R_4}\right)+V_{R2}\left(-\frac{1}{R_3}\right)=\frac{V_{S1}}{R_4} \qquad V_{R1}\left(-\frac{1}{R_3}\right)+V_{R2}\left(\frac{1}{R_5}+\frac{1}{R_2}+\frac{1}{R_3}\right)=-\frac{V_{S2}}{R_5}$$

$$\frac{1}{R_1}+\frac{1}{R_3}+\frac{1}{R_4}=\frac{1}{500\cdot 10^{-3}}+\frac{1}{700\cdot 10^{-3}}+\frac{1}{200\cdot 10^{-3}}=8.43\ \Omega^{-1}$$

$$\frac{1}{R_5}+\frac{1}{R_2}+\frac{1}{R_3}=\frac{1}{333\cdot 10^{-3}}+\frac{1}{167\cdot 10^{-3}}+\frac{1}{700\cdot 10^{-3}}=10.42\ \Omega^{-1}$$

$$\frac{1}{R_3}=\frac{1}{700\cdot 10^{-3}}=1.43\ \Omega^{-1}$$

$$\frac{V_{S1}}{R_4}=\frac{110}{200\cdot 10^{-3}}=550 \text{ A} \qquad \frac{V_{S2}}{R_5}=\frac{110}{333\cdot 10^{-3}}=330 \text{ A}$$

$$V_{R1}=\frac{\begin{vmatrix} 550 & -1.43 \\ -330 & 10.42 \end{vmatrix}}{\begin{vmatrix} 8.43 & -1.43 \\ -1.43 & 10.42 \end{vmatrix}}=\frac{(5731)-(472)}{(87.84)-(2.04)}=61.30 \text{ V}$$

$$V_{R1}=\frac{\begin{vmatrix} 8.429 & 550 \\ -1.429 & -330 \end{vmatrix}}{85.790}=\frac{(-2782)-(-786)}{85.80}=-23.26 \text{ V}$$

$$KVL: \quad -V_{R1}+V_{R3}+V_{R2}=0 \qquad V_{R3}=V_{R1}-V_{R2}=84.59 \text{ V}$$

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Problem 3.23

Solution:

Known quantities:

Circuit shown in Figure P3.23

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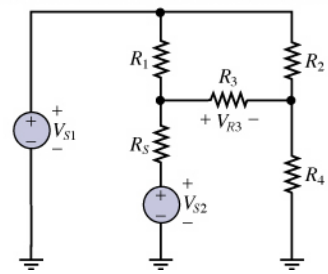

$V_{S2} = \text{kT} \quad \text{k} = 10 \text{ V/°C}$

$V_{S1} = 24 \text{ V} \quad R_S = R_1 = 12 \text{ k}\Omega$

$R_2 = 3 \text{ k}\Omega \quad R_3 = 10 \text{ k}\Omega$

$R_4 = 24 \text{ k}\Omega \quad V_{R3} = -2.524 \text{ V}$

The voltage across R_3, which is given, indicates the temperature.

Find:

The temperature, T.

Analysis:

Specify nodes (A between R_1 and R_3, C between R_3 and R_2) and polarities of voltages (V_A from ground to A, Vc from ground to C, and V_{R3} from C to A). When using KCL, assume unknown currents flow out.

$$KVL: \quad -V_A + V_{R3} + V_C = 0$$
$$V_C = V_A - V_{R3}$$

Now write KCL at node C, substitute for V_C, solve for V_A:

$$KCL: \quad \frac{V_C - V_{S1}}{R_2} + \frac{V_C - V_A}{R_3} + \frac{V_C}{R_4} = 0$$

$$-\frac{V_A}{R_3} - \frac{V_{S1}}{R_2} + (V_A - V_{R3})\left(\frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4}\right) = 0$$

$$V_A = \frac{\frac{V_{S1}}{R_2} + V_{R3}\left(\frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4}\right)}{\frac{1}{R_2} + \frac{1}{R_4}} = \frac{\frac{24}{3 \cdot 10^3} + (-2.524)\left(\frac{1}{3 \cdot 10^3} + \frac{1}{10 \cdot 10^3} + \frac{1}{24 \cdot 10^3}\right)}{\frac{1}{3 \cdot 10^3} + \frac{1}{24 \cdot 10^3}} = 18.14 \text{ V}$$

$$V_C = V_A - V_{R3} = 18.14 - (-2.524) = 20.66 \text{ V}$$

Now write KCL at node A and solve for V_{S2} and T:

$$KCL: \quad \frac{V_A - V_{S1}}{R_1} + \frac{V_A - V_{S2}}{R_S} + \frac{V_A - V_C}{R_3} = 0$$

$$V_{S2} = V_A + \frac{R_S}{R_1}(V_A - V_{S1}) + \frac{R_S}{R_3}(V_A - V_C) =$$

$$= 18.14 + \frac{12 \cdot 10^3}{12 \cdot 10^3}(18.14 - 24) + \frac{12 \cdot 10^3}{10 \cdot 10^3}(18.14 - 20.66) = 9.26 \text{ V}$$

$$\text{T} = \frac{V_{S2}}{\text{k}} = \frac{9.26}{10} = 0.926 \text{ °C}$$

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Problem 3.24

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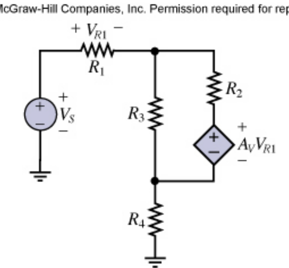

Solution:

Known quantities:

Circuit shown in Figure P3.24

$V_S = 5$ V $\quad A_V = 70 \quad R_1 = 2.2$ kΩ

$R_2 = 1.8$ kΩ $\quad R_3 = 6.8$ kΩ $\quad R_4 = 220$ Ω

Find:

The voltage across R_4 using KCL and node voltage analysis.

Analysis:

Node analysis is not a method of choice because the dependent source is [1] a voltage source and [2] a floating source. Both factors cause difficulties in a node analysis. A ground is specified. There are three unknown node voltages, one of which is the voltage across R_4. The dependent source will introduce two additional unknowns, the current through the source and the controlling voltage (across R_1) that is not a node voltage. Therefore 5 equations are required:

$$[1] KCL \frac{V_1 - V_S}{R_1} + \frac{V_1 - V_3}{R_3} + \frac{V_1 - V_2}{R_2} = 0 [2] KCL \frac{V_2 - V_1}{R_2} - I_{CS} = 0$$

$$[3] KCL \frac{V_3 - V_1}{R_3} + I_{CS} + \frac{V_3}{R_4} = 0 [4] KVL - V_S + V_{R1} + V_1 = 0 V_{R1} = V_S - V_1$$

$$[5] KVL - V_3 - A_V V_{R1} + V_2 = 0 V_2 = V_3 + A_V V_{R1} = V_3 + A_V (V_S - V_1)$$

Substitute using Equation [5] into Equations [1], [2] and [3] and eliminate V_2 (because it only appears twice in these equations). Collect terms:

$$V_1\left(\frac{1}{R_1} + \frac{1}{R_3} + \frac{1}{R_2} + \frac{A_V}{R_2}\right) + V_3\left(-\frac{1}{R_3} - \frac{1}{R_2}\right) + I_{CS}(0) = \frac{V_S}{R_1} + \frac{V_S A_V}{R_2}$$

$$V_1\left(-\frac{1}{R_2} - \frac{A_V}{R_2}\right) + V_3\left(\frac{1}{R_2}\right) + I_{CS}(-1) = -\frac{V_S A_V}{R_2}$$

$$V_1\left(-\frac{1}{R_3}\right) + V_3\left(\frac{1}{R_3} + \frac{1}{R_4}\right) + I_{CS}(+1) = 0$$

$$\frac{1}{R_2} = \frac{1}{1.8 \cdot 10^3} = 555.6 \cdot 10^{-6}\ \Omega^{-1} \qquad \frac{1}{R_3} = \frac{1}{6.8 \cdot 10^3} = 147.1 \cdot 10^{-6}\ \Omega^{-1}$$

$$\frac{1}{R_3} + \frac{1}{R_2} = \frac{1}{6.8 \cdot 10^3} + \frac{1}{1.8 \cdot 10^3} = 702.6 \cdot 10^{-6}\ \Omega^{-1}$$

$$\frac{1}{R_3} + \frac{1}{R_4} = \frac{1}{6.8 \cdot 10^3} + \frac{1}{0.22 \cdot 10^3} = 4.69 \cdot 10^{-3}\ \Omega^{-1} \qquad \frac{1}{R_2} + \frac{A_V}{R_2} = \frac{1+70}{1.8 \cdot 10^3} = 39.44 \cdot 10^{-3}\ \Omega^{-1}$$

$$\frac{1}{R_1} + \frac{1}{R_3} + \frac{1}{R_2} + \frac{A_V}{R_2} = \frac{1}{2.2 \cdot 10^3} + \frac{1}{6.8 \cdot 10^3} + \frac{1+70}{1.8 \cdot 10^3} = 40.05 \cdot 10^{-3}\ \Omega^{-1}$$

$$\frac{V_S A_V}{R_2} = \frac{(5)(70)}{1.8 \cdot 10^3} = 194.4 \text{ mA} \qquad \frac{V_S}{R_1} + \frac{V_S A_V}{R_2} = \frac{5}{2.2 \cdot 10^3} + \frac{(5)(70)}{1.8 \cdot 10^3} = 196.7 \text{ mA}$$

Solving, we have: $\quad V_{R4} = V_3 = 5.1$ mV

Notes:

1. This solution was not difficult in terms of theory, but was terribly long and arithmetically cumbersome. This was because the wrong method was used. There are only 2 mesh currents in the circuit; the sources were voltage sources; therefore, a mesh analysis is the method of choice.
2. In general, a node analysis will have fewer unknowns (because one node is the ground or reference node) and will, in such cases, be preferable.

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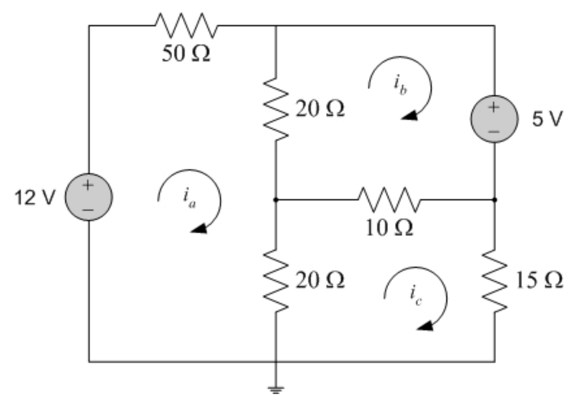
Problem 3.25

Solution:

Known quantities:
The values of the resistors and of the voltage sources (see Figure P3.25).

Find:
The voltage across the $10\ \Omega$ resistor in the circuit of Figure P3.25 using mesh current analysis.



Analysis:

For mesh (a):

$$i_a(50+20+20)-i_b(20)-i_c(20)=12$$

For mesh (b):

$$-i_a(20)+i_b(20+10)-i_c(10)+5=0$$

For mesh (c):

$$-i_a(20)-i_b(10)+i_c(20+10+15)=0$$

Solving,

$i_a = 127.5$ mA

$i_b = -67.8$ mA

$i_c = 41.6$ mA

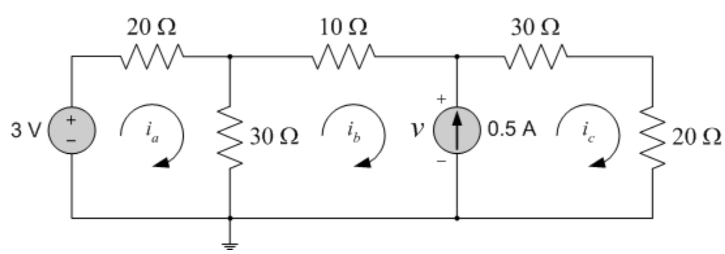
and $v_{R_4} = 10\ (i_b - i_c) = 10\ (-0.109) = -1.09$ V.

Problem 3.26

Solution:

Known quantities:
The values of the resistors, of the voltage source and of the current source in the circuit of Figure P3.26.

Find:
The voltage across the current source using mesh current analysis.



Analysis:
For mesh (a):

$$i_a(20+30)+i_b(-30)=3$$

For meshes (b) and (c):

$$i_a(-30)+i_b(10+30)+i_c(30+20)=0$$

For the current source: $i_c - i_b = 0.5$

Solving, $i_a = -133$ mA, $i_b = -322$ mA and $i_c = 178$ mA.

Therefore, $v = i_c(30+20) = 8.89$ V.

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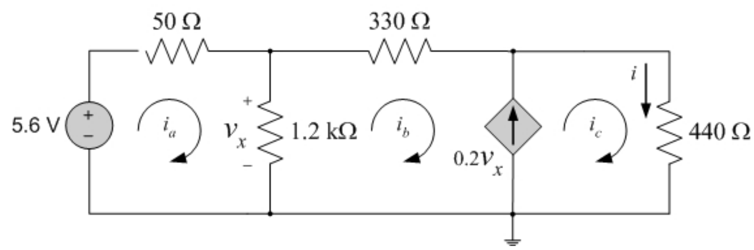
Problem 3.27

Solution:

Known quantities:
The values of the resistors and of the voltage source in the circuit of Figure P3.27.



Find:
The current i through the resistance R_4 mesh current analysis.

Analysis:
For mesh (a):

$$i_a(50+1200)+i_b(-1200)=5.6$$

For meshes (b) and (c):

$$i_a(-1200)+i_b(1200+330)+i_c(440)=0$$

For the current source:

$$i_c-i_b=0.2v_x=0.2\left(1200\left(i_a-i_b\right)\right)=240\left(i_a-i_b\right)$$

Solving,

$i_a=136$ mA, $i_b=137$ mA and $i_c=-106$ mA.

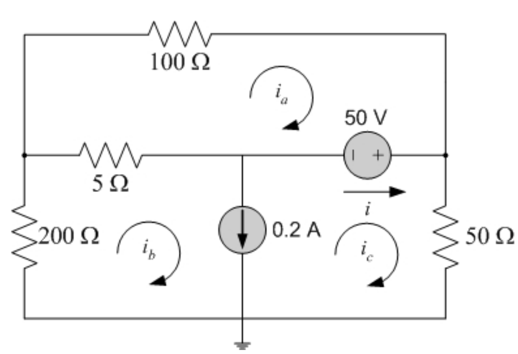
Therefore,
$i=i_c=-106$ mA.

Problem 3.28

Solution:

Known quantities:
The values of the resistors, of the voltage source and of the current source in the circuit of Figure P3.9.

Find:
The current through the voltage source using mesh current analysis.



Analysis:
For mesh (a):

$$i_a(100+5)+i_b(-5)+50=0$$

For the current source:

$$i_b-i_c=0.2$$

For meshes (b) and (c):

$$-i_a(5)+i_b(200+5)+i_c(50)=50$$

Solving, $i_a=-465$ mA, $i_b=226$ mA and $i_c=26$ mA.

Therefore,

$i=i_c-i_a=491$ mA.

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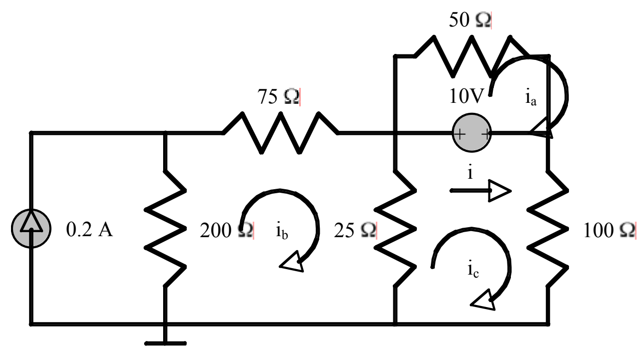
Problem 3.29

Solution:

Known quantities:
The values of the resistors and of the current source in the circuit of Figure P3.10.

Find:
The current through the voltage source in the circuit of Figure P3.10 using mesh current analysis.

Analysis:



For mesh (a):

$$i_a(100)+10=0$$

For mesh (b):

$$i_b(200+75+25)+i_c(-25)+0.2\,(-200)=0$$

For mesh (c):

$$i_b(-25)+i_c(50+25)=10$$

Solving,

$i_a=-100$ mA, $i_b=148$ mA and $i_c=183$ mA.

Therefore,

$$i=i_c-i_a=283\text{ mA}$$

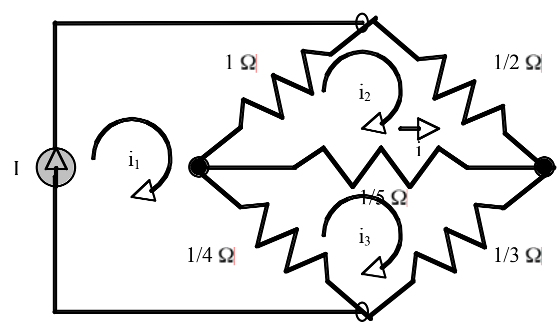
Problem 3.30

Solution:

Known quantities:
The values of the resistors in the circuit of Figure P3.30.

Find:
The current in the circuit of Figure P3.30 using mesh current analysis.

Analysis:



Since I is unknown, the problem will be solved in terms of this current.

For mesh #1, it is obvious that: $i_1=I$

For mesh #2: $i_1(-1)+i_2\left(1+\frac{1}{2}+\frac{1}{5}\right)+i_3\left(-\frac{1}{5}\right)=0$

For mesh #3: $i_1\left(-\frac{1}{4}\right)+i_2\left(-\frac{1}{5}\right)+i_3\left(\frac{1}{4}+\frac{1}{3}+\frac{1}{5}\right)=0$

Solving, $i_2=0.645I$, $i_3=0.483I$

Then, $i=i_3-i_2$ and $i=0.483I-0.645I=-0.163I$

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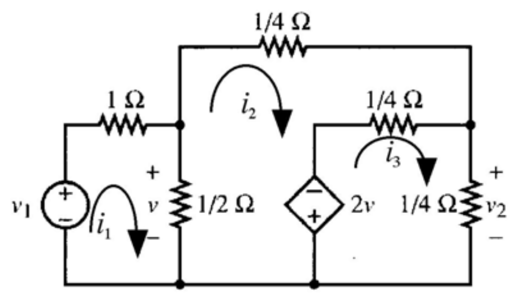
Problem 3.31

Solution:

Known quantities:
The values of the resistors of the circuit in Figure P3.31.

Find:
The voltage gain, $A_V = \frac{v_2}{v_1}$, in the circuit of Figure P3.31 using mesh current analysis.

Analysis:
Note that $v = \frac{i_1 - i_2}{2}$



For mesh #1:

$$i_1\left(1+\frac{1}{2}\right)+i_2\left(-\frac{1}{2}\right)+i_3(0)=v_1$$

For mesh #2:

$$i_1\left(-\frac{1}{2}\right)+i_2\left(\frac{1}{2}+\frac{1}{4}+\frac{1}{4}\right)+i_3\left(-\frac{1}{4}\right)=2v$$

or

$$i_1(-1.5)+i_2(2)+i_3(-0.25)=0$$

For mesh #3:

$$i_1(0)+i_2\left(-\frac{1}{4}\right)+i_3\left(\frac{1}{4}+\frac{1}{4}\right)=-2v$$

or

$$i_1(1)+i_2(-1.25)+i_3(0.5)=0$$

Solving, $\quad i_3 = -0.16 v_1$

from which $\quad v_2 = \frac{1}{4} i_3 = -0.04 v_1$

and $\quad A_V = \frac{v_2}{v_1} = -0.04$

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Problem 3.32

Solution:

Known quantities:

Circuit in Figure P3.21 and the values of the voltage sources, $V_{S1} = V_{S2} = 450$ V, and the values of the 5 resistors:

$R_1 = 8\ \Omega \qquad R_2 = 5\ \Omega$

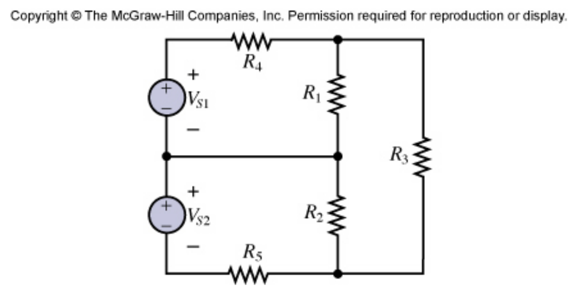
$R_4 = R_5 = 0.25\ \Omega \qquad R_3 = 32\ \Omega$

Find:

The voltages across R_1, R_2 and R_3 using KCL and node analysis.

Analysis:

Choose a ground/reference node. The node common to the two voltage sources is the best choice. Specify polarity of voltages and direction of the currents.



$$KCL: \quad \frac{V_{R1}-V_{S1}}{R_4}+\frac{V_{R1}-0}{R_1}+\frac{V_{R1}-V_{R2}}{R_3}=0$$

$$KCL: \quad \frac{V_{R2}-(-V_{S2})}{R_5}+\frac{V_{R2}-0}{R_2}+\frac{V_{R2}-V_{R1}}{R_3}=0$$

Collect terms in terms of the unknown node voltages:

$$V_{R1}\left(\frac{1}{R_4}+\frac{1}{R_1}+\frac{1}{R_3}\right)+V_{R2}\left(-\frac{1}{R_3}\right)=\frac{V_{S1}}{R_4}$$

$$V_{R1}\left(-\frac{1}{R_3}\right)+V_{R2}\left(\frac{1}{R_5}+\frac{1}{R_2}+\frac{1}{R_3}\right)=-\frac{V_{S2}}{R_5}$$

Evaluate the coefficients of the unknown node voltages:

$$\frac{V_{S1}}{R_4}=\frac{V_{S2}}{R_5}=\frac{450}{0.25}=1.8\ \text{kA} \qquad \frac{1}{R_3}=\frac{1}{32}=0.03125\ \Omega^{-1}$$

$$\frac{1}{R_1}+\frac{1}{R_4}+\frac{1}{R_3}=\frac{1}{0.25}+\frac{1}{8}+\frac{1}{32}=4.14\,\Omega^{-1}$$

$$\frac{1}{R_5}+\frac{1}{R_2}+\frac{1}{R_3}=\frac{1}{0.25}+\frac{1}{5}+\frac{1}{32}=4.23\Omega^{-1}$$

$$V_{R1}=\frac{\begin{vmatrix}1800 & -31.25\cdot 10^{-3}\\ -1800 & 4.23\end{vmatrix}}{\begin{vmatrix}4.16 & -31.25\cdot 10^{-3}\\ -31.25\cdot 10^{-3} & 4.23\end{vmatrix}}=429.5\ \text{V}$$

$$V_{R2}=\frac{\begin{vmatrix}4.156 & 1800\\ -31.25\cdot 10^{-3} & -1800\end{vmatrix}}{17.59}=-422.2\ \text{V}$$

$$KVL: \quad -V_{R1}+V_{R3}+V_{R2}=0$$

$$V_{R3}=V_{R1}-V_{R2}=852.0\ \text{V}$$

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Problem 3.33

Solution:

Known quantities:

Circuit in Figure P3.33 with the values of the voltage sources, $V_{S1} = V_{S2} = 115 \text{ V}$, and the values of the 5 resistors:

$R_1 = R_2 = 5\ \Omega \qquad R_3 = 10\ \Omega$

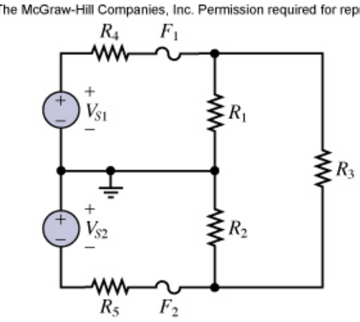
$R_4 = R_5 = 200\ \text{m}\Omega$

Find:

The new voltages across R_1, R_2 and R_3, in case F_1 "blows" or opens using KCL and node analysis.

Analysis:

Specify polarity of voltages. The ground is already specified. The current through the fuse F_1 is zero.



$$KCL: \quad 0 + \frac{V_{R1} - 0}{R_1} + \frac{V_{R1} - V_{R2}}{R_3} = 0$$

$$KCL: \quad \frac{V_{R2} - (-V_{S2})}{R_5} + \frac{V_{R2} - 0}{R_2} + \frac{V_{R2} - V_{R1}}{R_3} = 0$$

Collect terms in unknown node voltages:

$$V_{R1}\left(\frac{1}{R_1} + \frac{1}{R_3}\right) + V_{R2}\left(-\frac{1}{R_3}\right) = 0$$

$$V_{R1}\left(-\frac{1}{R_3}\right) + V_{R2}\left(\frac{1}{R_5} + \frac{1}{R_2} + \frac{1}{R_3}\right) = -\frac{V_{S2}}{R_5}$$

$$\frac{1}{R_3} = \frac{1}{10} = 0.1\ \Omega^{-1} \qquad \frac{1}{R_1} + \frac{1}{R_3} = 0.3\ \Omega^{-1}$$

$$\frac{V_{S2}}{R_5} = \frac{115}{200 \cdot 10^{-3}} = 575 \text{ A} \qquad \frac{1}{R_5} + \frac{1}{R_2} + \frac{1}{R_3} = 5.3\ \Omega^{-1}$$

$$V_{R1} = \frac{\begin{vmatrix} 0 & -0.1 \\ -575 & 5.3 \end{vmatrix}}{\begin{vmatrix} 0.3 & -0.1 \\ -0.1 & 5.3 \end{vmatrix}} = \frac{(0) - (57.5)}{(1.59) - (0.01)} = -36.39 \text{ V}$$

$$V_{R2} = \frac{\begin{vmatrix} 0.3 & 0 \\ -\,-0.1 & -575 \end{vmatrix}}{1.58} = \frac{(-172.5) - (0)}{1.58} = -109.2 \text{ V}$$

$$KVL: \quad \begin{aligned} &-V_{R1} + V_{R3} + V_{R2} = 0 \\ &V_{R3} = V_{R1} - V_{R2} = 72.81 \text{ V} \end{aligned}$$

$$KVL: \quad \begin{aligned} &-V_{S1} + V_{R4} + V_F + V_{R1} = 0 \qquad V_{R4} = I_1 R_4 = 0 \\ &V_F = 115 - 0 - (-36.39) = 151.4 \text{ V} \end{aligned}$$

Note the voltages are strongly dependent on the loads (R_1, R_2 and R_3) connected at the time the fuse blows. With other loads, the result will be quite different.

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Problem 3.34

Solution:

Known quantities:

Circuit in Figure P3.33 and the values of the voltage sources, $V_{S1} = V_{S2} = 120 \text{ V}$, and the values of the 5 resistors:

$R_1 = R_2 = 2\ \Omega \qquad R_3 = 8\ \Omega$

$R_4 = R_5 = 250\ \text{m}\Omega$

Find:

The voltages across R_1, R_2, R_3, and F_1 in case F_1 "blows" or opens using KCL and node analysis.

Analysis:

Specify polarity of voltages. The ground is already specified. The current through the fuse F_1 is zero.

$$KCL: \quad 0 + \frac{V_{R1} - 0}{R_1} + \frac{V_{R1} - V_{R2}}{R_3} = 0$$

$$KCL: \quad \frac{V_{R2} - (-V_{S2})}{R_5} + \frac{V_{R2} - 0}{R_2} + \frac{V_{R2} - V_{R1}}{R_3} = 0$$

$$V_{R1}\left(\frac{1}{R_1} + \frac{1}{R_3}\right) + V_{R2}\left(-\frac{1}{R_3}\right) = 0$$

$$V_{R1}\left(-\frac{1}{R_3}\right) + V_{R2}\left(\frac{1}{R_5} + \frac{1}{R_2} + \frac{1}{R_3}\right) = -\frac{V_{S2}}{R_5}$$

$$\frac{1}{R_3} = \frac{1}{8} = 0.125\ \Omega^{-1} \qquad \frac{1}{R_1} + \frac{1}{R_3} = 0.625\ \Omega^{-1}$$

$$\frac{V_{S2}}{R_5} = \frac{120}{250 \cdot 10^{-3}} = 480 \text{ A} \qquad \frac{1}{R_5} + \frac{1}{R_2} + \frac{1}{R_3} = 4.625\ \Omega^{-1}$$

$$V_{R1} = \frac{\begin{vmatrix} 0 & -0.125 \\ -480 & 4.625 \end{vmatrix}}{\begin{vmatrix} 0.625 & -0.125 \\ -0.125 & 4.625 \end{vmatrix}} = \frac{(0) - (60)}{(2.89) - (0.016)} = -20.87 \text{ V}$$

$$V_{R2} = \frac{\begin{vmatrix} 0.625 & 0 \\ -0.125 & -480 \end{vmatrix}}{2.87} = \frac{(-300) - (0)}{2.87} = -104.35 \text{ V}$$

$$KVL: \quad \begin{aligned} &-V_{R1} + V_{R3} + V_{R2} = 0 \\ &V_{R3} = V_{R1} - V_{R2} = 83.48 \text{ V} \end{aligned}$$

$$KVL: \quad \begin{aligned} &-V_{S1} + V_{R4} + V_F + V_{R1} = 0 \qquad V_{R4} = I_1 R_4 = 0 \\ &V_F = 120 - 0 - (-20.87) = 140.9 \text{ V} \end{aligned}$$

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Problem 3.35

Solution:

Known quantities:

The values of the voltage sources, $V_{S1} = V_{S2} = V_{S3} = 170\text{ V}$, and the values of the 6 resistors in the circuit of Figure P3.35:

$R_{W1} = R_{W2} = R_{W3} = 0.7\ \Omega$

$R_1 = 1.9\,\Omega \qquad R_2 = 2.3\ \Omega \qquad R_3 = 11\ \Omega$

Find:

a. The number of unknown node voltages and mesh currents.
b. Unknown node voltages.

Analysis:

a) If the node common to the three sources is chosen as the ground/reference node, and the series resistances are combined into single equivalent resistances, there is only one unknown node voltage. On the other hand, there are two unknown mesh currents.
b) A node analysis is the method of choice! Specify polarity of voltages and direction of currents.

$R_{eq1} = R_{W1} + R_1 = 2.6\ \Omega \qquad R_{eq2} = R_{W2} + R_2 = 3.0\ \Omega$

$R_{eq3} = R_{W3} + R_3 = 11.7\ \Omega$

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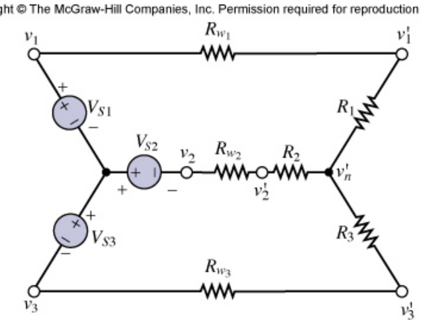

KCL:

$$\frac{v_N - V_{S1}}{R_{eq1}} + \frac{v_N - (-V_{S2})}{R_{eq2}} + \frac{v_N - (-V_{S3})}{R_{eq3}} = 0$$

$$v_N = \frac{\frac{V_{S1}}{R_{eq1}} - \frac{V_{S2}}{R_{eq2}} - \frac{V_{S3}}{R_{eq3}}}{\frac{1}{R_{eq1}} + \frac{1}{R_{eq2}} + \frac{1}{R_{eq3}}} = \frac{\frac{170}{2.6} - \frac{170}{3.0} - \frac{170}{11.7}}{\frac{1}{2.6} + \frac{1}{3.0} + \frac{1}{11.7}} = \text{-7.234 V}$$

KVL:

$$-V_{S1} + I_1 R_{W1} + I_1 R_1 + v_N = 0$$

$$I_1 = \frac{V_{S1} - V_N}{R_{W1} + R_1} = \frac{170 - (-7.234)}{2.6} = 68.167\text{ A}$$

Problem 3.36

Solution:

Known quantities:

The values of the voltage sources, $V_{S1} = V_{S2} = V_{S3} = 170\text{ V}$, the common node voltage, $V_N = 28.94\text{ V}$,and the values of the 6 resistors in the circuit of Figure P3.35:

$R_{W1} = R_{W2} = R_{W3} = 0.7\ \Omega$

$R_1 = 1.9\ \Omega \qquad R_2 = 2.3\ \Omega \qquad R_3 = 11\ \Omega$

Find:

The current through and voltage across R_1.

Analysis:

KVL: $\quad -V_{S1} + I_1 R_{W1} + I_1 R_1 + V_N = 0 \qquad I_1 = \dfrac{V_{S1} - V_N}{R_{W1} + R_1} = \dfrac{170 - 28.94}{2.6} = 54.26\text{A}$

OL: $\quad V_{R1} = I_1 R_1 = (54.26)(1.9) = 103.1\text{ V}$

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Problem 3.37

Solution:

Known quantities:
The values of the voltage sources, $V_{S1} = V_{S2} = V_{S3} = 170\ \text{V}$, and the values of the 6 resistors in the circuit of Figure P3.35:

$R_{W1} = R_{W2} = R_{W3} = 0.7\ \Omega$

$R_1 = 1.9\ \Omega \qquad R_2 = 2.3\ \Omega \qquad R_3 = 11\ \Omega$

Find:
The mesh (or loop) equations and any additional equation required to determine the current through R_1 in the circuit shown in Figure P3.24.

Analysis:
KVL: $\quad -V_{S1} + I_1 R_{W1} + I_1 R_1 + (I_1 - I_2)R_2 + (I_1 - I_2)R_{W2} - V_{S2} = 0$

KVL: $\quad V_{S2} + (I_2 - I_1)R_{W2} + (I_2 - I_1)R_2 + I_2 R_3 + I_2 R_{W3} + V_{S3} = 0$

$$I_1(R_1 + R_{W1} + R_2 + R_{W2}) + I_2(-R_2 - R_{W2}) = V_{S1} + V_{S2}$$
$$I_1(-R_2 - R_{W2}) + I_2(R_2 + R_{W2} + R_3 + R_{W3}) = -V_{S2} - V_{S3}$$
$$I_{R1} = I_1 = \frac{\begin{vmatrix} (V_{S1} + V_{S2}) & -(R_2 + R_{W2}) \\ -(V_{S2} + V_{S3}) & (R_2 + R_{W2} + R_3 + R_{W3}) \end{vmatrix}}{\begin{vmatrix} (R_1 + R_{W1} + R_2 + R_{W2}) & -(R_2 + R_{W2}) \\ -(R_2 + R_{W2}) & (R_2 + R_{W2} + R_3 + R_{W3}) \end{vmatrix}}$$

Problem 3.38

Solution:

Known quantities:
The values of the voltage sources, $V_{S1} = 90\ \text{V}$, $\quad V_{S2} = V_{S3} = 110\ \text{V}$, and the values of the 6 resistors in the circuit of Figure P3.35:

$R_{W1} = R_{W2} = R_{W3} = 1.3\ \Omega$

$R_1 = 7.9\ \Omega \qquad R_2 = R_3 = 3.7\ \Omega$

Find:
The branch currents, using KVL and loop analysis.

Analysis:
Three equations are required. Voltages will be summed around the 2 loops that are meshes, and KCL at the common node between the resistances. Assume directions of the branch currents and the associated polarities of the voltages. After like terms are collected:

KVL: $\quad -V_{S1} + I_1 R_{W1} + I_1 R_1 + (I_1 - I_2)R_2 + (I_1 - I_2)R_{W2} - V_{S2} = 0$

KVL: $\quad V_{S2} + (I_2 - I_1)R_{W2} + (I_2 - I_1)R_2 + I_2 R_3 + I_2 R_{W3} + V_{S3} = 0$

KCL: $\quad I_3 = I_1 + I_2$

Plugging in the given parameters results in the following system of equations:

$14.2 I_1 - 5.0 I_2 = 200$

$9.2 I_1 - 10.0 I_2 = 220$

$I_3 = I_1 + I_2$

Solving the system of equations gives: $\quad I_1 = 9.375\text{A} \qquad I_2 = -13.375\text{A} \qquad I_3 = -4.000\text{A}$

Hence, the assumed polarity of the second and third branch currents is actually reversed.

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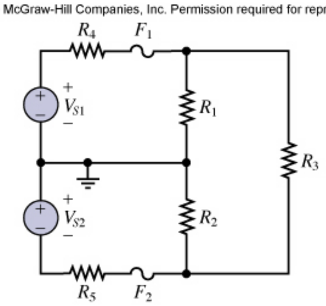
Problem 3.39



Solution:

Known quantities:

The of Figure P3.33.The value of $V_{S1}, V_{S2}, R_1, R_2, R_3, R_4, R_5$.

Find:

Using KVL and mesh analyze the voltage across R_1, R_2, R_3 under normal conditions.

Analysis:

a) KVL:

At node 1: $\dfrac{V_{S1}-V_1}{R_4} = \dfrac{V_1-V_2}{R_1} + \dfrac{V_1-V_3}{R_3}$ (1)

At node 2: $V_2 = 0$ (2)

At node 3: $\dfrac{V_3+V_{S2}}{R_5} = \dfrac{-V_3}{R_2} + \dfrac{V_1-V_3}{R_3}$ (3)

Combine (1), (2), (3), we have $V_1 = 106.5$ V, $V_2 = 0$ V, $V_3 = -106.5$ V

So the voltage across R_3 is 106.5-(-106.5) = 213 V.

b)Mesh:

Mesh 1(left up): $V_{S1} - R_4 i_1 - R_1(i_1 - i_3) = 0$ (1)

Mesh 2(left down): $V_{S2} - R_2(i_2 - i_3) - R_5 i_2 = 0$ (2)

Mesh 3(right): $-R_3 i_3 - R_2(i_3 - i_2) - R_1(i_3 - i_1) = 0$ (3)

Combine (1), (2), (3),

We have: $i_1 = 42.6$ A, $i_2 = 42.6$ A, $i_3 = 21.3$ A ,

So the voltage across R_1 is $0 + (i_1 - i_3)\cdot R_1 = 106.5$ V

the voltage across R_2 is $0 - (i_2 - i_3)\cdot R_2 = -106.5$ V

the voltage across R_3 is $i_3 \cdot R_3 = 213$ V

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Section 3.5: Superposition

Problem 3.40

Solution:

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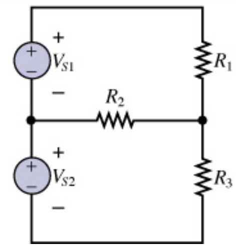


Known quantities:

The values of the voltage sources, $V_{S1} = 110\text{ V}$, $V_{S2} = 90\text{ V}$ and the values of the 3 resistors in the circuit of Figure P3.40:

$R_1 = 560\ \Omega$ $\quad R_2 = 3.5\ k\Omega$ $\quad R_3 = 810\ \Omega$

Find:

The current through R_1 due only to the source V_{S2}.

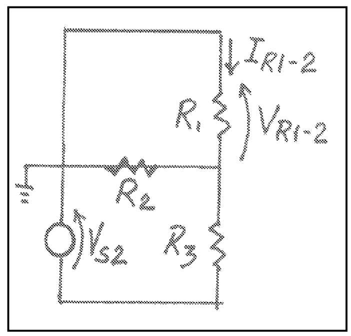
Analysis:

Suppress V_{S1}. Redraw the circuit. Specify polarity of V_{R1}. Choose ground.

$$KCL: \quad \frac{-V_{R1-2} - 0}{R_1} + \frac{-V_{R1-2} - 0}{R_2} + \frac{-V_{R1-2} - (-V_{S2})}{R_3} = 0$$

$$V_{R1-2} = \frac{\frac{V_{S2}}{R_3}}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}} = \frac{\frac{90}{810}}{\frac{1}{560} + \frac{1}{3500} + \frac{1}{810}} = 33.61\text{ V}$$

$$OL: \quad I_{R1-2} = \frac{V_{R1-2}}{R_1} = \frac{33.61}{560} = 60.02\text{ mA}$$



Problem 3.41

Solution:

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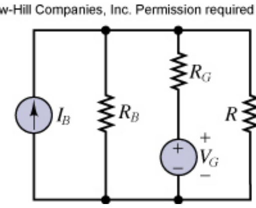

Known quantities:

The values of the current source, of the voltage source and of the resistors in the circuit of Figure P3.41:

$I_B = 12\text{A}$ $R_B = 1\Omega$ $V_G = 12\text{V}$ $R_G = 0.3\Omega$ $R = 0.23\Omega$

Find:

The voltage across R_1 using superposition.

Analysis:

Specify a ground node and the polarity of the voltage across R. Suppress the voltage source by replacing it with a short circuit. Redraw the circuit.

$$KCL: \quad -I_B + \frac{V_{R-I}}{R_B} + \frac{V_{R-I}}{R_G} + \frac{V_{R-I}}{R} = 0 \qquad V_{R-I} = \frac{I_B}{\frac{1}{R_B} + \frac{1}{R_G} + \frac{1}{R}} = \frac{12}{\frac{1}{1} + \frac{1}{0.3} + \frac{1}{0.23}} = 1.38\text{ V}$$

Suppress the current source by replacing it with an open circuit.

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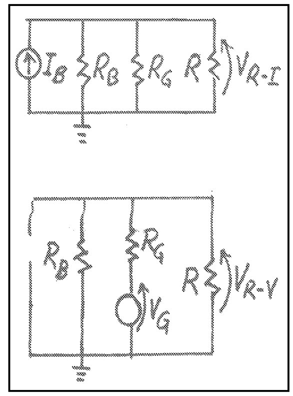
$$KCL: \quad \frac{V_{R-V}}{R_B} + \frac{V_{R-V} - V_G}{R_G} + \frac{V_{R-V}}{R} = 0$$

$$V_{R-V} = \frac{\dfrac{V_G}{R_G}}{\dfrac{1}{R_B} + \dfrac{1}{R_G} + \dfrac{1}{R}} = \frac{\dfrac{12}{0.3}}{\dfrac{1}{1} + \dfrac{1}{0.3} + \dfrac{1}{0.23}} = 4.61\text{V} \qquad V_R = V_{R-I} + V_{R-V} = 5.99\text{V}$$



Note: Superposition essentially doubles the work required to solve this problem. The voltage across R can easily be determined using a single *KCL*.

Problem 3.42

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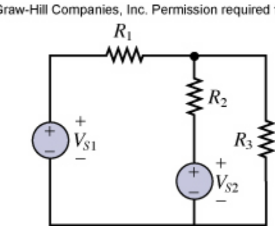


Solution:

Known quantities:

The values of the voltage sources and of the resistors in the circuit of Figure P3.42:

$V_{S1} = V_{S2} = 12$ V

$R_1 = R_2 = R_3 = 1$ kΩ

Find:

The voltage across R_2 using superposition.

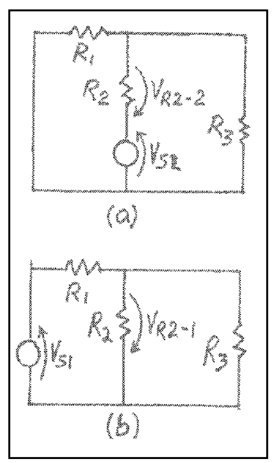
Analysis:

Specify the polarity of the voltage across R_2. Suppress the voltage source V_{S1} by replacing it with a short circuit.

Redraw the circuit.

$$R_{eq} = R_1 \| R_3 = \frac{1}{2} 1 \text{ k}\Omega = 0.5 \text{ k}\Omega$$

$$V_{R2-2} = V_{S2} \frac{R_2}{R_2 + R_{eq}} = \frac{(12)(1000)}{1000 + 500} = 8 \text{ V}$$



Suppress the voltage source V_{S2} by replacing it with a short circuit. Redraw the circuit.

$$R_{eq} = R_2 \| R_3 = \frac{1}{2} 1 \text{ k}\Omega = 0.5 \text{ k}\Omega$$

$$V_{R2-1} = -V_{S1} \frac{R_{eq}}{R_1 + R_{eq}} = \frac{(12 \text{ V})(0.5 \text{ k}\Omega)}{1 \text{ k}\Omega + 0.5 \text{ k}\Omega} = -4 \text{ V}$$

$$V_{R2} = V_{R2-1} + V_{R2-2} = -4 \text{ V} + 8 \text{ V} = 4 \text{ V}$$

Note: Although superposition is necessary to solve some circuits, it is a very inefficient and very cumbersome way to solve a circuit. This method should, if at all possible, be avoided. It must be used when the sources in a circuit are AC sources with different frequencies, or where some sources are DC and others are AC.

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Problem 3.43

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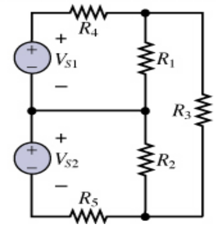

Solution:

Known quantities:

The values of the voltage sources and of the resistors in the circuit of Figure P3.43:

$V_{S1} = V_{S2} = 450$ V

$R_1 = 7\ \Omega \qquad R_2 = 5\Omega \qquad R_3 = 10\Omega \qquad R_4 = R_5 = 1\Omega$

Find:

The component of the current through R_3 that is due to V_{S2}, using superposition.

Analysis:

Suppress V_{S1} by replacing it with a short circuit. Redraw the circuit. A solution using equivalent resistances looks reasonable. R_1 and R_4 are in parallel:

$$R_{14} = \frac{R_1 R_4}{R_1 + R_4} = \frac{(7)(1)}{7+1} = 0.875\Omega$$

R_{14} is in series with R_3:

$$R_{143} = R_{14} + R_3 = 0.875 + 10 = 10.875\ \Omega$$

$$R_{eq} = R_5 + (R_2 \| R_{143}) = R_5 + \frac{R_2 R_{143}}{R_2 + R_{143}} = 1 + \frac{(5)(10.875)}{5+10.875} = 4.425\ \Omega$$

OL: $\quad I_S = \frac{V_{S2}}{R_{eq}} = \frac{450}{4.425} = 101.695\ \text{A}$

CD: $\quad I_{R3-2} = \frac{I_S R_2}{R_2 + R_{143}} = \frac{(101.695)(5)}{5+10.875} = 32.03\ \text{A}$

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Problem 3.44

Solution:

Known quantities:

The values of the voltage sources and of the resistors in the circuit of Figure P3.35:

$V_{S1} = V_{S2} = V_{S3} = 170 \text{ V}$

$R_{W1} = R_{W2} = R_{W3} = 0.7 \ \Omega$

$R_1 = 1.9 \ \Omega \qquad R_2 = 2.3 \ \Omega \qquad R_3 = 11 \ \Omega$

Find:

The current through R_1, using superposition.

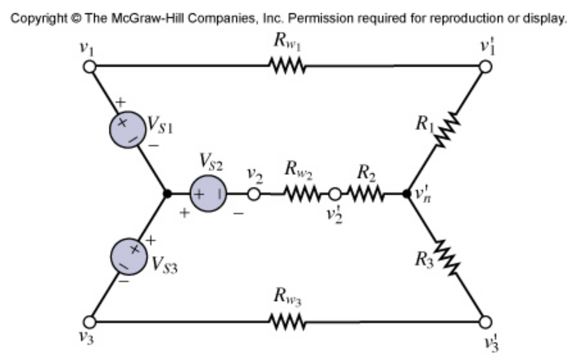
Analysis:

$R_{eq1} = R_{W1} + R_1 = 2.6 \ \Omega \qquad R_{eq2} = R_{W2} + R_2 = 3\Omega \qquad R_{eq3} = R_{W3} + R_3 = 11.7\Omega$

Specify the direction of I_1. Suppress V_{S2} and V_{S3}. Redraw circuit.

$$R_{eq} = R_{eq1} + \frac{R_{eq2}R_{eq3}}{R_{eq2} + R_{eq3}} = 4.99 \ \Omega$$

$$I_{I-1} = \frac{V_{S1}}{R_{eq}} = 34.08 \text{ A}$$



Suppress V_{S1} and V_{S3}. Redraw circuit.

$$KCL: \quad \frac{V_A - (-V_{S2})}{R_{eq2}} + \frac{V_A}{R_{eq1}} + \frac{V_A}{R_{eq3}} = 0$$

$$V_A = -\frac{V_{S2}}{1 + \frac{R_{eq2}}{R_{eq1}} + \frac{R_{eq2}}{R_{eq3}}} = -70.54 \text{ V}$$

$$I_{I-2} = -\frac{V_A}{R_{eq1}} = 27.13 \text{ A}$$

Suppress V_{S1} and V_{S2}. Redraw circuit.

$$KCL: \quad \frac{V_A - (-V_{S3})}{R_{eq3}} + \frac{V_A - 0}{R_{eq1}} + \frac{V_A - 0}{R_{eq2}} = 0$$

$$V_A = -\frac{V_{S3}}{1 + \frac{R_{eq3}}{R_{eq1}} + \frac{R_{eq3}}{R_{eq2}}} = 18.09 \text{ V}$$

$$I_{I-3} = -\frac{V_A}{R_{eq1}} = -6.96 \text{ A}$$

$$I = I_{I-1} + I_{I-2} + I_{I-3} = 54.25 \text{ A}$$

Note: Superposition should be used only for special conditions, as stated in the solution to Problem 3.42. In the problem above a better method is:

a. mesh analysis using *KVL* (2 unknowns)

b. node analysis using *KCL* (1 unknown but current must be obtained using *OL*).

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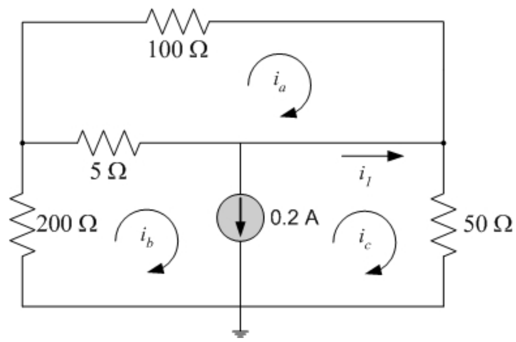
Problem 3.45

Solution:

Known quantities:
The values of the resistors, of the voltage source and of the current source in the circuit of Figure P3.9.

Find:
The current through the voltage source using superpoistion.

Analysis:
(1) Suppress voltage source *V*. Redraw the circuit.



For mesh (a): $i_a(100+5)+i_b(-5)=0$

For the current source: $i_b-i_c=0.2$

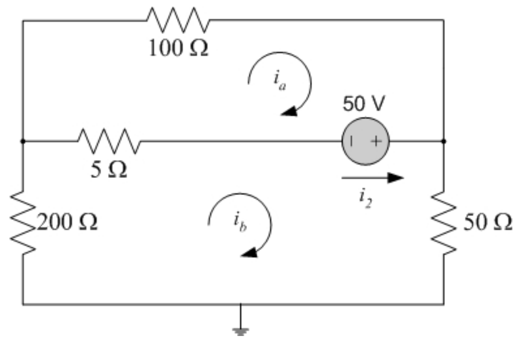
For meshes (b) and (c): $-i_a(5)+i_b(200+5)+i_c(50)=0$

Solving,

$i_a=2\text{ mA}$, $i_b=39\text{ mA}$ and $i_c=-161\text{ mA}$.

Therefore, $i_1=i_c-i_a=-163\text{ mA}$.

(2) Suppress current source *I*. Redraw the circuit.



For mesh (a): $i_a(100+5)+i_b(-5)+50=0$

For mesh (b): $-i_a(5)+i_b(200+5+50)=50$

Solving,

$i_a=-467\text{mA}$ and $i_b=187\text{ mA}$.

Therefore,

$i_2=i_b-i_a=654\text{ mA}$.

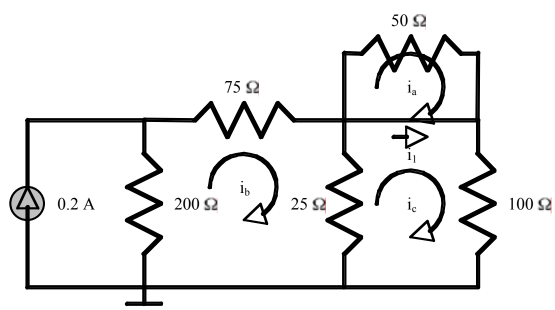
Using the principle of superposition, $i=i_1+i_2=491\text{ mA}$

Problem 3.46

Solution:

Known quantities:
The values of the resistors, of the voltage source and of the current source in the circuit of Figure P3.6.

Find:
The current through the voltage source using superposition.



Analysis:
(1) Suppress voltage source *V*. Redraw the circuit.

For mesh (a): $i_a=0$

For mesh (b): $i_b(200+75+25)+i_c(-25)-40=0$

For mesh (c): $i_b(-25)+i_c(25+100)=0$

Solving,

$i_b=136\text{ mA}$ and $i_c=27\text{ mA}$.

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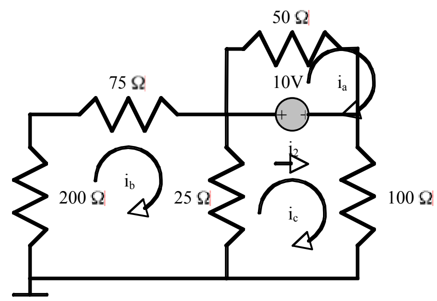
Therefore, $i_1 = i_c = 27 \text{ mA}$.

(2) Suppress current source *I*. Redraw the circuit.

For mesh (a): $i_a(50) - 10 = 0$

For mesh (b): $i_b(200 + 75 + 25) + i_c(-25) = 0$

For mesh (c): $i_b(-25) + i_c(25 + 100) = -10$



Solving,

$i_a = 200 \text{ mA}$, $i_b = -6.8 \text{ mA}$ and $i_c = -81 \text{ mA}$.

Therefore,

$i_2 = i_c - i_a = -281 \text{ mA}$.

Using the principle of superposition, $i = i_1 + i_2 = -254 \text{ mA}$

Problem 3.47

Solution:

Known quantities:

The voltage source value, 3 V, and the five resistance values, indicated in Figure P3.11.

Find:

The current, i, drawn from the independent voltage source using superposition.

Analysis:

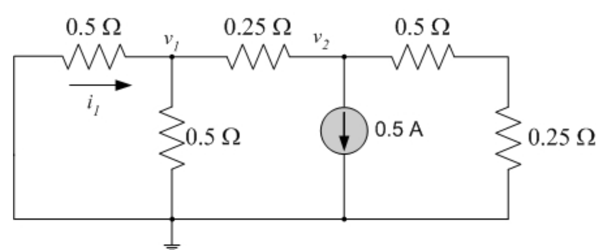
(1) Suppress voltage source *V*. Redraw the circuit.

At node 1:

$$\frac{v_1}{0.5} + \frac{v_1}{0.5} + \frac{v_1 - v_2}{0.25} = 0$$

At node 2:

$$\frac{v_2 - v_1}{0.25} + \frac{v_2}{0.75} + 0.5 = 0$$



Solving the system, we obtain:

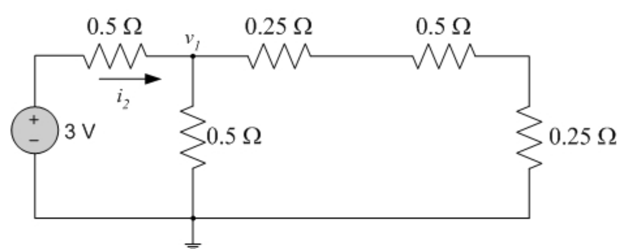
$v_1 = -0.075 \text{ V}$, $v_2 = -0.15 \text{ V}$

Therefore, $i_1 = -\frac{v_1}{0.5} = 150 \text{ mA}$.

(2) Suppress current source *I*. Redraw the circuit.

At node 1:

$$\frac{v_1 - 3}{0.5} + \frac{v_1}{0.5} + \frac{v_1}{(0.25 + 0.5 + 0.25)} = 0$$



Solving,

$v_1 = 1.2 \text{ V}$

Therefore, $i_1 = \frac{3 - v_1}{0.5} = 3.6 \text{ A}$.

Using the principle of superposition,

$i = i_1 + i_2 = 3.75 \text{ A}$

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Problem 3.48

Solution:

Known quantities:

Circuit in Figure P3.23:

$$V_{S2} = \text{kT} \qquad \text{k} = 10 \text{ V/°C}$$
$$V_{S1} = 24 \text{ V} \qquad R_S = R_1 = 12 \text{ k}\Omega$$
$$R_2 = 3 \text{ k}\Omega \qquad R_3 = 10 \text{ k}\Omega$$
$$R_4 = 24 \text{ k}\Omega \qquad V_{R3} = -2.524 \text{ V}.$$

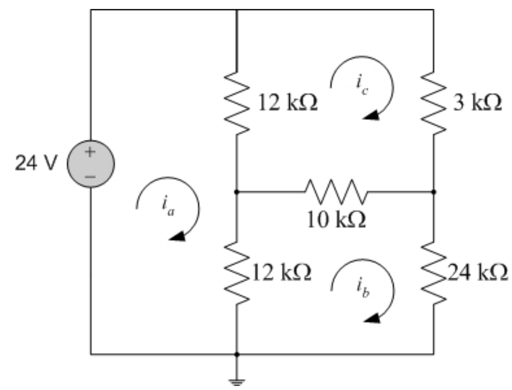
The voltage across R_3, which is given, indicates the temperature.

Find:

The temperature, T using superposition.

Analysis:

(1) Suppress voltage source V_{S2}. Redraw the circuit.



For mesh (a):

$$i_a(24k) + i_b(-12k) + i_c(-12k) = 24$$

For mesh (b):

$$i_a(-12k) + i_b(46k) + i_c(-10k) = 0$$

For mesh (c):

$$i_a(-12k) + i_b(-10k) + i_c(25k) = 0$$

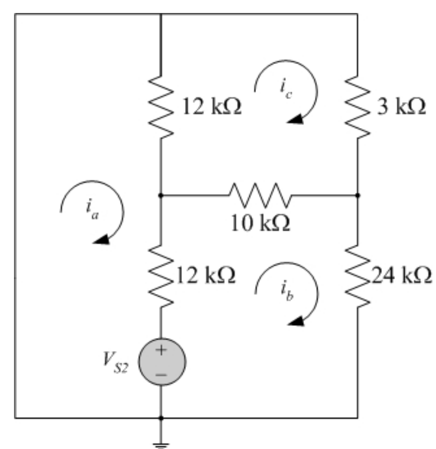
Solving,

$i_a = 2.08 \text{ mA}$, $i_b = 0.83 \text{ mA}$ and $i_c = 1.33 \text{ mA}$.

Therefore,

$$V_{R3,S2} = 10000(i_b - i_c) = -5 \text{ V}.$$

(2) Suppress voltage source V_{S1}. Redraw the circuit.



For mesh (a):

$$i_a(24k) + i_b(-12k) + i_c(-12k) + 10T = 0$$

For mesh (b):

$$i_a(-12k) + i_b(46k) + i_c(-10k) = 10T$$

For mesh (c):

$$i_a(-12k) + i_b(-10k) + i_c(25k) = 0$$

Solving,

$i_a = -0.52T \text{ mA}$, $i_b = 0.029T \text{ mA}$ and $i_c = -0.2381T \text{ mA}$.

Therefore,

$$V_{R3,S1} = 10000(i_b - i_c) = 2.671T \text{ V}.$$

Using the principle of superposition,

$$V_{R3} = V_{R3,S2} + V_{R3,S1} = -5 + 2.671T = -2.524 \text{ V}$$

Therefore,

$$T = 0.926 \text{ °C}.$$

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Problem 3.49

Solution:

Known quantities:

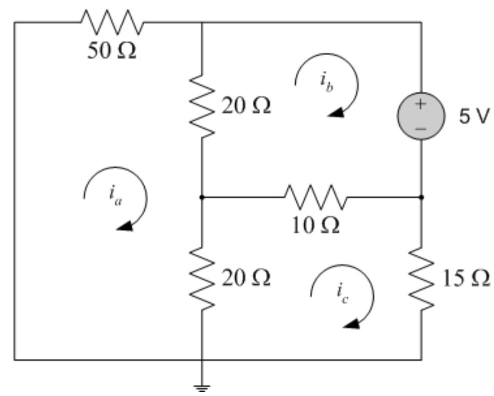
The values of the resistors and of the voltage sources (see Figure P3.25).

Find:

The voltage across the $10\ \Omega$ resistor in the circuit of Figure P3.14 using superposition.

Analysis:

(1) Suppress voltage source V_{S1}. Redraw the circuit.



For mesh (a):

$$i_a(50+20+20)-i_b(20)-i_c(20)=0$$

For mesh (b):

$$-i_a(20)+i_b(20+10)-i_c(10)+5=0$$

For mesh (c):

$$-i_a(20)-i_b(10)+i_c(20+10+15)=0$$

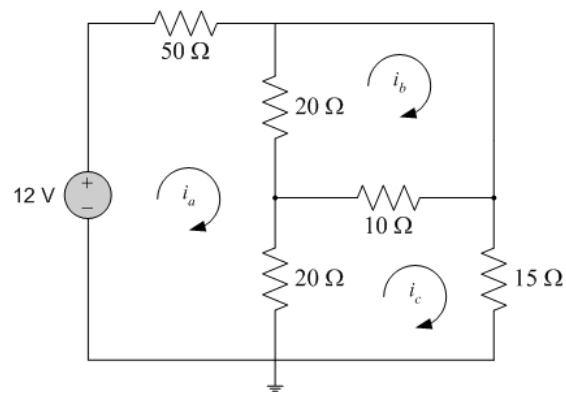
Solving,

$i_a=-73.8\text{ mA}$, $i_b=-245\text{ mA}$ and $i_c=-87.2\text{ mA}$.

Therefore,

$$V_{10\Omega,S1}=10(i_b-i_c)=-1.578\text{ V}.$$

(2) Suppress voltage source V_{S2}. Redraw the circuit.



For mesh (a):

$$i_a(50+20+20)-i_b(20)-i_c(20)=12$$

For mesh (b):

$$-i_a(20)+i_b(20+10)-i_c(10)=0$$

For mesh (c):

$$-i_a(20)-i_b(10)+i_c(20+10+15)=0$$

Solving,

$i_a=201\text{ mA}$, $i_b=177\text{ mA}$ and $i_c=129\text{ mA}$.

Therefore,

$$V_{10\Omega,S1}=10(i_b-i_c)=0.48\text{ V}.$$

Using the principle of superposition,

$$V_{10\Omega}=V_{10\Omega,S2}+V_{10\Omega,S1}=-1.09\text{ V}.$$

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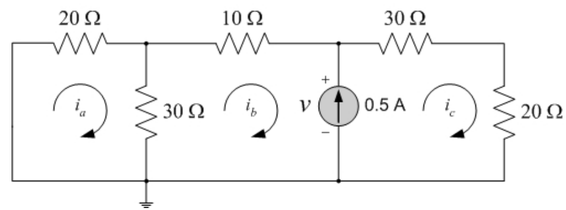
Problem 3.50

Solution:

Known quantities:
The values of the resistors, of the voltage source and of the current source in the circuit of Figure P3.26.

Find:
The voltage across the current source using superposition.

Analysis:
(1) Suppress voltage source. Redraw the circuit.



For mesh (a):

$$i_a(20+30)+i_b(-30)=0$$

For meshes (b) and (c):

$$i_a(-30)+i_b(10+30)+i_c(30+20)=0$$

For the current source:

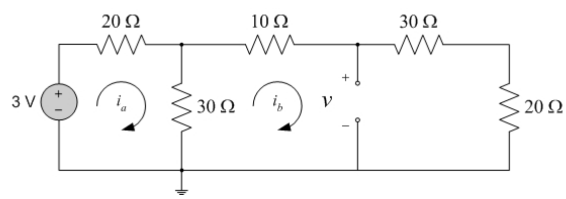
$$i_c - i_b = 0.5$$

Solving,

$i_a = -208$ mA, $i_b = -347$ mA and $i_c = 153$ mA.

Therefore,
$v_V = i_c(30+20) = 7.65$ V.

(2) Suppress current source. Redraw the circuit.



For mesh (a):

$$i_a(20+30)+i_b(-30)=3$$

For mesh (b):

$$i_a(-30)+i_b(90)=0$$

Solving,

$i_a = 75$ mA and $i_b = 25$ mA.

Therefore,
$v_I = i_b(30+20) = 1.25$ V.

Using the principle of superposition,
$v = v_V + v_I = 8.9$ V.

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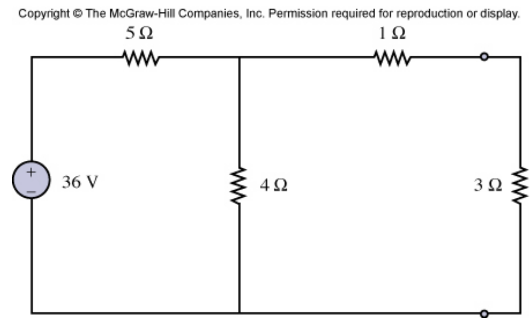
Problem 3.51

Solution:



Known quantities:
Circuit shown in Figure P3.51.

Find:
Thevenin equivalent circuit

Analysis:
$R_{TH} = 1\Omega + 4\Omega \| 5\Omega = 3.22\Omega$

$$R_{TH} = 1 + \frac{1}{\frac{1}{5}+\frac{1}{4}} = 1 + \frac{20}{9} = \frac{29}{9}\,\Omega = 3.222\,\Omega$$

Voltage divider gives

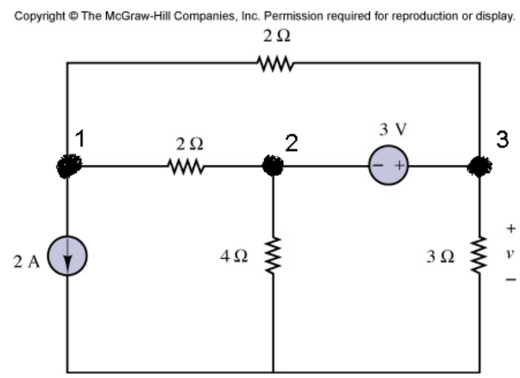
$$V = \left(\frac{4}{4+5}\right)36 = 16\text{ V}$$

KVL:

$v_{oc} =$ -0(1) + $v = v = 16\text{V}$

Problem 3.52

Solution:



Known quantities:
Circuit shown in Figure P3.52.

Find:
Thevenin equivalent circuit and the voltage across resistance 3Ω

Analysis:
KVL: $v_3 = 3 + v_2$,

Find v_{oc} (3 Ω disconnected)

KCL Node 1: $2 + \frac{1}{2}(v_1 - v_2) + \frac{1}{2}[v_1 - (3 + v_2)] = 0$

KCL Nodes 2 & 3:

$$\frac{1}{2}(v_2 - v_1) + \frac{1}{4}v_2 + \frac{1}{2}[(3+v_2) - v_1] + 0 = 0$$

$$\left.\begin{aligned} 1v_1 - 1v_2 &= -\frac{1}{2} \\ -1v_1 + \frac{5}{4}v_2 &= -\frac{3}{2} \end{aligned}\right\} \Rightarrow \quad \begin{aligned} v_1 &= -\frac{17}{2} = -8.5\text{ V} \\ v_2 &= -8\ V \Rightarrow v_{TH} = v_3 = v_2 + 3 = -5\text{ V} \end{aligned}$$

Set all independent sources to zero

$R_{TH} = 4\Omega$

$$v = \frac{3}{4+3}(-5) = -\frac{15}{7}\text{ V=-2.14 V}$$

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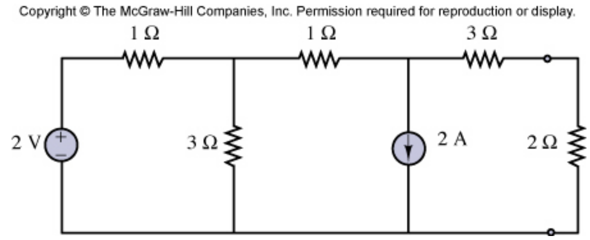
Problem 3.53

Solution:

Known quantities:
Circuit shown in Figure P3.53.

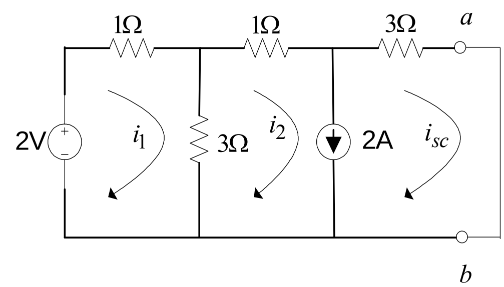
Find:
Norton equivalent circuit

Analysis:



$R_N = 3\Omega + 1\Omega + (3\Omega \| 1\Omega) = 4.75\Omega$

Using the mesh analysis approach



$4i_1 - 3i_2 = 2$

$-3i_1 + 4i_2 + 3i_{SC} = 0$

$i_2 - i_{SC} = 2$

Solving, $i_{SC} = -0.42\text{A} \Rightarrow i_N = -0.42$ A

It means the magnitude of i_{SC} is 0.42A and the direction of i_{SC} is count-clockwise.

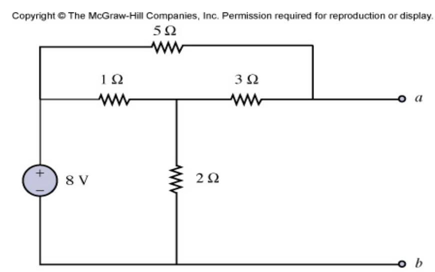
Problem 3.54

Solution:

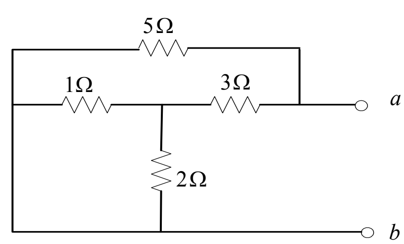
Known quantities:
Circuit shown in Figure P3.54.

Find:
Norton equivalent circuit

Analysis:



$R_N = 5\Omega \| (3\Omega + 2\Omega \| 1\Omega) = 2.12\Omega$



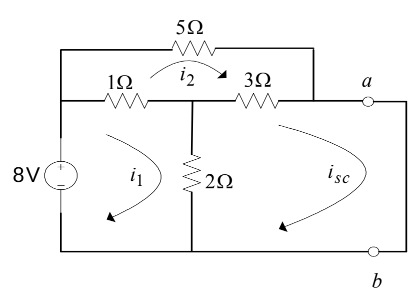
Using mesh analysis,

$8 - 1(i_1 - i_2) - 2(i_1 - i_{SC}) = 0$

$-1(i_2 - i_1) - 5i_2 - 3(i_2 - i_{SC}) = 0$

$-2(i_{SC} - i_1) - 3(i_{SC} - i_2) = 0$

Solving, $i_{SC} = 3.05\text{A} \Rightarrow I_N = 3.05A$.



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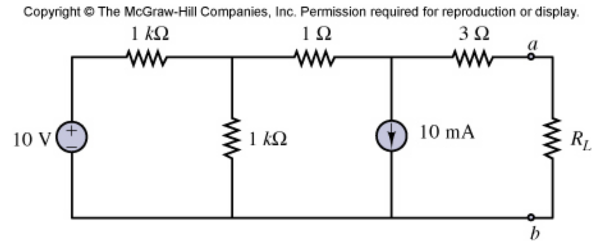
Problem 3.55

Solution:

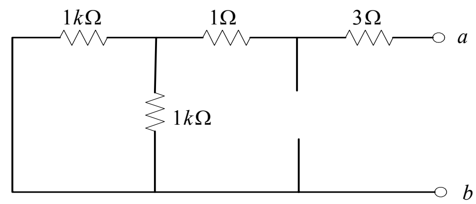


Known quantities:
Circuit shown in Figure P3.55.

Find:
Thevenin equivalent circuit

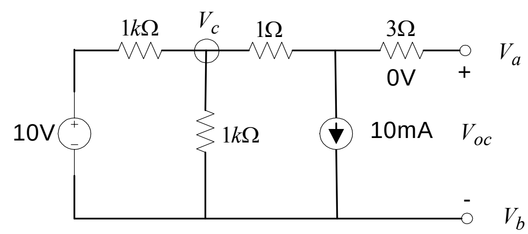
Analysis:

To find R_T, we zero the two sources by shorting the voltage source and opening the current source. The resulting circuit is shown in the left:



Therefore, $R_T = 1{,}000 \| 1{,}000 + 1 + 3 = 504\,\Omega$.

To find V_{oc}, we assume V_b as reference (i.e., zero) and apply nodal analysis.



$$\frac{V_c - V_a}{1} = 0.01$$

$$\frac{10 - V_c}{1000} = \frac{V_c}{1000} + 0.01$$

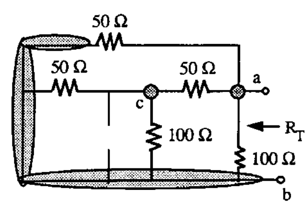
Then, $V_a = -0.01\text{V}$

Therefore, $V_{OC} = -0.01\,\text{V}$.

It means that a is negative side, b is positive side while the magnitude of V_{oc} is 0.01V.

Problem 3.56

Solution:

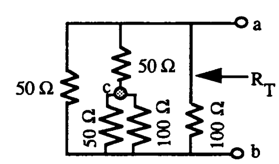


Known quantities:
Circuit shown in Figure P3.56.

Find:
Thevenin equivalent circuit

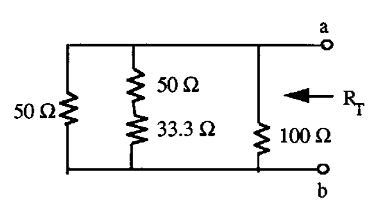
Analysis:

To find R_T, we need to make the current source an open circuit and the voltage sources short circuits, as follows:



Note that this circuit has only three nodes. Thus, we can re-draw the circuit as shown:

and combine the two parallel resistors to obtain:



Thus, $R_T = 50 \| (50 + 33.3) \| 100 = 23.81\,\Omega$

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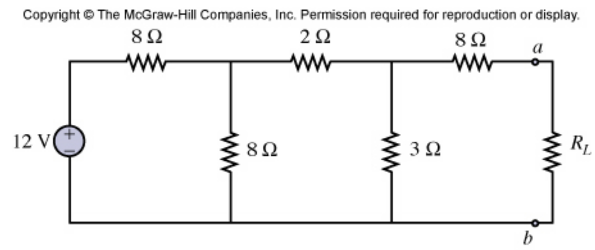
Problem 3.57

Solution:

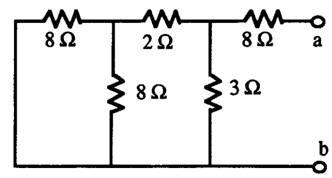
Known quantities:
Circuit shown in Figure P3.57.

Find:
Thevenin equivalent circuit

Analysis:



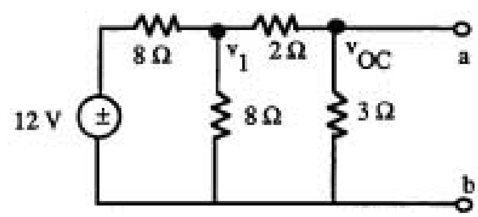
To find R_T,



Therefore,

$$R_T = \{[(8 \| 8) + 2] \| 3\} + 8 = 10\,\Omega$$

To find v_{OC}, nodal analysis can be applied. Note that the 8 Ω resistor may be omitted because no current flows through it, and it therefore does not affect v_{OC}.



$$\left(\frac{1}{8}+\frac{1}{8}+\frac{1}{2}\right)v_1 - \frac{1}{2}v_{OC} = \frac{12}{8}$$

$$-\frac{1}{2}v_1 + \left(\frac{1}{2}+\frac{1}{3}\right)v_{OC} = 0$$

or

$$3v_1 - 2v_{OC} = 6$$

$$-3v_1 + 5v_{OC} = 0$$

Therefore, $v_{OC} = 2\text{ V}$

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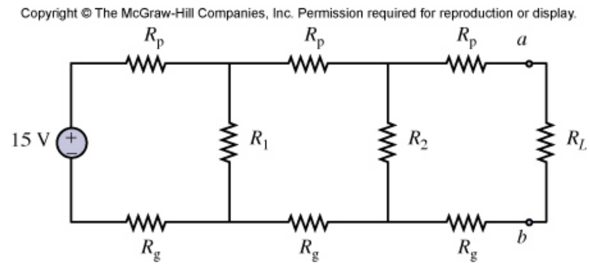
Problem 3.58



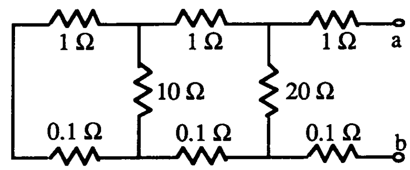
Solution:

Known quantities:
Circuit shown in Figure P3.58.

Find:
Thevenin equivalent circuit

Analysis:

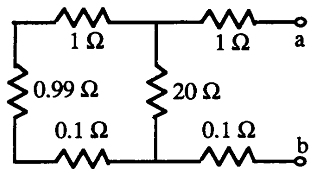
To find R_T, we short circuit the source



Starting from the left side,

$(1+0.1)||10 = 0.99\,\Omega$,

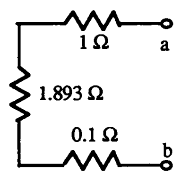
$(1+0.99+0.1)||20 = 1.893\,\Omega$



Therefore, we have

$R_T \;=\; 1.893 \;+\; 0.1 \;+\; 1 = \; 2.993\,\Omega$.

To find v_{oc} , we apply mesh analysis:



Two resistors are omitted because no current flows through them and they, therefore, do not affect v_{OC}.

$(1+0.1+10)\, i_1 \text{-} 10 i_2 = 15$

$(1+20+0.1+10)\, i_2$ -10 i_1=0 Solving for i_2,

$i_2 = \; 0.612$ A

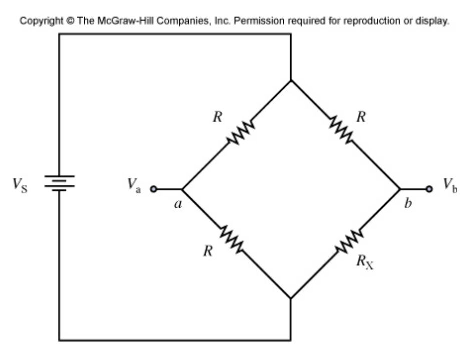
we obtain,

$v_T = v_{OC} = 20\; i_2 = 12.24$ V

Problem 3.59

Solution:

Known quantities:
Circuit shown in Figure P3.59.



Find:
Value of resistance R_x

Analysis:

a) We have $V_{ab} = V_a \text{-} V_b = \dfrac{R}{R+R} V_S \text{-} \dfrac{R_x}{R+R_x} V_S$

$$\boxed{V_{ab} = \frac{1}{2} V_S \text{ - } \frac{R_x}{R+R_x} V_S}$$

b) For $R \;=\; 1$ kW , $V_s \;=\; 12$ V , $V_{ab} \;=\; 12$ mV ,

$$0.012 = 6\text{-}\frac{R_x}{1000+R_x}12 \qquad R_x = 996\Omega$$

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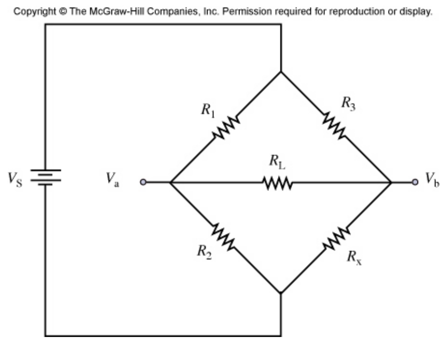
Problem 3.60



Solution:

Known quantities:
Circuit shown in Figure P3.60.

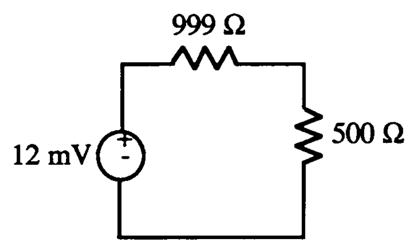
Find:
a) Thevenin equivalent resistance
b) Power dissipated by R_L
c) Power dissipated by R_T and R_L
d) Power dissipated by the bridge without the load resistor

Analysis:

To find R_T, short circuit v_S. Thus,

$$R_T = (R_1 \,||\, R_2) + (R_3 \,||\, R_x) = 999\ \Omega$$

$$v_T = v_S - \frac{R_x}{R + R_x} v_S = 12\text{mV}$$



b) Using the circuit shown:

$$P_{500\Omega} = \frac{v^2}{R} = 32.04 \times 10^{-9} = 32\ \text{nW}$$

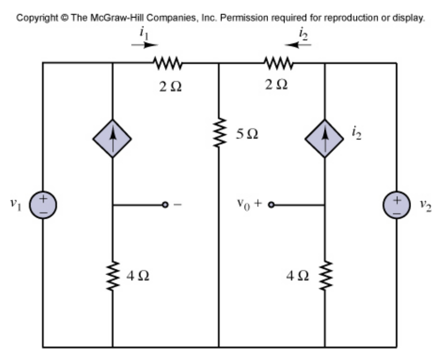
c) Using the previous circuit,

$$P_{RT} = \frac{v^2}{R_T} = 64\ \text{nW}$$

d) With no load resistor, $P_{dissipated} = \frac{12^2}{2000} + \frac{12^2}{1996} = 144.1\ \text{mW}$

Problem 3.61

Note: the dependent current source on the left should be labeled i_1. Further, assume that the two voltage sources do not source any current.



Solution:

Known quantities:
Circuit shown in Figure P3.61.

Find:
v_o as an expression of v_1 and v_2.

Analysis:

Taking the bottom node as the reference,

$v_{O^-} = -4i_1,\ v_{O^+} = -4i_2$

Then, $v_O = v_{O^+} - v_{O^-} = -4i_2 + 4i_1 = 4(i_1 - i_2)$

But, $i_1 = \frac{1}{2}[v_1 - 5(i_1 + i_2)],\quad i_2 = \frac{1}{2}[v_2 - 5(i_1 + i_2)]$

So, $\quad v_O = 2(v_1 - v_2)$

Note: v_1 and v_2 do not source any current.

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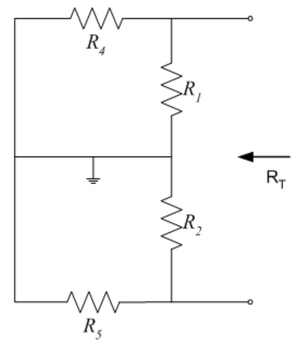
Problem 3.62

Solution:

Known quantities:

The schematic of the circuit (see Figure P3.5).



Find:

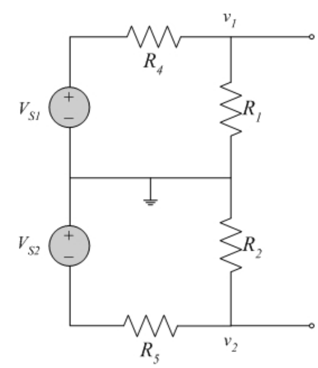
The Thévenin equivalent resistance seen by resistor R_3, the Thévenin (open-circuit) voltage and the Norton (short-circuit) current when R_3 is the load.

Analysis:

(1) Remove the load, leaving the load terminals open circuited, and the voltage sources. Redraw the circuit.

$$R_T = R_1 \parallel R_4 + R_2 \parallel R_5 = \frac{R_1 R_4}{R_1 + R_4} + \frac{R_2 R_5}{R_2 + R_5}$$

(2) Remove the load, leaving the load terminals open circuited. Redraw the circuit.



For node #1: $\dfrac{v_1}{R_1} + \dfrac{v_1 - V_{S1}}{R_4} = 0$

For node #2: $\dfrac{v_2}{R_2} + \dfrac{v_2 + V_{S2}}{R_5} = 0$

Solving the system,

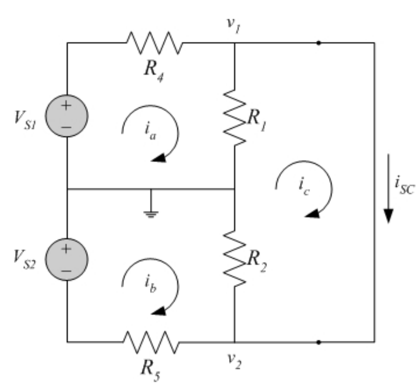
$$v_1 = \frac{R_1}{R_1 + R_4} V_{S1}$$

$$v_2 = -\frac{R_2}{R_2 + R_5} V_{S2}$$

Therefore,

$$v_{OC} = v_1 - v_2 = \frac{R_1}{R_1 + R_4} V_{S1} + \frac{R_2}{R_2 + R_5} V_{S2}$$

(3) Replace the load with a short circuit. Redraw the circuit.



For mesh (a): $i_a(R_1 + R_4) - R_1 i_c = V_{S1}$

For mesh (b): $i_b(R_2 + R_5) - R_2 i_c = V_{S2}$

For mesh (c): $-R_1 i_a - R_2 i_b + i_c(R_1 + R_2) = 0$

Solving the system,

$$i_a = \frac{(R_1R_2 + R_1R_5 + R_2R_5)V_{S1} + R_1R_2V_{S2}}{R_1R_4(R_2 + R_5) + R_2R_5(R_1 + R_4)}$$

$$i_b = \frac{R_1R_2V_{S1} + (R_1R_2 + R_1R_4 + R_2R_4)V_{S2}}{R_1R_4(R_2 + R_5) + R_2R_5(R_1 + R_4)}$$

$$i_c = \frac{R_1(R_2 + R_5)V_{S1} + R_2(R_1 + R_4)V_{S2}}{R_1R_4(R_2 + R_5) + R_2R_5(R_1 + R_4)}$$

Therefore,

$$i_{SC} = i_c = \frac{R_1(R_2 + R_5)V_{S1} + R_2(R_1 + R_4)V_{S2}}{R_1R_4(R_2 + R_5) + R_2R_5(R_1 + R_4)}$$

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Problem 3.63

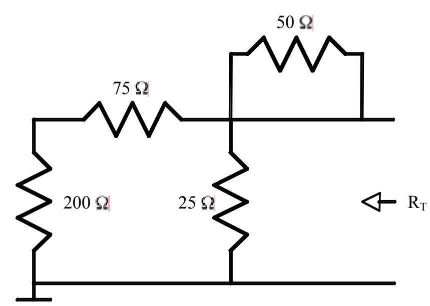
Solution:

Known quantities:
The schematic of the circuit (see Figure P3.10).

Find:
The Thévenin equivalent resistance seen by resistor R_5, the Thévenin (open-circuit) voltage and the Norton (short-circuit) current when R_5 is the load.

Analysis:
(1) Remove the load, leaving the load terminals open circuited, and the voltage sources. Redraw the circuit.

$$R_T = 25\ \Omega \,\|\, (75\ \Omega + 200\ \Omega) = 22.92\ \Omega$$



(2) Remove the load, leaving the load terminals open circuited.
Redraw the circuit.

For node #1:

$$\frac{v_1}{200} + \frac{v_1 - v_2}{75} = 0.2$$

For node #2:

$$\frac{v_2 - v_1}{75} + \frac{v_2}{25} + \frac{v_2 - v_3}{50} + i_{10V} = 0$$

For node #3:

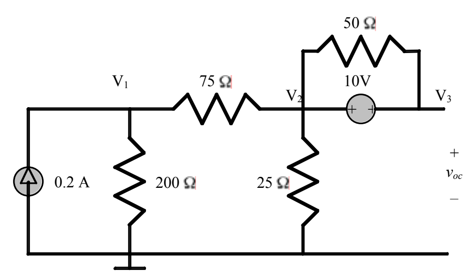
$$\frac{v_3 - v_2}{50} = i_{10V}$$

For the voltage source:

$$v_3 + 10 = v_2$$

Solving the system,
$v_1 = 13.33$ V, $v_2 = 3.33$ V and $v_3 = -6.67$ V.
Therefore,

$$v_{OC} = v_3 = -6.67 \text{ V}.$$



(3) Replace the load with a short circuit. Redraw the circuit.

For mesh (a):

$$i_a(50) = 10$$

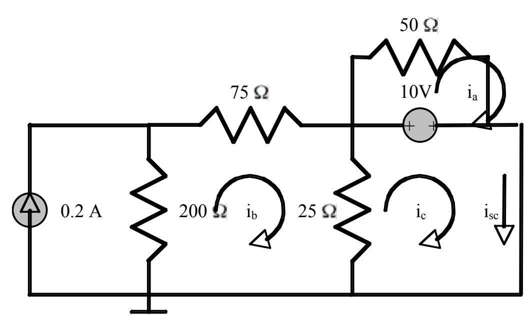
For mesh (b):

$$i_b(300) - i_c(25) = 40$$

For mesh (c):

$$i_b(25) - i_c(25) = 10$$

Solving the system,
$i_a = 200$ mA, $i_b = 109$ mA and $i_c = -291$ mA.
Therefore,
$i_{SC} = i_c = -291$ mA.



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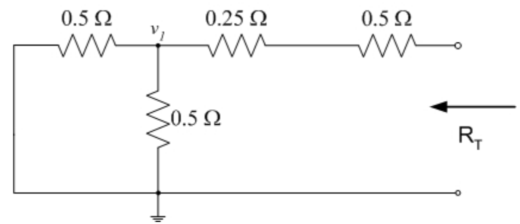
Problem 3.64

Solution:

Known quantities:
The schematic of the circuit (see Figure P3.23).

Find:
The Thévenin equivalent resistance seen by resistor R_5, the Thévenin (open-circuit) voltage and the Norton (short-circuit) current when R_5 is the load.



Analysis:
(1) Remove the load, leaving the load terminals open circuited, and the voltage sources. Redraw the circuit.

$$R_T = 0.5\ \Omega + 0.25\ \Omega + (0.5\ \Omega \parallel 0.5\ \Omega) = 1\ \Omega$$

(2) Remove the load, leaving the load terminals open circuited. Redraw the circuit.

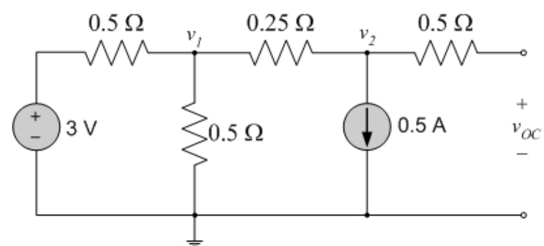
For node #1:

$$\frac{v_1 - 3}{0.5} + \frac{v_1}{0.5} + \frac{v_1 - v_2}{0.25} = 0$$

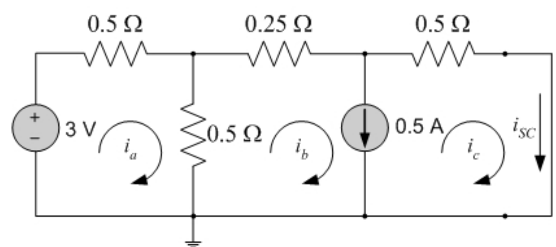
For node #2:

$$\frac{v_2 - v_1}{0.25} + 0.5 = 0$$

Solving the system,
$v_1 = 1.375\ \text{V}$ and $v_2 = 1.25\ \text{V}$.
Therefore,
$v_{OC} = v_2 = 1.25\ \text{V}$.



(3) Replace the load with a short circuit. Redraw the circuit.



For mesh (a):

$$i_a(0.5 + 0.5) - i_b(0.5) = 3$$

For meshes (b) and (c):

$$-i_a(0.5) + i_b(0.5 + 0.25) + i_c(0.5) = 0$$

For the current source:

$$i_b - i_c = 0.5$$

Solving the system,

$i_a = 3.875\ \text{A}$, $i_b = 1.75\ \text{A}$ and $i_c = 1.25\ \text{A}$.
Therefore,
$i_{SC} = i_c = 1.25\ \text{A}$.

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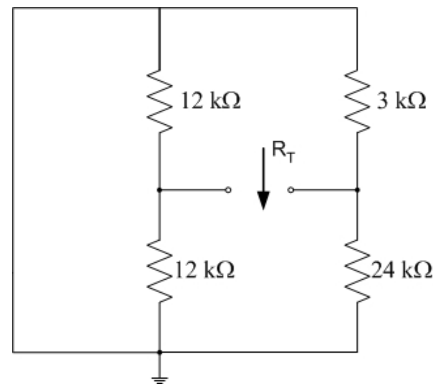
Problem 3.65

Solution:



Known quantities:
The schematic of the circuit (see Figure P3.23).

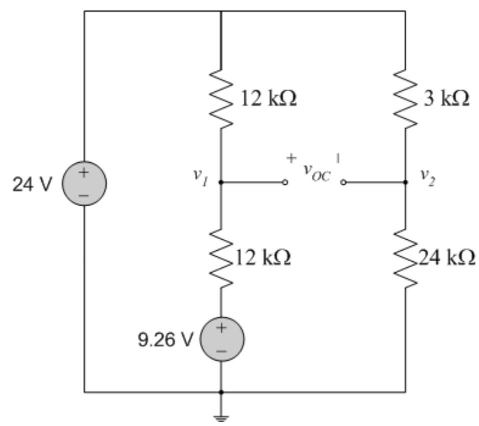
Find:
The Thévenin equivalent resistance seen by resistor R_3, the Thévenin (open-circuit) voltage and the Norton (short-circuit) current when R_3 is the load.

Assumption:
As in P3.12, we assume $T = 0.926\,°\text{C}$, so that $V_{S2} = 9.26\text{ V}$.

Analysis:
(1) Remove the load, leaving the load terminals open circuited, and the voltage sources. Redraw the circuit.

$R_T = 12\text{ k}\Omega \,\|\, 12\text{ k}\Omega + 3\text{ k}\Omega \,\|\, 24\text{ k}\Omega = 8.67\text{ k}\Omega$

(2) Remove the load, leaving the load terminals open circuited.
Redraw the circuit.



For node #1:

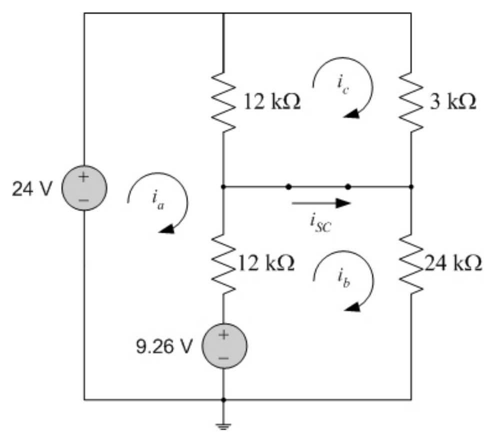
$$\frac{v_1 - 24}{12000} + \frac{v_1 - 9.26}{12000} = 0$$

For node #2:

$$\frac{v_2 - 24}{3000} + \frac{v_2}{24000} = 0$$

Solving the system,
$v_1 = 16.63\text{ V}$ and $v_2 = 21.33\text{ V}$.
Therefore,
$v_{OC} = v_1 - v_2 = -4.7\text{ V}$.

(3) Replace the load with a short circuit. Redraw the circuit.



For mesh (a):

$i_a(24k) - i_b(12k) - i_c(12k) = 24 - 9.26$

For mesh (b):

$-i_a(12k) + i_b(36k) = 9.26$

For mesh (c):

$-i_a(12k) + i_c(15k) = 0$

Solving the system,

$i_a = 1.71\text{ mA}$, $i_b = 0.83\text{ mA}$ and $i_c = 1.37\text{ mA}$.
Therefore,
$i_{SC} = i_b - i_c = -0.54\text{ mA}$.

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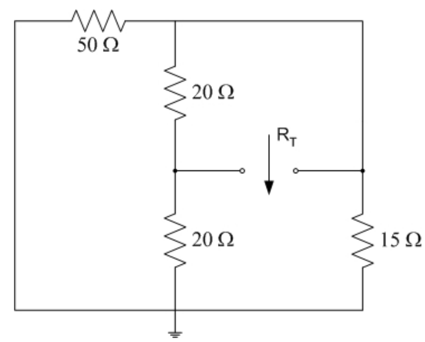
Problem 3.66

Solution:



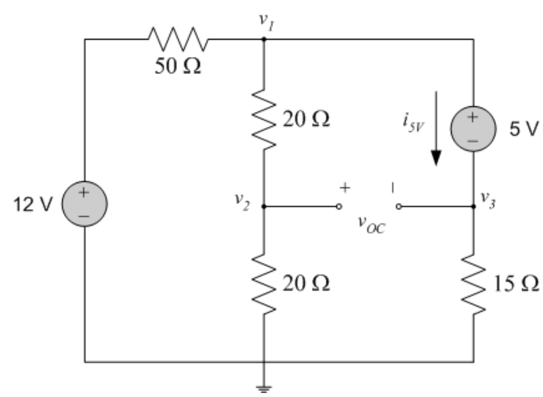
Known quantities:
The schematic of the circuit (see Figure P3.25).

Find:
The Thévenin equivalent resistance seen by resistor R_4, the Thévenin (open-circuit) voltage and the Norton (short-circuit) current when R_4 is the load.

Analysis:
(1) Remove the load, leaving the load terminals open circuited, and the voltage sources. Redraw the circuit.

$$R_T = R_2 \parallel \left(R_3 + \left(R_1 \parallel R_5\right)\right) = 20\ \Omega \parallel \left(20\ \Omega + \left(50\ \Omega \parallel 15\ \Omega\right)\right) = 12.24\ \Omega$$

(2) Remove the load, leaving the load terminals open circuited. Redraw the circuit.



For node #1:

$$\frac{v_1 - 12}{50} + \frac{v_1 - v_2}{20} + i_{5V} = 0$$

For node #2:

$$\frac{v_2 - v_1}{20} + \frac{v_2}{20} = 0$$

For node #3:

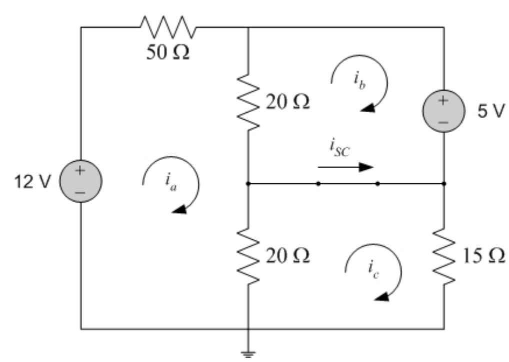
$$\frac{v_3}{15} - i_{5V} = 0$$

For the 5-V voltage source:

$$v_1 - v_3 = 5$$

Solving the system,
$v_1 = 5.14\ \text{V}$, $v_2 = 2.57\ \text{V}$, $v_1 = 0.13\ \text{V}$ and $i_{5V} = 8.95\ \text{mA}$.
Therefore,
$v_{OC} = v_2 - v_3 = 2.44\ \text{V}$.

(3) Replace the load with a short circuit. Redraw the circuit.



For mesh (a):

$$i_a(90) - i_b(20) - i_c(20) = 12$$

For mesh (b):

$$-i_a(20) + i_b(20) + 5 = 0$$

For mesh (c):

$$-i_a(20) + i_c(35) = 0$$

Solving the system,
$i_a = 119.5\ \text{mA}$, $i_b = -130.5\ \text{mA}$ and $i_c = 68.3\ \text{mA}$.
Therefore,

$$i_{SC} = i_c - i_b = 198.8\ \text{mA}.$$

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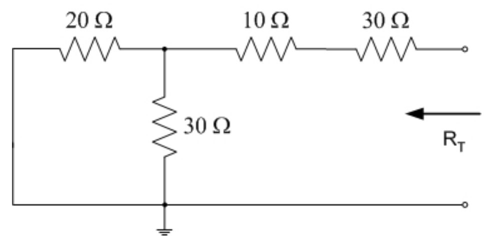
Problem 3.67

Solution:

Known quantities:
The schematic of the circuit (see Figure P3.26).

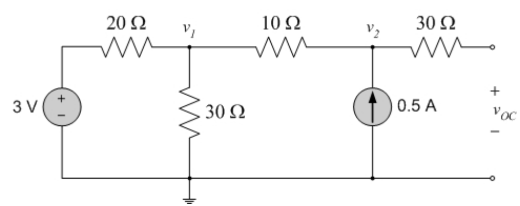


Find:
The Thévenin equivalent resistance seen by resistor R_5, the Thévenin (open-circuit) voltage and the Norton (short-circuit) current when R_5 is the load.

Analysis:
(1) Remove the load, leaving the load terminals open circuited, and the voltage sources. Redraw the circuit.

$R_T = 30\ \Omega + 10\ \Omega + (20\ \Omega \,\|\, 30\ \Omega) = 52\ \Omega$

(2) Remove the load, leaving the load terminals open circuited. Redraw the circuit.

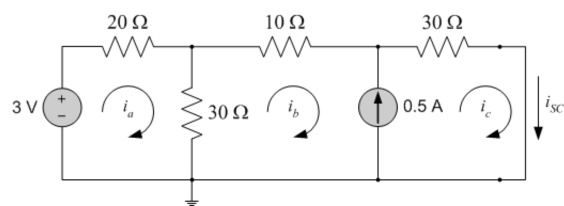


For node #1: $\dfrac{v_1-3}{20}+\dfrac{v_1}{30}+\dfrac{v_1-v_2}{10}=0$

For node #2: $\dfrac{v_2-v_1}{10}=0.5$

Solving the system,
$v_1 = 7.8\text{ V}$ and $v_2 = 12.8\text{ V}$.
Therefore, $v_{OC} = v_2 = 12.8\text{ V}$.

(3) Replace the load with a short circuit. Redraw the circuit.



For mesh (a): $i_a(20+30)-i_b(30)=3$

For meshes (b) and (c): $-i_a(30)+i_b(30+10)+i_c(30)=0$

For the current source:

$i_c - i_b = 0.5$

Solving the system,

$i_a = -92\text{ mA}$, $i_b = -254\text{ mA}$ and $i_c = 246\text{ mA}$.
Therefore,
$i_{SC} = i_c = 246\text{ mA}$.

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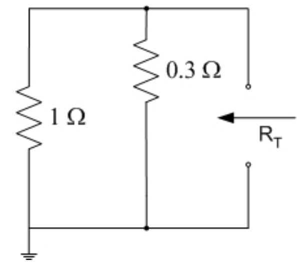
Problem 3.68

Solution:

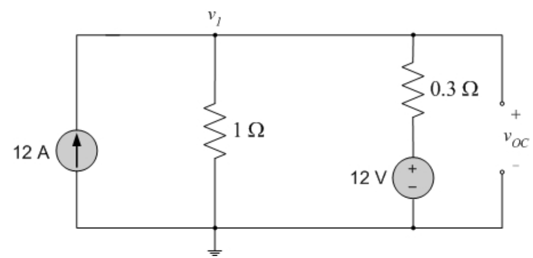
Known quantities:
The schematic of the circuit (see Figure P3.41).



Find:
The Thévenin equivalent resistance seen by resistor R, the Thévenin (open-circuit) voltage and the Norton (short-circuit) current when R is the load.

Analysis:
(1) Remove the load, leaving the load terminals open circuited, and the voltage sources. Redraw the circuit.

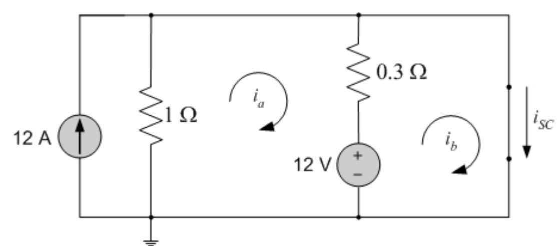
$R_T = 1\ \Omega \,\|\, 0.3\ \Omega = 0.23\ \Omega$



(2) Remove the load, leaving the load terminals open circuited. Redraw the circuit.

For node #1: $\dfrac{v_1}{1} + \dfrac{v_1 - 12}{0.3} = 12$

Solving,
$v_1 = 12\text{ V}$.
Therefore,
$v_{OC} = v_1 = 12\text{ V}$.



(3) Replace the load with a short circuit. Redraw the circuit.

For mesh (a): $i_a(1+0.3) - i_b(0.3) - 12(1) + 12 = 0$

For mesh (b): $-i_a(0.3) + i_b(0.3) = 12$

Solving the system,
$i_a = 12\text{ A}$ and $i_b = 52\text{ A}$.
Therefore,
$i_{SC} = i_b = 52\text{ A}$.

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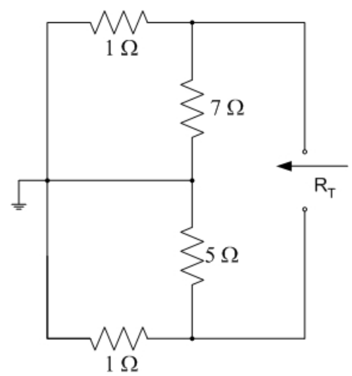
Problem 3.69



Solution:

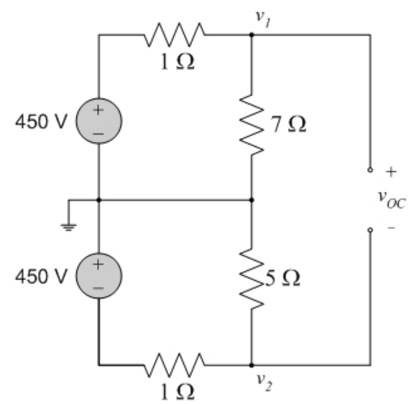
Known quantities:
The schematic of the circuit (see Figure P3.43).

Find:
The Thévenin equivalent resistance seen by resistor R_3, the Thévenin (open-circuit) voltage and the Norton (short-circuit) current when R_3 is the load.

Analysis:
(1) Remove the load, leaving the load terminals open circuited, and the voltage sources. Redraw the circuit.

$R_T = 1\ \Omega \,\|\, 7\ \Omega + 1\ \Omega \,\|\, 5\ \Omega = 1.71\ \Omega$

(2) Remove the load, leaving the load terminals open circuited. Redraw the circuit.

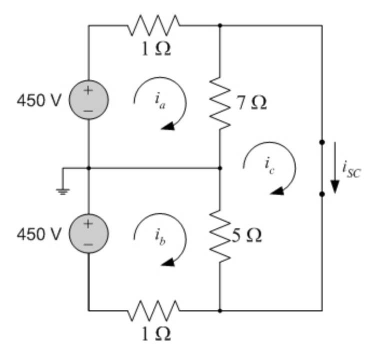


For node #1: $\frac{v_1 - 450}{1} + \frac{v_1}{7} = 0$

For node #2: $\frac{v_2 + 450}{1} + \frac{v_2}{5} = 0$

Solving the system,
$v_1 = 393.75$ V and $v_2 = -375$ V.
Therefore,
$v_{OC} = v_1 - v_2 = 768.75$ V.

(3) Replace the load with a short circuit. Redraw the circuit.



For mesh (a):
$i_a(1+7) - i_c(7) = 450$

For mesh (b):
$i_b(5+1) - i_c(5) = 450$

For mesh (c):
$-i_a(7) - i_b(5) + i_c(7+5) = 0$

Solving the system,
$i_a = 450$ A, $i_b = 450$ A and $i_c = 450$ A.
Therefore,
$i_{SC} = i_c = 450$ A.

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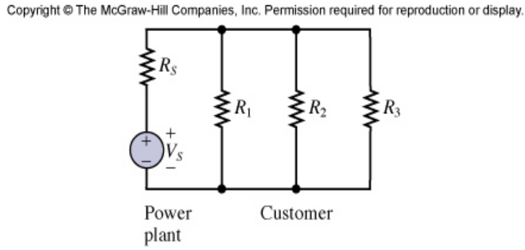
Problem 3.70



Solution:

Known quantities:

The values of the voltage source, $V_S = 110$ V, and the values of the 4 resistors in the circuit of Figure P3.70: $R_1 = R_2 = 930\ \text{m}\Omega$ $\quad R_3 = 100\ \text{m}\Omega$ $\quad R_S = 19\ \text{m}\Omega$

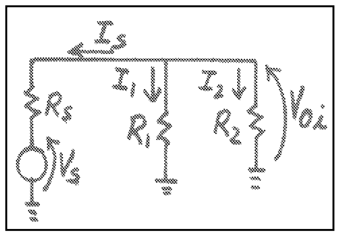
Find:

The change in the voltage across the total load, when the customer connects the third load R_3 in parallel with the other two loads.

Analysis:

Choose a ground. If the node at the bottom is chosen as ground (which grounds one terminal of the ideal source), the only unknown node voltage is the required voltage. Specify directions of the currents and polarities of voltages.

Without R_3:



KCL: $\quad I_S + I_1 + I_2 = 0$

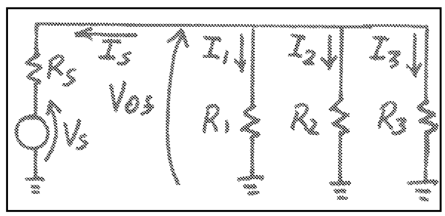
OL:

$$\frac{V_{RS}}{R_S} + \frac{V_{R1}}{R_1} + \frac{V_{R2}}{R_2} = 0$$

$$\frac{V_{Oi} - V_S}{R_S} + \frac{V_{Oi} - 0}{R_1} + \frac{V_{Oi} - 0}{R_2} = 0$$

$$V_{Oi} = \frac{\frac{V_S}{R_S}}{\frac{1}{R_S} + \frac{1}{R_1} + \frac{1}{R_2}} \frac{R_S}{R_S} = \frac{110}{1.04086} = 105.7\ \text{V}$$

With R_3:



KCL: $\quad I_S + I_1 + I_2 + I_3 = 0$

OL:

$$\frac{V_{RS}}{R_S} + \frac{V_{R1}}{R_1} + \frac{V_{R2}}{R_2} + \frac{V_{R3}}{R_3} = 0$$

$$\frac{V_{Of} - V_S}{R_S} + \frac{V_{Of} - 0}{R_1} + \frac{V_{Of} - 0}{R_2} + \frac{V_{Of} - 0}{R_3} = 0$$

$$V_{Of} = \frac{\frac{V_S}{R_S}}{\frac{1}{R_S} + \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}} \frac{R_S}{R_S} = \frac{110}{1.04086 + 0.19} = 89.37\ \text{V}$$

Therefore, the voltage decreased by: $\qquad \Delta V_o = V_{Of} - V_{Oi} = -16.33\ \text{V}$

Notes:

1. "Load" to an EE usually means current rather than resistance.
2. Additional load reduces the voltage supplied to the customer because of the additional voltage dropped across the losses in the distribution system.

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Problem 3.71

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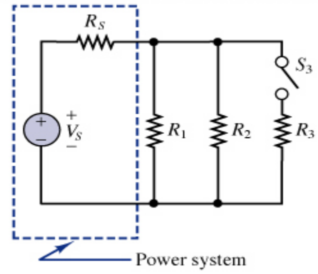

Solution:

Known quantities:

The values of the voltage source, $V_S = 450$ V, and the values of the 4 resistors in the circuit of Figure P3.71.
$R_1 = R_2 = 1.3\ \Omega$ $\quad R_3 = 500\ \text{m}\Omega$ $\quad R_S = 19\ \text{m}\Omega$

Find:

The change in the voltage across the total load, when the customer connects the third load R_3 in parallel with the other two loads.

Analysis:

See Solution to Problem 3.70 for a detailed mathematical analysis.

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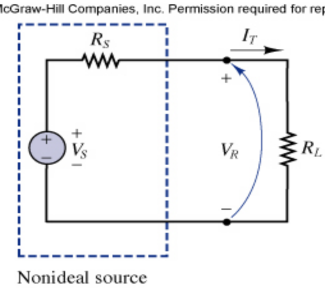

Problem 3.72

Solution:

Known quantities:

The circuit shown in Figure P3.72, the values of the terminal voltage, V_T, before and after the application of the load, respectively $V_T = 20$ V and $V_T = 18$ V, and the value of the load resistor $R_L = 2.7\ \text{k}\Omega$.

Find:

The internal resistance and the voltage of the ideal source.

Analysis:

KVL: $\quad -V_S + I_T R_S + V_T = 0$

If $\quad I_T = 0$: $\quad V_S = V_T = 20$ V

If $\quad V_T = 18$ V:

OL: $\quad I_T = \dfrac{V_T}{R_L} = 6.67$ mA $\quad$ and $\quad R_S = \dfrac{V_S - V_T}{I_T} = 300\ \Omega$

Note that R_S is an equivalent resistance, representing the various internal losses of the source and is not physically a separate component. V_S is the voltage generated by some internal process. The source voltage can be measured directly by reducing the current supplied by the source to zero, i.e., no-load or open-circuit conditions. The source resistance cannot be directly measured; however, it can be determined, as was done above, using the interaction of the source with an external load.

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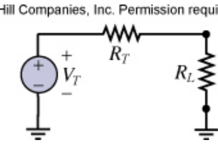
Section 3.7: Maximum power transfer

Problem 3.73

Solution:



Known quantities:
The values of the voltage and of the resistor in the equivalent circuit of Figure P3.73: $V_{TH} = 12 \text{ V}; R_{eq} = 8\,\Omega$

Assumptions:
Assume the conditions for maximum power transfer exist.

Find:
a. The value of R_L.
b. The power developed in R_L.
c. The efficiency of the circuit, that is the ratio of power absorbed by the load to power supplied by the source.

Analysis:
a. For maximum power transfer: $R_L = R_{eq} = 8\,\Omega$

b. *VD*: $$V_{RL} = \frac{V_{TH} R_L}{R_{eq} + R_L} = \frac{(12)(8)}{8+8} = 6 \text{ V}$$

$$P_{RL} = \frac{V^2{}_{RL}}{R_L} = \frac{(6)^2}{8} = 4.5 \text{ W}$$

c. $$\eta = \frac{P_0}{P_S} = \frac{P_{RL}}{P_{Req} + P_{RL}} = \frac{I_S^2 R_L}{I_S^2 R_{eq} + I_S^2 R_L} = \frac{R_L}{R_{eq} + R_L} = 0.5 = 50\%$$

Problem 3.74

Solution:

Known quantities:
The values of the voltage and of the resistor in the equivalent circuit of Figure P3.73: $V_{TH} = 300 \text{ V};\ R_{eq} = 600\ \Omega$

Assumptions:
Assume the conditions for maximum power transfer exist.

Find:
a. The value of R_L.
b. The power developed in R_L.
c. The efficiency of the circuit, that is the ratio of power absorbed by the load to power supplied by the source.

Analysis:
a. For maximum power transfer: $R_L = R_{eq} = 600\ \Omega$

b. *VD*: $$V_{RL} = \frac{V_{TH} R_L}{R_{eq} + R_L} = \frac{(35)(600)}{600+600} = 17.5 \text{ V}$$

$$P_{RL} = \frac{V^2{}_{RL}}{R_L} = \frac{(17.5)^2}{600} = 510.4 \text{ mW}$$

c. $$\eta = \frac{P_0}{P_S} = \frac{P_{RL}}{P_{Req} + P_{RL}} = \frac{I_S^2 R_L}{I_S^2 R_{eq} + I_S^2 R_L} = \frac{R_L}{R_{eq} + R_L} = 0.5 = 50\%$$

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Problem 3.75

Solution:

Known quantities:
The values of the voltage source, $V_S = 12$ V, and of the resistance representing the internal losses of the source, $R_S = 0.3\ \Omega$, in the circuit of Figure P3.59.

Find:
a. Plot the power dissipated in the load as a function of the load resistance. What can you conclude from your plot?
b. Prove, analytically, that your conclusion is valid in all cases.

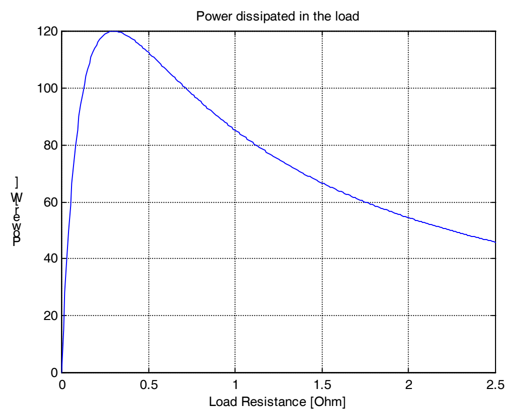
Analysis:

a. *KVL*:

$$-V_S = IR_S + IR = 0$$

$$I = \frac{V_S}{R_S + R} \qquad P_R = I^2 R$$

R [Ω]	I [A]	P_R [W]
0	40	0.0
0.1	30	90.0
0.3	20	120.0
0.9	10	90.0
2.1	5	52.5



b. $$P_R = I^2 R = \frac{V_S^2 R}{(R + R_S)^2} = V_S^2 R (R + R_S)^{-2}$$

$$\frac{dP_R}{dR} = V_S^2 (1)(R + R_S)^{-2} + V_S^2 (R)(-2)(R + R_S)^{-3}(1) = 0$$

$$(R + R_S)^1 - 2R = 0 \quad \Rightarrow \quad R = R_S$$

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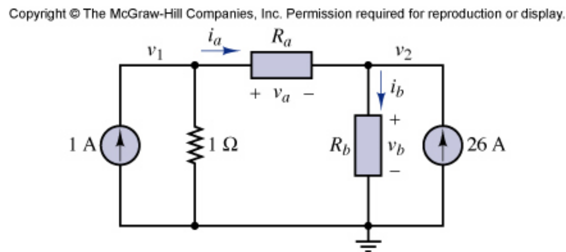
Section 3.8: Nonlinear circuit elements

Problem 3.76

Solution:

Known quantities:
The two nonlinear resistors, in the circuit of Figure P3.76, are characterized by:

$i_a = 2v_a^3 \qquad i_b = v_b^3 + 10v_b$



Find:
The node voltage equations in terms of v_1 and v_2.

Analysis:

At node 1, $\quad \frac{v_1}{1} + i_a = 1 \Rightarrow v_1 + 2v_a^3 = 1$

At node 2, $\quad i_b - i_a = 26 \Rightarrow v_b^3 + 10v_b - 2v_a^3 = 26$

But $v_a = v_1 - v_2$ and $v_b = v_2$. Therefore, the node equations are

$v_1 + 2(v_1 - v_2)^3 = 1 \qquad$ and $\qquad v_2^3 + 10v_2 - 2(v_1 - v_2)^3 = 26$

Problem 3.77

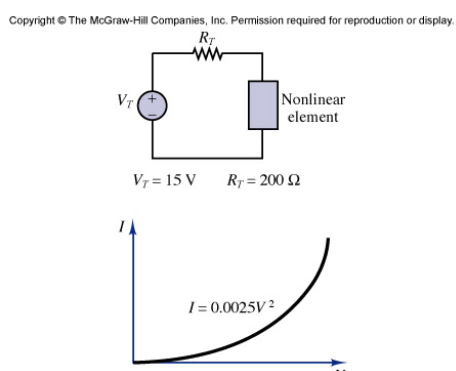
Solution:

Known quantities:
The characteristic *I-V* curve shown in Figure P3.77, and the values of the voltage, $V_T = 15$ V, and of the resistance, $R_T = 200\,\Omega$, in the circuit of Figure P3.77.

Find:
a. The operating point of the element that has the characteristic curve shown in Figure P3.61.
b. The incremental resistance of the nonlinear element at the operating point of part a.
c. If V_T were increased to 20 V, find the new operating point and the new incremental resistance.

Analysis:

a. *KVL*:
$$-15 + 200I + V = 0$$
$$-15 + 200\left(0.0025V^2\right) + V = 0$$



Solving for V and I,

$I = 52.2$ mA $\qquad V = 4.57$ V or -6.57 V

The second voltage value is physically impossible.

b. $R_{\text{inc}} = 10(0.0522)^{-0.5} = 43.8\ \Omega$

c. $I = 73$ mA $\qquad V = 5.40$ V $\qquad R_{\text{inc}} = 37\ \Omega$

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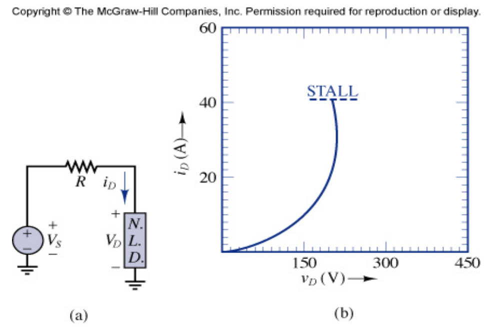
Problem 3.78



Solution:

Known quantities:

The characteristic I-V curve shown in Figure P3.78, and the values of the voltage, $V_S = 450$ V, and of the resistance, $R = 9\,\Omega$, in the circuit of Figure P3.78.

Find:

The current through and the voltage across the nonlinear device.

Analysis:

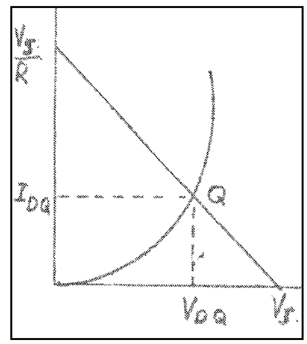
The *I-V* characteristic for the nonlinear device is given. Plot the circuit *I-V* characteristic, i.e., the DC load line.

KVL: $\quad -V_S + I_D R + V_D = 0$

$$I_D = \frac{V_S - V_D}{R} = \frac{450 - V_D}{9} =$$

$$= 0 \text{ A} \qquad \text{if} \quad V_D = 450 \text{ V}$$

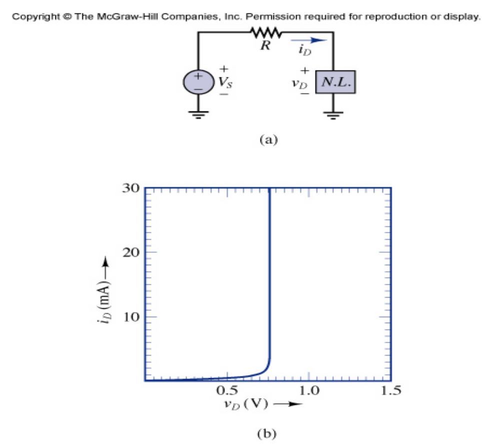
$$= 50 \text{ A} \qquad \text{if} \quad V_D = 0$$



The DC load line [circuit characteristic] is linear. Plotting the two intercepts above and connecting them with a straight line gives the DC load line. The solution for V and I is at the intersection of the device and circuit characteristics:

$I_{DQ} \approx 26$ A $\quad V_{DQ} \approx 210$ V.

Problem 3.79



Solution:

Known quantities:

The *I-V* characteristic shown in Figure P3.79, and the values of the voltage, $V_S = V_T = 1.5$ V, and of the resistance, $R = R_{eq} = 60\ \Omega$, in the circuit of Figure P3.63.

Find:

The current through and the voltage across the nonlinear device.

Analysis:

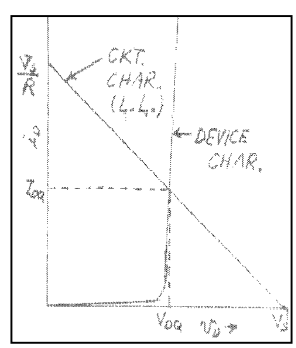
The solution is at the intersection of the device and circuit characteristics. The device *I-V* characteristic is given. Determine and plot the circuit *I-V* characteristic.

KVL: $\quad -V_S + I_D R + V_D = 0$

$$I_D = \frac{V_S - V_D}{R} = \frac{1.5\text{ V} - \text{V}_D}{60\ \Omega} =$$

$$= 0 \text{ A} \qquad \text{if} \quad V_D = 1.5 \text{ V}$$

$$= 25 \text{ mA} \qquad \text{if} \quad V_D = 0$$



The DC load line [circuit characteristic] is linear. Plotting the two intercepts above and connecting them with a straight line gives the DC load line. The solution is at the intersection of the device and circuit characteristics, or "Quiescent", or "Q", or "DC operating" point:

$I_{DQ} \approx 12$ mA $\quad V_{DQ} \approx 0.77$ V.

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Problem 3.80

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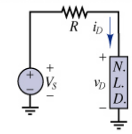
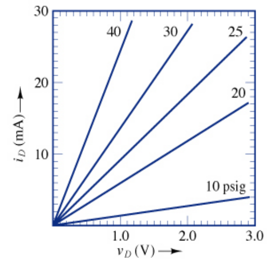


(a)



(b)

Solution:

Known quantities:

The *I-V* characteristic shown in Figure P3.80 as a function of pressure.

$V_S = V_T = 2.5\ \text{V} \qquad R = R_{eq} = 125\ \Omega$

Find:

The DC load line, the voltage across the device as a function of pressure, and the current through the nonlinear device when $p = 30$ psig.

Analysis:

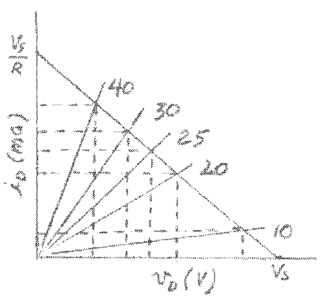
Circuit characteristic [DC load line]: *KVL*:

$-V_S + I_D R + V_D = 0$

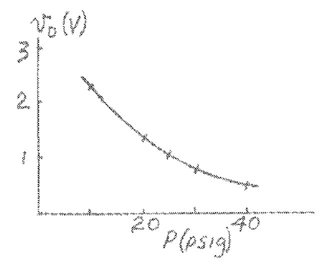
$$I_D = \frac{V_S - V_D}{R} = \frac{2.5\ \text{V} - V_D}{125\ \Omega} = 0\ \text{A} \qquad \text{if} \qquad V_D = 2.5\ \text{V}$$

$$= 20\ \text{mA} \qquad \text{if} \qquad V_D = 0$$

The circuit characteristic is a linear relation. Plot the two intercepts and connect with a straight line to plot the DC load line. Solutions are at the intersections of the circuit with the device characteristics, i.e.:



p [psig]	V_D [V]
10	2.14
20	1.43
25	1.18
30	0.91
40	0.60



The function is nonlinear. At $p = 30$ psig: $\qquad V_D = 1.08\ \text{V} \qquad I_D = 12.5\ \text{mA}$.

Problem 3.81

Solution:

Known quantities:

The *I-V* characteristic of the nonlinear device in the circuit shown in Figure P3.81:

$$I_D = I_0 e^{\frac{v_D}{V_T}}$$

$I_0 = 10^{-15}\ \text{A} \qquad V_T = 26\ \text{mV}$

$V_S = V_T = 1.5\ \text{V}$

$R = R_{ea} = 60\ \Omega$

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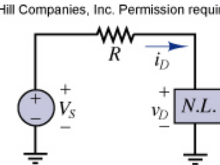

Find:

An expression for the DC load line. The voltage across and current through the nonlinear device.

Analysis:

Circuit characteristic [DC load line]:

KVL: $\quad -V_S + I_D R + V_D = 0$

$$[1] \qquad I_D = \frac{V_S - V_D}{R} = \frac{1.5 - V_D}{60}$$

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[2] $\quad V_D = V_T \ln\left(\dfrac{I_D}{I_0}\right) = 0.026 \cdot \ln\left(\dfrac{I_D}{10^{-15}}\right)$

Iterative procedure:
Initially guess $V_D = 750 \text{ mV}$. Note this voltage must be between zero and the value of the source voltage.
Then:
a. Use Equation [1] to compute a new I_D.
b. Use Equation [2] to compute a new V_D.
c. Iterate, i.e., go step a. and repeat.

V_D [mV]	I_D [mA]
750	12.5
784.1	11.93
782.9	11.95
782.9	11.95
…	…

$I_{DQ} \approx 11.95 \text{ mA} \quad V_{DQ} \approx 782.9 \text{ mV}$.

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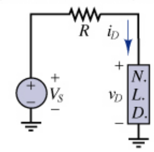
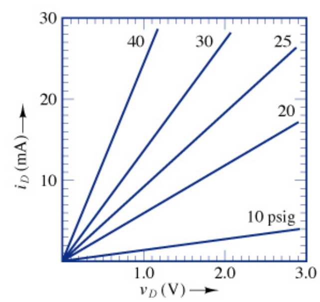
Problem 3.82



(a)



(b)

Solution:

Known quantities:

The *I-V* characteristic shown in Figure P3.82 as a function of pressure.

$V_S = V_T = 2.5\,\text{V} \qquad R = R_{eq} = 125\ \Omega$

Find:

The DC load line, and the current through the nonlinear device when p = 40 psig.

Analysis:

Circuit characteristic [DC load line]:

KVL: $\quad -V_S + I_D R + V_D = 0$

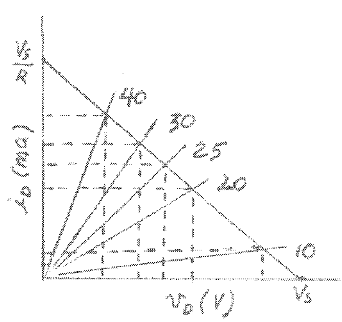
$$I_D = \frac{V_S - V_D}{R} = \frac{2.5\text{ V} - V_D}{125\Omega} =$$

$$= 0 \text{ A} \qquad \text{if} \qquad V_D = 2.5 \text{ V}$$

$$= 20 \text{ mA} \qquad \text{if} \qquad V_D = 0$$

The circuit characteristic is a linear relation that can be plotted by plotting the two intercepts and connecting them with a straight line. Solutions are at the intersections of the circuit and device characteristics.

At $p = 40$ psig: $\qquad V_D = 0.60 \text{ V} \qquad I_D = 15.2 \text{ mA}$



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Problem 3.83

Solution:

Known quantities:
Circuit shown in Figure P3.83 and the program flowchart

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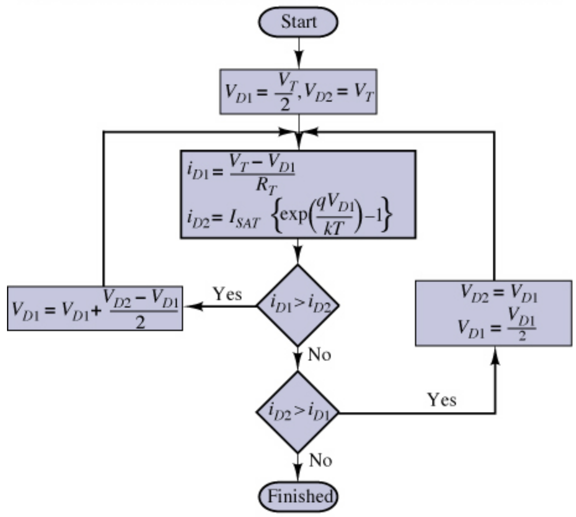
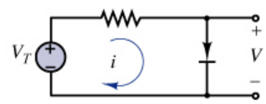


Find:
a) Graphical analysis of diode current and diode voltage.

Analysis:
a) For every voltage value for the diode, we can calculate the corresponding current. Therefore we can calculate the voltage in the whole circuit. The intersection of voltage circuit and the thevenin equivalent voltage shows the answer.

$v_D \approx 0.65$

$i_D \approx 0.5$

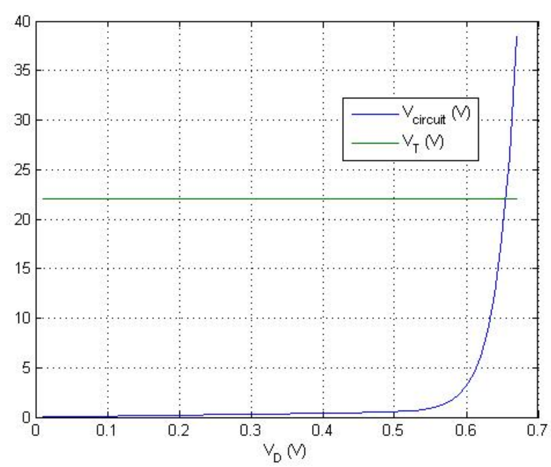


b) Run the attached Matlab code, we can have the following answer. They are close to the answer we got above.

$v_D \approx 0.64$

$i_D \approx 0.52$

```
clc;clear;close all;
ISAT=10e-12;kTq=0.0259;VT=12;RT=22;
VD1=VT/2;
VD2=VT;
flag=1;
while flag
    iD1=(VT-VD1)/RT;
    iD2=ISAT*(exp(VD1/kTq)-1);
    if iD1>iD2
        VD1=VD1+(VD2-VD1)/2;
    else
        VD2=VD1;
        VD1=VD1/2;
    end
    if abs(VD2-VD1)<10E-6;
        flag=0
    end
end
iD1
VD1
```



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