EN2042102 วงจรไฟฟ้าและอิเล็กทรอนิกส์

Circuits and Electronics

บทที่ 4 ทฤษฎีโครงข่ายไฟฟ้า

Electrical Network Theorems

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OBJECTIVES

- Become familiar with the superposition theorem and its unique ability to separate the impact of each source on the quantity of interest.
- Be able to apply Thévenin's theorem to reduce any two-terminal, series-parallel network with any number of sources to a single voltage source and series resistor.
- Become familiar with Norton's theorem and how it can be used to reduce any two-terminal, seriesparallel network with any number of sources to a single current source and a parallel resistor.

LOGO

OBJECTIVES

- Understand how to apply the maximum power transfer theorem to determine the maximum power to a load and to choose a load that will receive maximum power.
- Become aware of the reduction powers of Millman’s theorem and the powerful implications of the substitution and reciprocity theorems.

LOGO

SUPERPOSITION THEOREM

- The **superposition theorem** is unquestionably one of the most powerful in this field.
- It has such widespread application that people often apply it without recognizing that their maneuvers are valid only because of this theorem.

LOGO

SUPERPOSITION THEOREM

- In general, the theorem can be used to do the following:
  - ***Analyze networks such as introduced in the last chapter that have two or more sources that are not in series or parallel.***
  - ***Reveal the effect of each source on a particular quantity of interest.***
  - ***For sources of different types (such as dc and ac, which affect the parameters of the network in a different manner) and apply a separate analysis for each type, with the total result simply the algebraic sum of the results.***

SUPERPOSITION THEOREM

- The superposition theorem states the following:
  - ***The current through, or voltage across, any element of a network is equal to the algebraic sum of the currents or voltages produced independently by each source.***

LOGO

SUPERPOSITION THEOREM

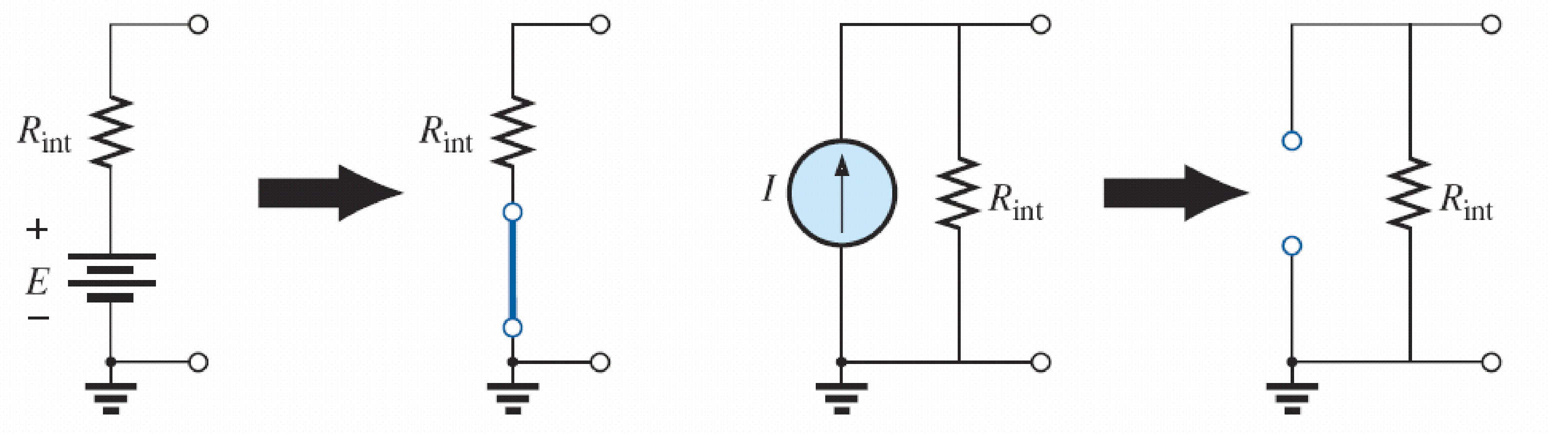

FIG. 9.1 *Removing a voltage source and a current source to permit the application of the superposition theorem.*

SUPERPOSITION THEOREM

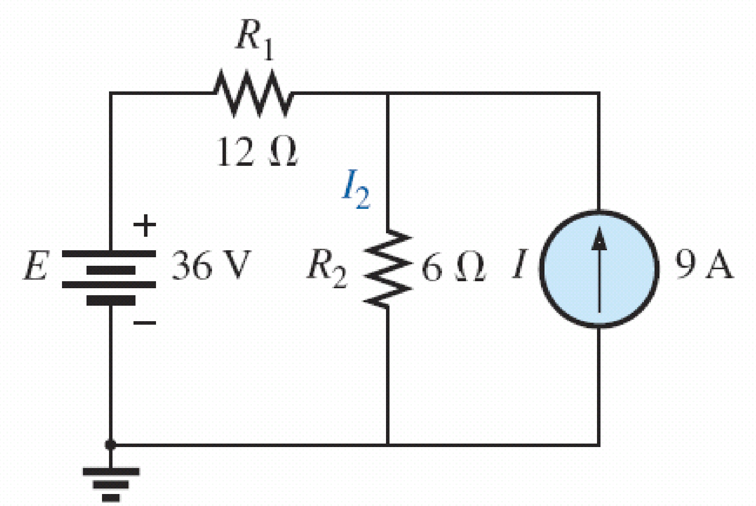

FIG. 9.2 *Network to be analyzed in Example 9.1 using the superposition theorem.*

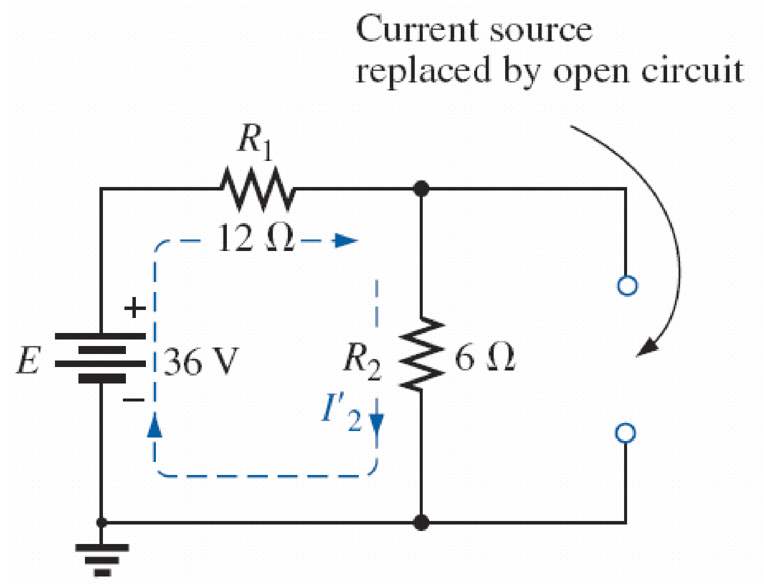

FIG. 9.3 *Replacing the 9 A current source in Fig. 9.2 by an open circuit to determine the effect of the 36 V voltage source on current I_2.*

LOGO

SUPERPOSITION THEOREM

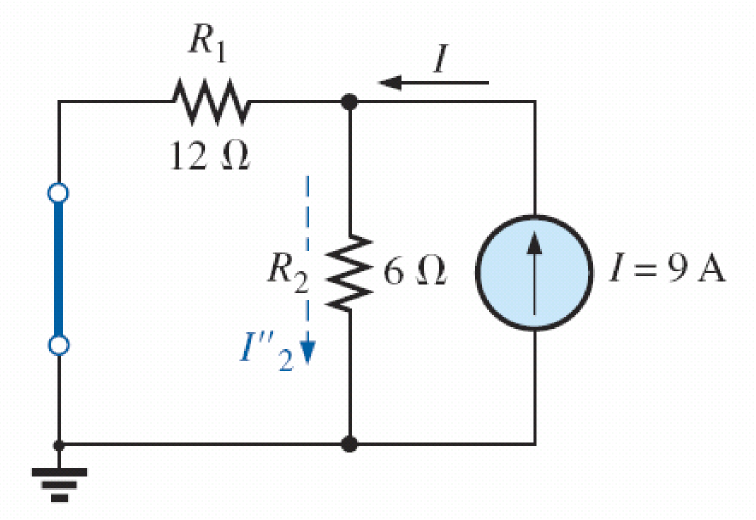

FIG. 9.4 *Replacing the 36 V voltage source by a short-circuit equivalent to determine the effect of the 9 A current source on current I_2.*

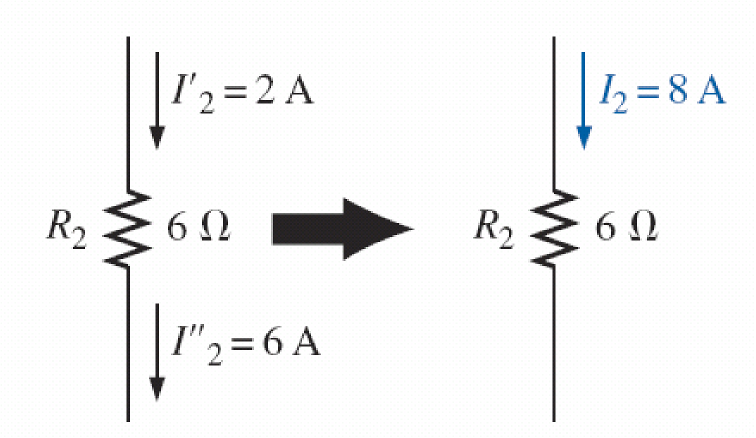

FIG. 9.5 *Using the results of Figs. 9.3 and 9.4 to determine current I_2 for the network in Fig. 9.2.*

LOGO

SUPERPOSITION THEOREM

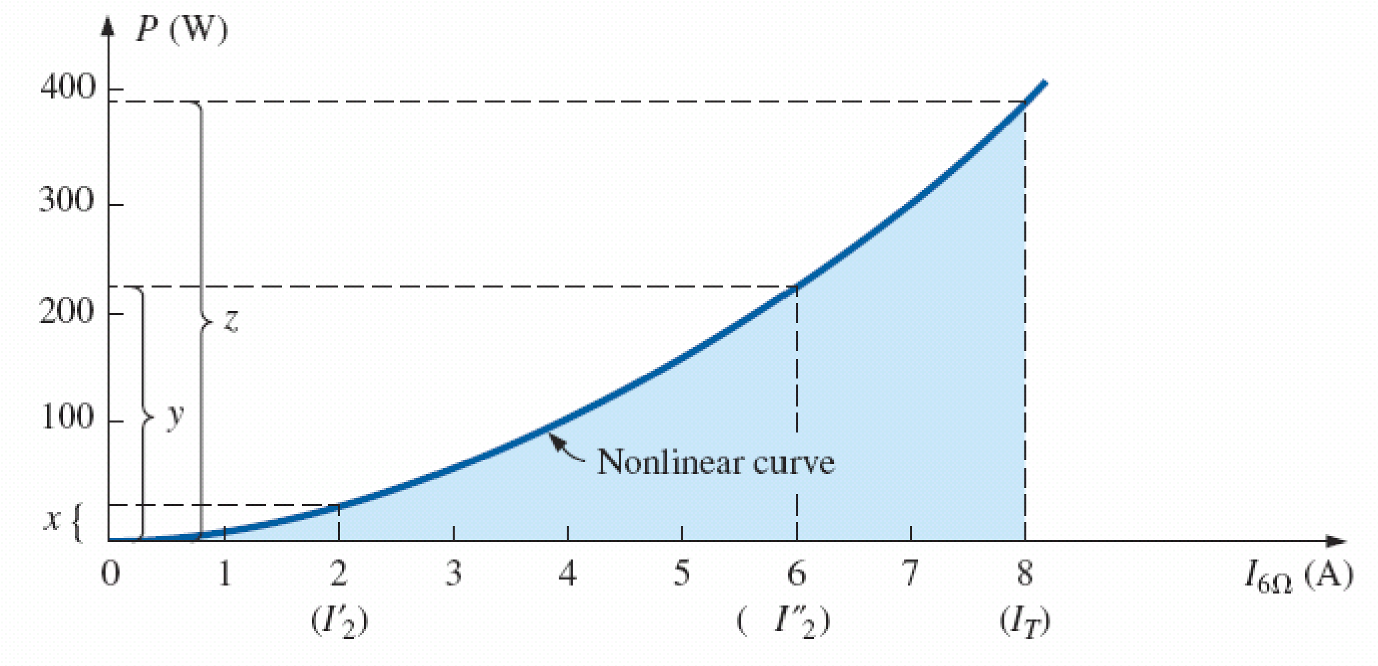

FIG. 9.6 *Plotting power delivered to the 6Ω resistor versus current through the resistor.*

LOGO

SUPERPOSITION THEOREM

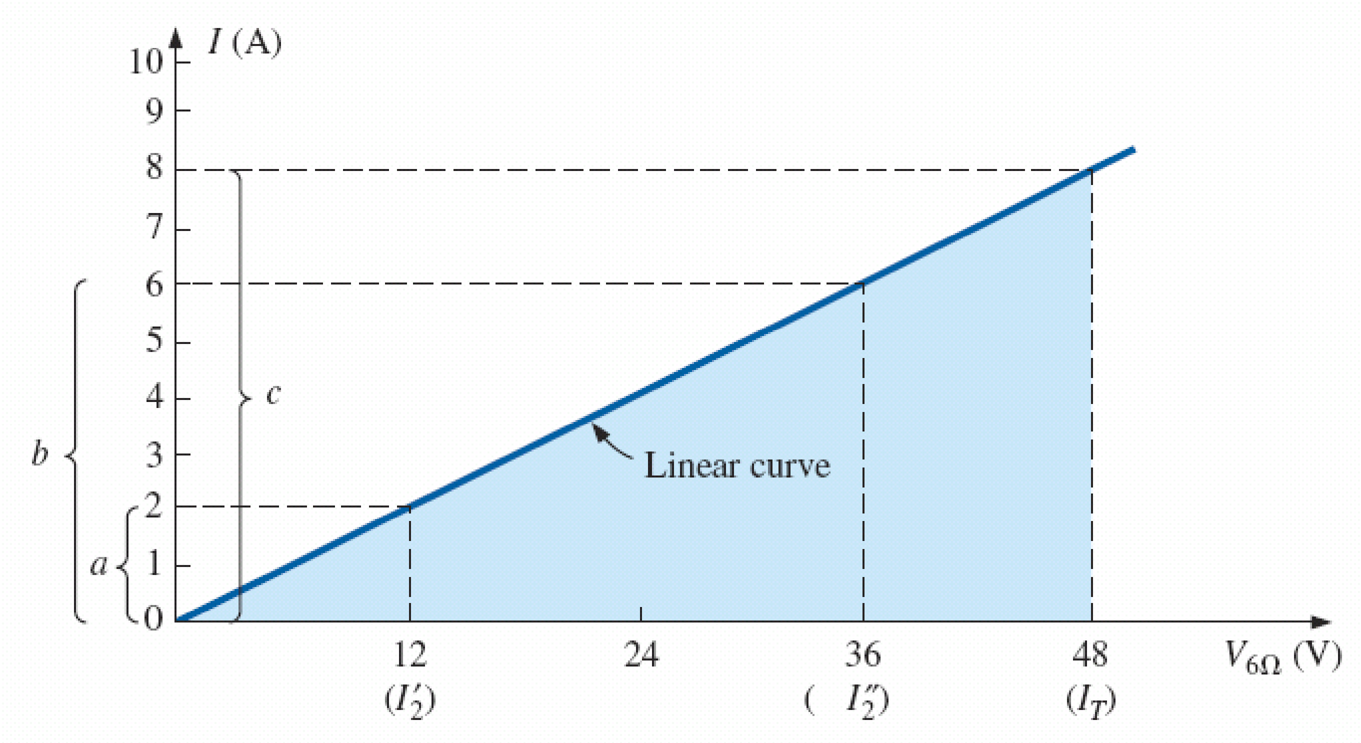

FIG. 9.7 *Plotting I versus V for the 6Ω resistor.*

LOGO

SUPERPOSITION THEOREM

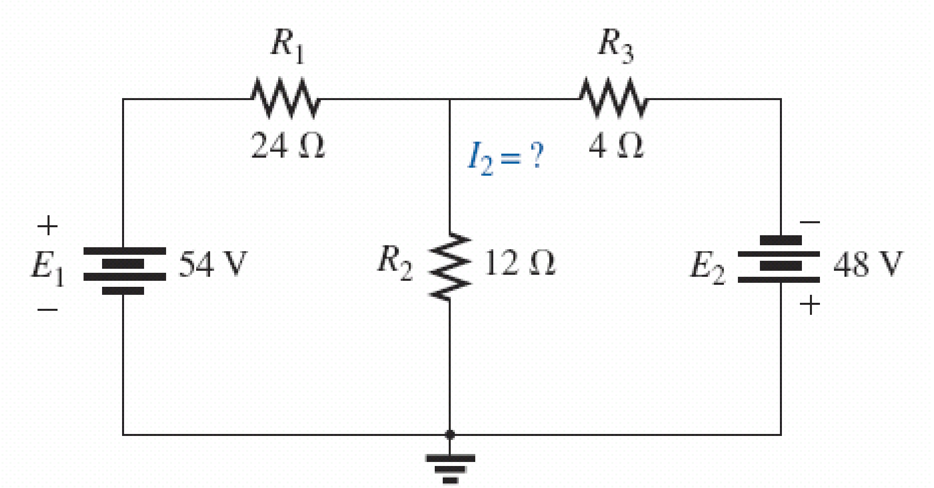

FIG. 9.8 *Using the superposition theorem to determine the current through the* 12Ω *resistor (Example 9.2).*

LOGO

SUPERPOSITION THEOREM

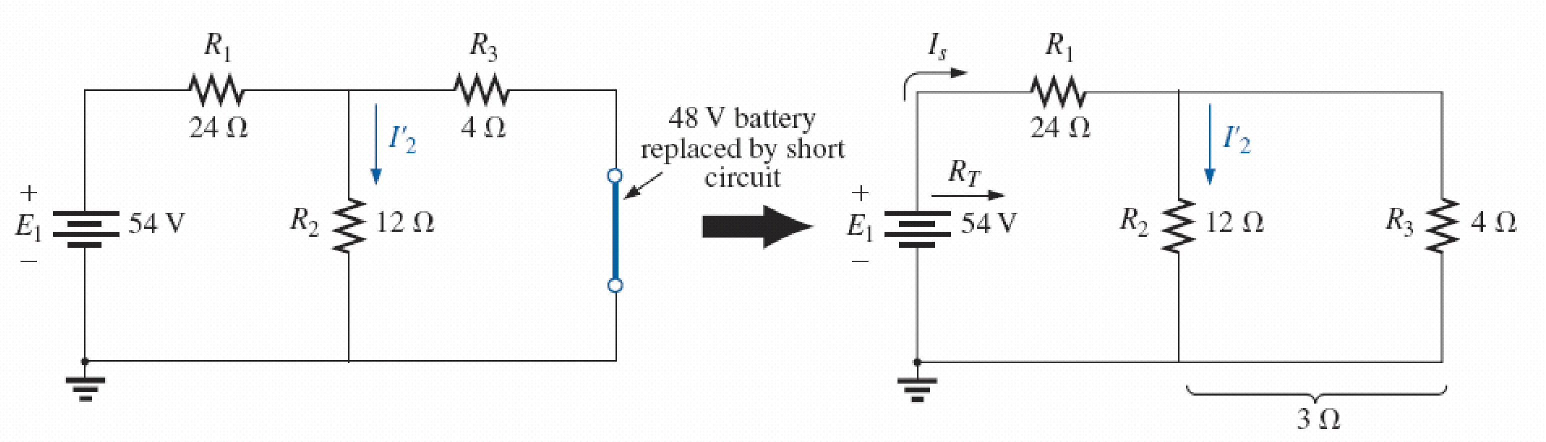

FIG. 9.9 *Using the superposition theorem to determine the effect of the 54 V voltage source on current I2 in Fig. 9.8.*

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SUPERPOSITION THEOREM

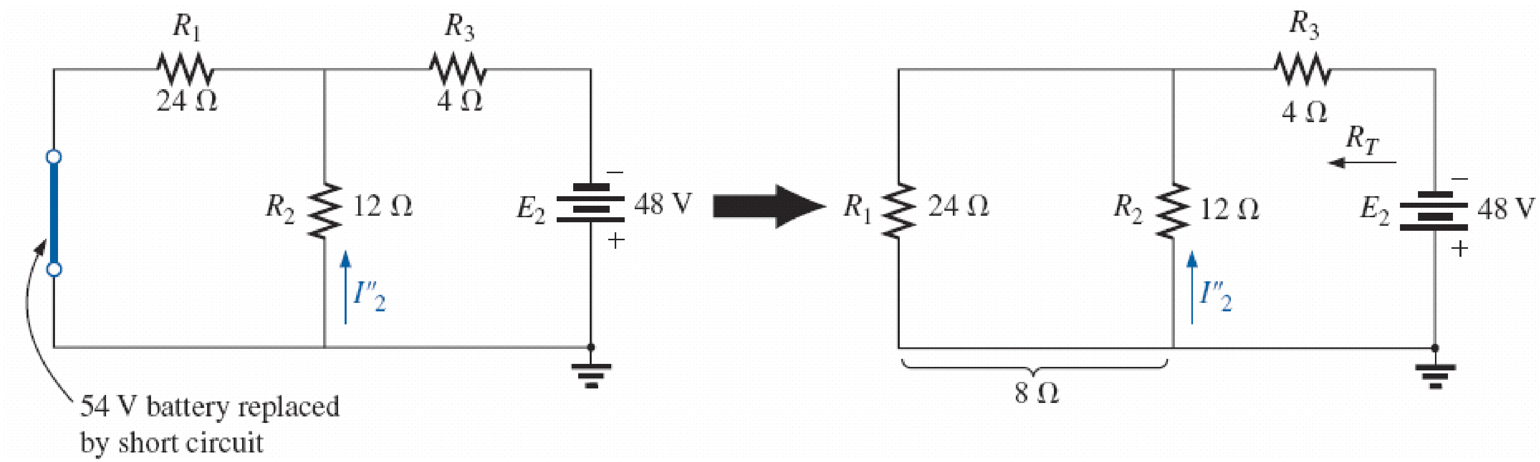

FIG. 9.10 *Using the superposition theorem to determine the effect of the 48 V voltage source on current I_2 in Fig. 9.8.*

LOGO

SUPERPOSITION THEOREM

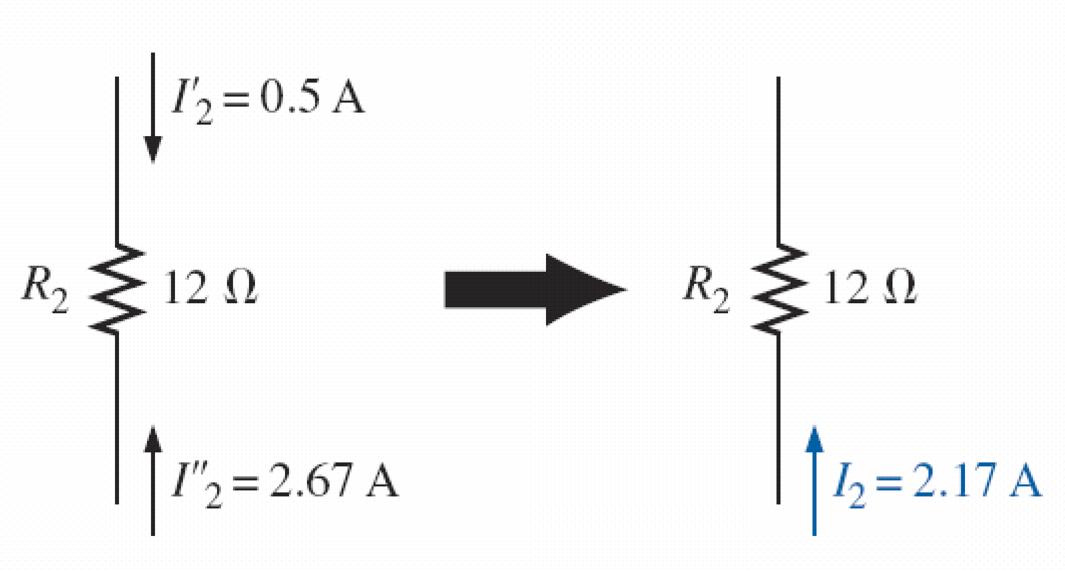

FIG. 9.11 *Using the results of Figs. 9.9 and 9.10 to determine current I2 for the network in Fig. 9.8.*

LOGO

SUPERPOSITION THEOREM

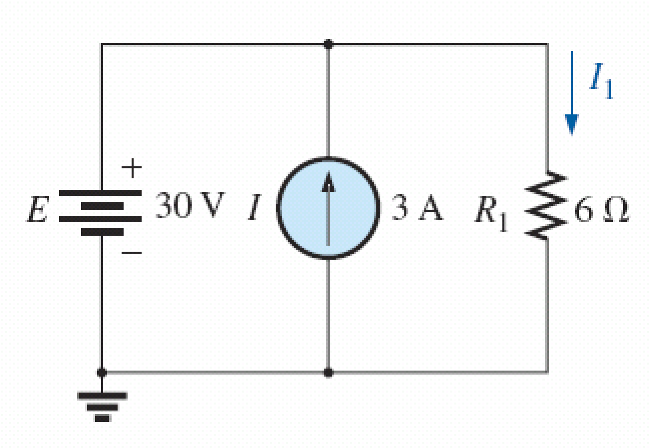

FIG. 9.12 *Two-source network to be analyzed using the superposition theorem in Example 9.3.*

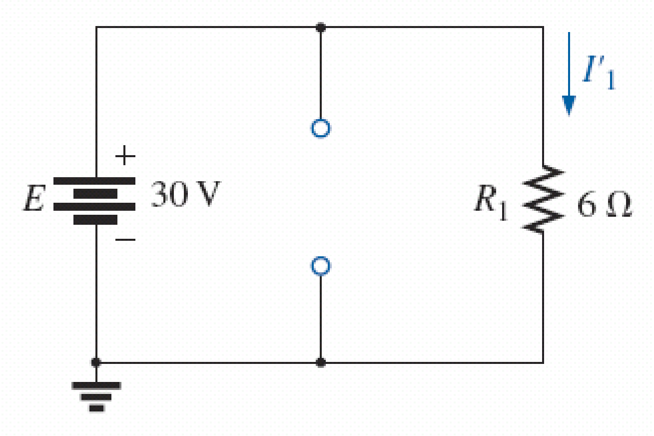

FIG. 9.13 *Determining the effect of the 30 V supply on the current I_1 in Fig. 9.12.*

LOGO

SUPERPOSITION THEOREM

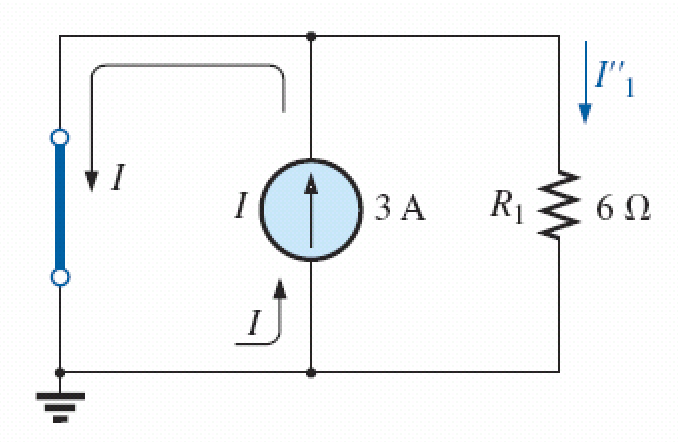

FIG. 9.14 *Determining the effect of the 3 A current source on the current I_1 in Fig. 9.12.*

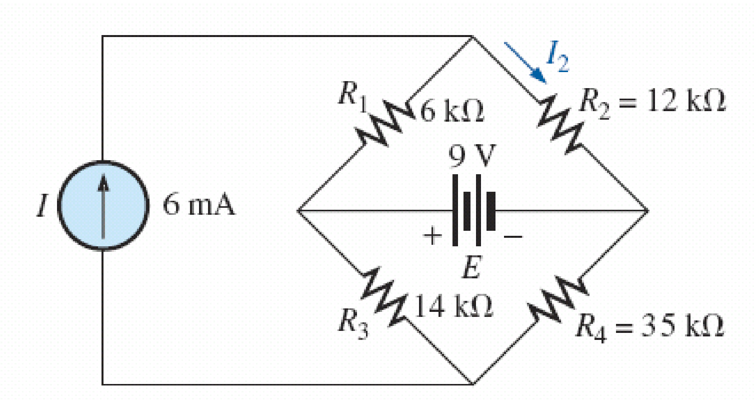

FIG. 9.15 *Example 9.4.*

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SUPERPOSITION THEOREM

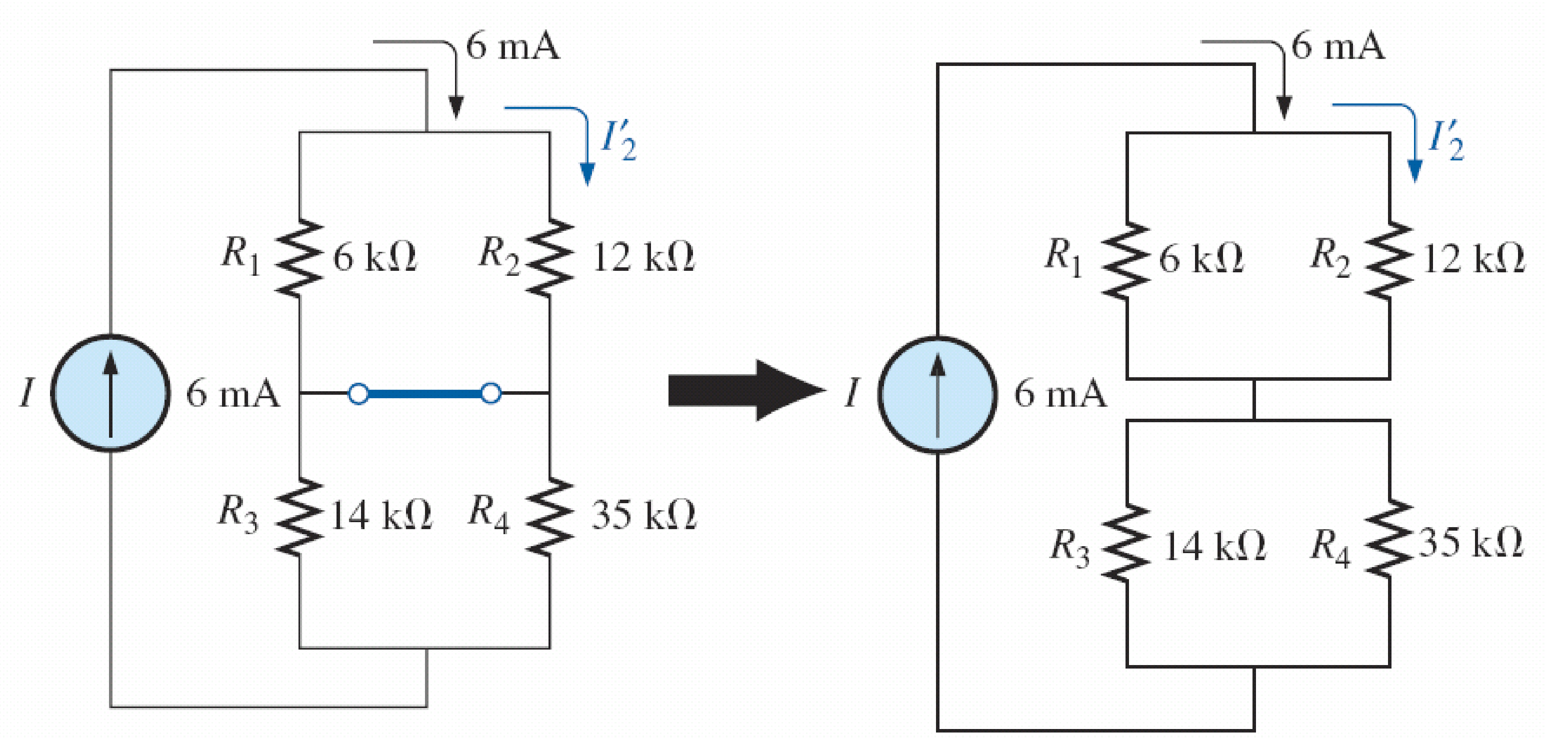

FIG. 9.16 *The effect of the current source I on the current I_2.*

LOGO

SUPERPOSITION THEOREM

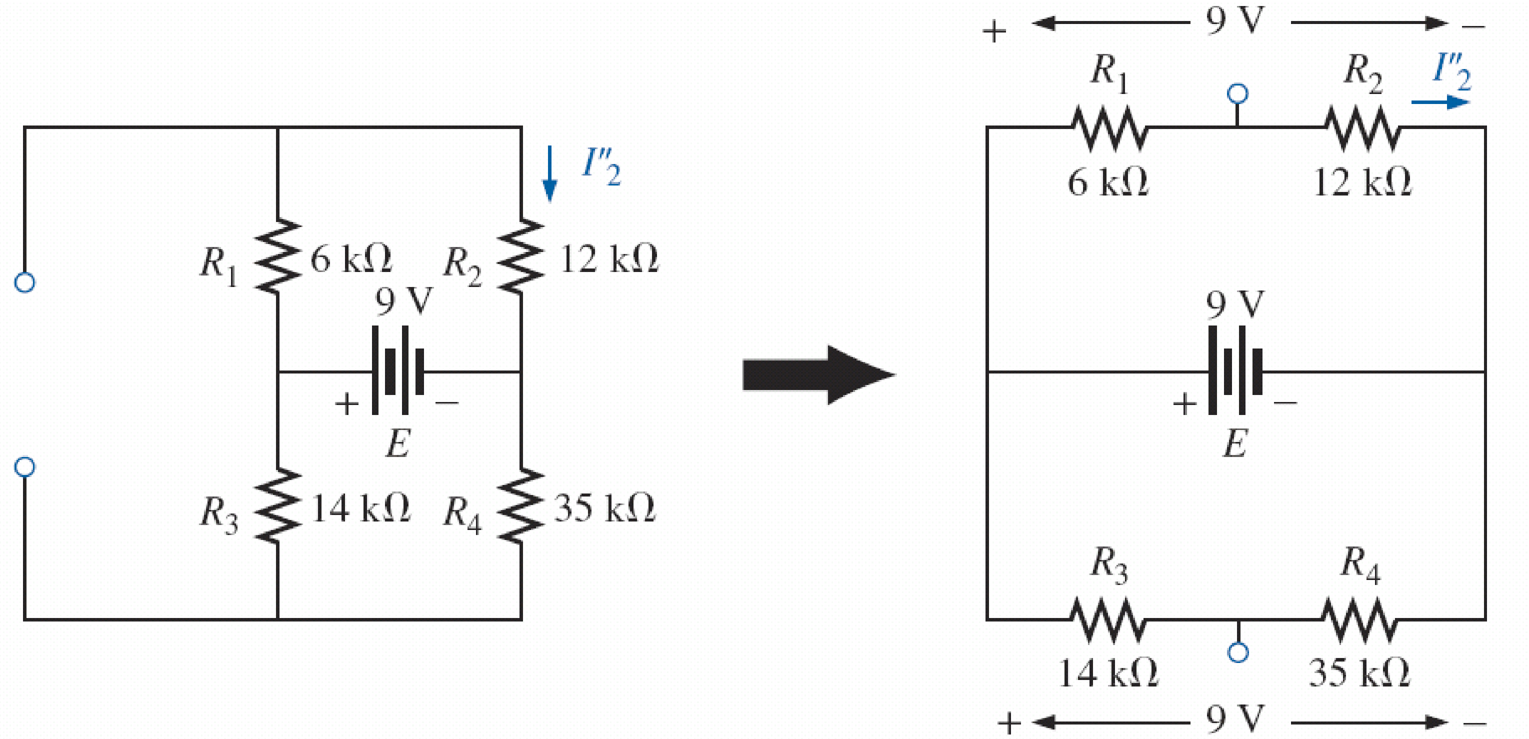

FIG. 9.17 *The effect of the voltage source E on the current I_2.*

LOGO

SUPERPOSITION THEOREM

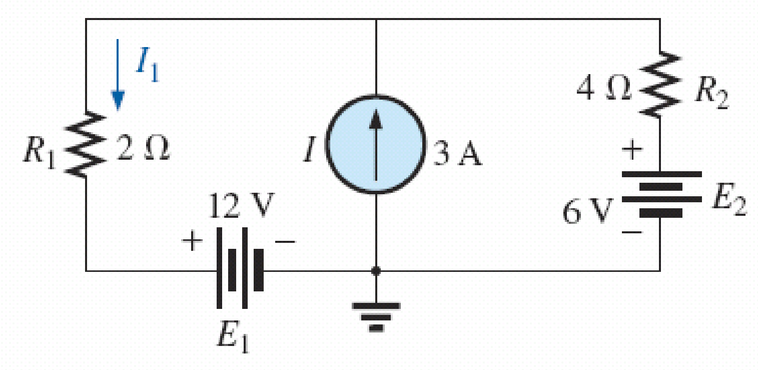

FIG. 9.18 *Example 9.5.*

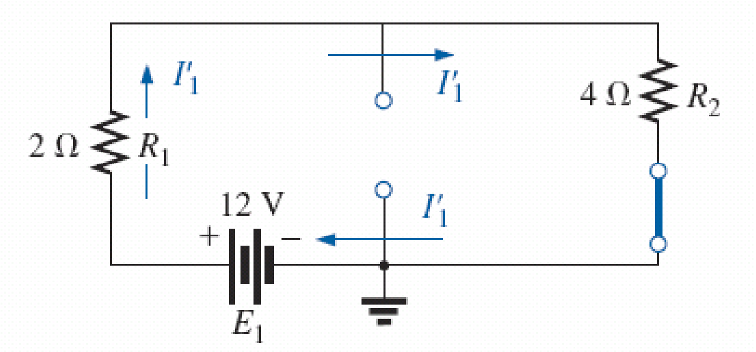

FIG. 9.19 *The effect of E_1 on the current I.*

LOGO

SUPERPOSITION THEOREM

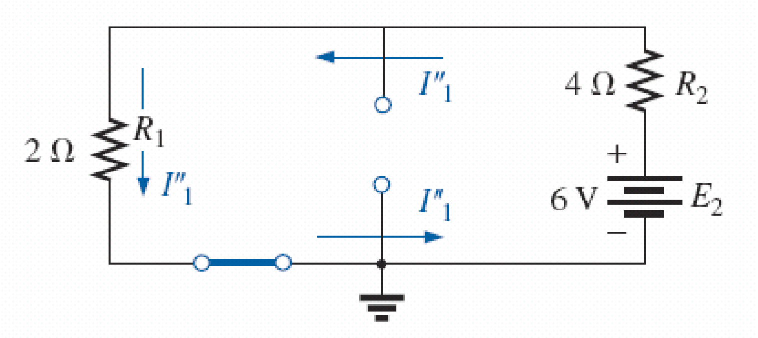

FIG. 9.20 *The effect of E_2 on the current I_1.*

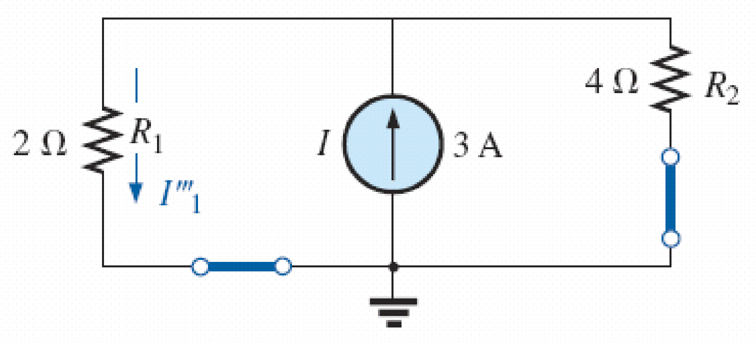

FIG. 9.21 *The effect of I on the current I_1*

LOGO

SUPERPOSITION THEOREM

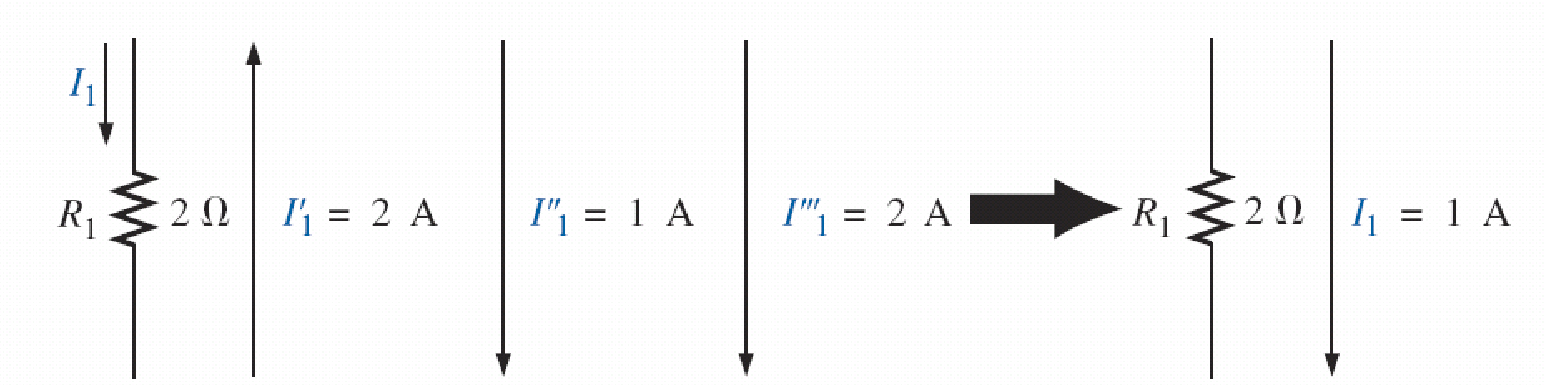

FIG. 9.22 *The resultant current* I_1.

LOGO

THÉVENIN’S THEOREM

- The next theorem to be introduced, **Thévenin’s theorem,** is probably one of the most interesting in that it permits the reduction of complex networks to a simpler form for analysis and design.

LOGO

THÉVENIN'S THEOREM

- In general, the theorem can be used to do the following:
  - ***Analyze networks with sources that are not in series or parallel.***
  - ***Reduce the number of components required to establish the same characteristics at the output terminals.***
  - ***Investigate the effect of changing a particular component on the behavior of a network without having to analyze the entire network after each change.***

LOGO

THÉVENIN'S THEOREM

- Thévenin's theorem states the following:
  - ***Any two-terminal dc network can be replaced by an equivalent circuit consisting solely of a voltage source and a series resistor as shown in Fig. 9.23.***

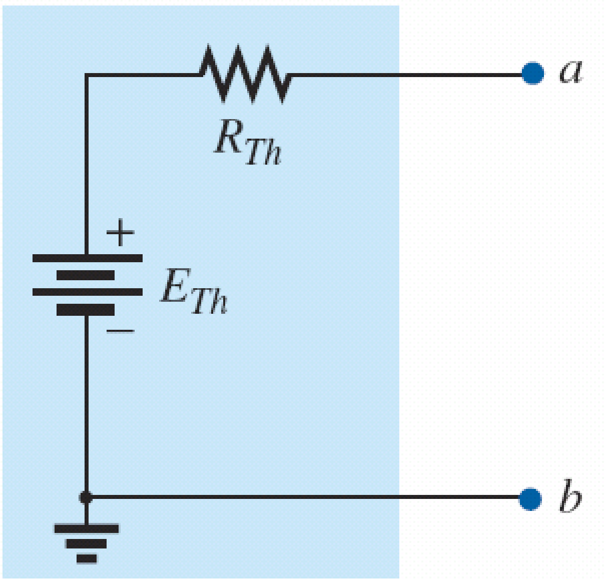

FIG. 9.23 *Thévenin equivalent circuit.*

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THÉVENIN'S THEOREM

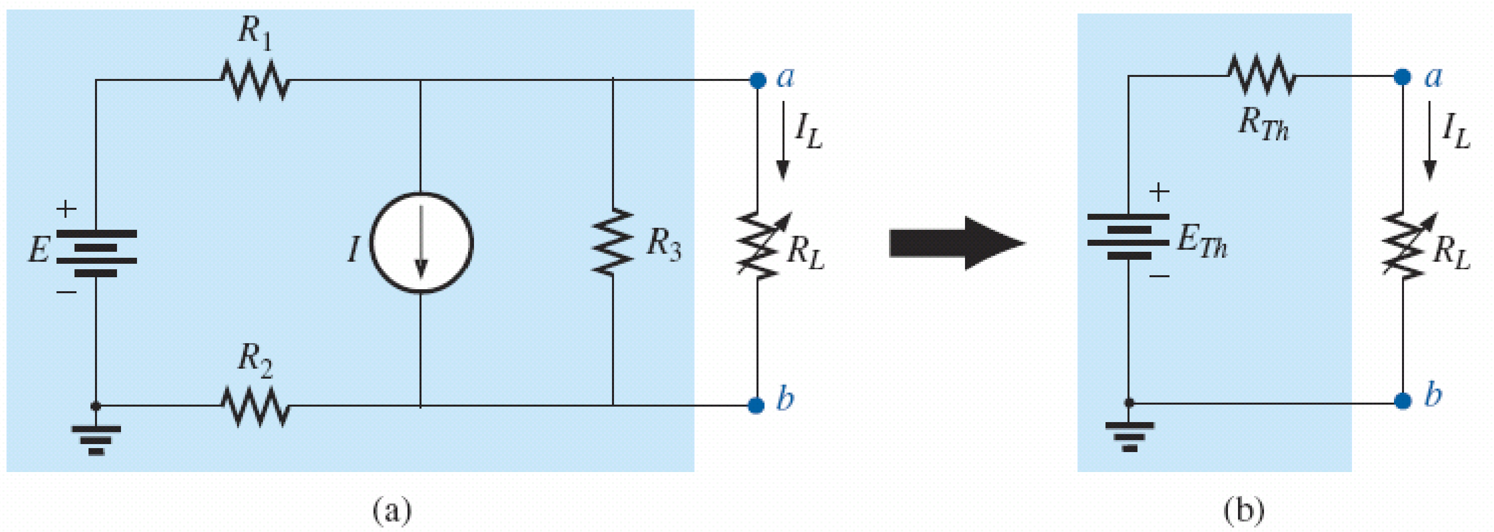

FIG. 9.25 *Substituting the Thévenin equivalent circuit for a complex network.*

LOGO

THÉVENIN'S THEOREM

Thévenin's Theorem Procedure

- *Preliminary:*

1. *Remove that portion of the network where the Thévenin equivalent circuit is found. In Fig. 9.25(a), this requires that the load resistor RL be temporarily removed from the network.*
2. *Mark the terminals of the remaining two-terminal network. (The importance of this step will become obvious as we progress through some complex networks.)*

THÉVENIN'S THEOREM

Thévenin's Theorem Procedure

- *R_{Th}:*
  - *3. Calculate R_{Th} by first setting all sources to zero (voltage sources are replaced by short circuits and current sources by open circuits) and then finding the resultant resistance between the two marked terminals. (If the internal resistance of the voltage and/or current sources is included in the original network, it must remain when the sources are set to zero.)*

LOGO

THÉVENIN'S THEOREM

Thévenin's Theorem Procedure

- ***E_{Th}:***
  - ***4. Calculate E_{Th} by first returning all sources to their original position and finding the open-circuit voltage between the marked terminals. (This step is invariably the one that causes most confusion and errors. In all cases, keep in mind that it is the opencircuit potential between the two terminals marked in step 2.)***

THÉVENIN'S THEOREM

Thévenin's Theorem Procedure

- ***Conclusion:***
  - ***5. Draw the Thévenin equivalent circuit with the portion of the circuit previously removed replaced between the terminals of the equivalent circuit. This step is indicated by the placement of the resistor R_L between the terminals of the Thévenin equivalent circuit as shown in Fig. 9.25(b).***

LOGO

THÉVENIN'S THEOREM

Thévenin's Theorem Procedure

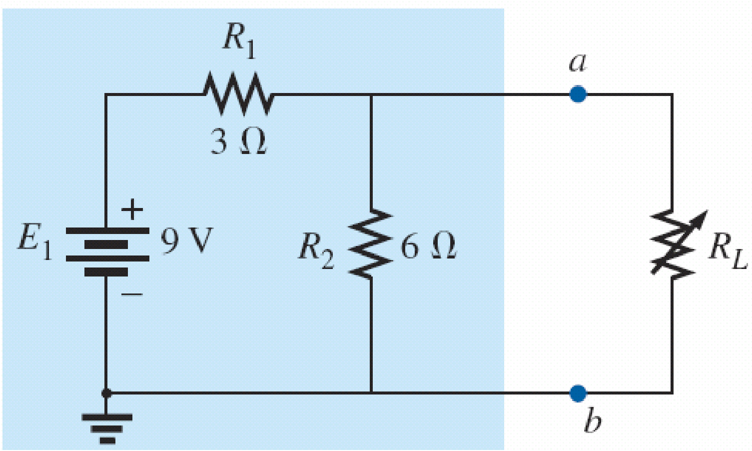

FIG. 9.26 *Example 9.6.*

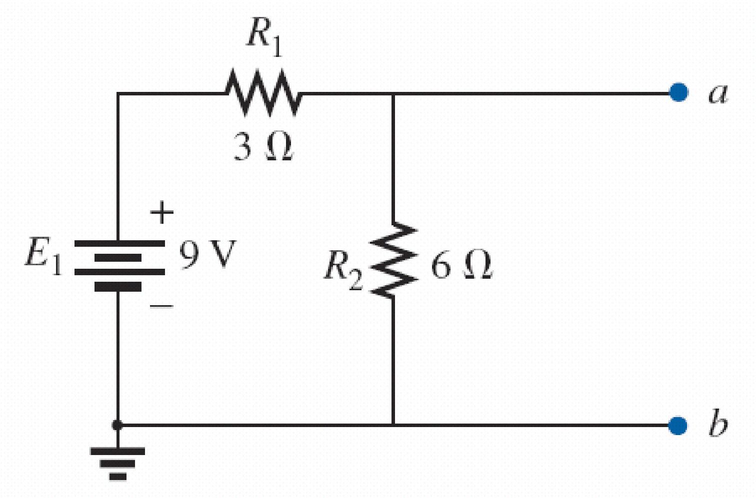

FIG. 9.27 *Identifying the terminals of particular importance when applying Thévenin's theorem.*

LOGO

THÉVENIN'S THEOREM

Thévenin's Theorem Procedure

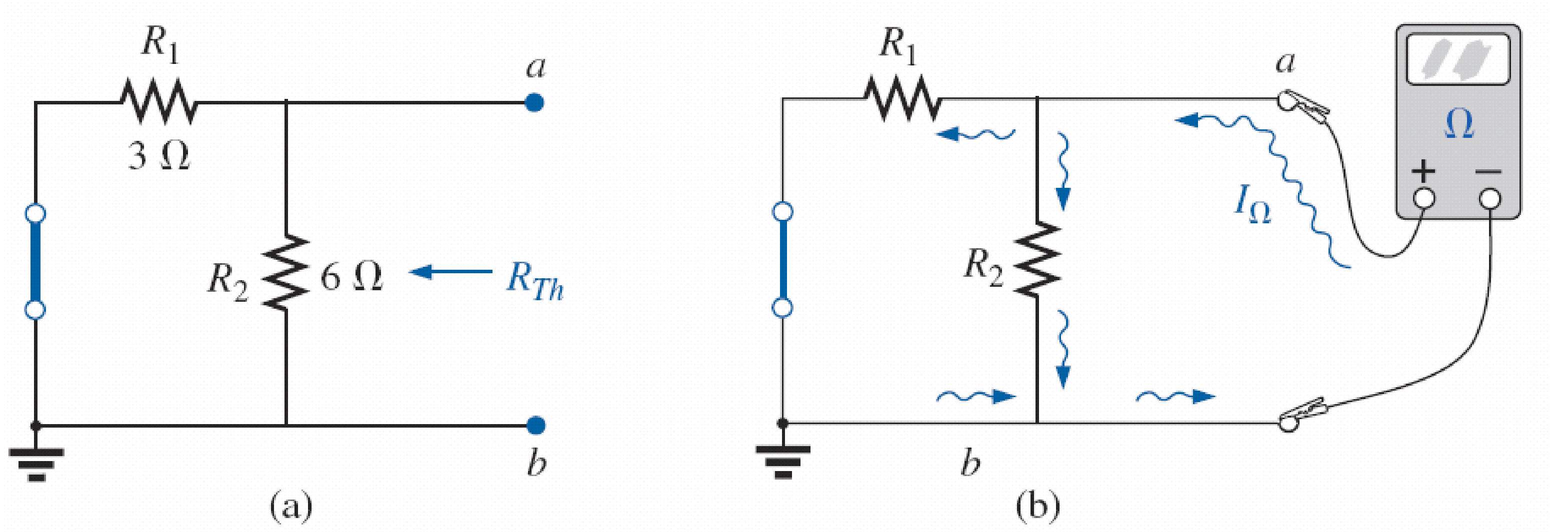

FIG. 9.28 *Determining R_{Th} for the network in Fig. 9.27.*

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THÉVENIN'S THEOREM

Thévenin's Theorem Procedure

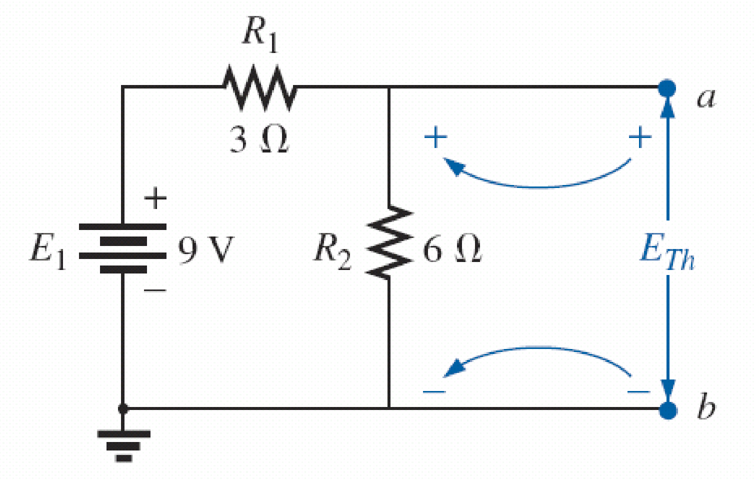

FIG. 9.29 *Determining E_{Th} for the network in Fig. 9.27.*

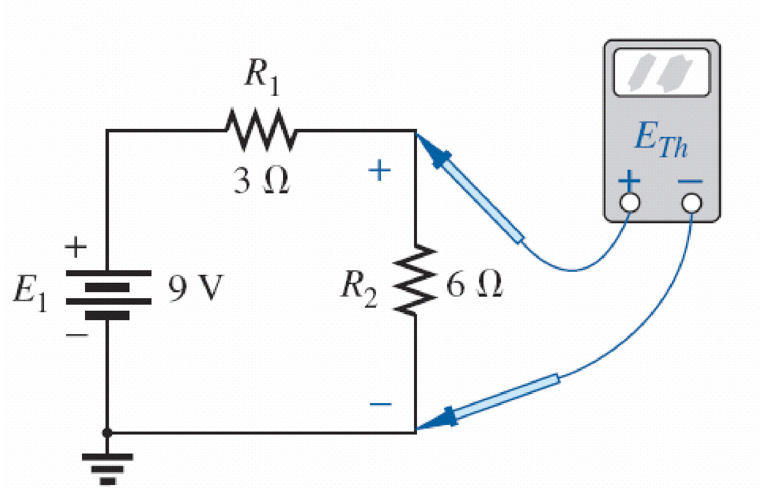

FIG. 9.30 *Measuring E_{Th} for the network in Fig. 9.27.*

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THÉVENIN'S THEOREM

Thévenin's Theorem Procedure

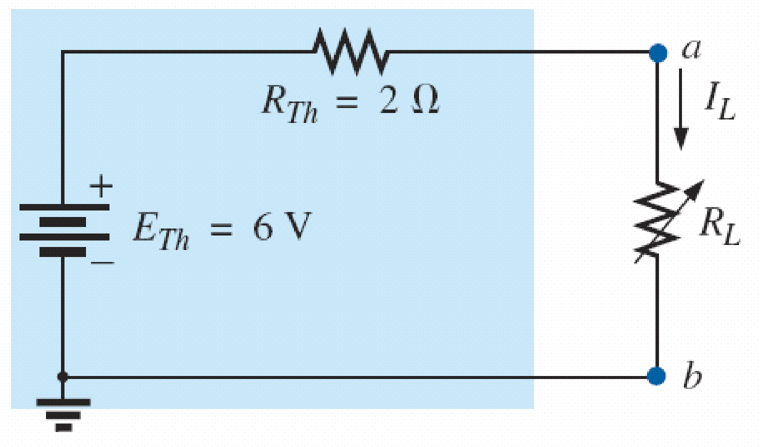

FIG. 9.31 *Substituting the Thévenin equivalent circuit for the network external to R_L in Fig. 9.26.*

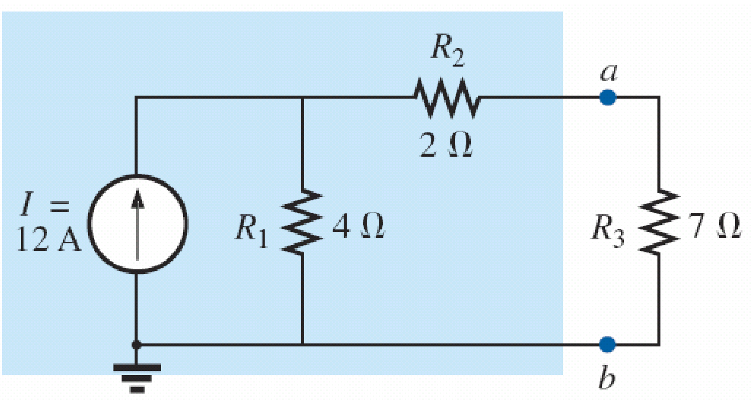

FIG. 9.32 *Example 9.7.*

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THÉVENIN'S THEOREM

Thévenin's Theorem Procedure

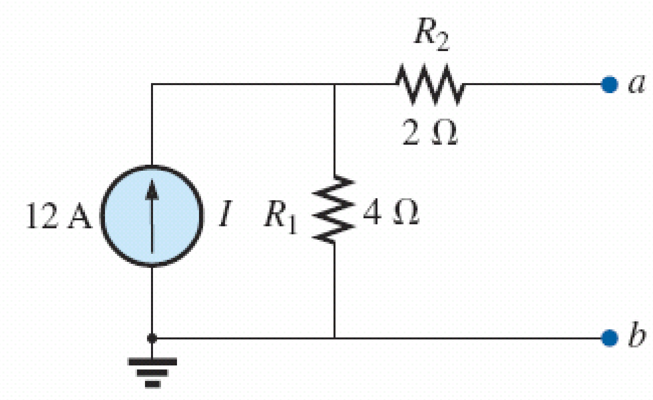

FIG. 9.33 *Establishing the terminals of particular interest for the network in Fig. 9.32.*

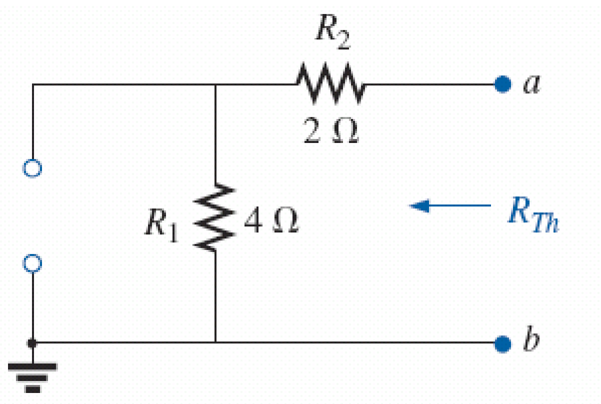

FIG. 9.34 *Determining R_{Th} for the network in Fig. 9.33.*

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THÉVENIN'S THEOREM

Thévenin's Theorem Procedure

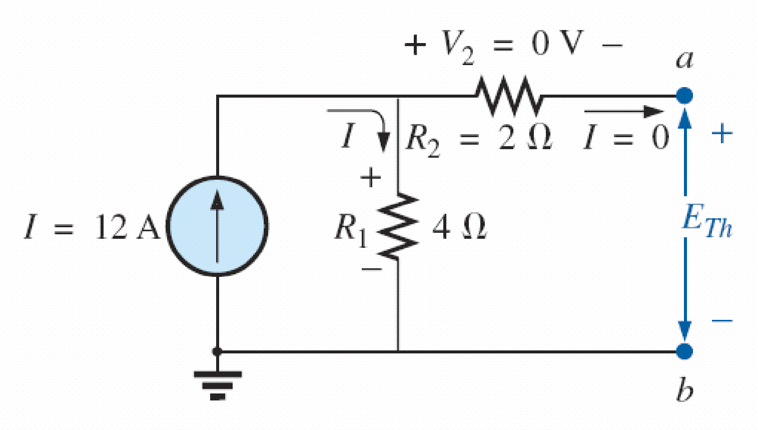

FIG. 9.35 *Determining E_{Th} for the network in Fig. 9.33.*

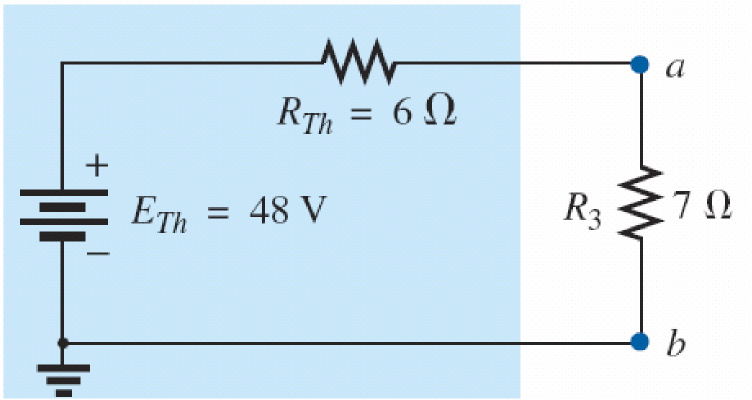

FIG. 9.36 *Substituting the Thévenin equivalent circuit in the network external to the resistor R_3 in Fig. 9.32.*

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THÉVENIN'S THEOREM

Thévenin's Theorem Procedure

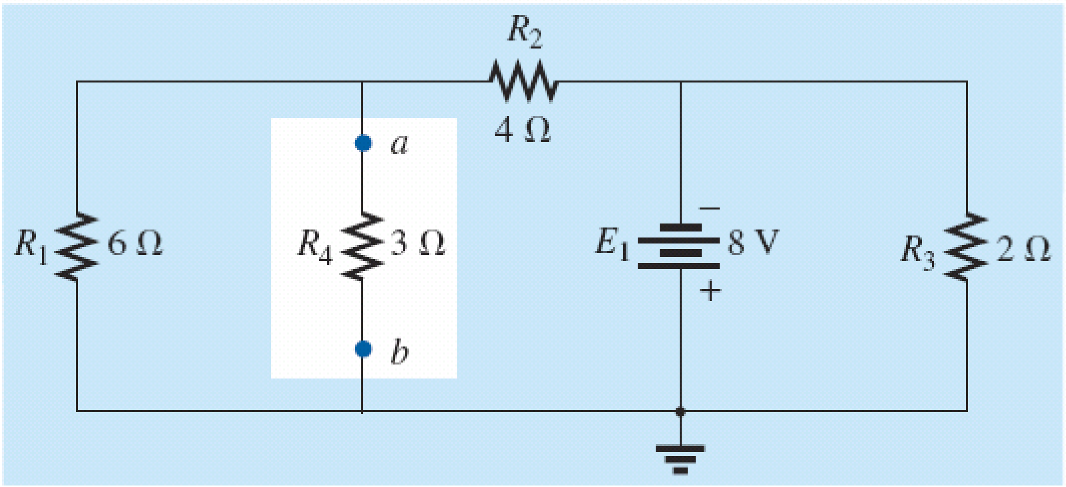

FIG. 9.37 *Example 9.8.*

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THÉVENIN'S THEOREM

Thévenin's Theorem Procedure

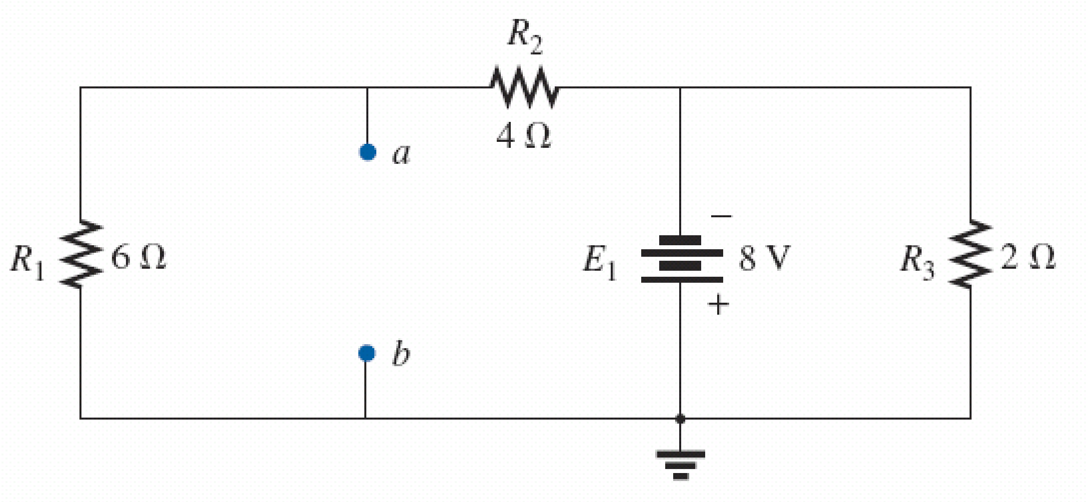

FIG. 9.38 *Identifying the terminals of particular interest for the network in Fig. 9.37.*

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THÉVENIN'S THEOREM

Thévenin's Theorem Procedure

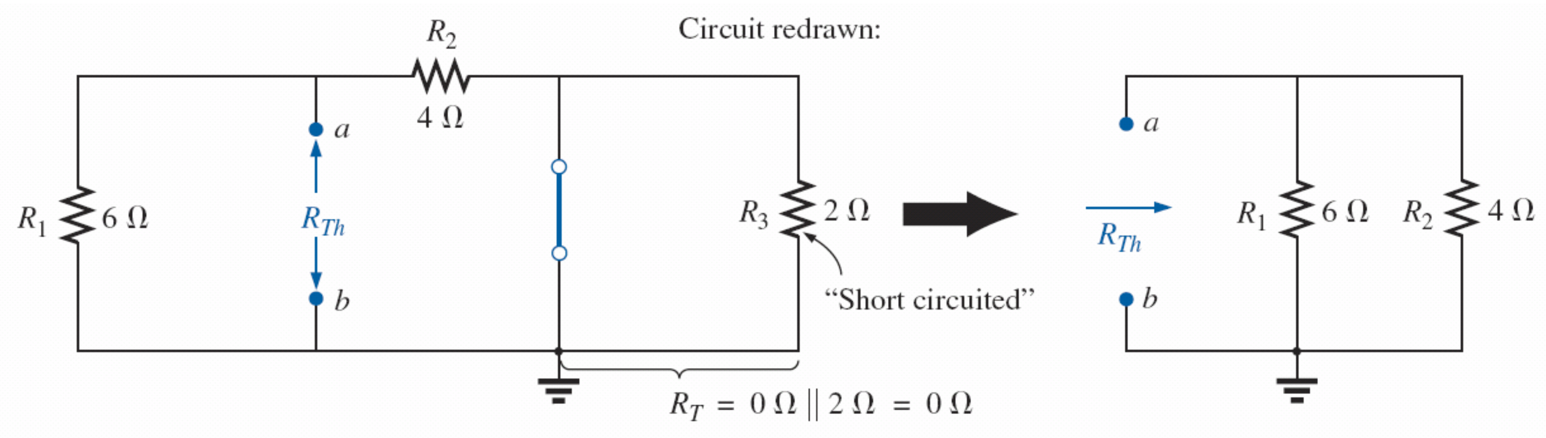

FIG. 9.39 *Determining R_{Th} for the network in Fig. 9.38.*

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THÉVENIN'S THEOREM

Thévenin's Theorem Procedure

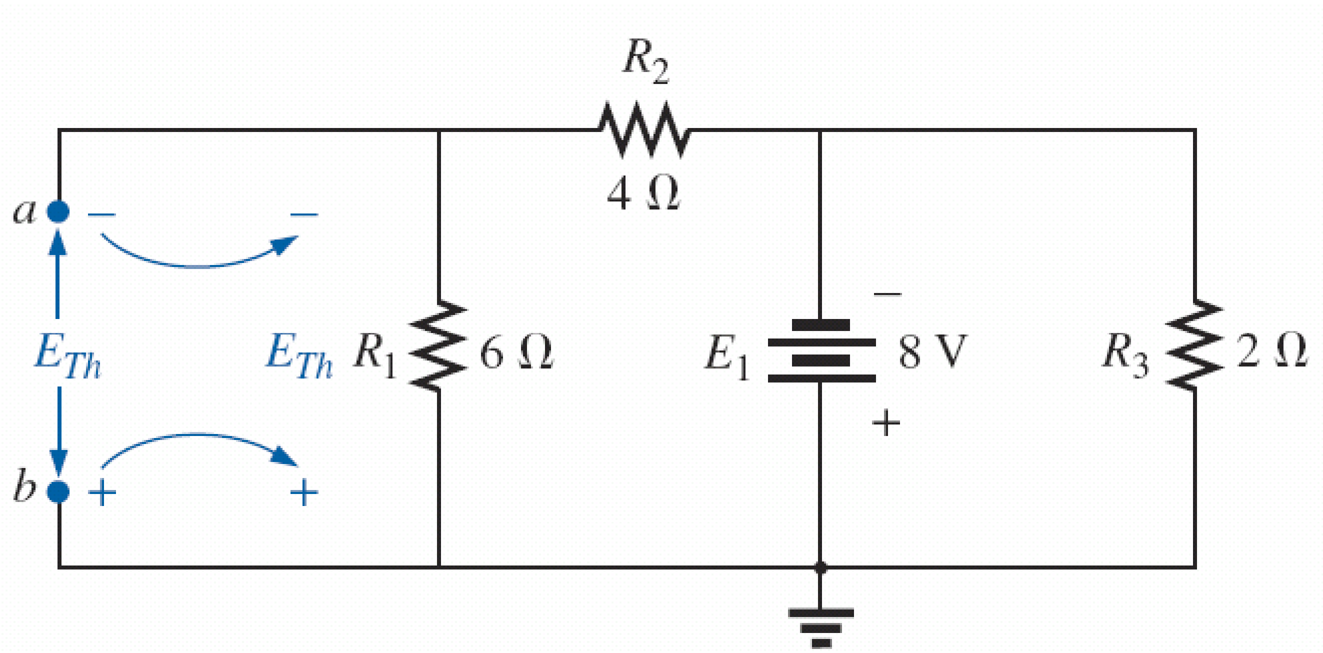

FIG. 9.40 *Determining E_{Th} for the network in Fig. 9.38.*

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THÉVENIN'S THEOREM

Thévenin's Theorem Procedure

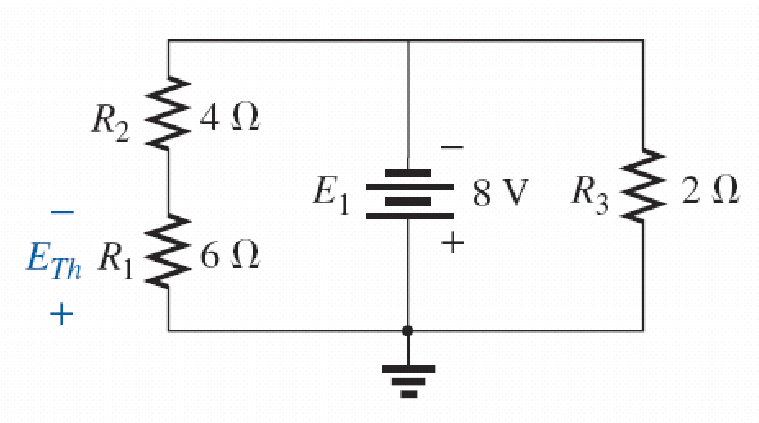

FIG. 9.41 *Network of Fig. 9.40 redrawn.*

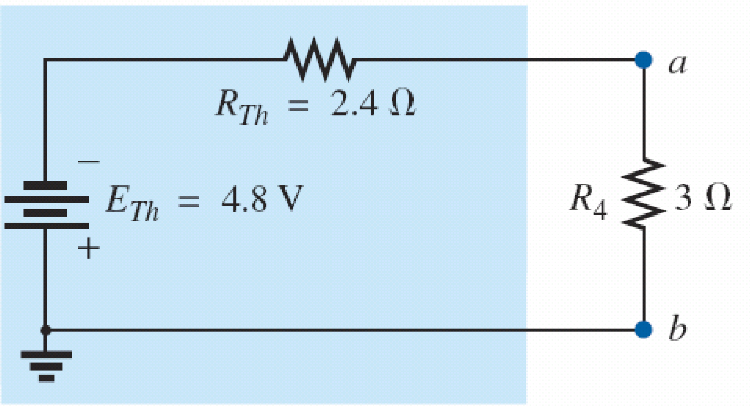

FIG. 9.42 *Substituting the Thévenin equivalent circuit for the network external to the resistor R_4 in Fig. 9.37.*

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THÉVENIN'S THEOREM

Thévenin's Theorem Procedure

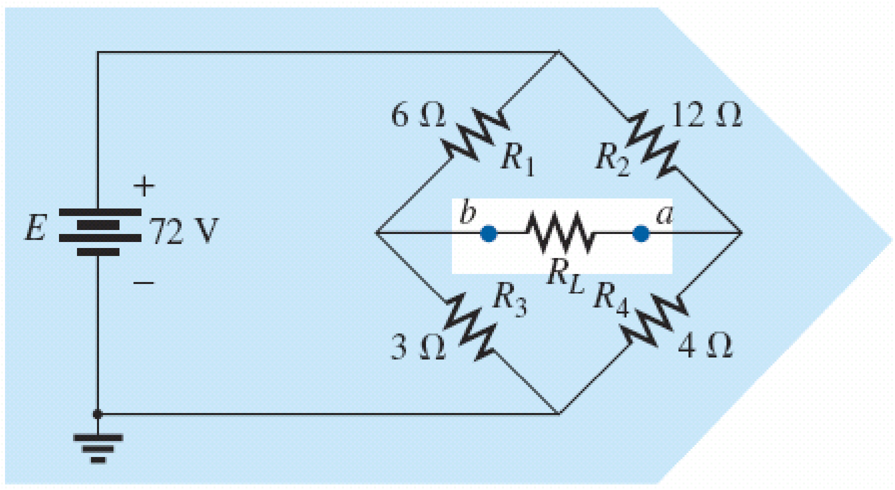

FIG. 9.43 *Example 9.9.*

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THÉVENIN'S THEOREM

Thévenin's Theorem Procedure

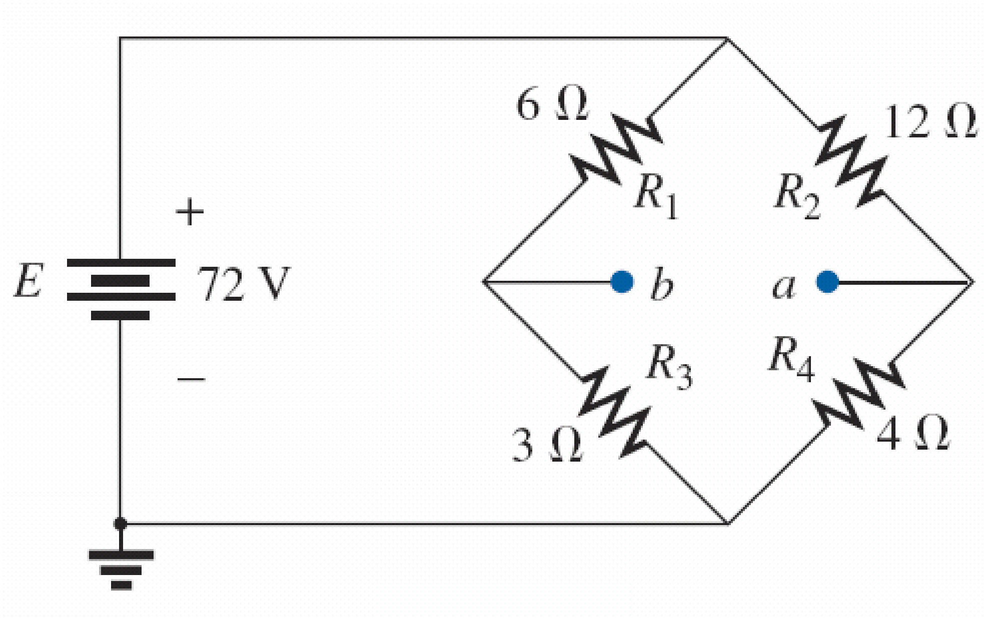

FIG. 9.44 *Identifying the terminals of particular interest for the network in Fig. 9.43.*

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THÉVENIN'S THEOREM

Thévenin's Theorem Procedure

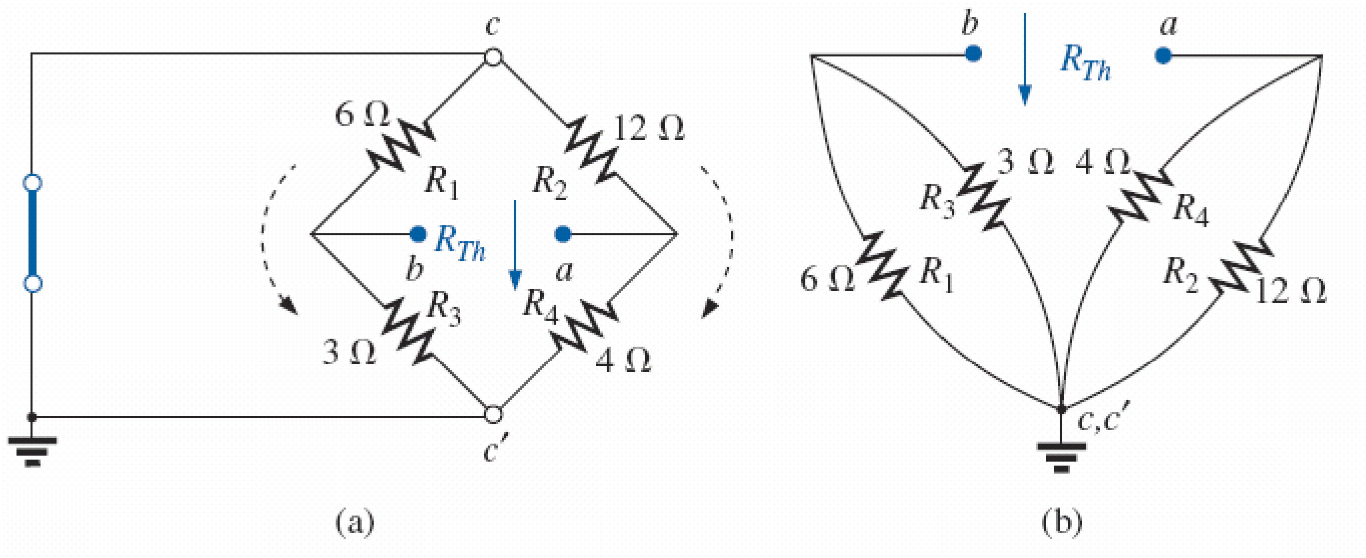

FIG. 9.45 *Solving for R_{Th} for the network in Fig. 9.44.*

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THÉVENIN'S THEOREM

Thévenin's Theorem Procedure

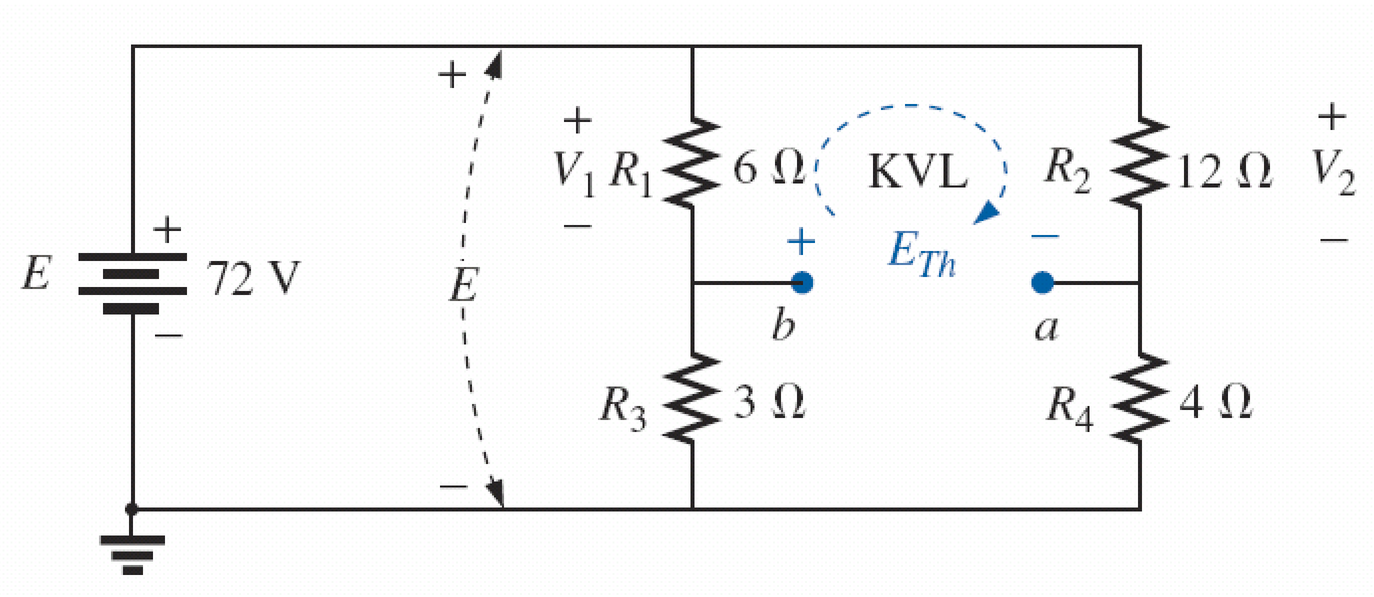

FIG. 9.46 *Determining E_{Th} for the network in Fig. 9.44.*

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THÉVENIN'S THEOREM

Thévenin's Theorem Procedure

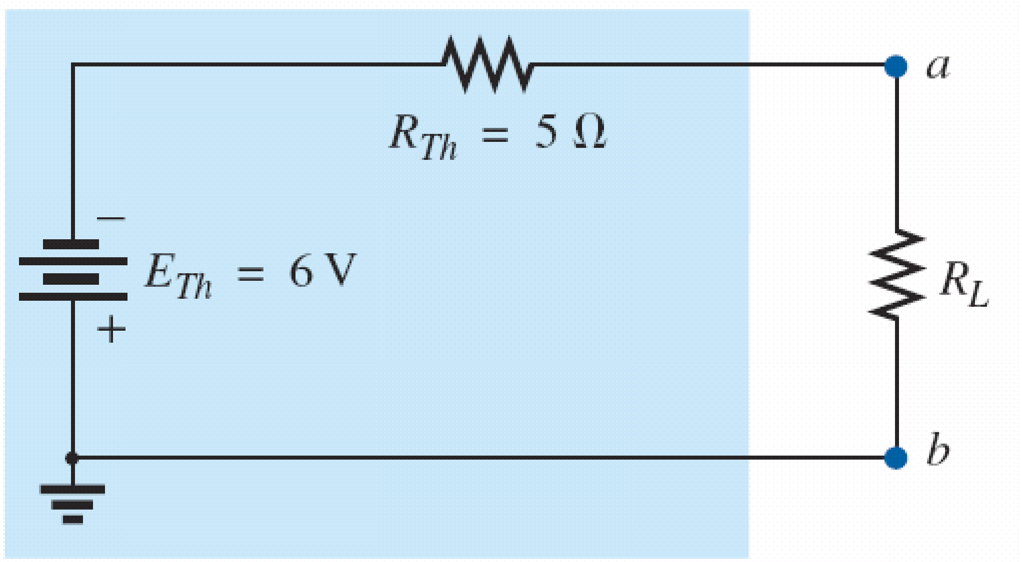

FIG. 9.47 *Substituting the Thévenin equivalent circuit for the network external to the resistor RL in Fig. 9.43.*

LOGO

THÉVENIN'S THEOREM

Thévenin's Theorem Procedure

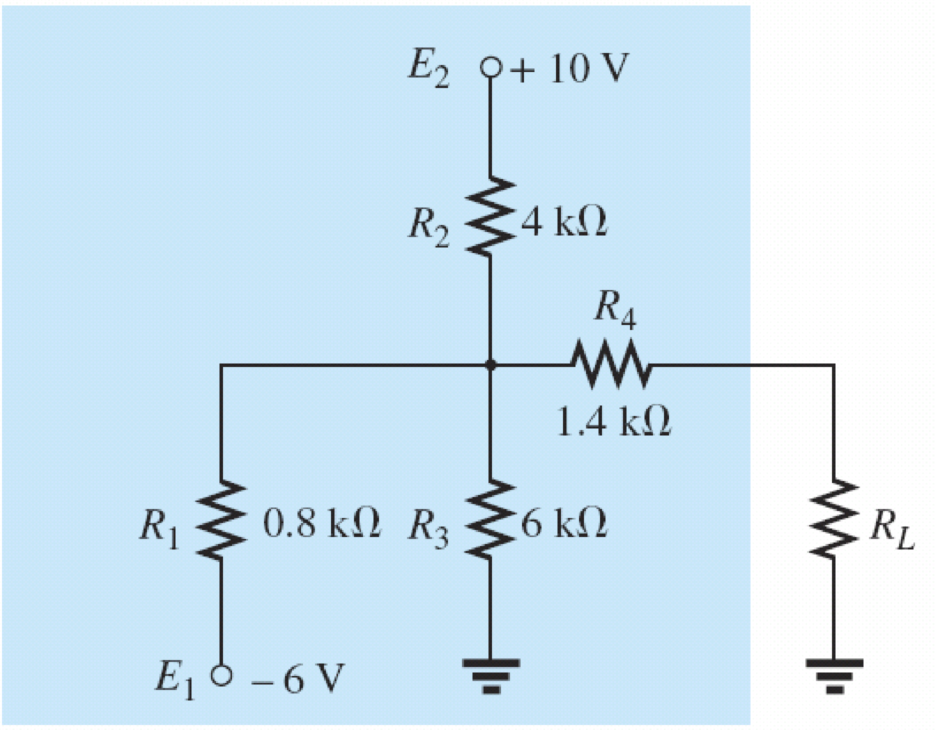

FIG. 9.48 *Example 9.10.*

LOGO

THÉVENIN'S THEOREM

Thévenin's Theorem Procedure

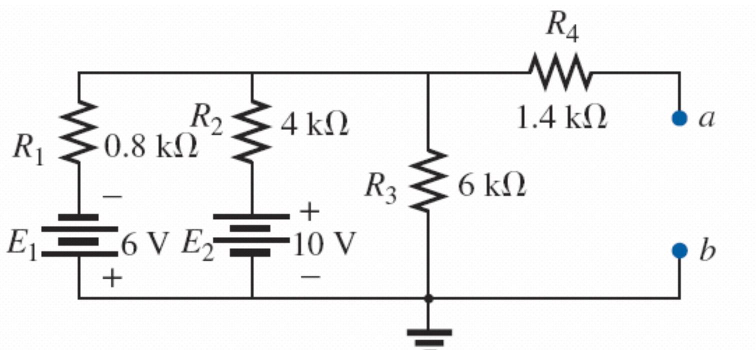

FIG. 9.49 *Identifying the terminals of particular interest for the network in Fig. 9.48.*

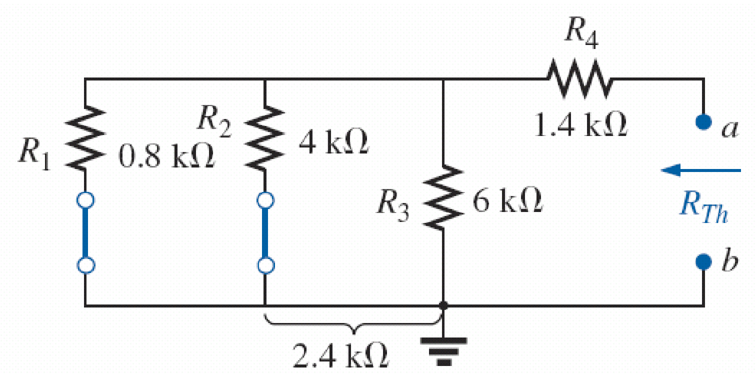

FIG. 9.50 *Determining R_{Th} for the network in Fig. 9.49.*

LOGO

THÉVENIN'S THEOREM

Thévenin's Theorem Procedure

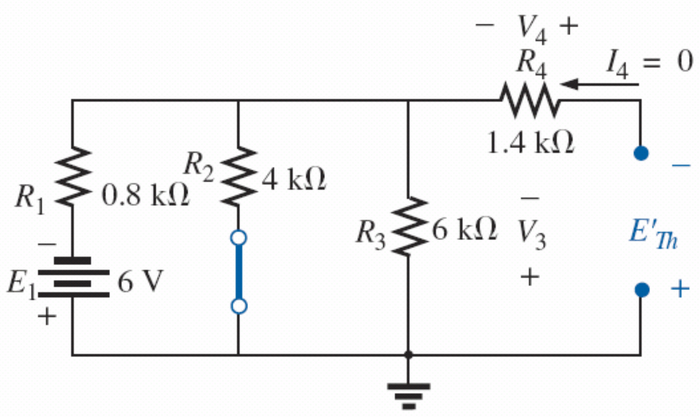

FIG. 9.51 *Determining the contribution to E_{Th} from the source E_1 for the network in Fig. 9.49.*

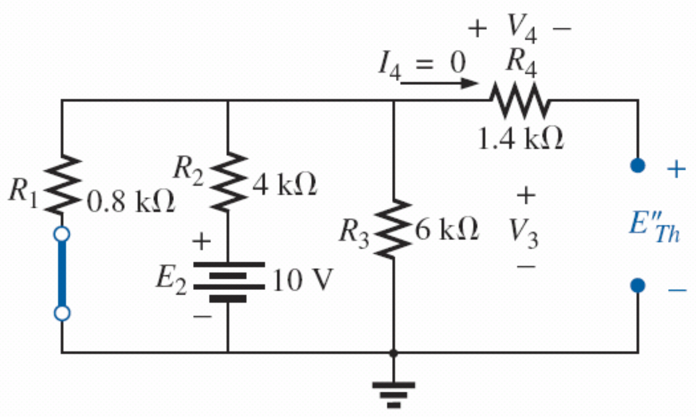

FIG. 9.52 *Determining the contribution to E_{Th} from the source E_2 for the network in Fig. 9.49.*

LOGO

THÉVENIN'S THEOREM

Thévenin's Theorem Procedure

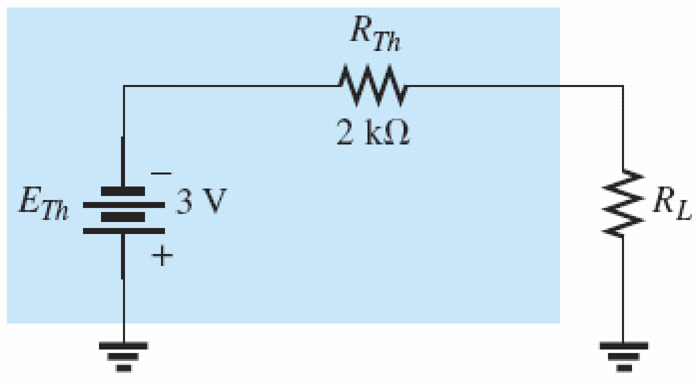

FIG. 9.53 *Substituting the Thévenin equivalent circuit for the network external to the resistor R_L in Fig. 9.48.*

LOGO

THÉVENIN'S THEOREM

Experimental Procedures

- Measuring E_{th}
- Measuring R_{Th}

LOGO

THÉVENIN'S THEOREM

Experimental Procedures

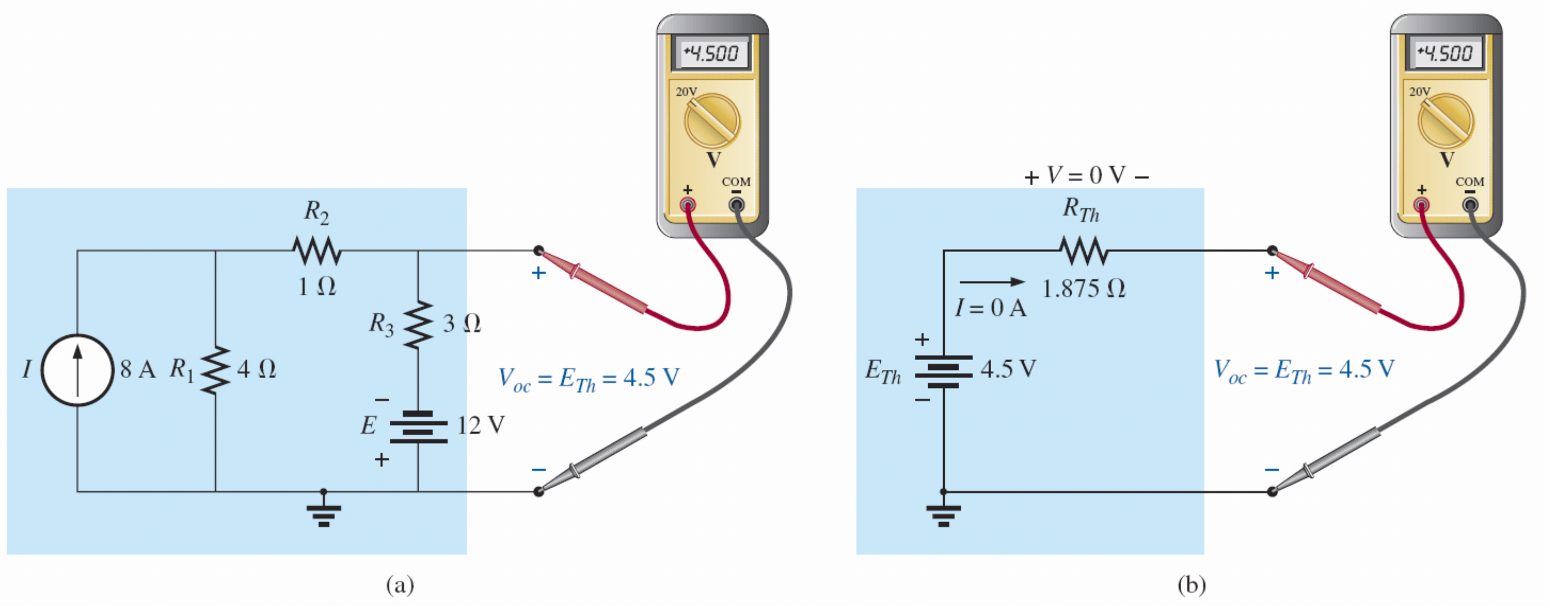

FIG. 9.54 *Measuring the Thévenin voltage with a voltmeter: (a) actual network; (b) Thévenin equivalent.*

LOGO

THÉVENIN'S THEOREM

Experimental Procedures

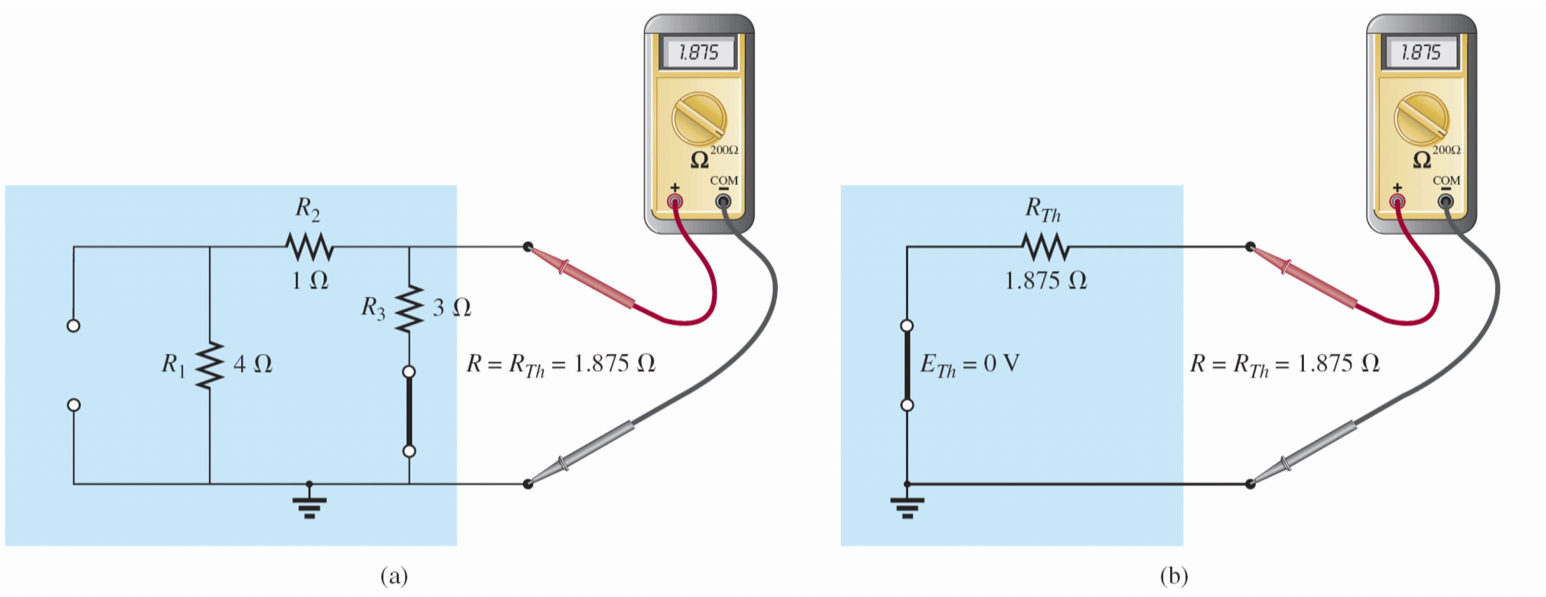

FIG. 9.55 *Measuring RTh with an ohmmeter: (a) actual network; (b) Thévenin equivalent.*

LOGO

THÉVENIN'S THEOREM

Experimental Procedures

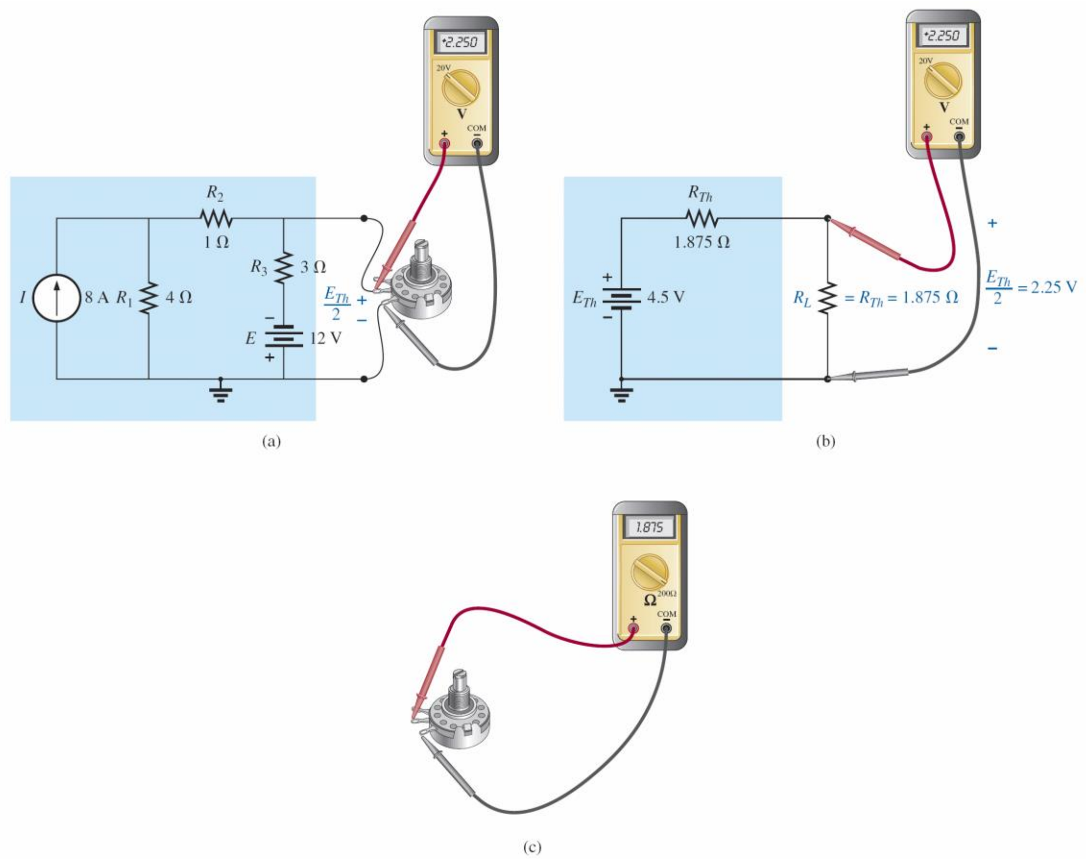

FIG. 9.56 *Using a potentiometer to determine RTh: (a) actual network; (b) Thévenin equivalent; (c) measuring RTh.*

LOGO

THÉVENIN'S THEOREM

Experimental Procedures

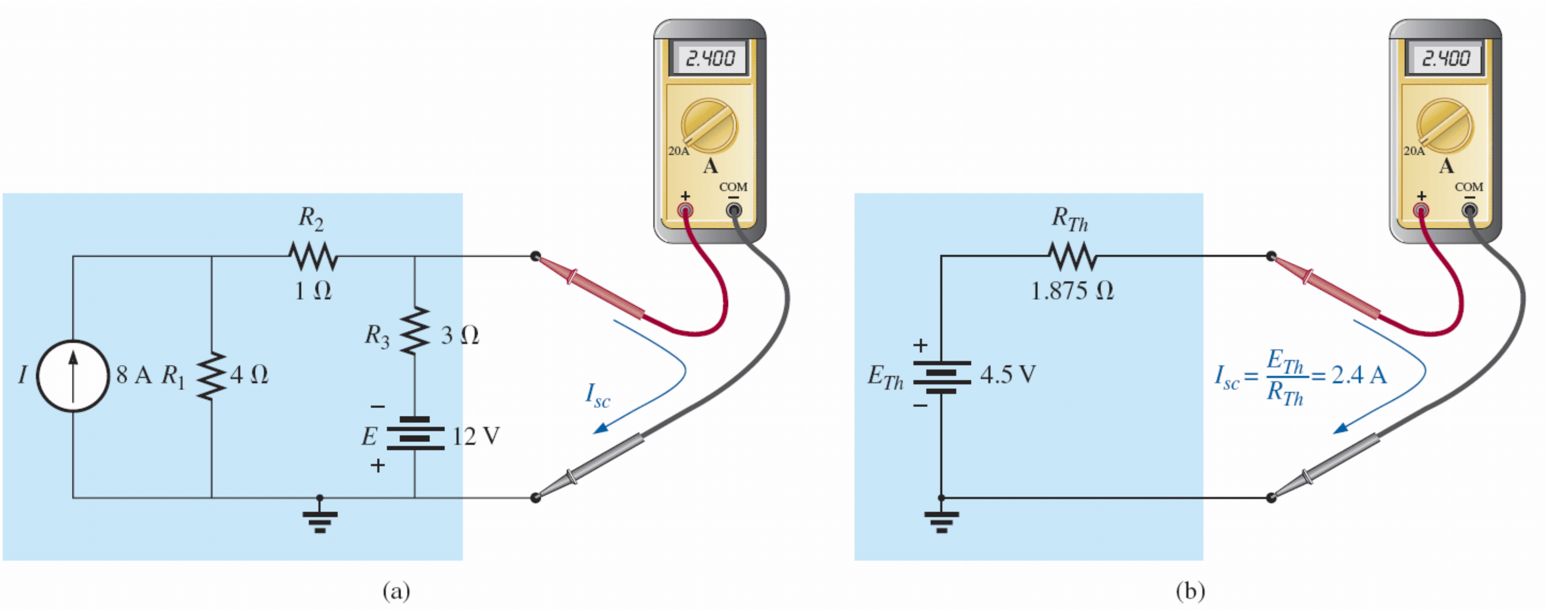

FIG. 9.57 *Determining RTh using the short-circuit current: (a) actual network; (b) Thévenin equivalent.*

LOGO

NORTON'S THEOREM

- In Section 8.3, we learned that every voltage source with a series internal resistance has a current source equivalent.
- The current source equivalent can be determined by **Norton's theorem**. It can also be found through the conversions of Section 8.3.
- The theorem states the following:
  - ***Any two-terminal linear bilateral dc network can be replaced by an equivalent circuit consisting of a current source and a parallel resistor, as shown in Fig. 9.59***

LOGO

NORTON'S THEOREM

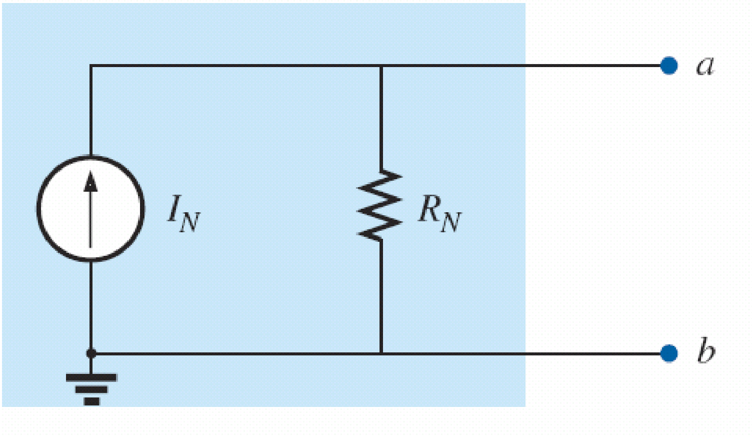

FIG. 9.59 *Norton equivalent circuit.*

LOGO

NORTON'S THEOREM

Norton's Theorem Procedure

- ***Preliminary:***
  - ***1. Remove that portion of the network across which the Norton equivalent circuit is found.***
  - ***2. Mark the terminals of the remaining two-terminal network.***

LOGO

NORTON'S THEOREM

Norton's Theorem Procedure

- *R_N:*
  - *3. Calculate R_N by first setting all sources to zero (voltage sources are replaced with short circuits and current sources with open circuits) and then finding the resultant resistance between the two marked terminals. (If the internal resistance of the voltage and/or current sources is included in the original network, it must remain when the sources are set to zero.) Since $R_N = R_{Th}$, the procedure and value obtained using the approach described for Thévenin's theorem will determine the proper value of R_N.*

LOGO

NORTON'S THEOREM

Norton's Theorem Procedure

- *I_N:*
  - *4. Calculate I_N by first returning all sources to their original position and then finding the short-circuit current between the marked terminals. It is the same current that would be measured by an ammeter placed between the marked terminals.*

LOGO

NORTON'S THEOREM

Norton's Theorem Procedure

- *Conclusion:*
  - *5. Draw the Norton equivalent circuit with the portion of the circuit previously removed replaced between the terminals of the equivalent circuit.*

LOGO

NORTON'S THEOREM

Norton's Theorem Procedure

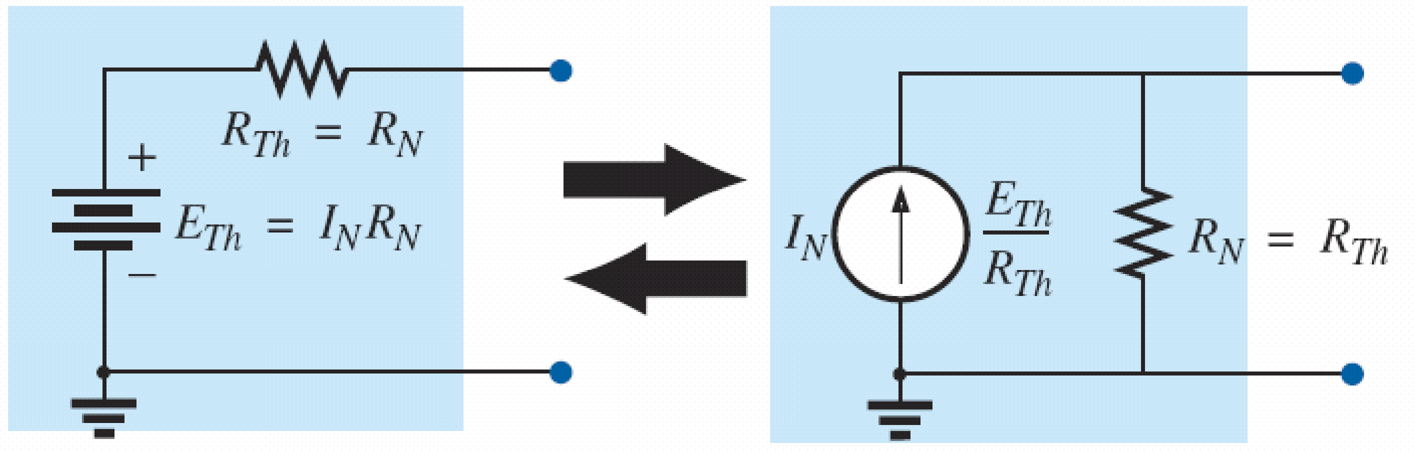

FIG. 9.60 *Converting between Thévenin and Norton equivalent circuits.*

LOGO

NORTON'S THEOREM

Norton's Theorem Procedure

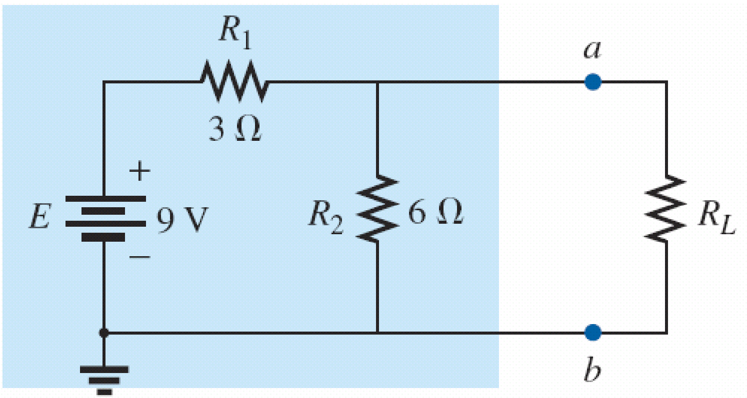

FIG. 9.61 *Example 9.11.*

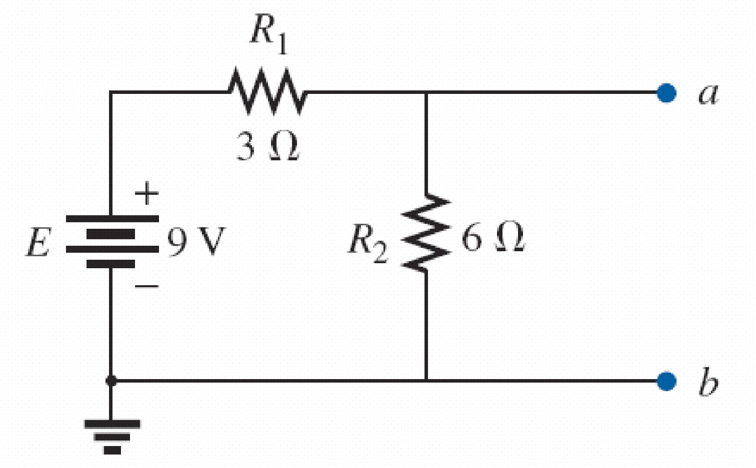

FIG. 9.62 *Identifying the terminals of particular interest for the network in Fig. 9.61.*

LOGO

NORTON'S THEOREM

Norton's Theorem Procedure

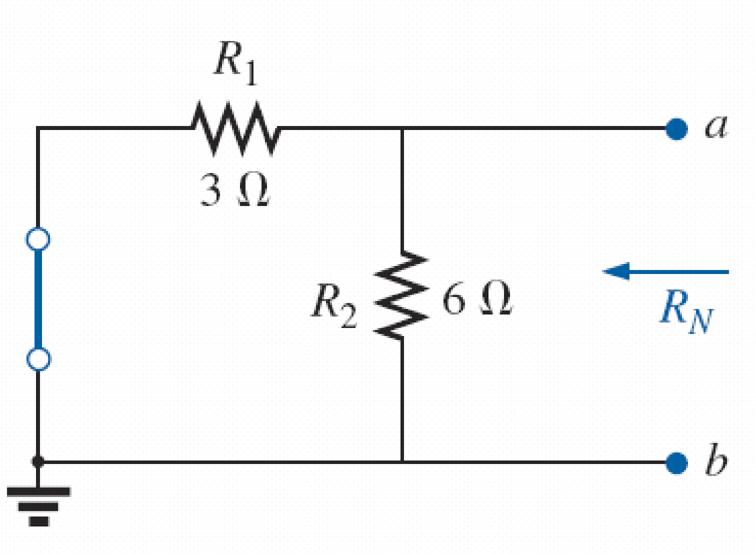

FIG. 9.63 *Determining R_N for the network in Fig. 9.62.*

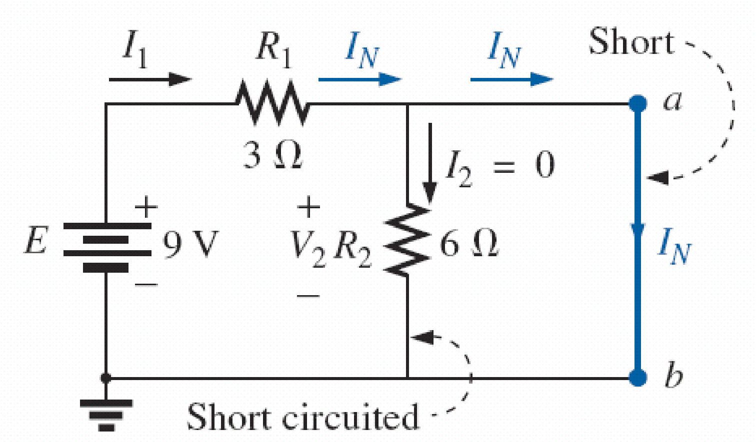

FIG. 9.64 *Determining I_N for the network in Fig. 9.62.*

LOGO

NORTON'S THEOREM

Norton's Theorem Procedure

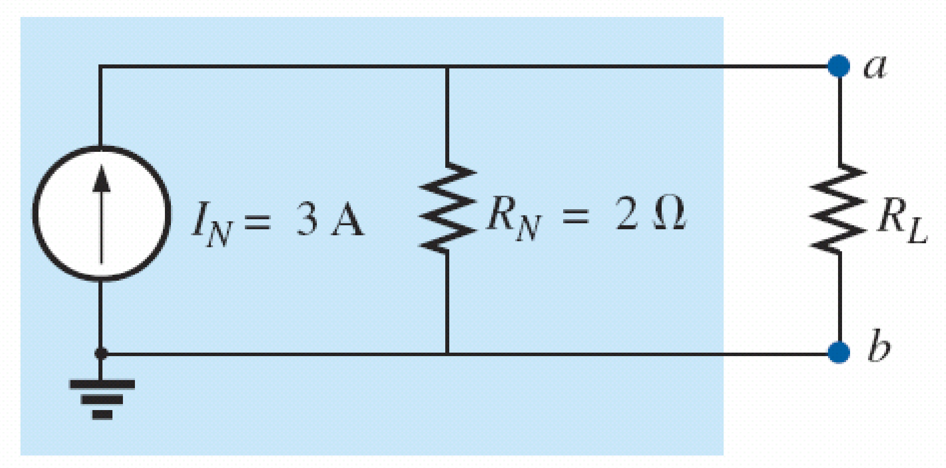

FIG. 9.65 *Substituting the Norton equivalent circuit for the network external to the resistor R_L in Fig. 9.61.*

LOGO

NORTON'S THEOREM

Norton's Theorem Procedure

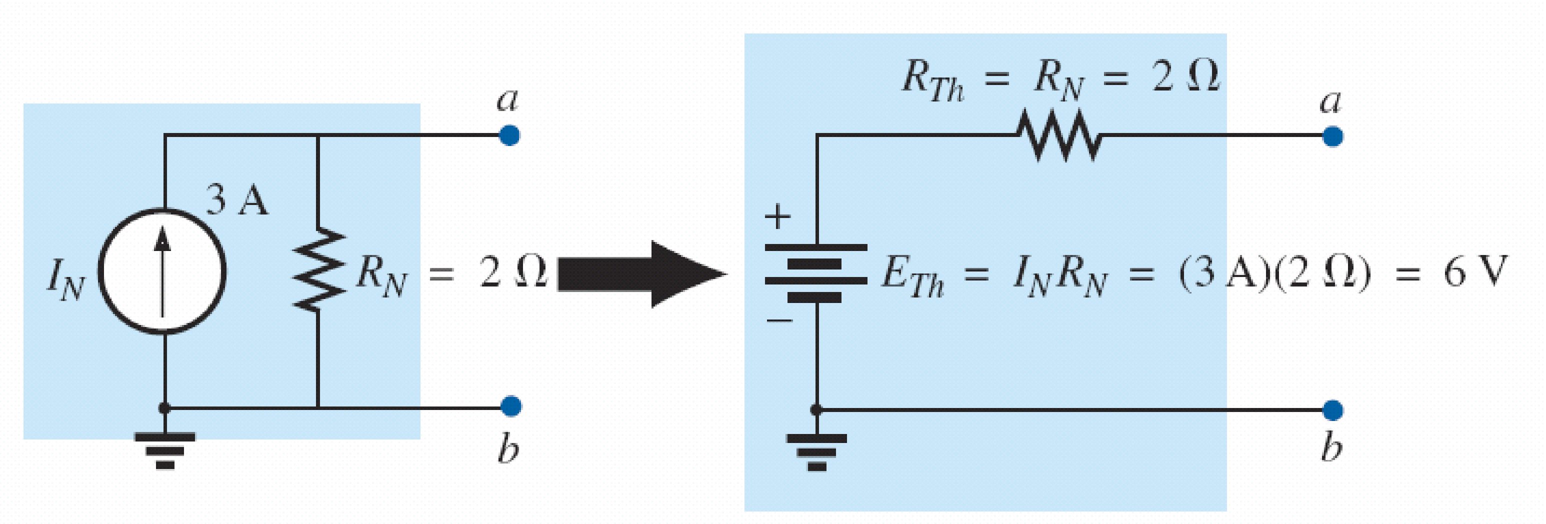

FIG. 9.66 *Converting the Norton equivalent circuit in Fig. 9.65 to a Thévenin equivalent circuit.*

LOGO

NORTON'S THEOREM

Norton's Theorem Procedure

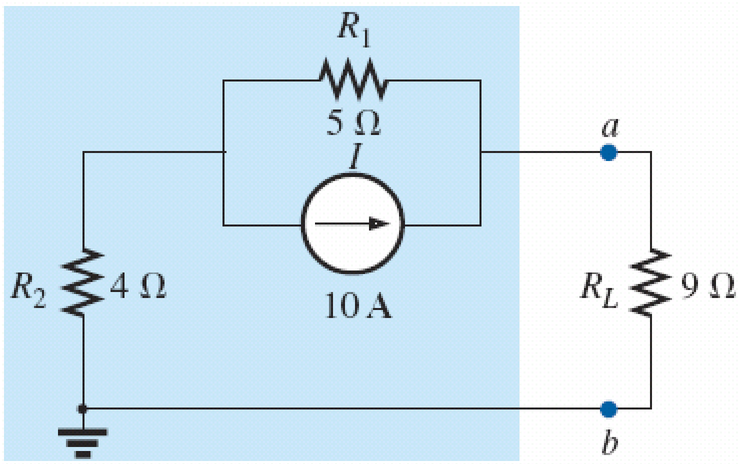

FIG. 9.67 *Example 9.12.*

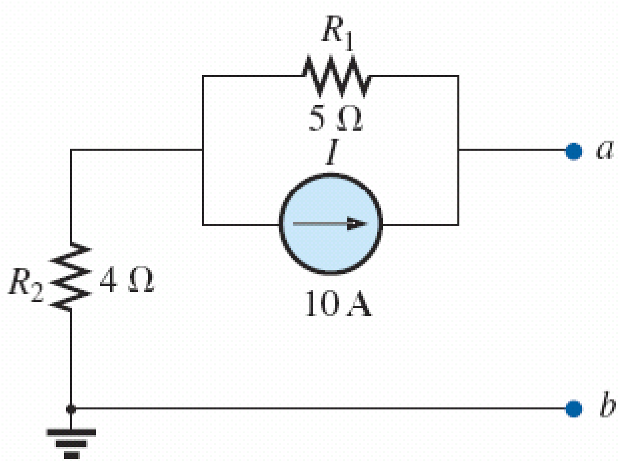

FIG. 9.68 *Identifying the terminals of particular interest for the network in Fig. 9.67.*

LOGO

NORTON'S THEOREM

Norton's Theorem Procedure

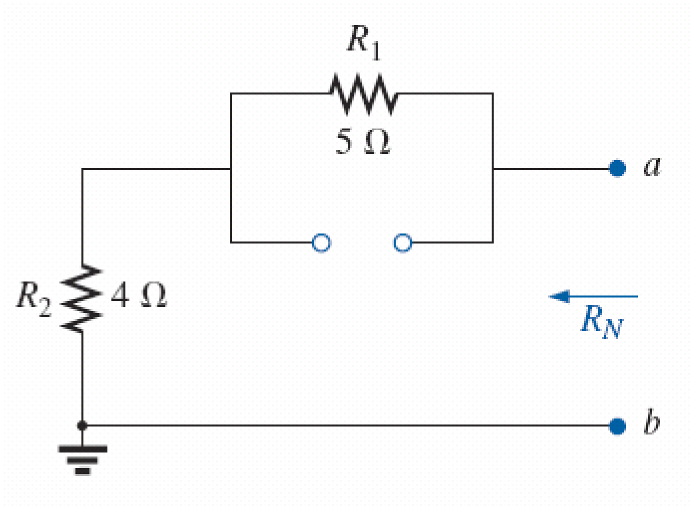

FIG. 9.69 *Determining R_N for the network in Fig. 9.68.*

LOGO

NORTON'S THEOREM

Norton's Theorem Procedure

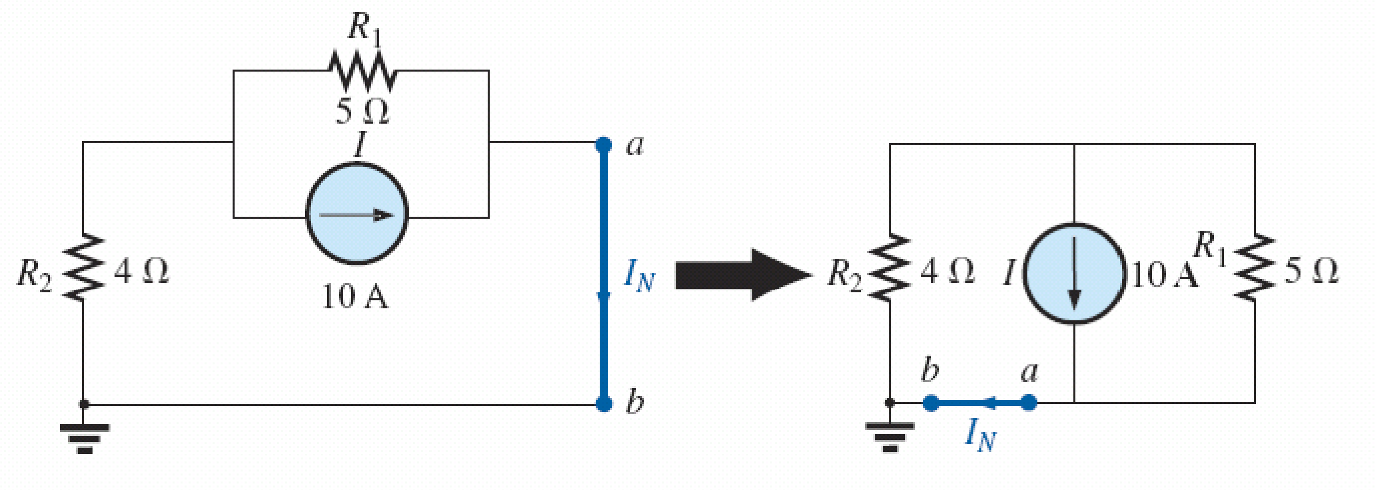

FIG. 9.70 *Determining I_N for the network in Fig. 9.68.*

LOGO

NORTON'S THEOREM

Norton's Theorem Procedure

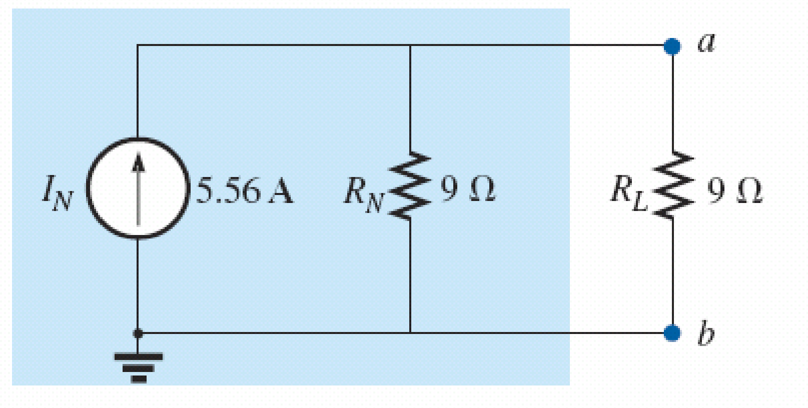

FIG. 9.71 *Substituting the Norton equivalent circuit for the network external to the resistor R_L in Fig. 9.67.*

LOGO

NORTON'S THEOREM

Norton's Theorem Procedure

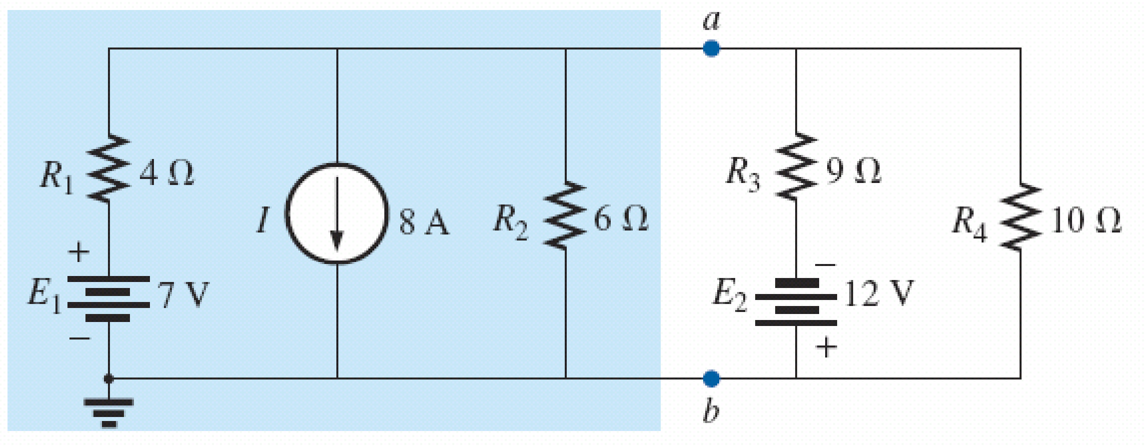

FIG. 9.72 *Example 9.13.*

LOGO

NORTON'S THEOREM

Norton's Theorem Procedure

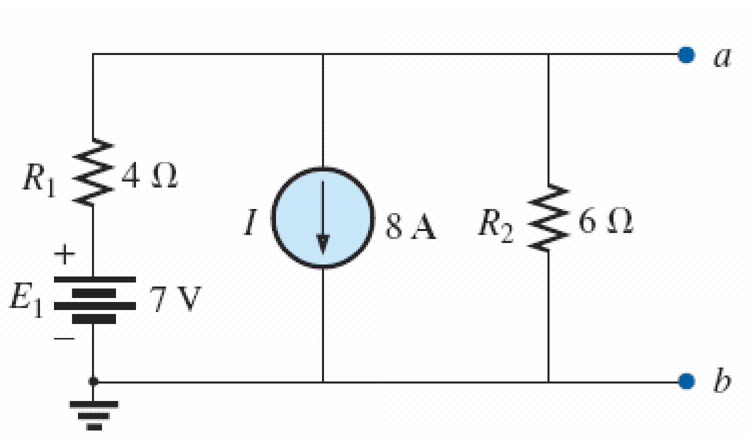

FIG. 9.73 *Identifying the terminals of particular interest for the network in Fig. 9.72.*

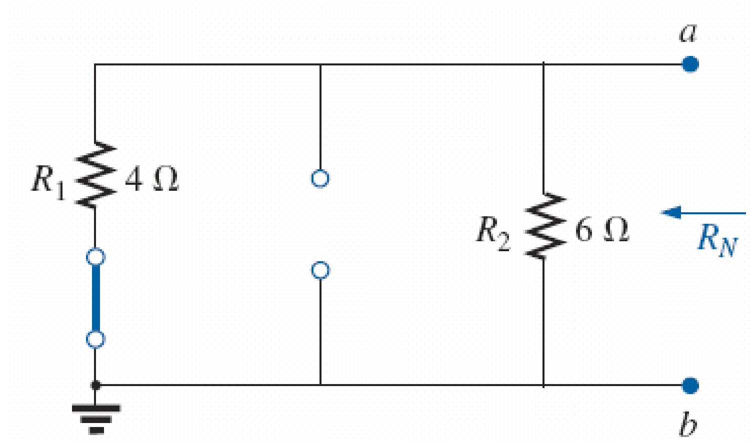

FIG. 9.74 *Determining R_N for the network in Fig. 9.73.*

LOGO

NORTON'S THEOREM

Norton's Theorem Procedure

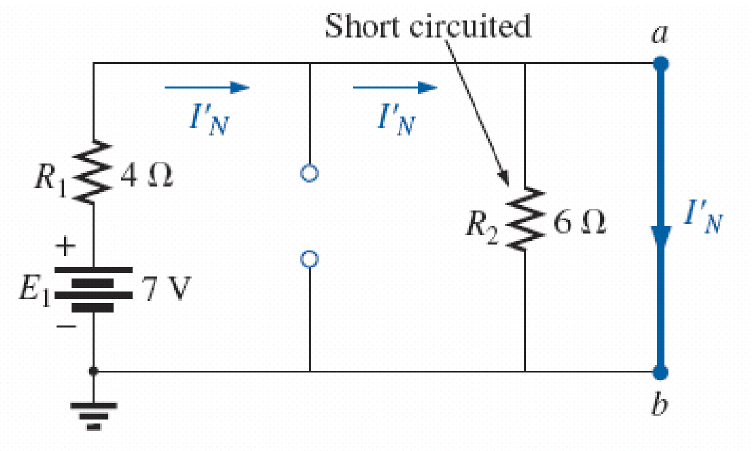

FIG. 9.75 *Determining the contribution to IN from the voltage source E_1.*

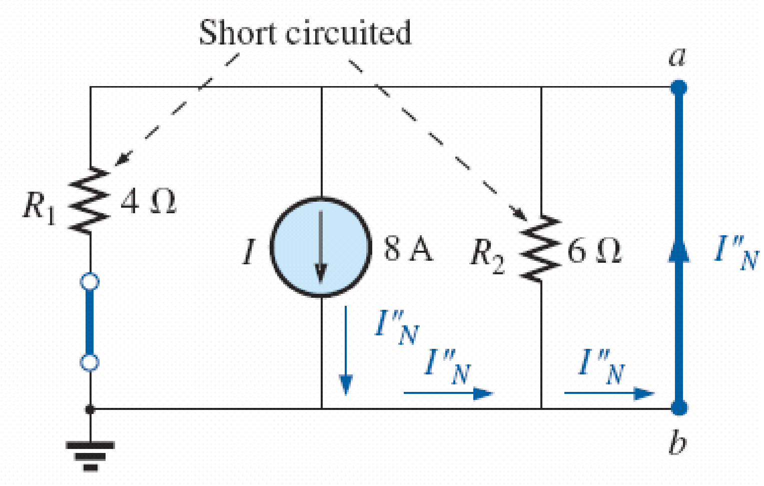

FIG. 9.76 *Determining the contribution to IN from the current source I.*

LOGO

NORTON'S THEOREM

Norton's Theorem Procedure

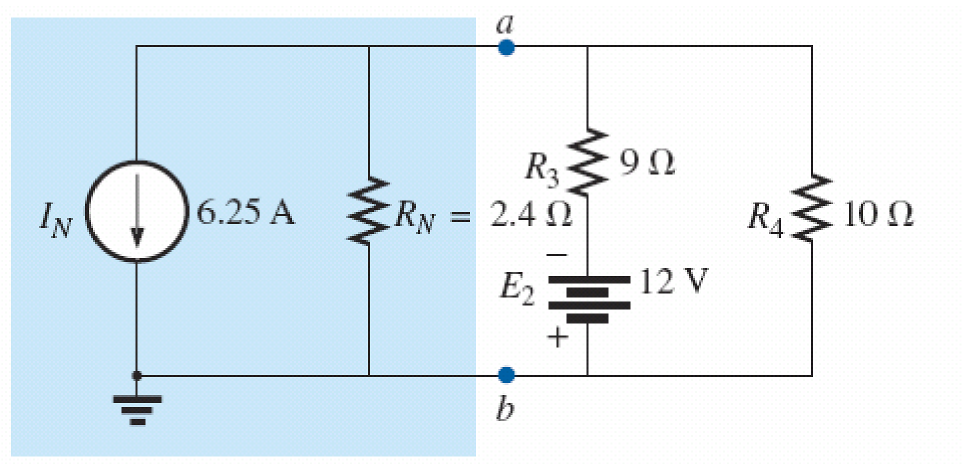

FIG. 9.77 *Substituting the Norton equivalent circuit for the network to the left of terminals a-b in Fig. 9.72.*

LOGO

NORTON'S THEOREM

Experimental Procedure

- The Norton current is measured in the same way as described for the short-circuit current (I_{sc}) for the Thévenin network.
- Since the Norton and Thévenin resistances are the same, the same procedures can be followed as described for the Thévenin network.

LOGO

Thank You !