EN2042102 วงจรไฟฟ้าและอิเล็กทรอนิกส์

Circuits and Electronics

บทที่ 2 พื้นฐานวงจรไฟฟ้า

สาขาวิชาวิศวกรรมคอมพิวเตอร์

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INTRODUCTION

- Two types of current are readily available to the consumer today.
  - One is *direct current* (dc), in which ideally the flow of charge (current) does not change in magnitude (or direction) with time.
  - The other is *sinusoidal alternating current* (ac), in which the flow of charge is continually changing in magnitude (and direction) with time.

INTRODUCTION

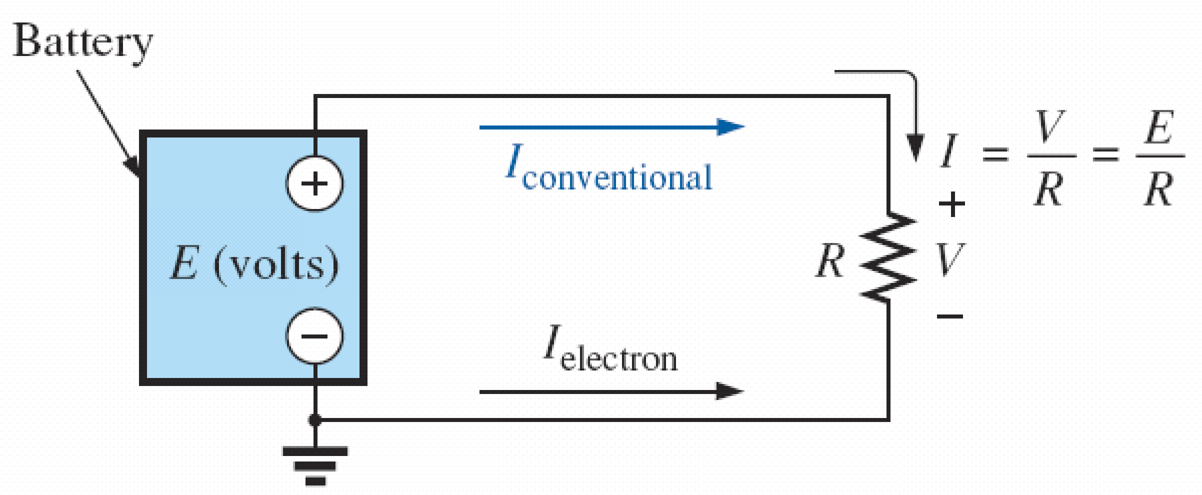


FIG. 5.1 *Introducing the basic components of an electric circuit.*

INTRODUCTION

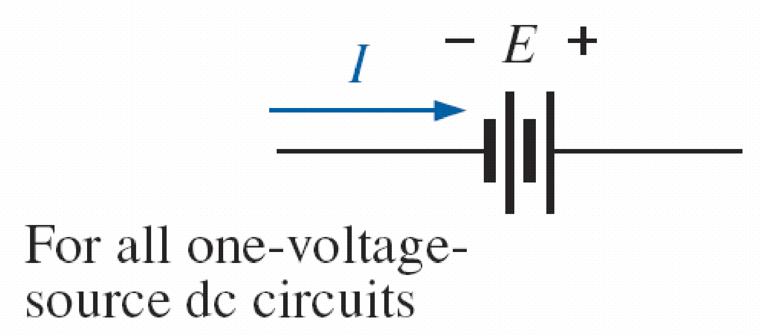


FIG. 5.2 *Defining the direction of conventional flow for single-source dc circuits.*

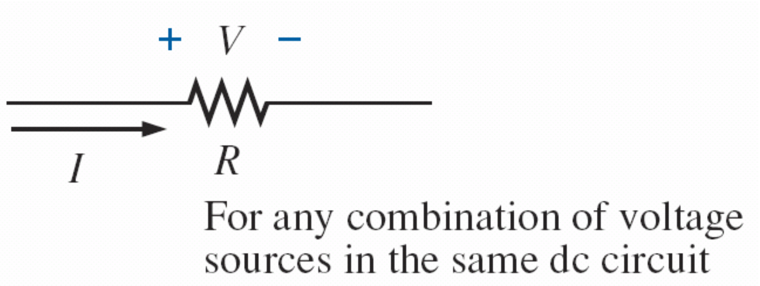


FIG. 5.3 *Defining the polarity resulting from a conventional current I through a resistive element.*

SERIES RESISTORS

- Before the series connection is described, first recognize that every fixed resistor has only two terminals to connect in a configuration—it is therefore referred to as a **two-terminal device.**

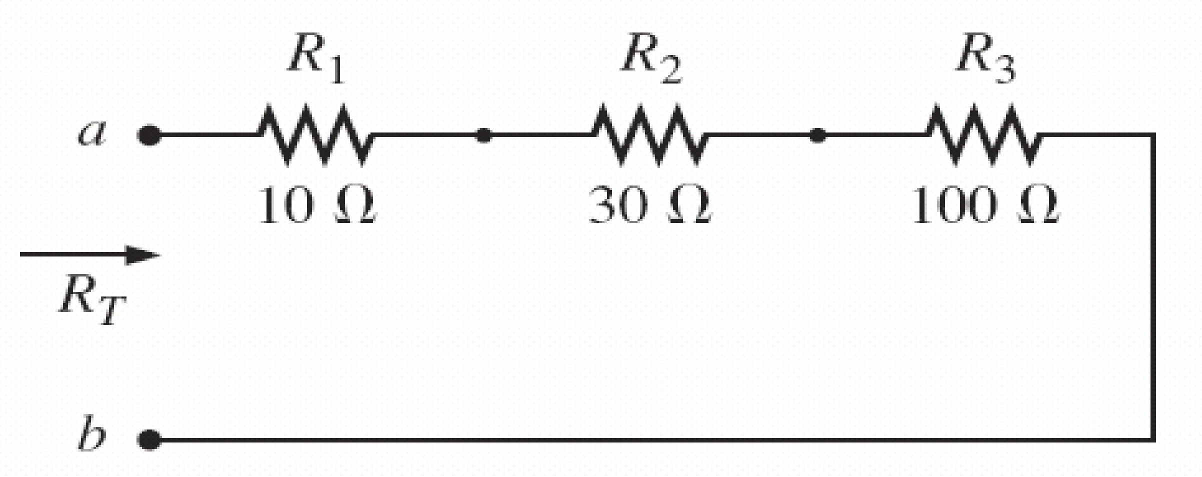


FIG. 5.4 *Series connection of resistors.*

SERIES RESISTORS

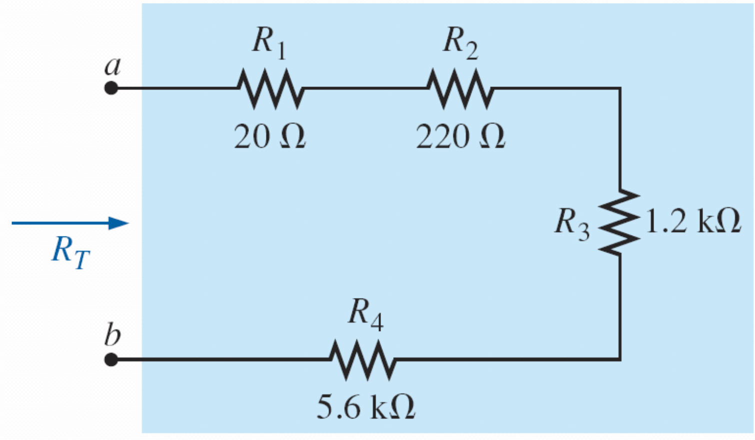


FIG. 5.6 *Series connection of resistors for Example 5.1.*

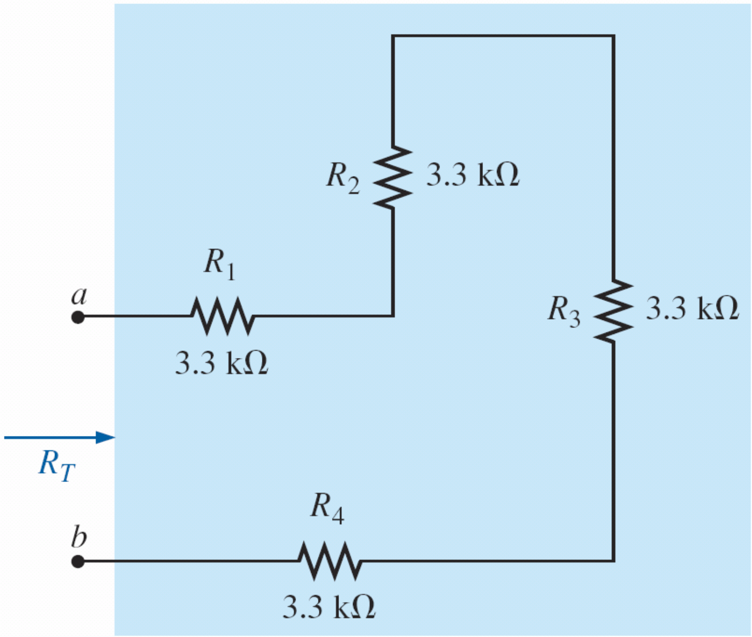


FIG. 5.7 *Series connection of four resistors of the same value (Example 5.2).*

LOGO

SERIES RESISTORS

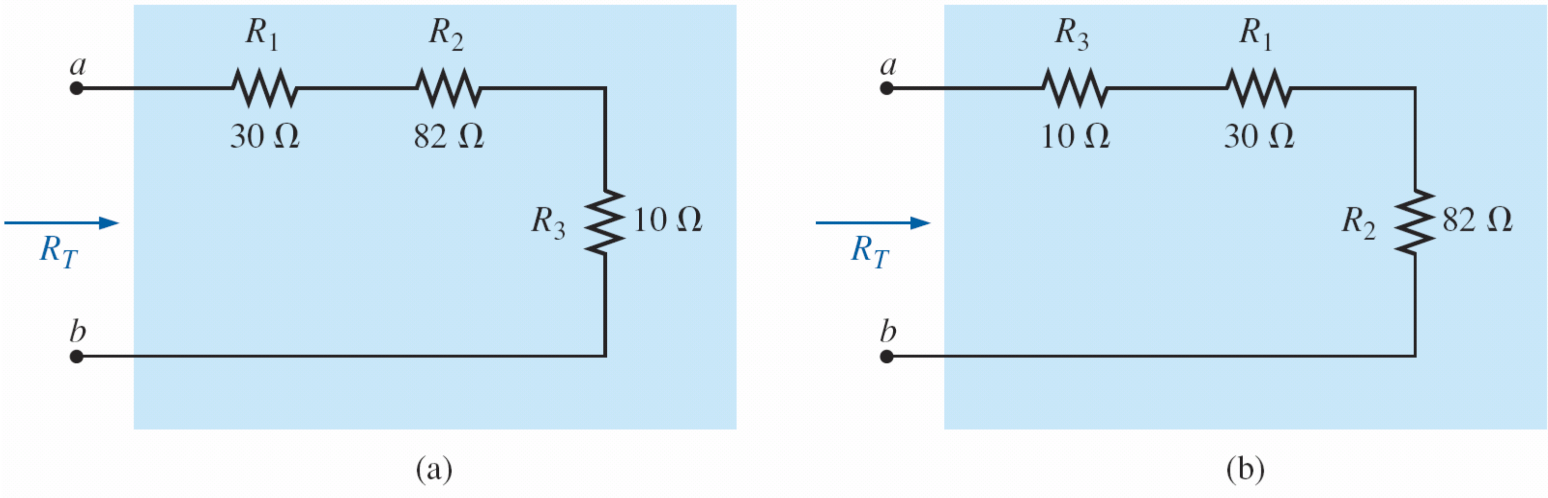


FIG. 5.8 *Two series combinations of the same elements with the same total resistance.*

LOGO

SERIES RESISTORS

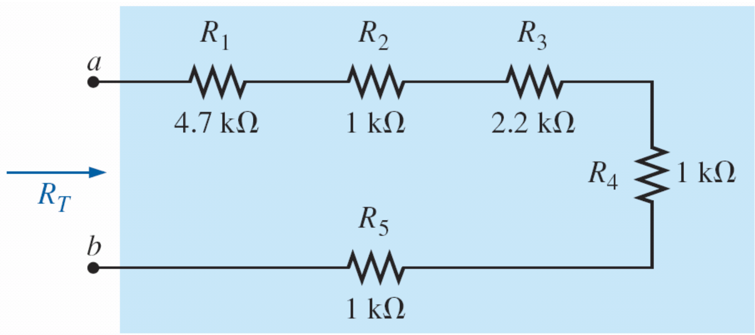


FIG. 5.9 *Series combination of resistors for Example 5.3.*

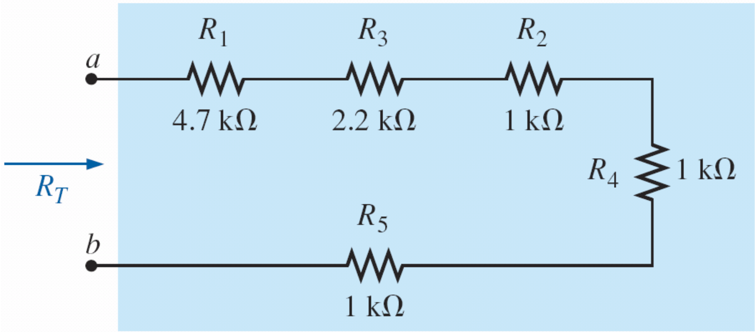


FIG. 5.10 *Series circuit of Fig. 5.9 redrawn to permit the use of Eq. (5.2): $R_T = NR$.*

SERIES RESISTORS

Instrumentation

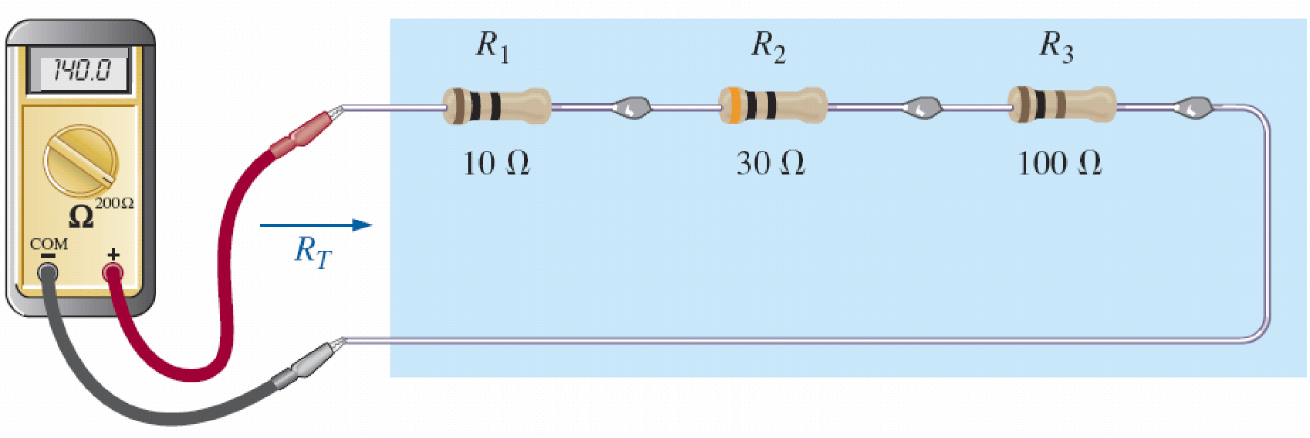


FIG. 5.11 *Using an ohmmeter to measure the total resistance of a series circuit.*

LOGO

SERIES CIRCUITS

- If we now take an 8.4 V dc supply and connect it in series with the series resistors in Fig. 5.4, we have the **series circuit** in Fig. 5.12.

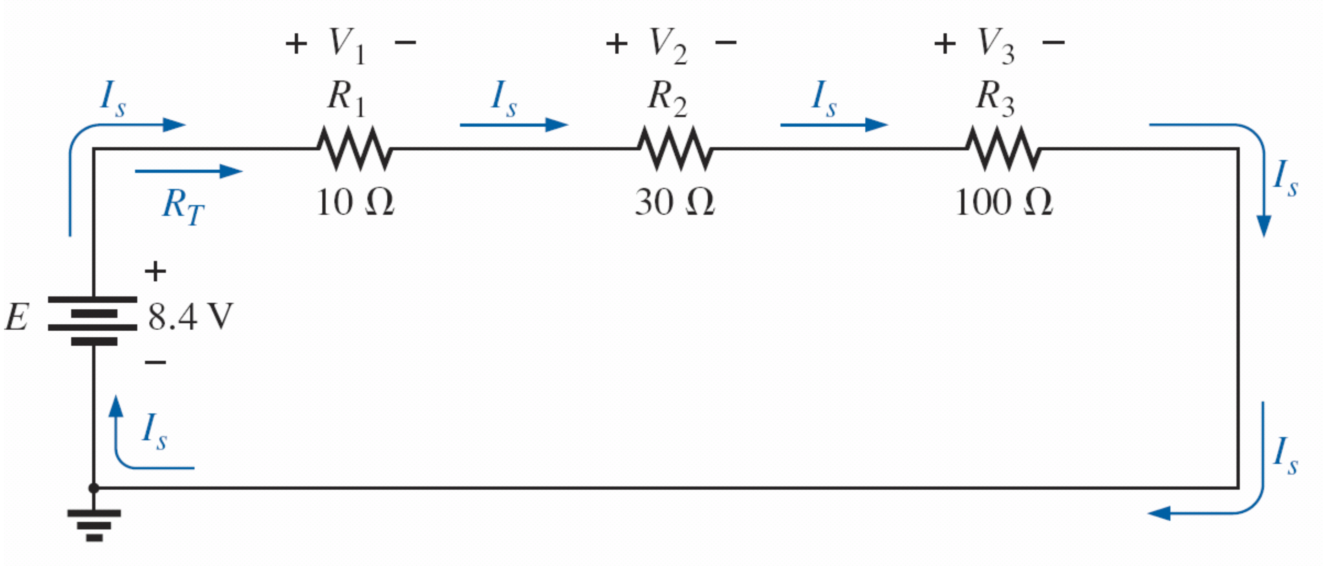


FIG. 5.12 *Schematic representation for a dc series circuit.*

LOGO

SERIES CIRCUITS

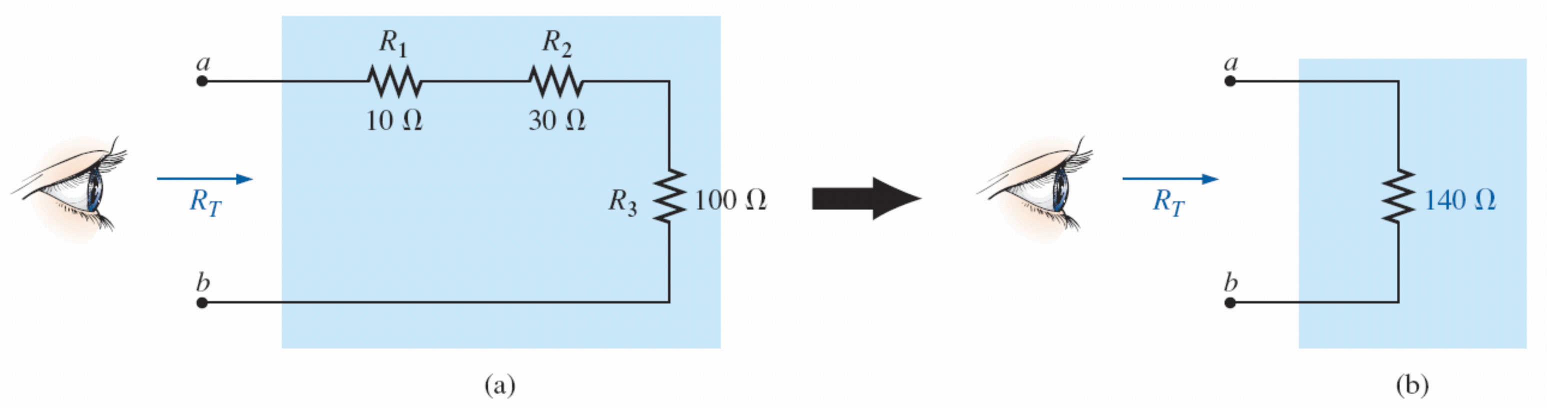


FIG. 5.13 *Resistance “seen” at the terminals of a series circuit.*

LOGO

SERIES CIRCUITS

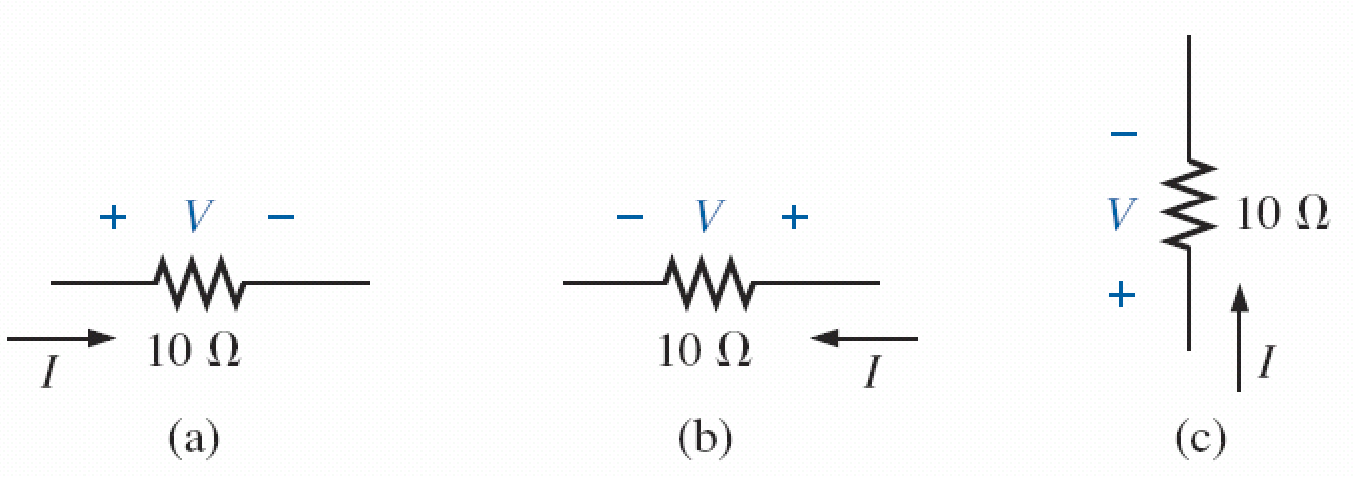


FIG. 5.14 *Inserting the polarities across a resistor as determined by the direction of the current.*

LOGO

SERIES CIRCUITS

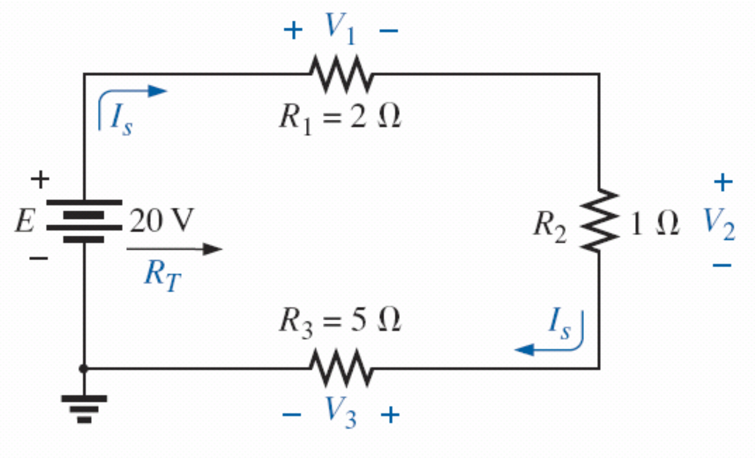


FIG. 5.15 *Series circuit to be investigated in Example 5.4.*

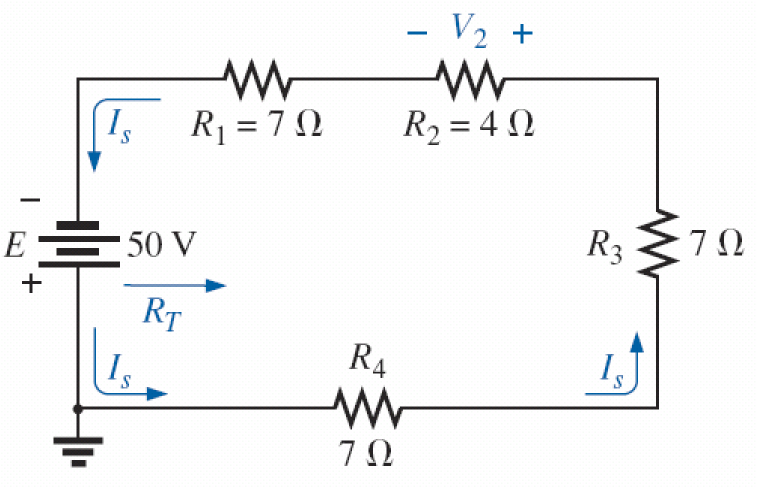


FIG. 5.16 *Series circuit to be analyzed in Example 5.5.*

LOGO

SERIES CIRCUITS

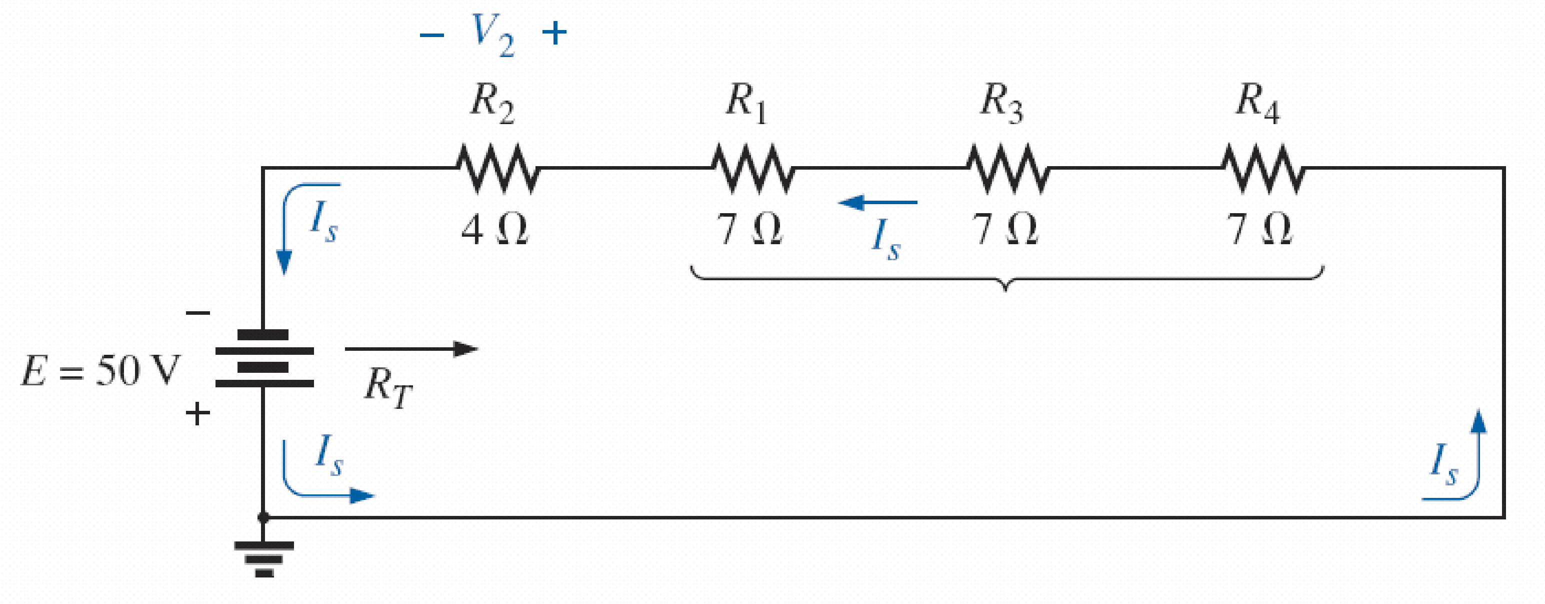


FIG. 5.17 *Circuit in Fig. 5.16 redrawn to permit the use of Eq. (5.2).*

LOGO

SERIES CIRCUITS

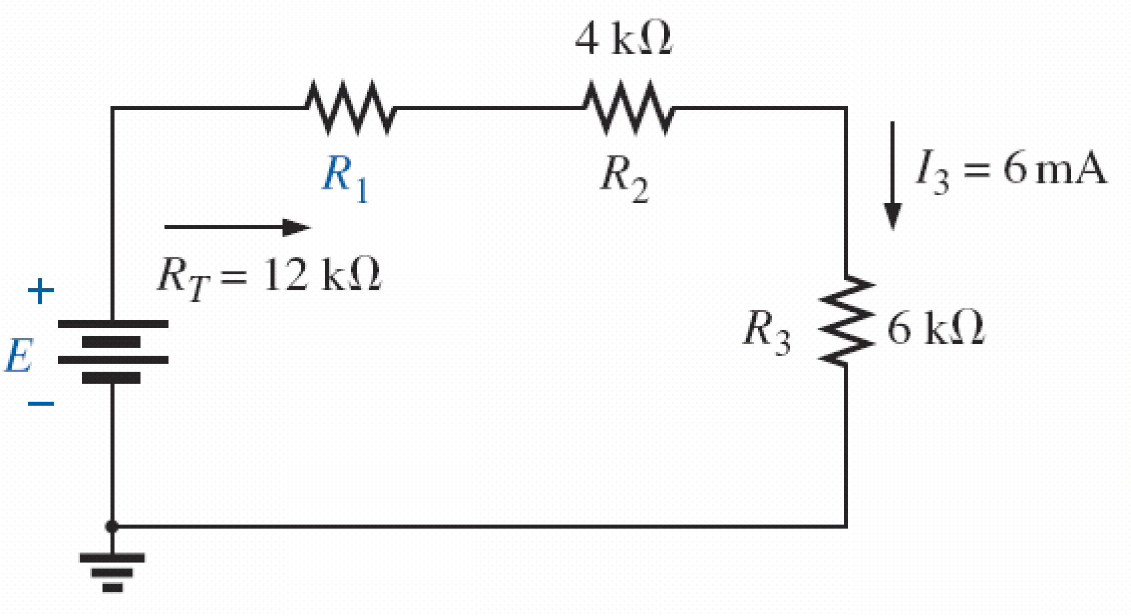


FIG. 5.18 *Series circuit to be analyzed in Example 5.6.*

SERIES CIRCUITS

Instrumentation

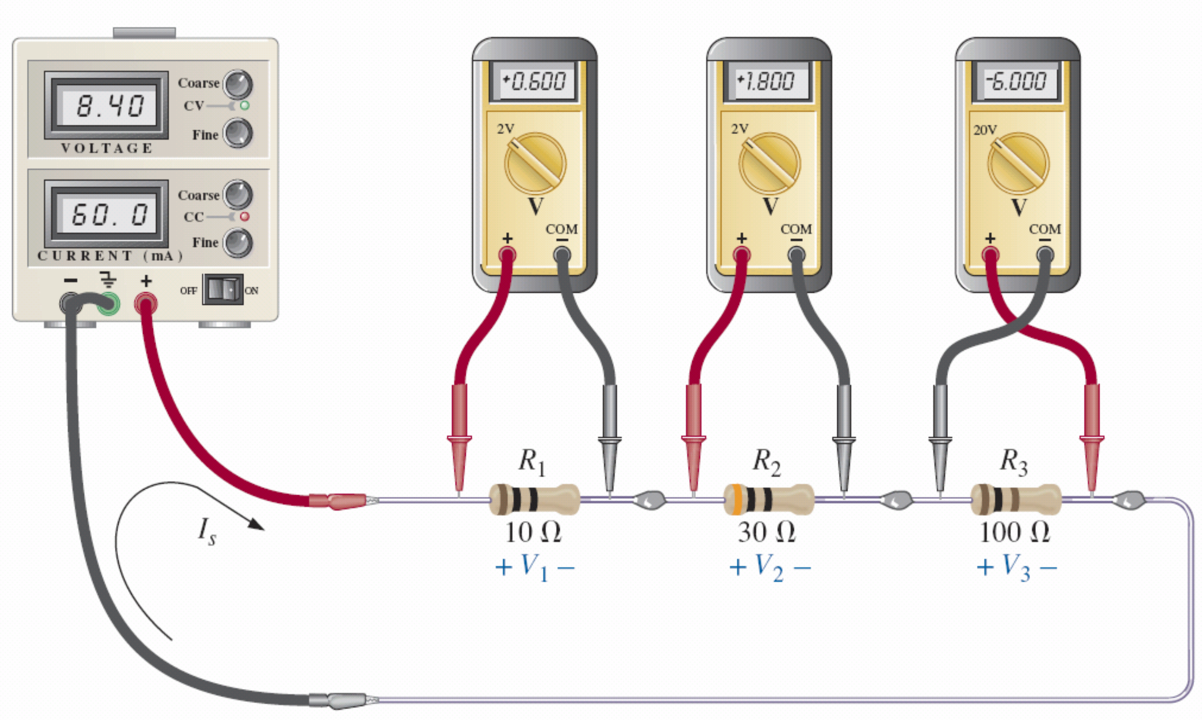


FIG. 5.19 *Using voltmeters to measure the voltages across the resistors in Fig. 5.12.*

LOGO

SERIES CIRCUITS

Instrumentation

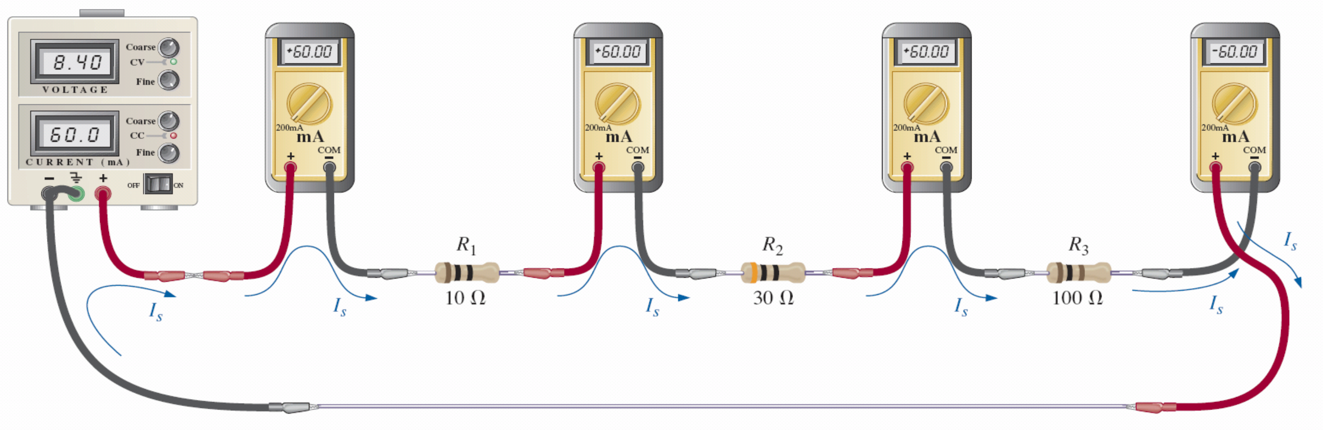


FIG. 5.20 *Measuring the current throughout the series circuit in Fig. 5.12.*

POWER DISTRIBUTION IN A SERIES CIRCUIT

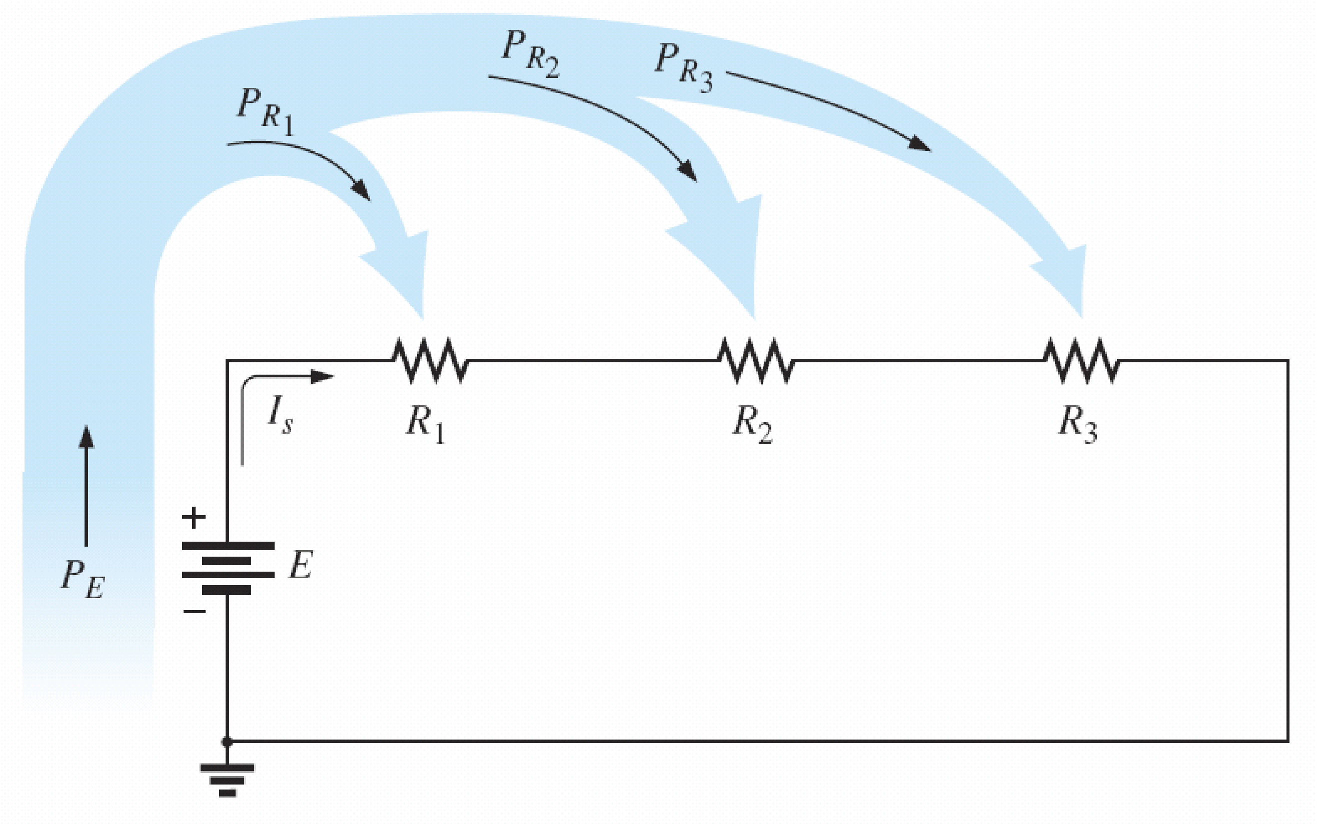


FIG. 5.21 *Power distribution in a series circuit.*

POWER DISTRIBUTION IN A SERIES CIRCUIT

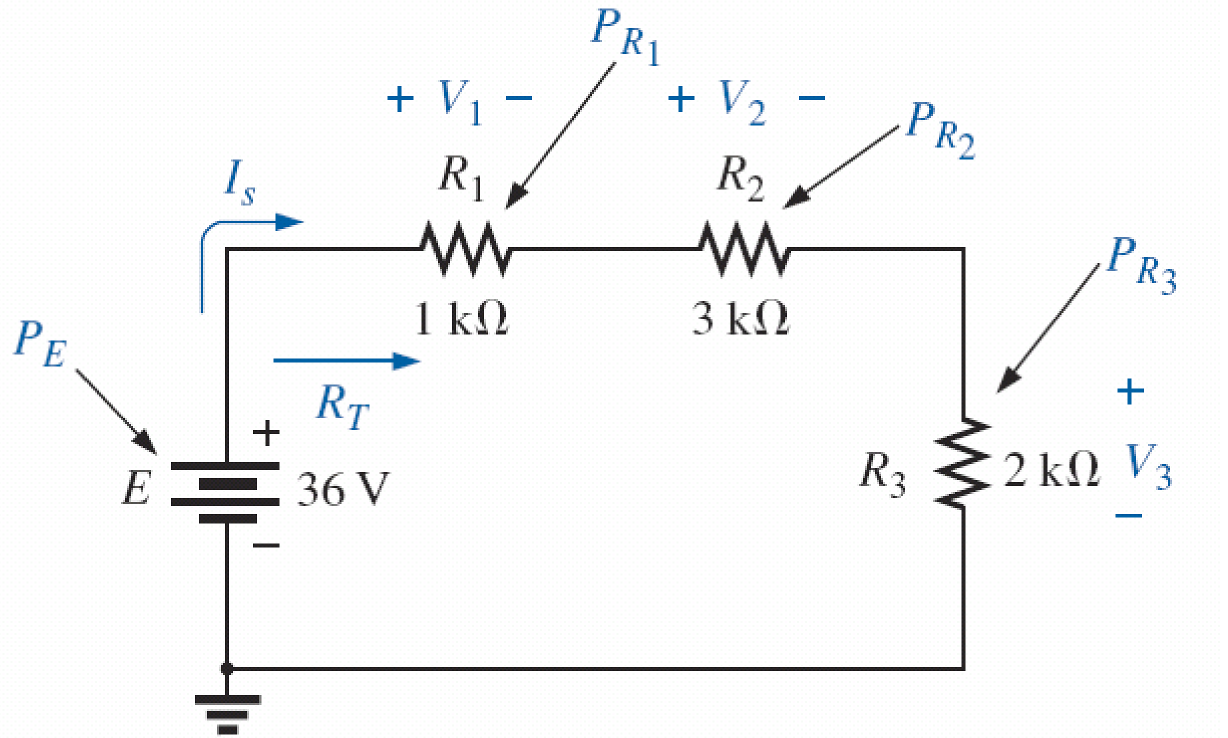


FIG. 5.22 *Series circuit to be investigated in Example 5.7.*

VOLTAGE SOURCES IN SERIES

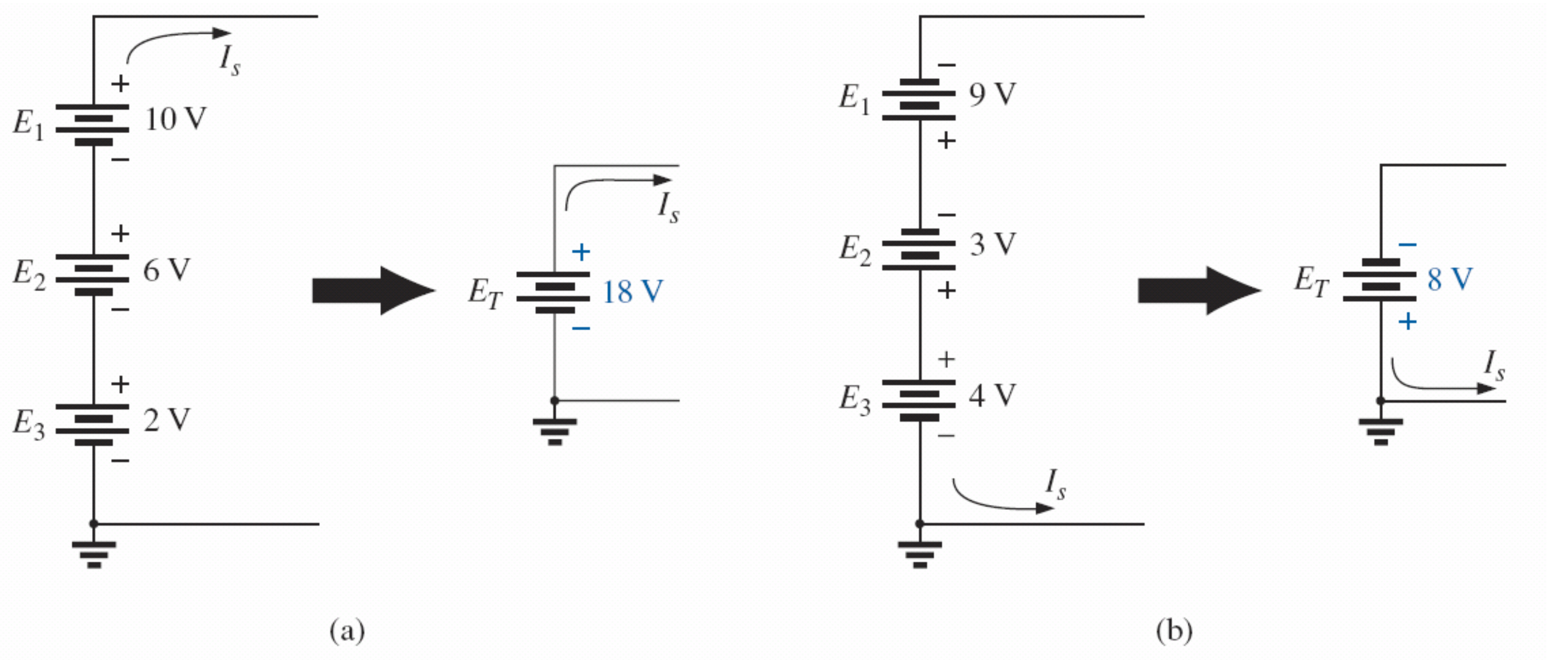


FIG. 5.23 *Reducing series dc voltage sources to a single source.*

LOGO

VOLTAGE SOURCES IN SERIES

Instrumentation

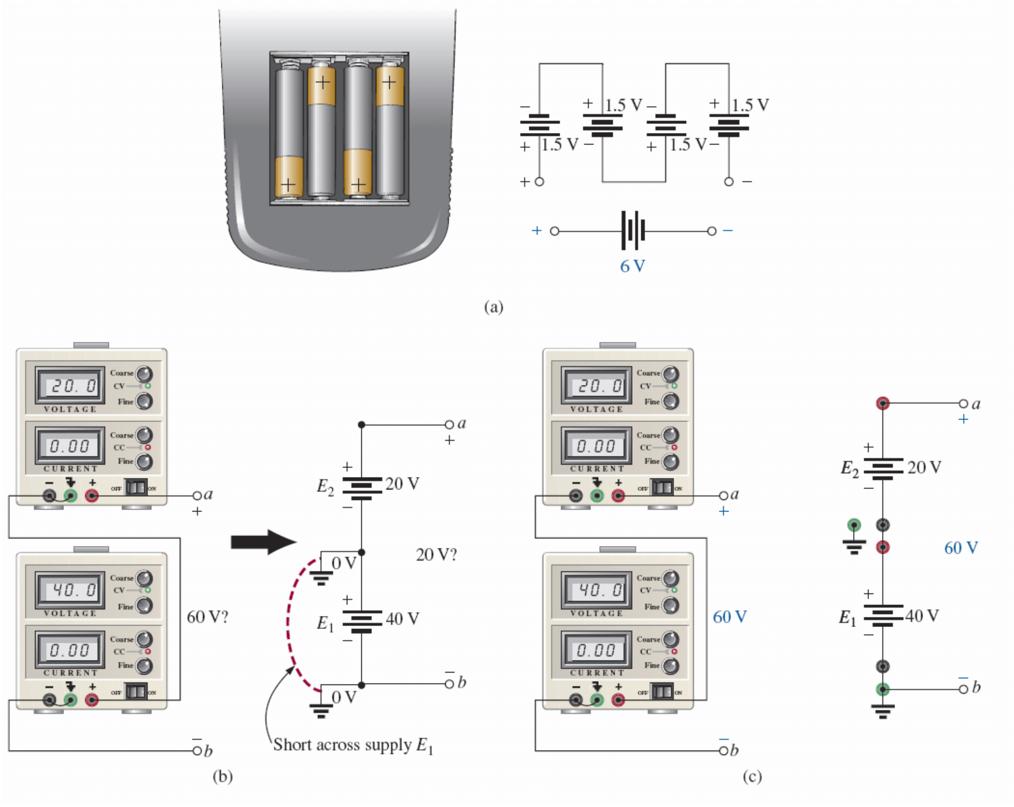


FIG. 5.24 *Series connection of dc supplies: (a) four 1.5 V batteries in series to establish a terminal voltage of 6 V; (b) incorrect connections for two series dc supplies; (c) correct connection of two series supplies to establish 60 V at the output terminals.*

KIRCHHOFF'S VOLTAGE LAW

- The law, called **Kirchhoff's voltage law (KVL),** was developed by Gustav Kirchhoff in the mid-1800s.

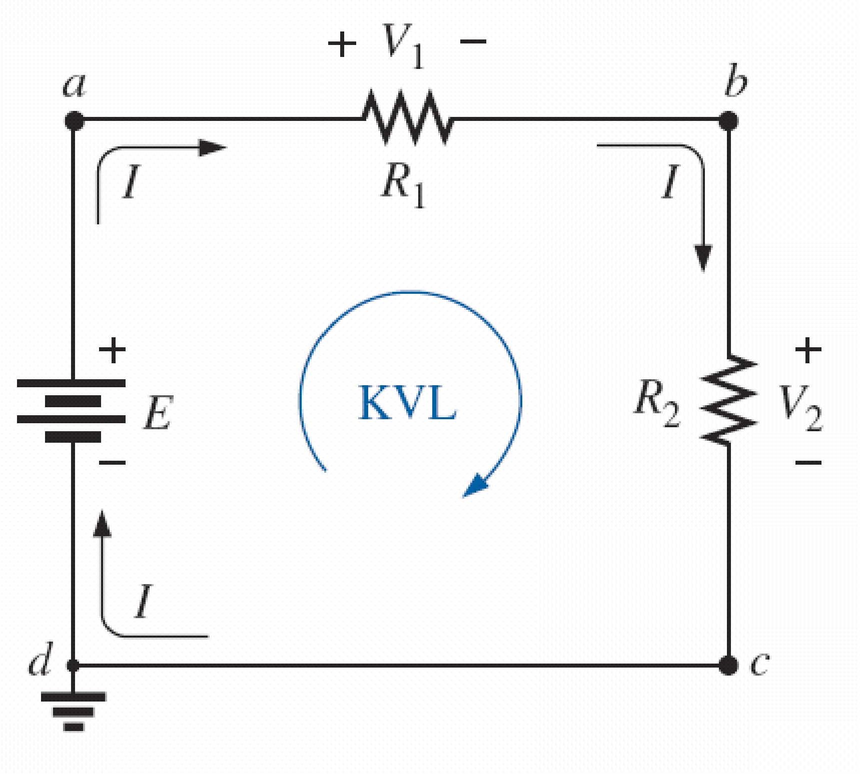


FIG. 5.26 *Applying Kirchhoff 's voltage law to a series dc circuit.*

KIRCHHOFF’S VOLTAGE LAW

- The law specifies that ***the algebraic sum of the potential rises and drops around a closed path (or closed loop) is zero.***

$$\boxed{\Sigma_{\circlearrowright} V = 0} \qquad \text{(Kirchhoff's voltage law in symbolic form)} \quad \textbf{(5.8)}$$

KIRCHHOFF'S VOLTAGE LAW

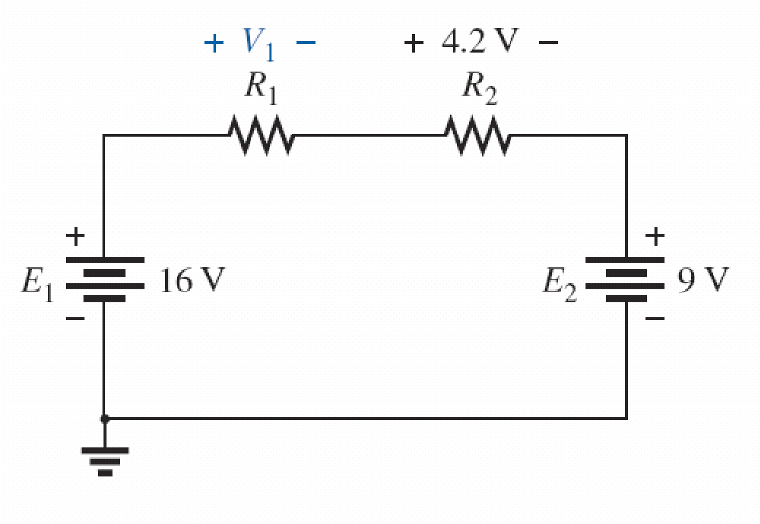


FIG. 5.27 *Series circuit to be examined in Example 5.8.*

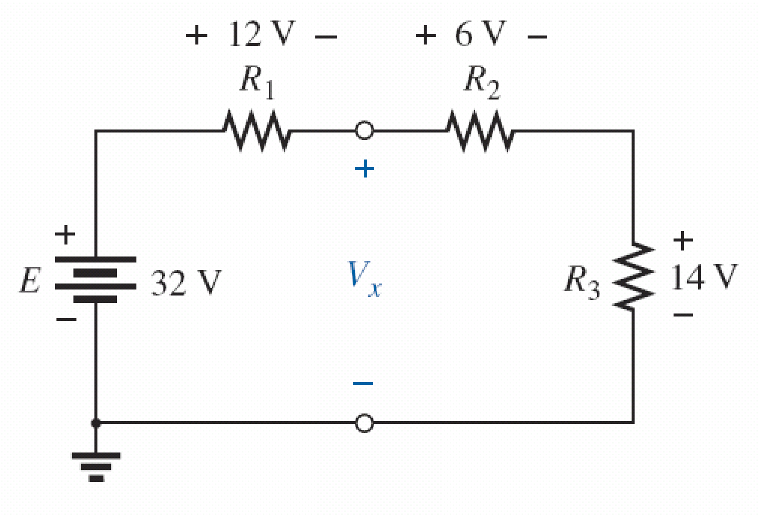


FIG. 5.28 *Series dc circuit to be analyzed in Example 5.9.*

LOGO

KIRCHHOFF'S VOLTAGE LAW

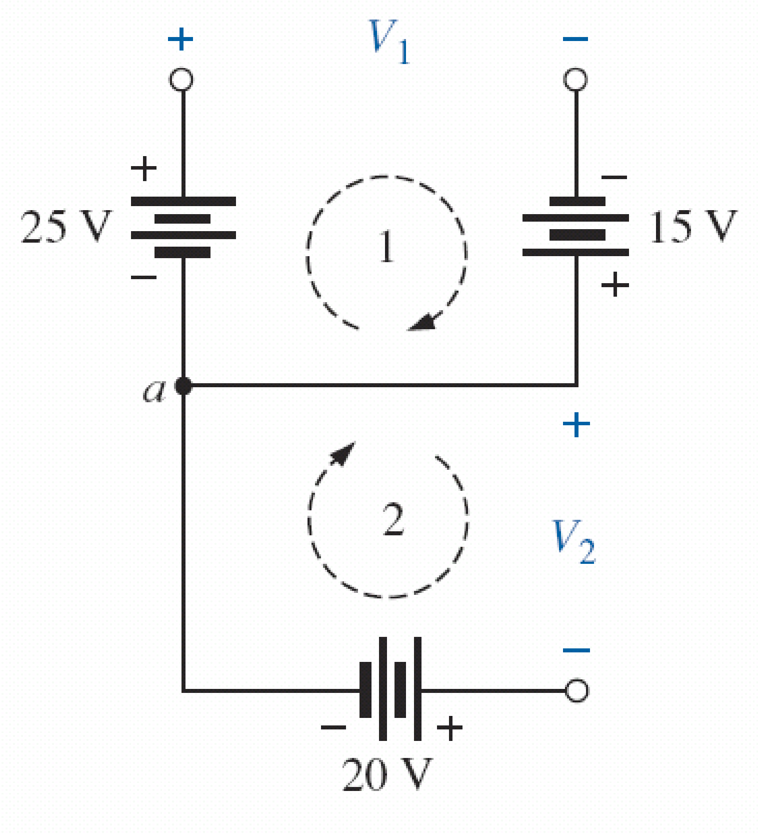


FIG. 5.29 *Combination of voltage sources to be examined in Example 5.10.*

KIRCHHOFF'S VOLTAGE LAW

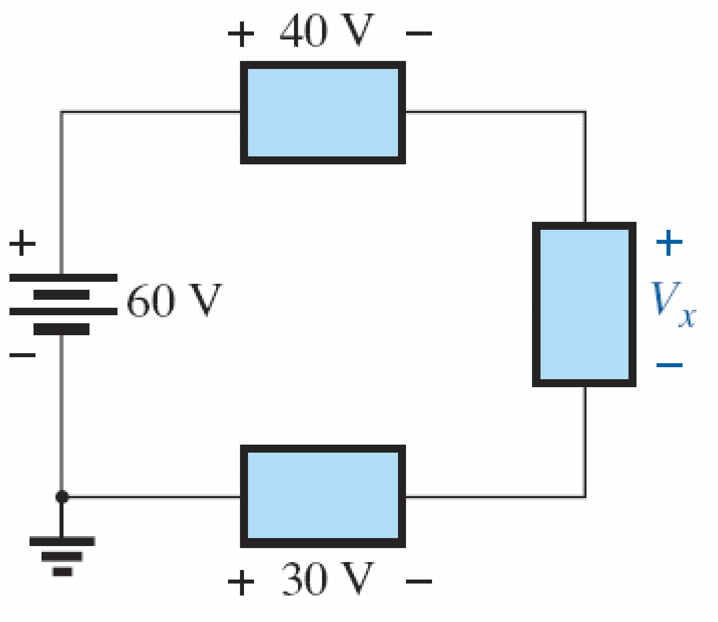


FIG. 5.30 *Series configuration to be examined in Example 5.11.*

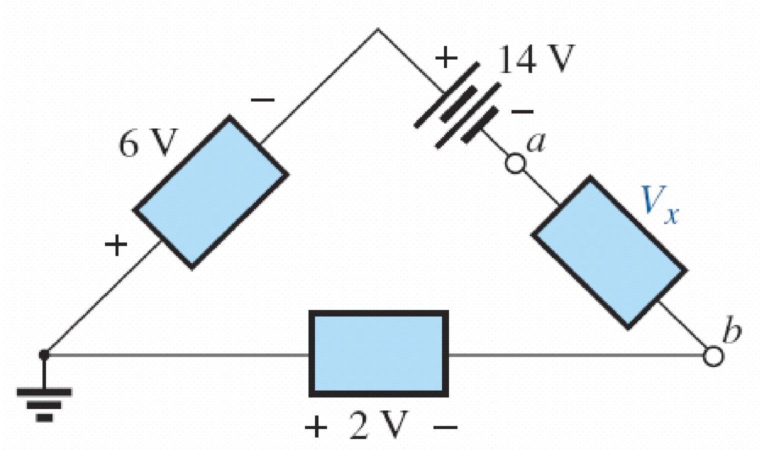


FIG. 5.31 *Applying Kirchhoff 's voltage law to a circuit in which the polarities have not been provided for one of the voltages (Example 5.12).*

LOGO

KIRCHHOFF’S VOLTAGE LAW

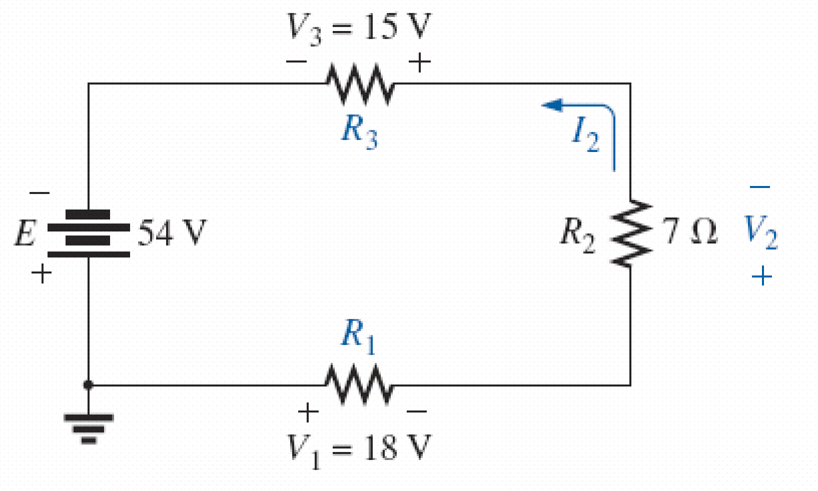


FIG. 5.32 *Series configuration to be examined in Example 5.13.*

VOLTAGE DIVISION IN A SERIES CIRCUIT

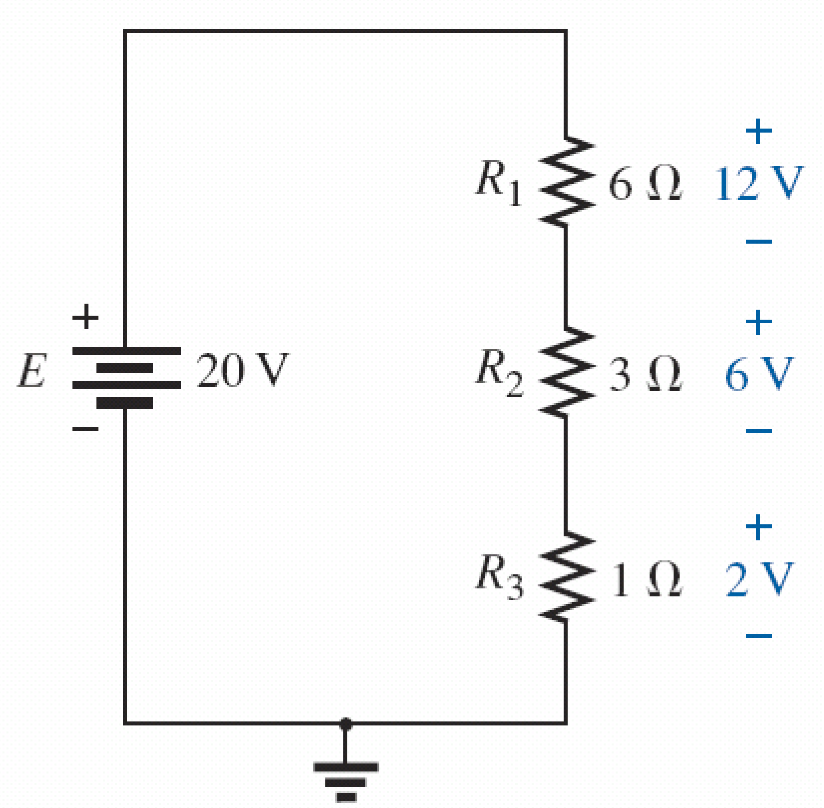


FIG. 5.33 *Revealing how the voltage will divide across series resistive elements.*

LOGO

VOLTAGE DIVISION IN A SERIES CIRCUIT

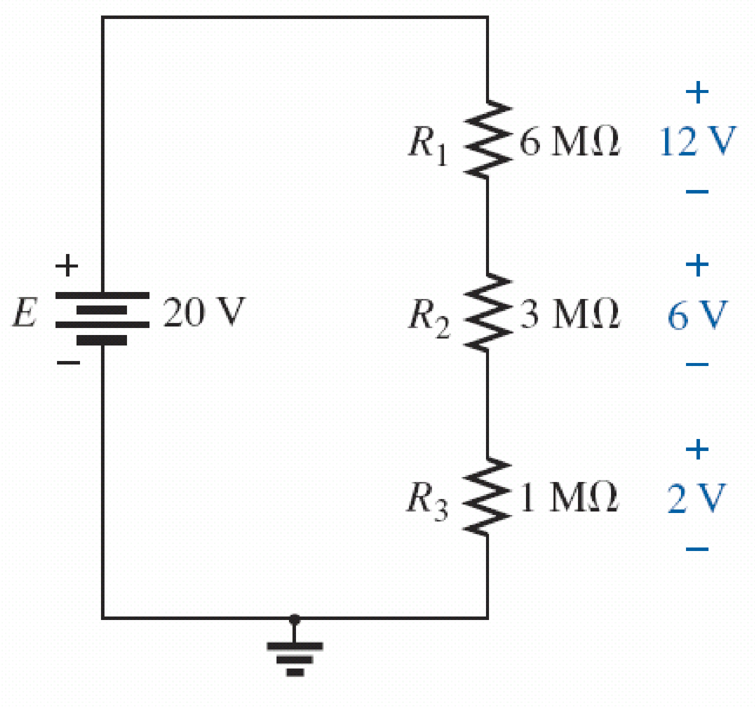


FIG. 5.34 *The ratio of the resistive values determines the voltage division of a series dc circuit.*

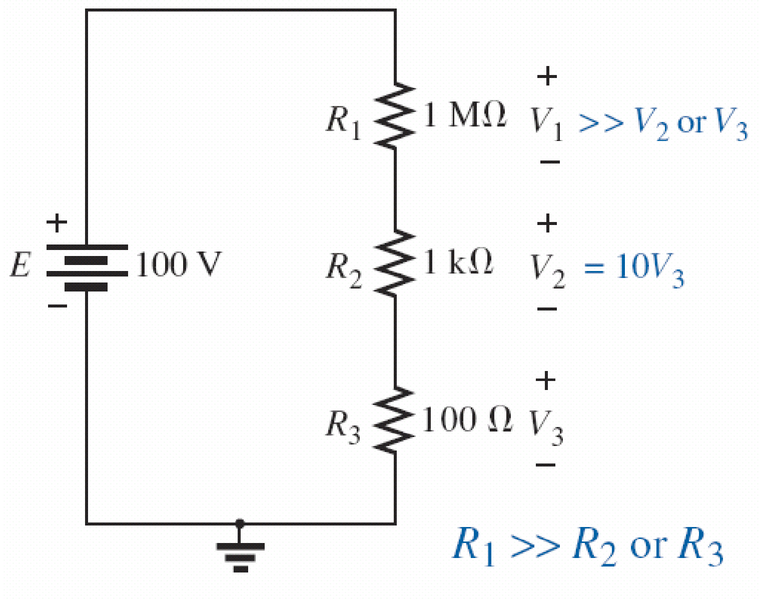


FIG. 5.35 *The largest of the series resistive elements will capture the major share of the applied voltage.*

LOGO

VOLTAGE DIVISION IN A SERIES CIRCUIT

Voltage Divider Rule (VDR)

- The **voltage divider rule (VDR)** permits the determination of the voltage across a series resistor without first having to determine the current of the circuit.
- The rule itself can be derived by analyzing the simple series circuit in Fig. 5.36.

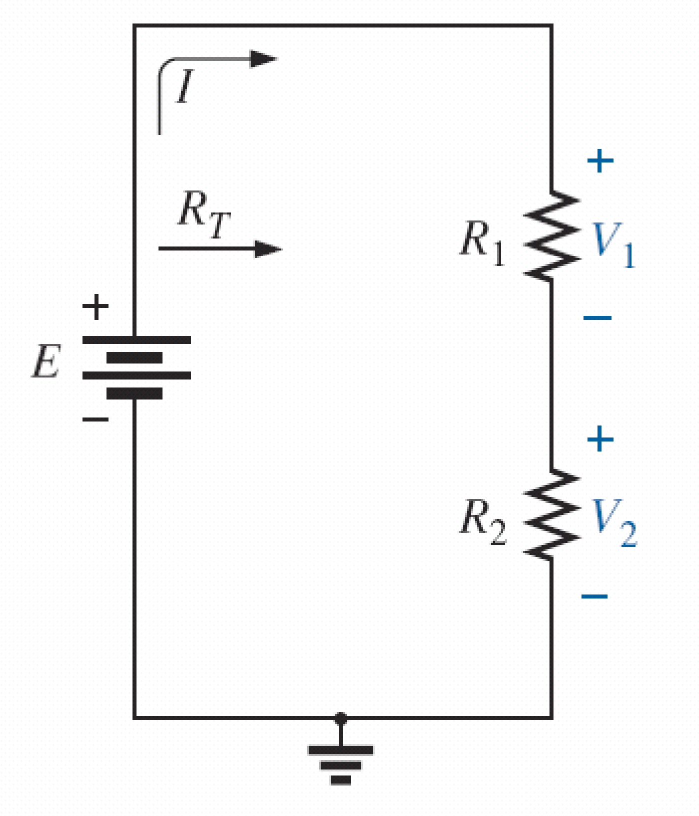


FIG. 5.36 *Developing the voltage divider rule.*

VOLTAGE DIVISION IN A SERIES CIRCUIT

Voltage Divider Rule (VDR)

- The voltage divider rule states that ***the voltage across a resistor in a series circuit is equal to the value of that resistor times the total applied voltage divided by the total resistance of the series configuration.***

VOLTAGE DIVISION IN A SERIES CIRCUIT

Voltage Divider Rule (VDR)

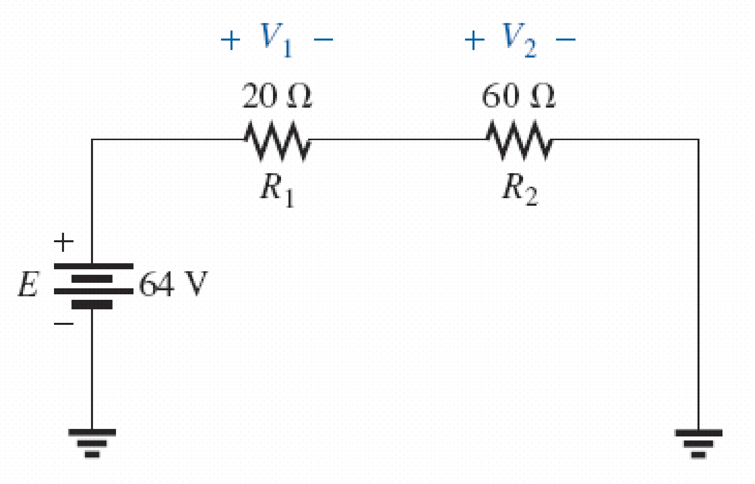


FIG. 5.37 *Series circuit to be examined using the voltage divider rule in Example 5.15.*

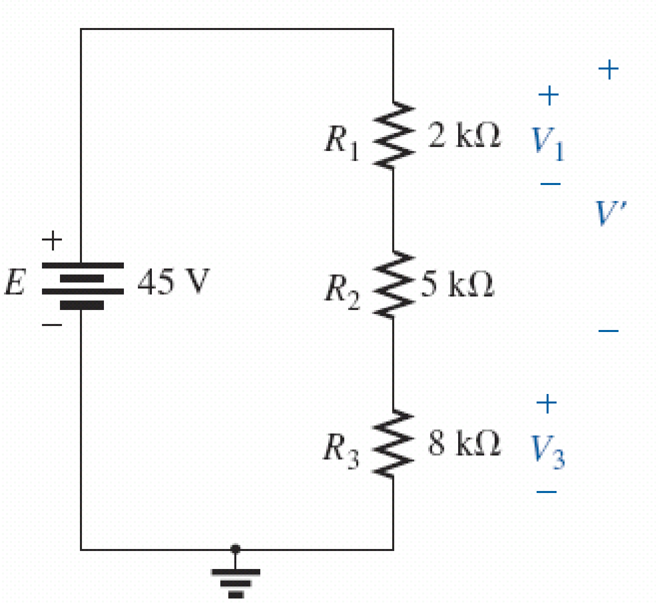


FIG. 5.38 *Series circuit to be investigated in Examples 5.16 and 5.17.*

VOLTAGE DIVISION IN A SERIES CIRCUIT

Voltage Divider Rule (VDR)

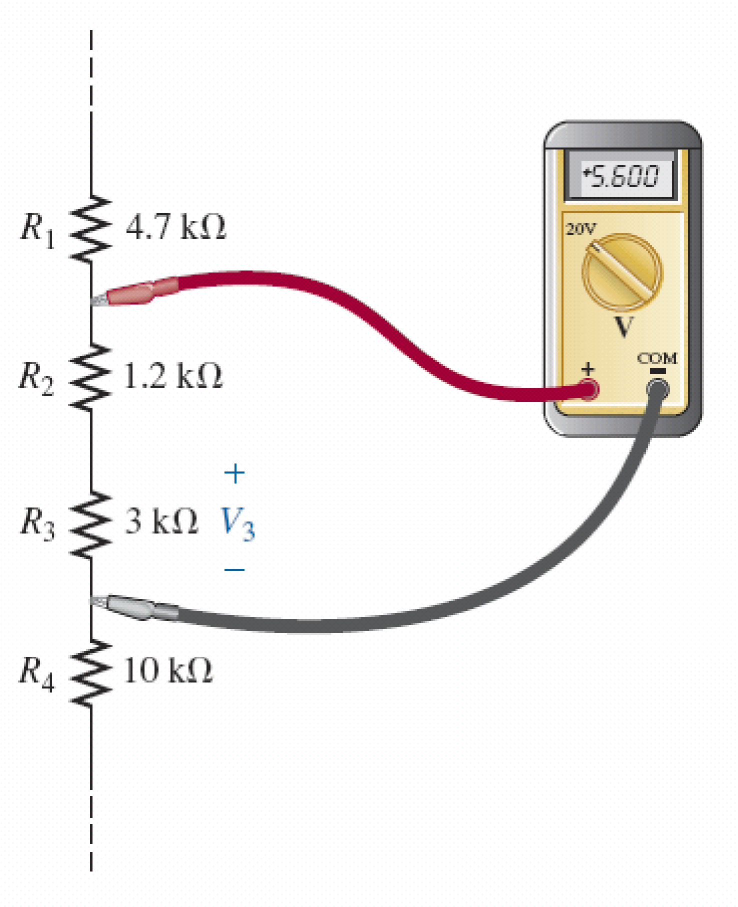


FIG. 5.39 *Voltage divider action for Example 5.18.*

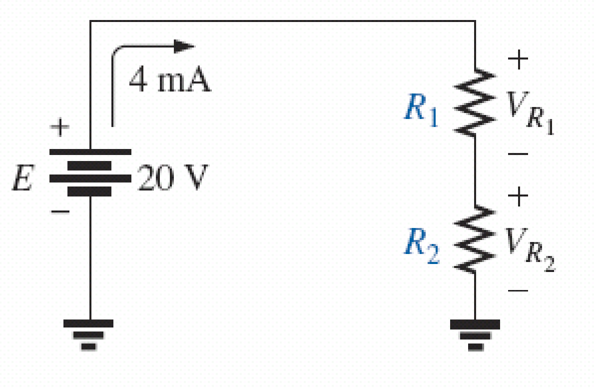


FIG. 5.40 *Designing a voltage divider circuit (Example 5.19).*

INTERCHANGING SERIES ELEMENTS

- The elements of a series circuit can be interchanged without affecting the total resistance, current, or power to each element.

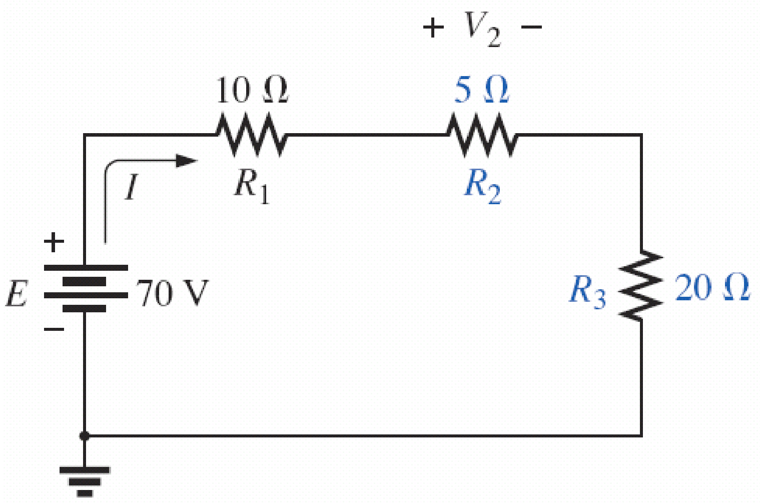


FIG. 5.41 *Series dc circuit with elements to be interchanged.*

LOGO

INTERCHANGING SERIES ELEMENTS

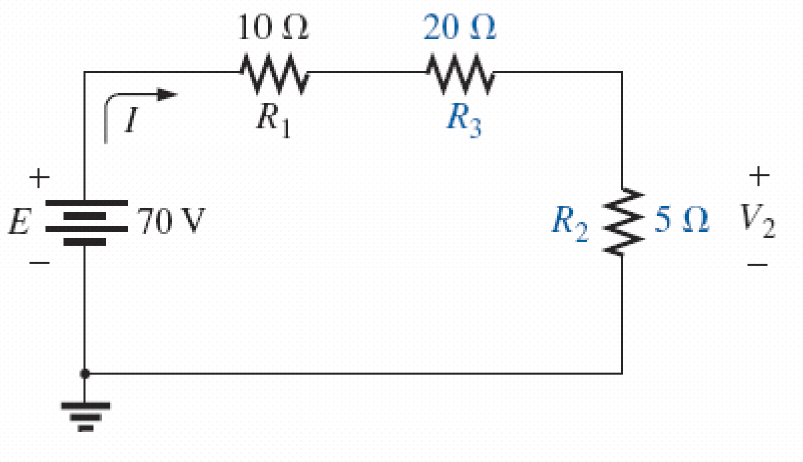


FIG. 5.42 *Circuit in Fig. 5.41 with R_2 and R_3 interchanged.*

LOGO

INTERCHANGING SERIES ELEMENTS

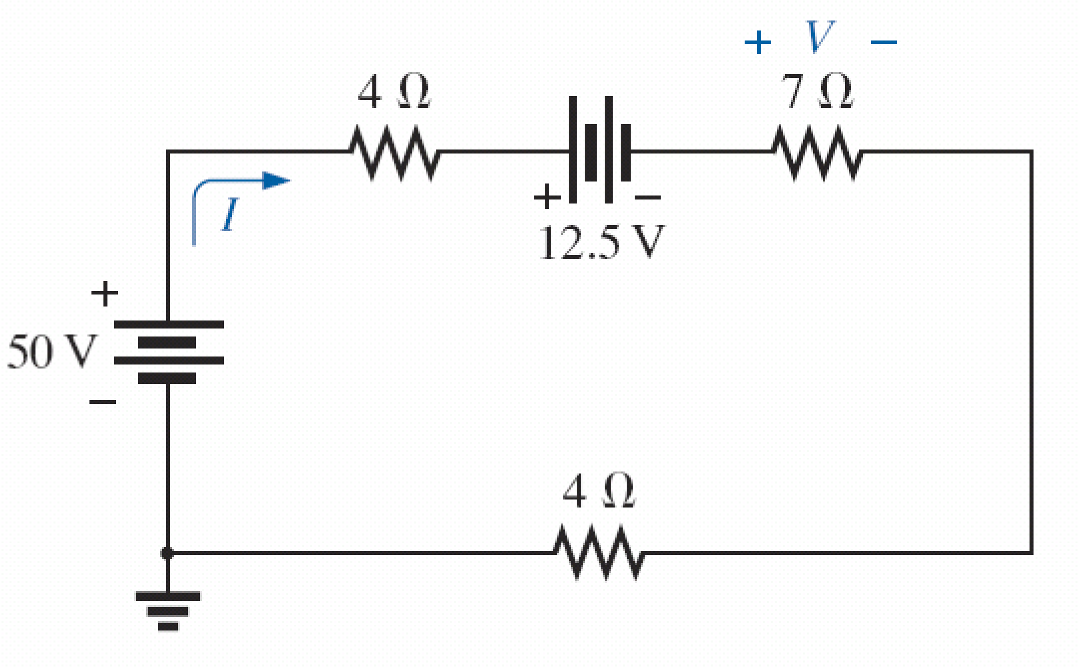


FIG. 5.43 *Example 5.20.*

LOGO

INTERCHANGING SERIES ELEMENTS

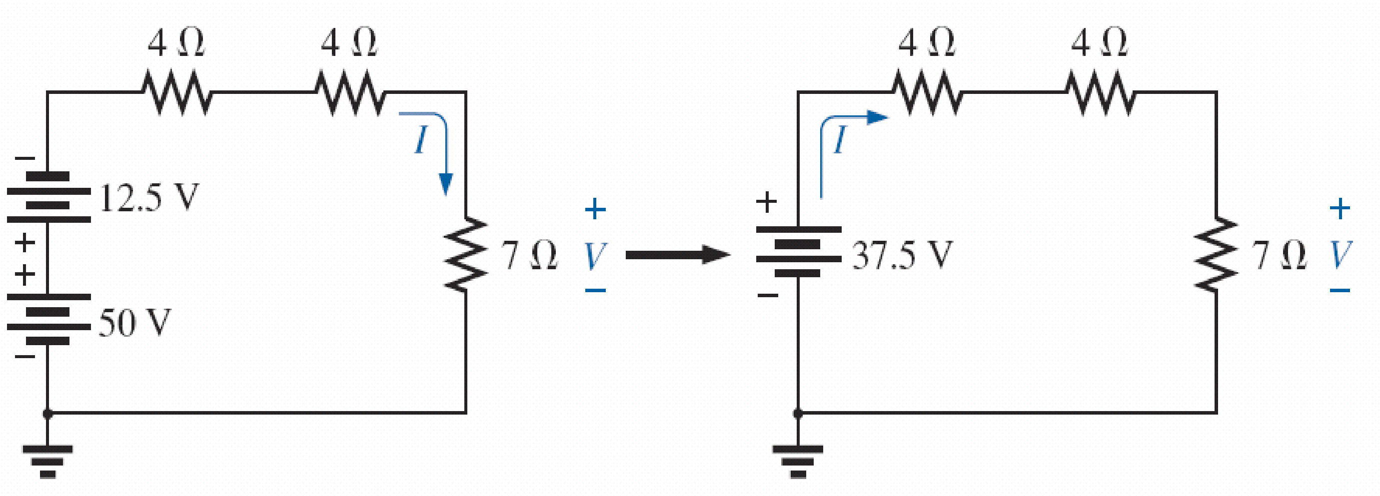


FIG. 5.44 *Redrawing the circuit in Fig. 5.43.*

LOGO

NOTATION

Voltage Sources and Ground

- Except for a few special cases, electrical and electronic systems are grounded for reference and safety purposes.
- The symbol for the ground connection appears in Fig. 5.45 with its defined potential level—zero volts.

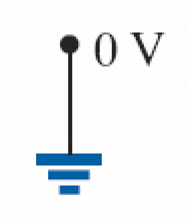


FIG. 5.45 *Ground potential.*

LOGO

NOTATION

Voltage Sources and Ground

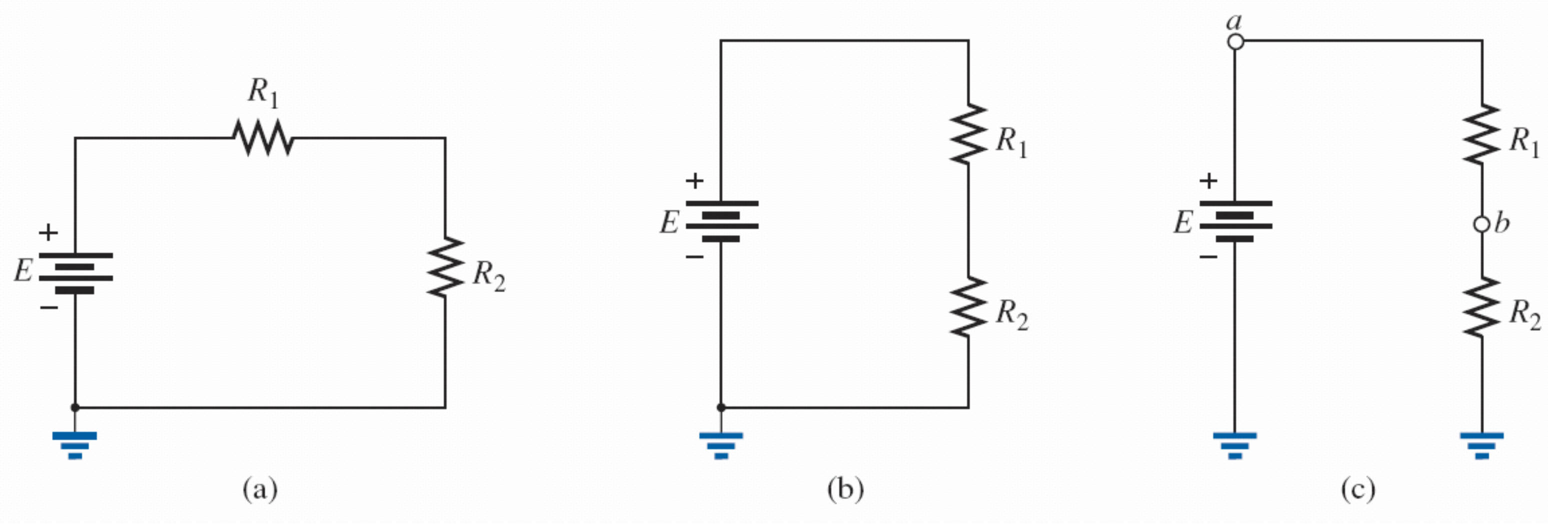


FIG. 5.46 *Three ways to sketch the same series dc circuit.*

NOTATION

Voltage Sources and Ground

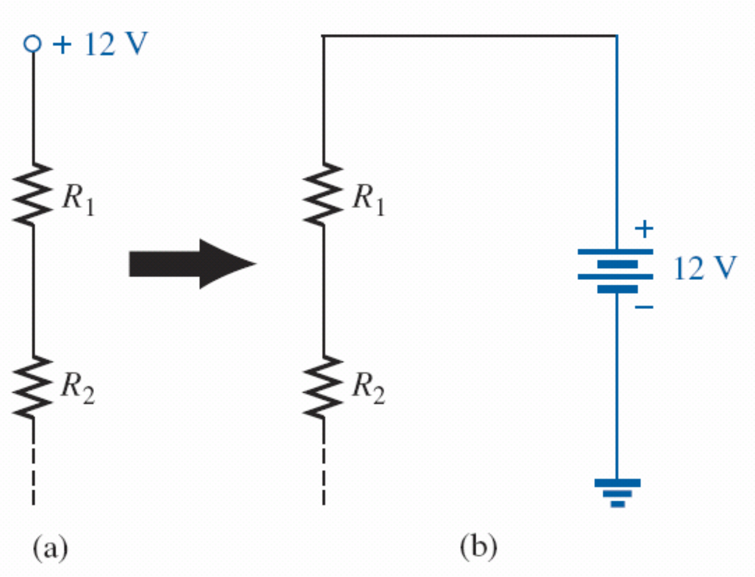


FIG. 5.47 *Replacing the special notation for a dc voltage source with the standard symbol.*

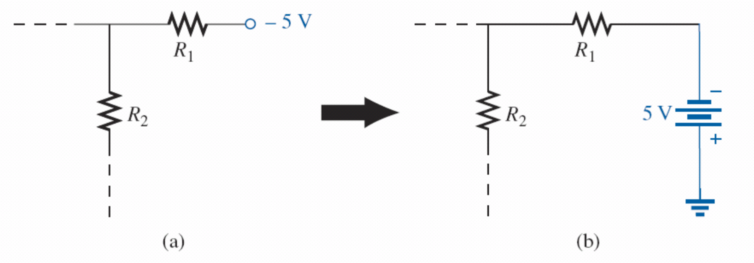


FIG. 5.48 *Replacing the notation for a negative dc supply with the standard notation.*

NOTATION

Voltage Sources and Ground

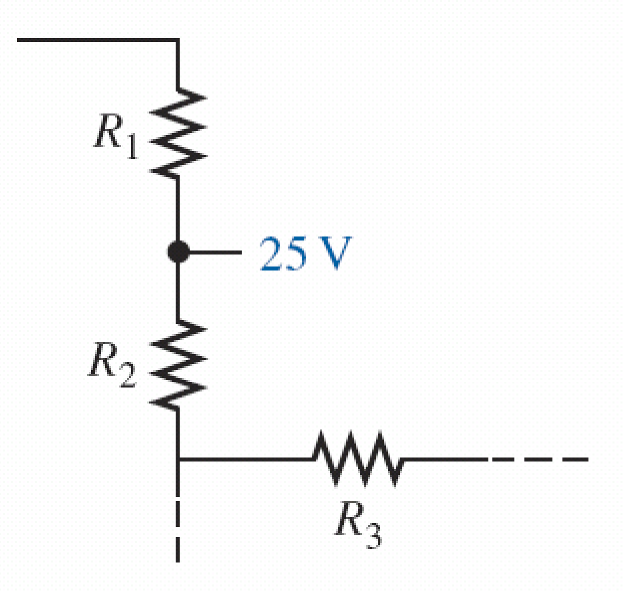


FIG. 5.49 *The expected voltage level at a particular point in a network if the system is functioning properly.*

NOTATION

Double-Subscript Notation

- The fact that voltage is an *across* variable and exists between two points has resulted in a double-subscript notation that defines the first subscript as the higher potential.

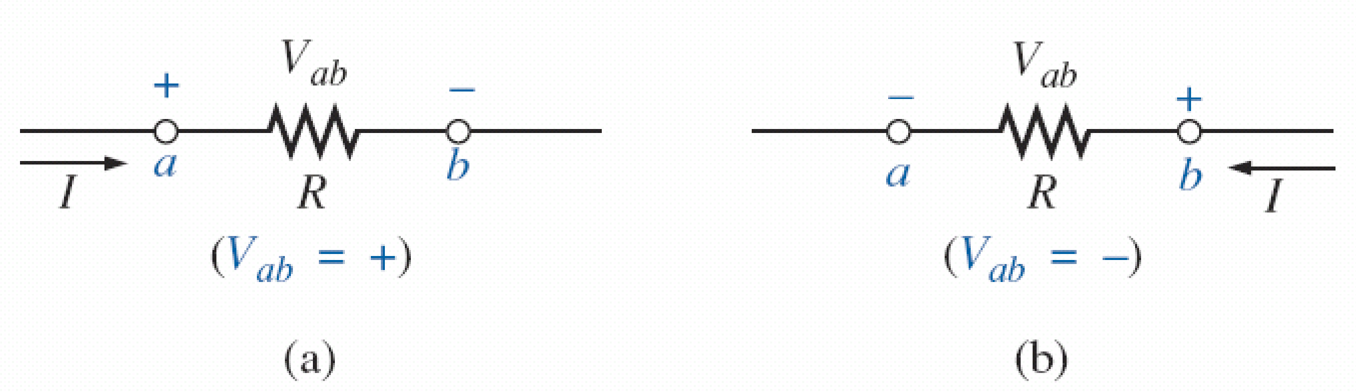


FIG. 5.50 *Defining the sign for double-subscript notation.*

LOGO

NOTATION

Double-Subscript Notation

- ***The double-subscript notation V_{ab} specifies point a as the higher potential.***
- ***If this is not the case, a negative sign must be associated with the magnitude of V_{ab}.***
- In other words, ***the voltage V_{ab} is the voltage at point a with respect to (w.r.t.) point b.***

NOTATION

Single-Subscript Notation

- If point *b* of the notation V_{ab} is specified as ground potential (zero volts), then a single-subscript notation can be used that provides the voltage at a point with respect to ground.

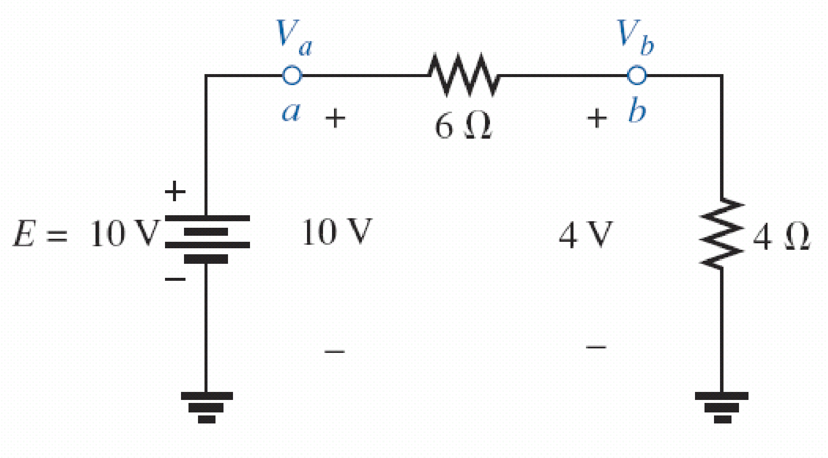


FIG. 5.51 *Defining the use of single-subscript notation for voltage levels.*

LOGO

NOTATION

General Comments

- A particularly useful relationship can now be established that has extensive applications in the analysis of electronic circuits.
- For the above notational standards, the following relationship exists:

$$\boxed{V_{ab} = V_a - V_b}$$

NOTATION

General Comments

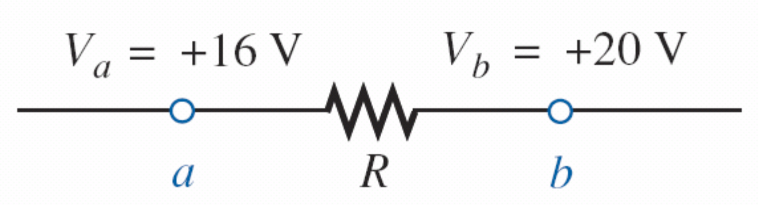


FIG. 5.52 *Example 5.21.*

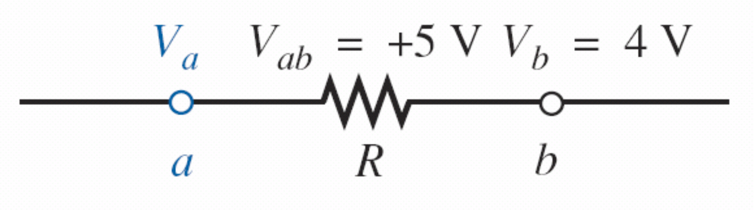


FIG. 5.53 *Example 5.22.*

NOTATION

General Comments

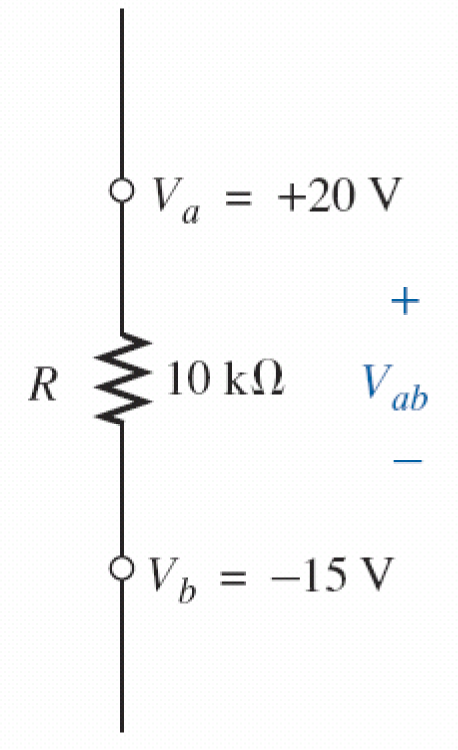


FIG. 5.54 *Example 5.23.*

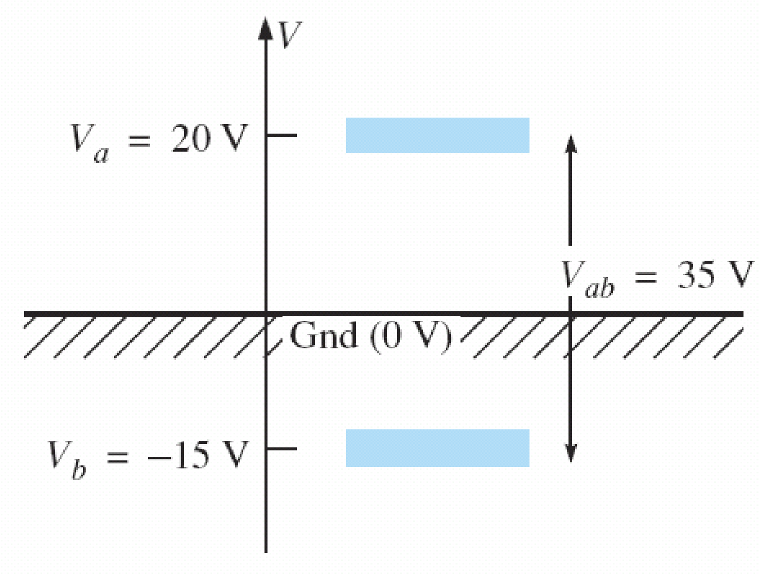


FIG. 5.55 *The impact of positive and negative voltages on the total voltage drop.*

LOGO

NOTATION

General Comments

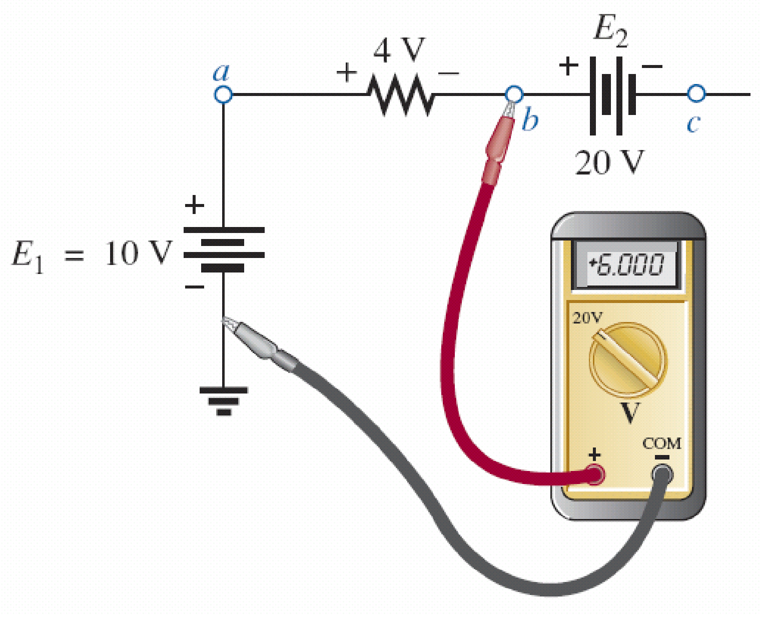


FIG. 5.56 *Example 5.24.*

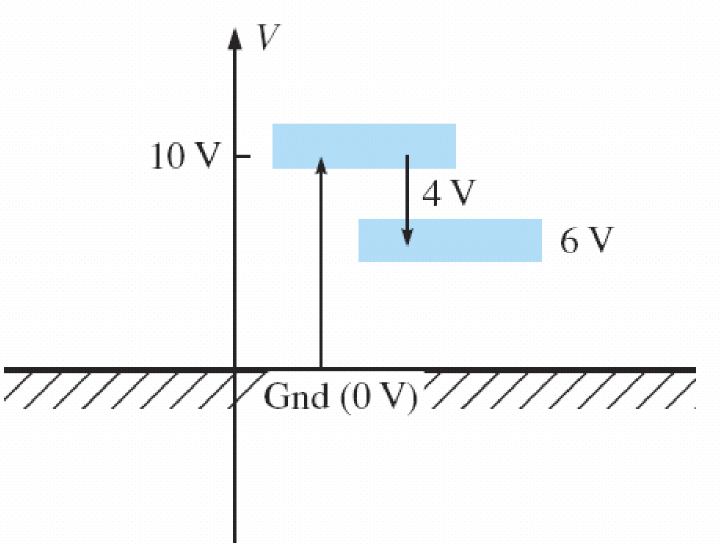


FIG. 5.57 *Determining V_b using the defined voltage levels.*

NOTATION

General Comments

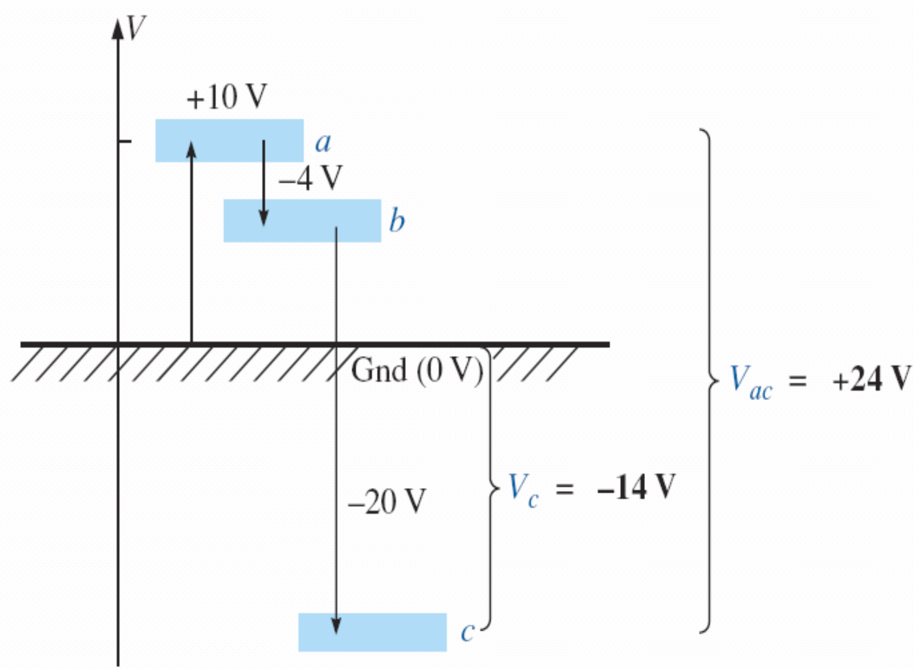


FIG. 5.58 *Review of the potential levels for the circuit in Fig. 5.56.*

LOGO

NOTATION

General Comments

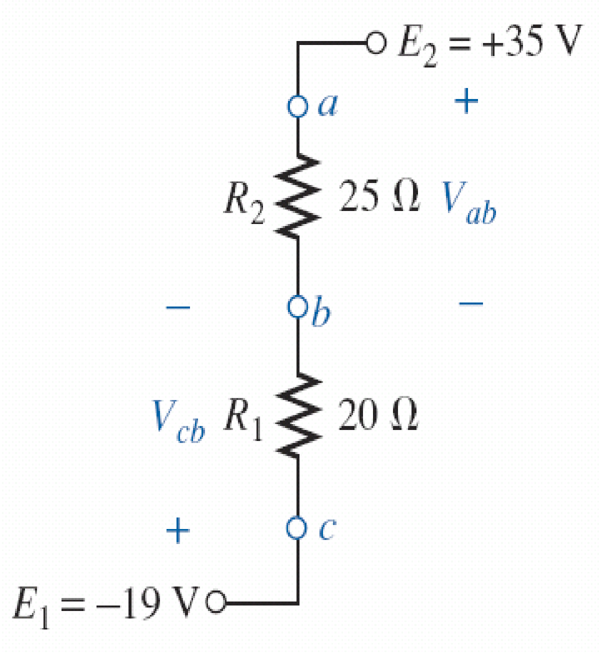


FIG. 5.59 *Example 5.25.*

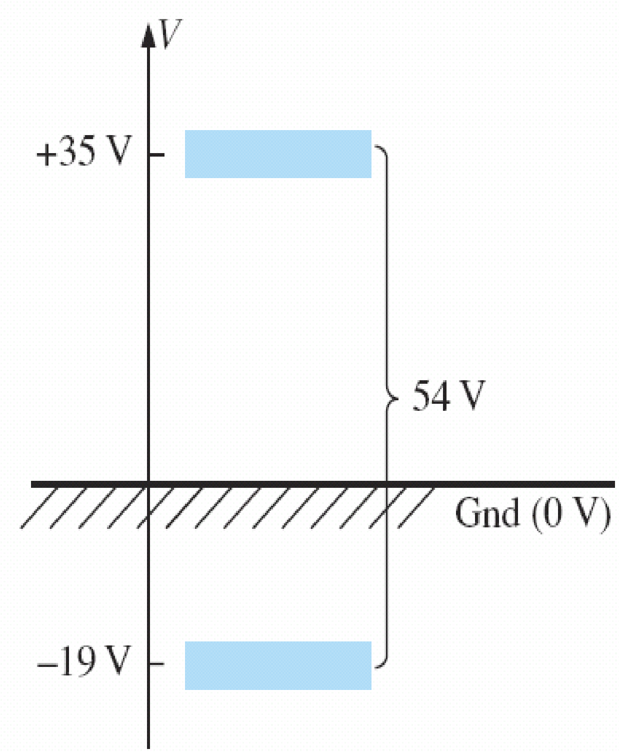


FIG. 5.60 *Determining the total voltage drop across the resistive elements in Fig 5.59.*

LOGO

NOTATION

General Comments

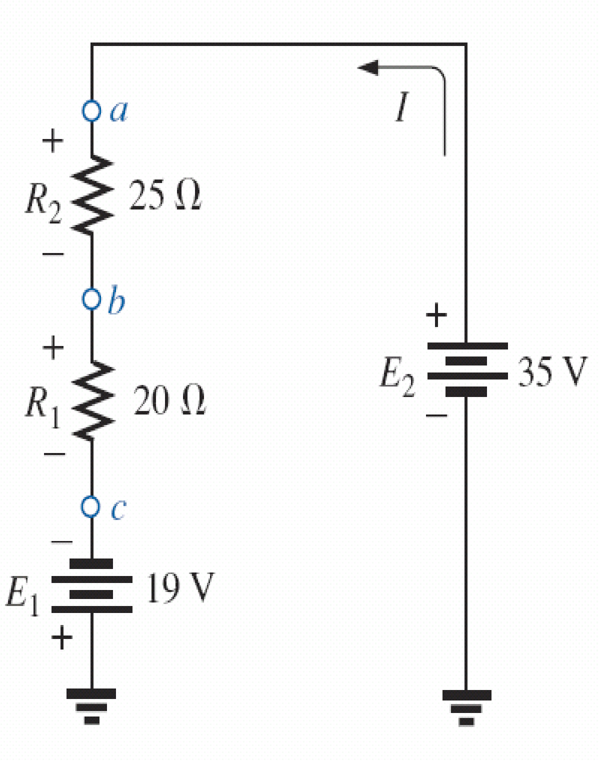


FIG. 5.61 *Redrawing the circuit in Fig. 5.59 using standard dc voltage supply symbols.*

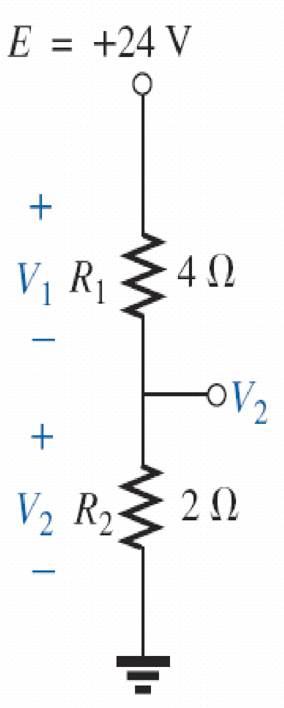


FIG. 5.62 *Example 5.26.*

LOGO

NOTATION

General Comments

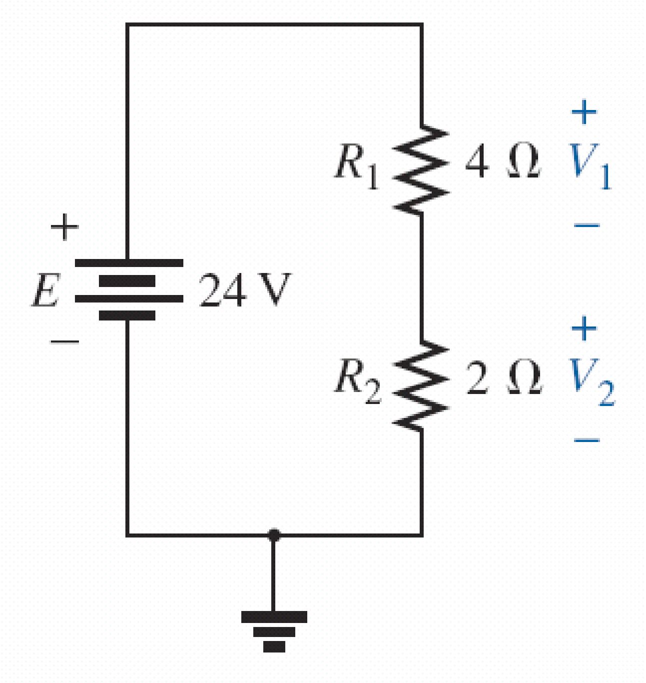


FIG. 5.63 *Circuit of Fig. 5.62 redrawn.*

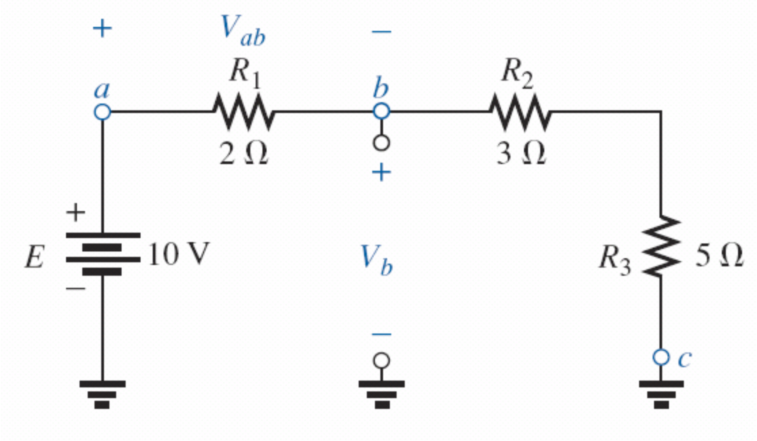


FIG. 5.64 *Example 5.27.*

VOLTAGE REGULATION AND THE INTERNAL RESISTANCE OF VOLTAGE SOURCES

- When you use a dc supply such as the generator, battery, or supply in Fig. 5.65, you initially assume that it will provide the desired voltage for any resistive load you may hook up to the supply.

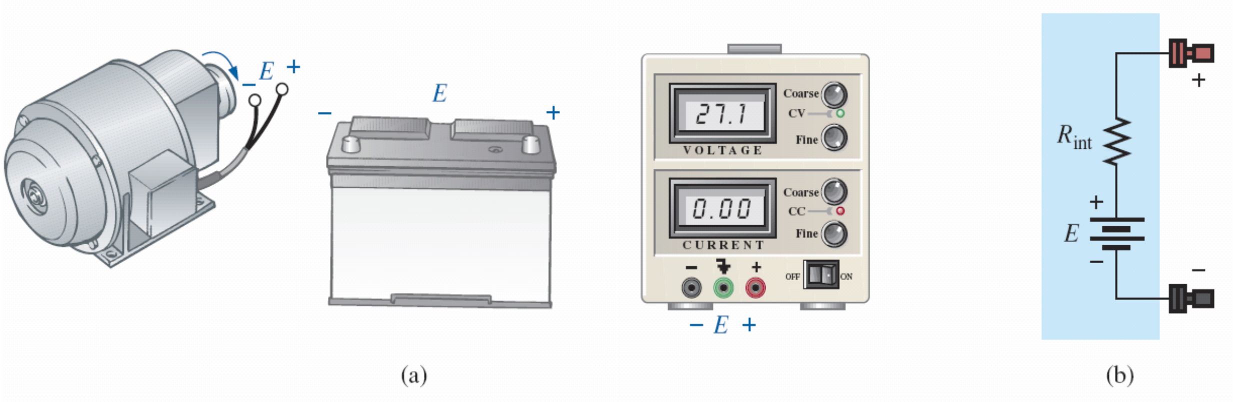


FIG. 5.65 *(a) Sources of dc voltage; (b) equivalent circuit.*

VOLTAGE REGULATION AND THE INTERNAL RESISTANCE OF VOLTAGE SOURCES

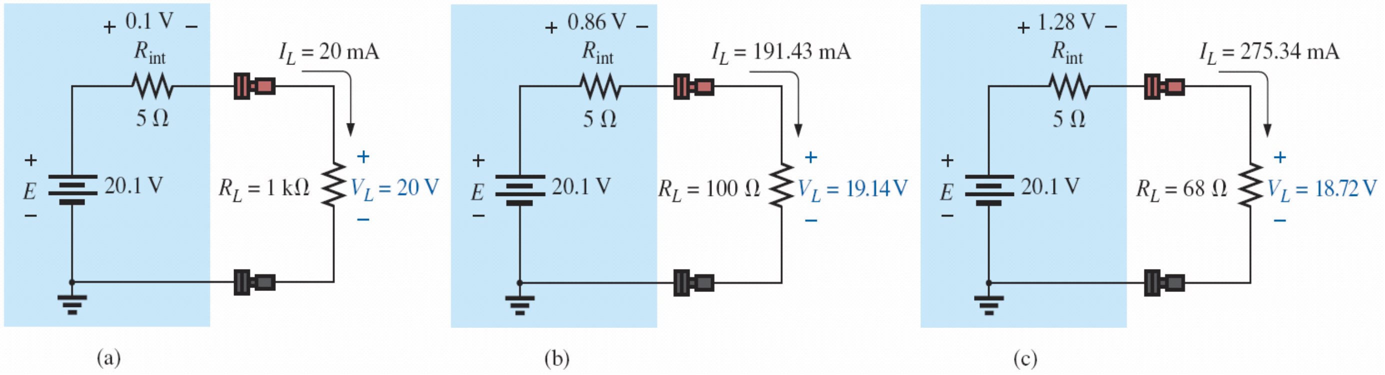


FIG. 5.66 *Demonstrating the effect of changing a load on the terminal voltage of a supply.*

LOGO

VOLTAGE REGULATION AND THE INTERNAL RESISTANCE OF VOLTAGE SOURCES

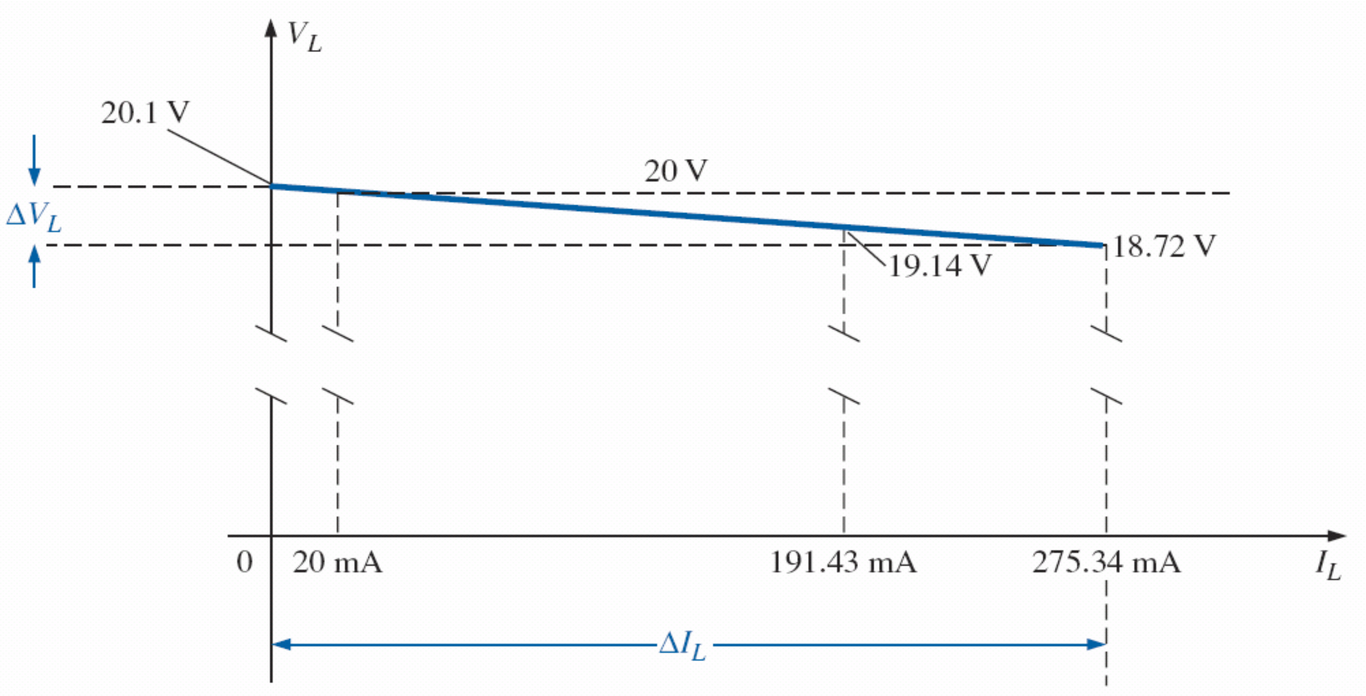


FIG. 5.67 *Plotting V_L versus I_L for the supply in Fig. 5.66.*

LOGO

VOLTAGE REGULATION AND THE INTERNAL RESISTANCE OF VOLTAGE SOURCES

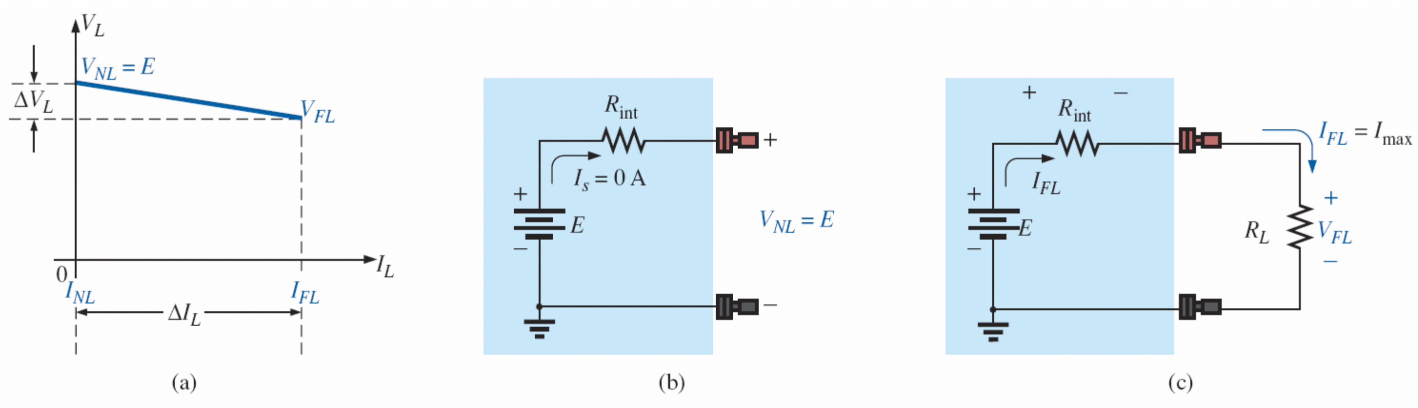


FIG. 5.68 *Defining the properties of importance for a power supply.*

VOLTAGE REGULATION AND THE INTERNAL RESISTANCE OF VOLTAGE SOURCES

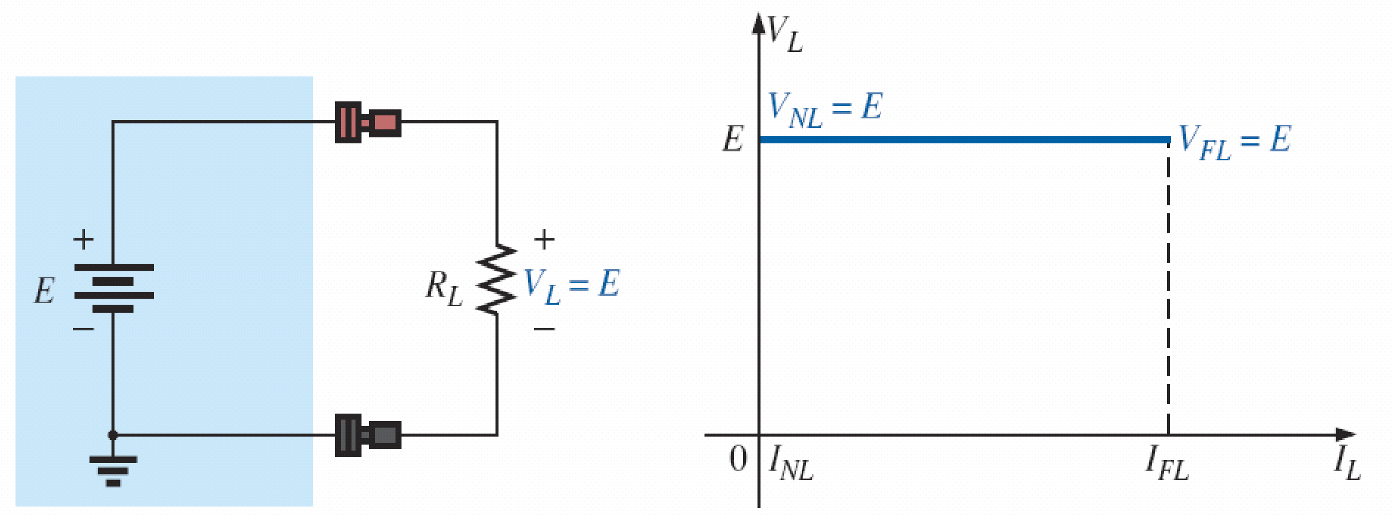


FIG. 5.69 *Ideal supply and its terminal characteristics.*

LOGO

VOLTAGE REGULATION AND THE INTERNAL RESISTANCE OF VOLTAGE SOURCES

- To help us anticipate the expected response of a supply, a defining quantity called **voltage regulation** (abbreviated *VR*; often called *load regulation* on specification sheets) was established.
- The basic equation in terms of the quantities in Fig. 5.68(a) is the following:

$$\boxed{VR = \frac{V_{NL} - V_{FL}}{V_{FL}} \times 100\%}$$

LOGO

VOLTAGE REGULATION AND THE INTERNAL RESISTANCE OF VOLTAGE SOURCES

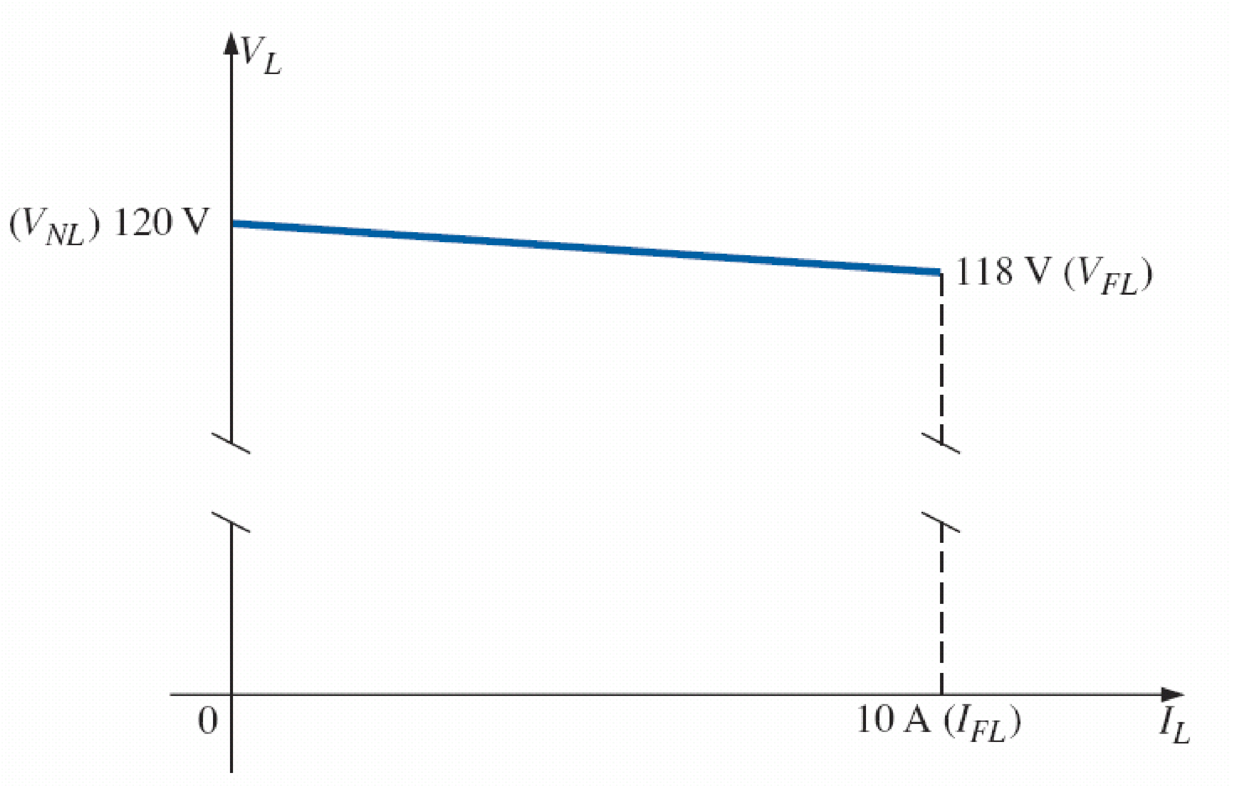


FIG. 5.70 *Terminal characteristics for the supply of Example 5.28.*

VOLTAGE REGULATION AND THE INTERNAL RESISTANCE OF VOLTAGE SOURCES

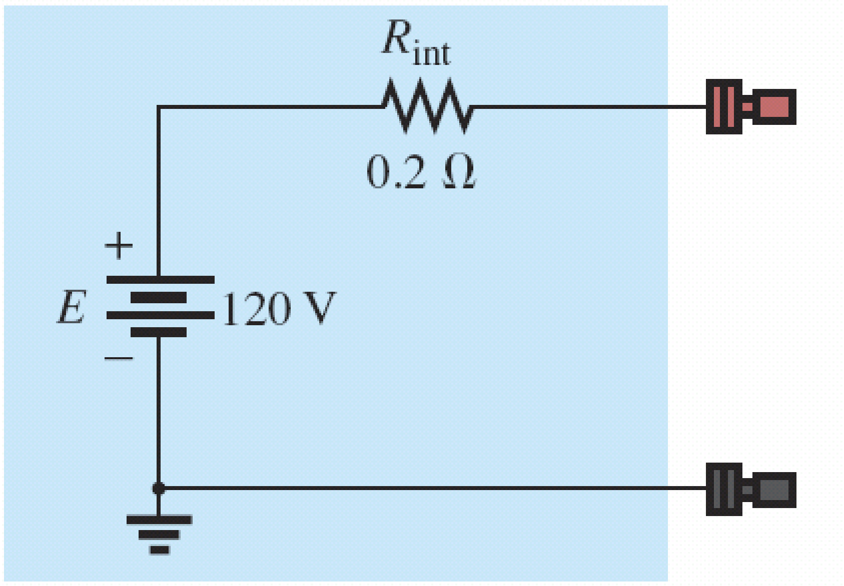


FIG. 5.71 *dc supply with the terminal characteristics of Fig. 5.70.*

VOLTAGE REGULATION AND THE INTERNAL RESISTANCE OF VOLTAGE SOURCES

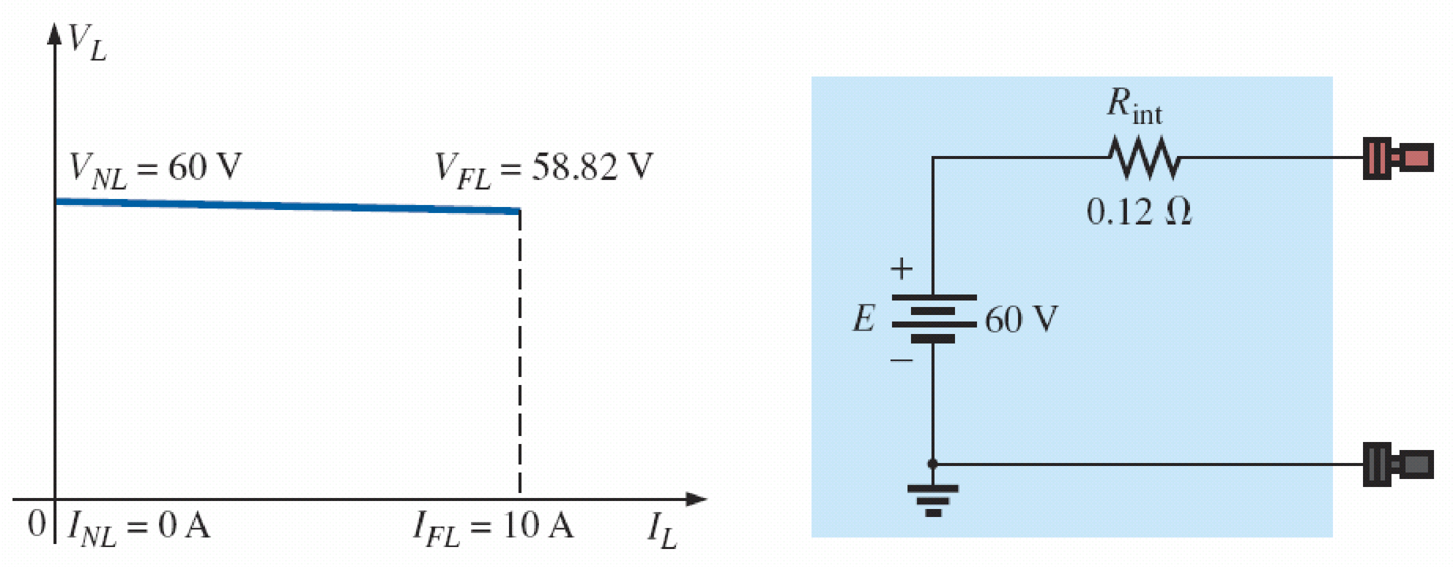


FIG. 5.72 *Characteristics and equivalent circuit for the supply of Example 5.29.*

LOGO

LOADING EFFECTS OF INSTRUMENTS

- In the previous section, we learned that power supplies are not the ideal instruments we may have thought they were.
- The applied load can have an effect on the terminal voltage.
- Fortunately, since today’s supplies have such small load regulation factors, the change in terminal voltage with load can usually be ignored for most applications.

LOGO

LOADING EFFECTS OF INSTRUMENTS

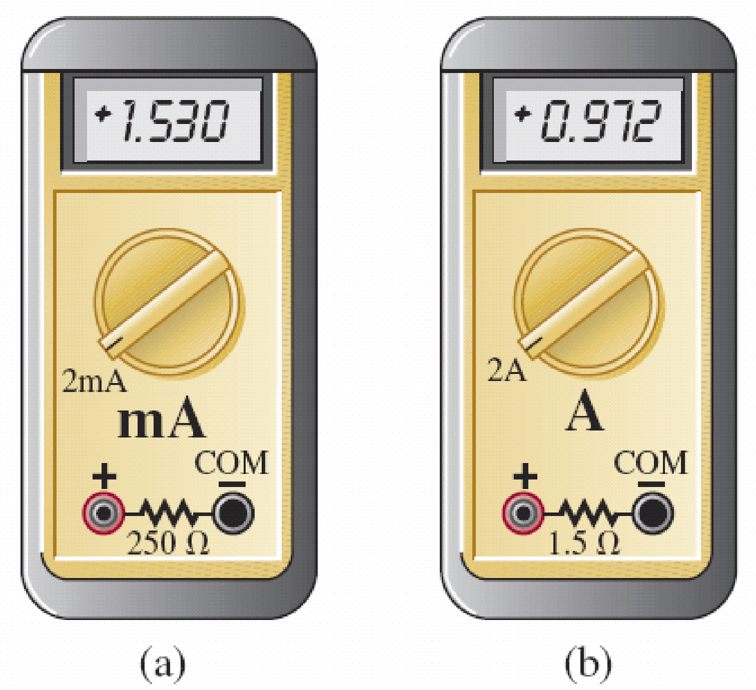
- If we now turn our attention to the various meters we use in the lab, we again find that they are not totally ideal:
    - ***Whenever you apply a meter to a circuit, you change the circuit and the response of the system. Fortunately, however, for most applications, considering the meters to be ideal is a valid approximation as long as certain factors are considered.***

LOGO

LOADING EFFECTS OF INSTRUMENTS

- For instance, ***any ammeter connected in a series circuit will introduce resistance to the series combination that will affect the current and voltages of the configuration.***
- The resistance between the terminals of an ammeter is determined by the chosen scale of the ammeter.
  - In general, ***for ammeters, the higher the maximum value of the current for a particular scale, the smaller will the internal resistance be.***

LOADING EFFECTS OF INSTRUMENTS



(a)

(b)

FIG. 5.73 *Including the effects of the internal resistance of an ammeter: (a) 2 mA scale; (b) 2 A scale.*

LOGO

LOADING EFFECTS OF INSTRUMENTS

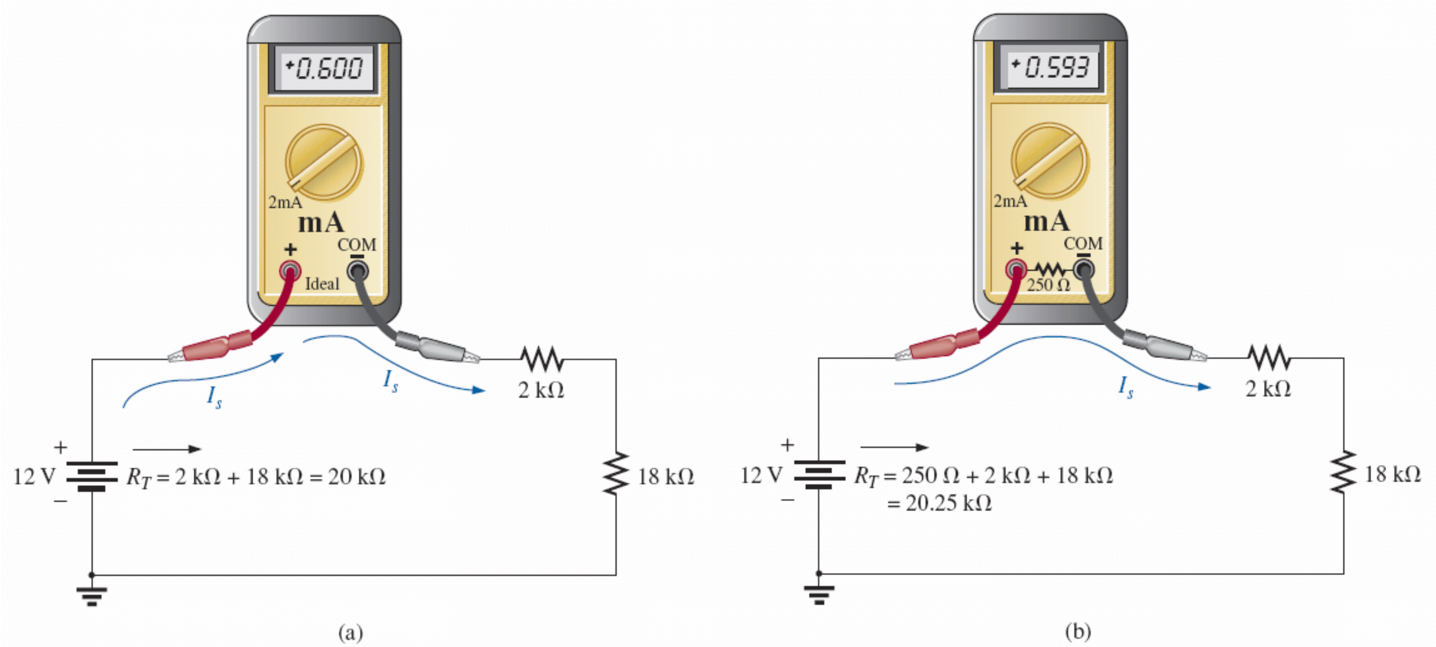


FIG. 5.74 *Applying an ammeter set on the 2 mA scale to a circuit with resistors in the kilohm range: (a) ideal; (b) practical.*

LOGO

PROTOBOARDS (BREADBOARDS)

- At some point in the design of any electrical/electronic system, a prototype must be built and tested.
- One of the most effective ways to build a testing model is to use the **protoboard** (in the past most commonly called a **breadboard**) in Fig. 5.75.

PROTOBOARDS (BREADBOARDS)

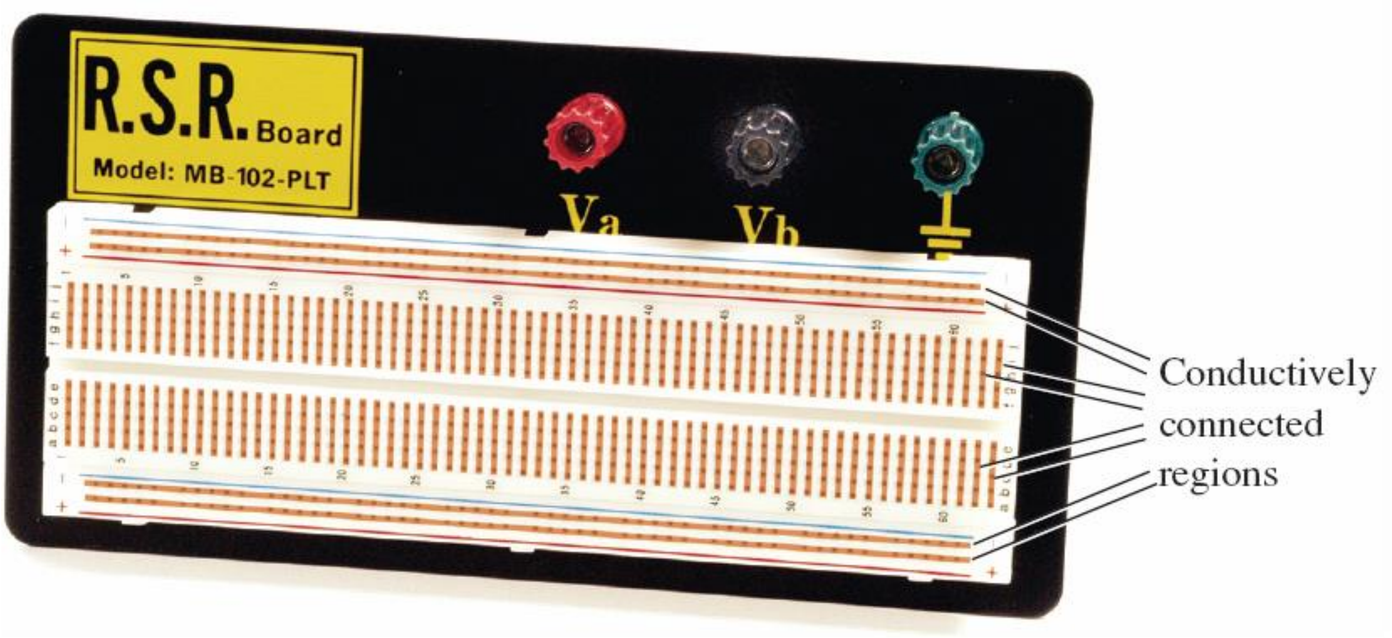


FIG. 5.75 *Protoboard with areas of conductivity defined using two different approaches.*

LOGO

PROTOBOARDS (BREADBOARDS)

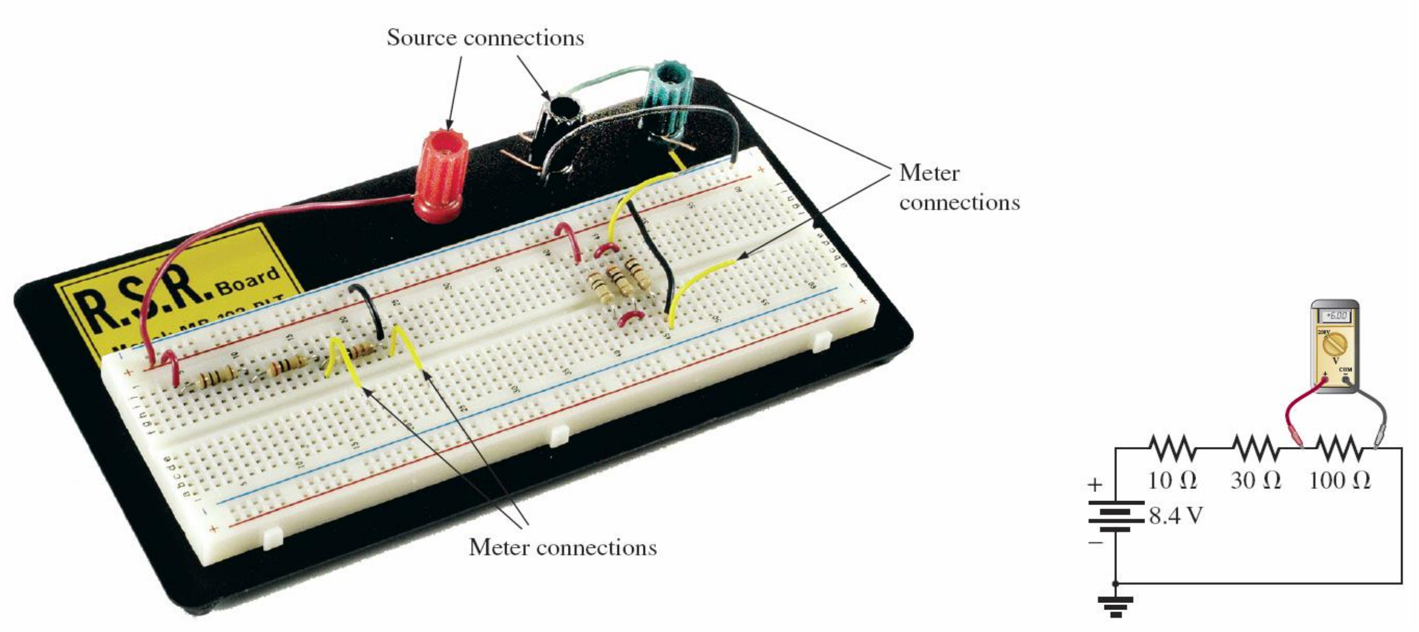


FIG. 5.76 *Two setups for the network in Fig. 5.12 on a protoboard with yellow leads added to each configuration to measure voltage* V_3 *with a voltmeter.*

LOGO

COMPUTER ANALYSIS

PSpice

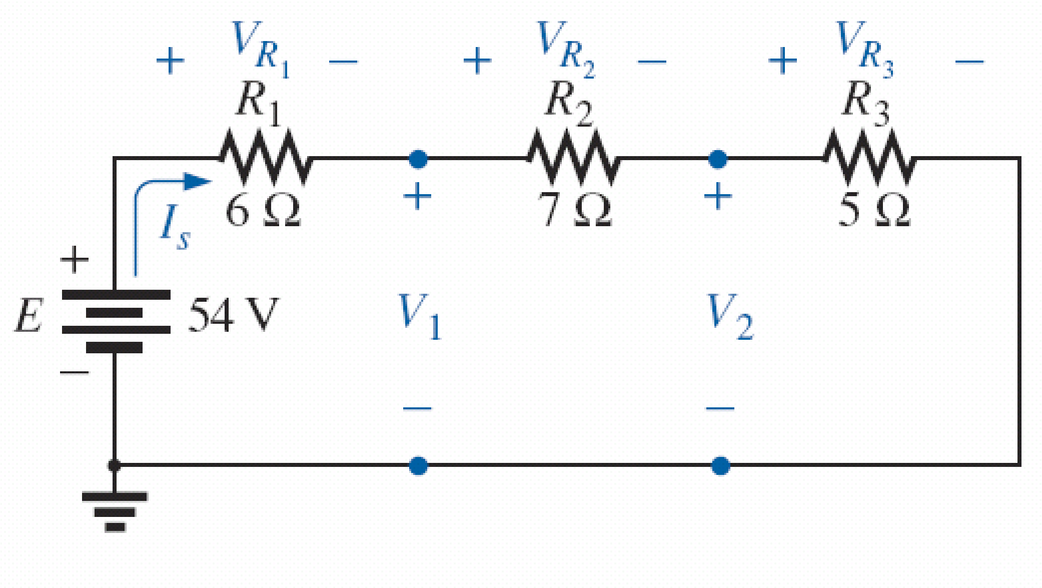


FIG. 5.82 *Series dc network to be analyzed using PSpice.*

LOGO

COMPUTER ANALYSIS

PSpice

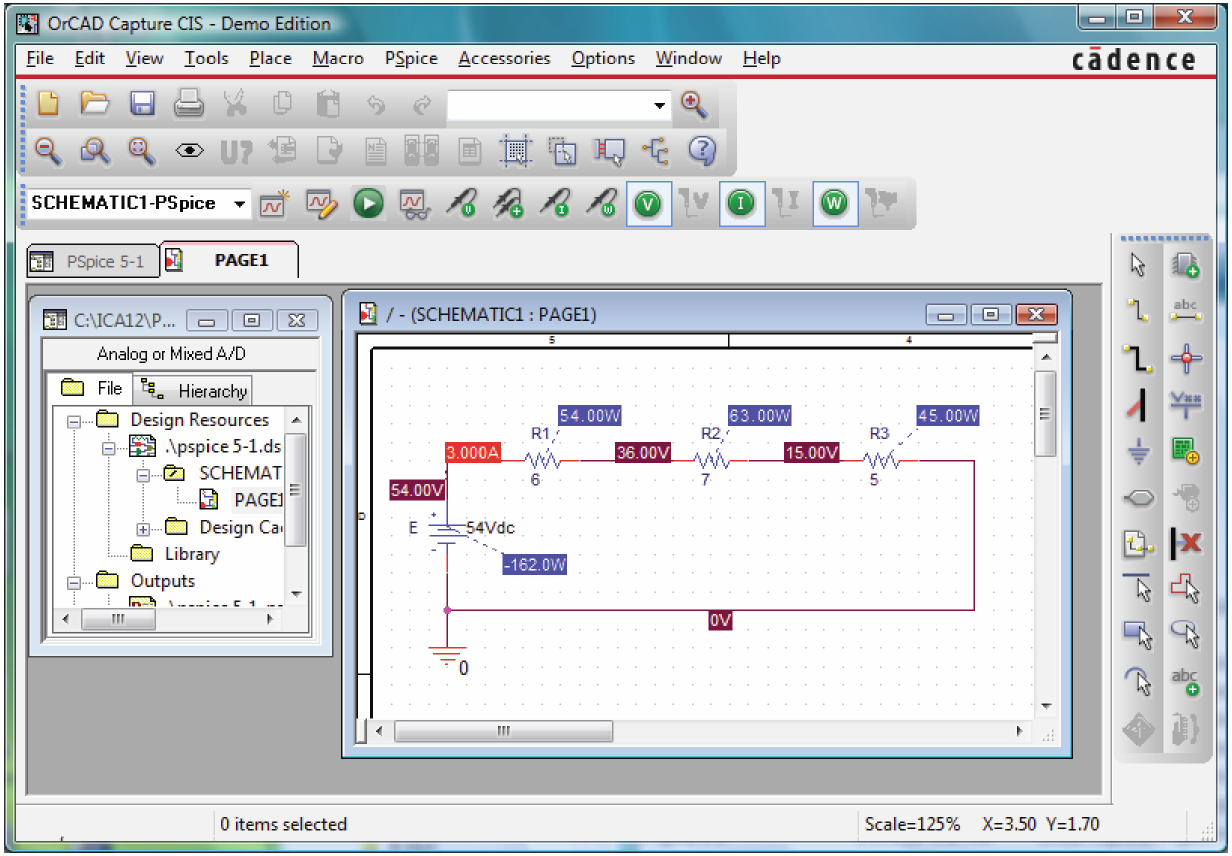


FIG. 5.83 *Applying PSpice to a series dc circuit.*

COMPUTER ANALYSIS

Multisim

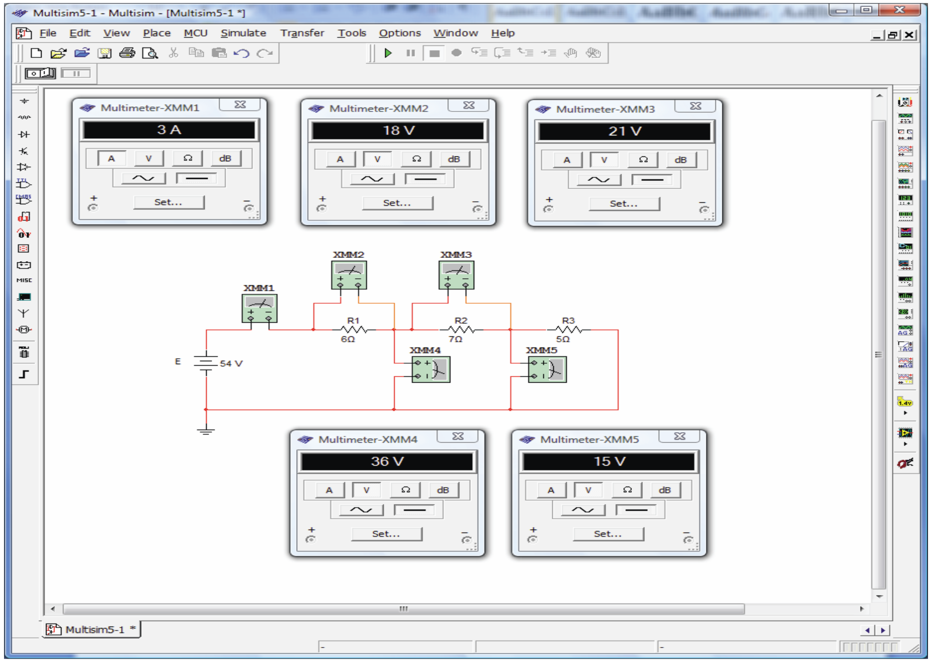


FIG. 5.84 *Applying Multisim to a series dc circuit.*

LOGO

Parallel dc Circuits

INTRODUCTION

- Two network configurations, series and parallel, form the framework for some of the most complex network structures.
- A clear understanding of each will pay enormous dividends as more complex methods and networks are examined.

PARALLEL RESISTORS

- The term *parallel* is used so often to describe a physical arrangement between two elements that most individuals are aware of its general characteristics.
  - In general, ***two elements, branches, or circuits are in parallel if they have two points in common.***

PARALLEL RESISTORS

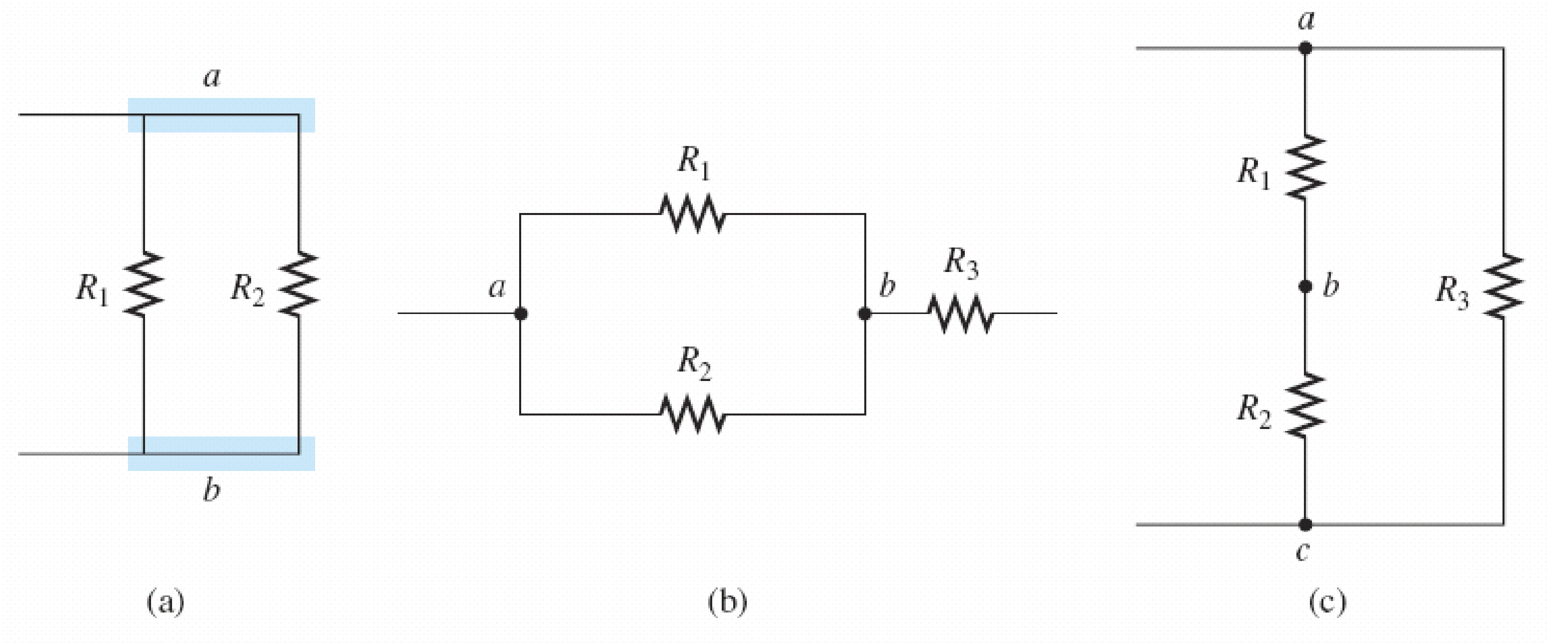


FIG. 6.1 *(a) Parallel resistors; (b) R_1 and R_2 are in parallel; (c) R_3 is in parallel with the series combination of R_1 and R_2.*

PARALLEL RESISTORS

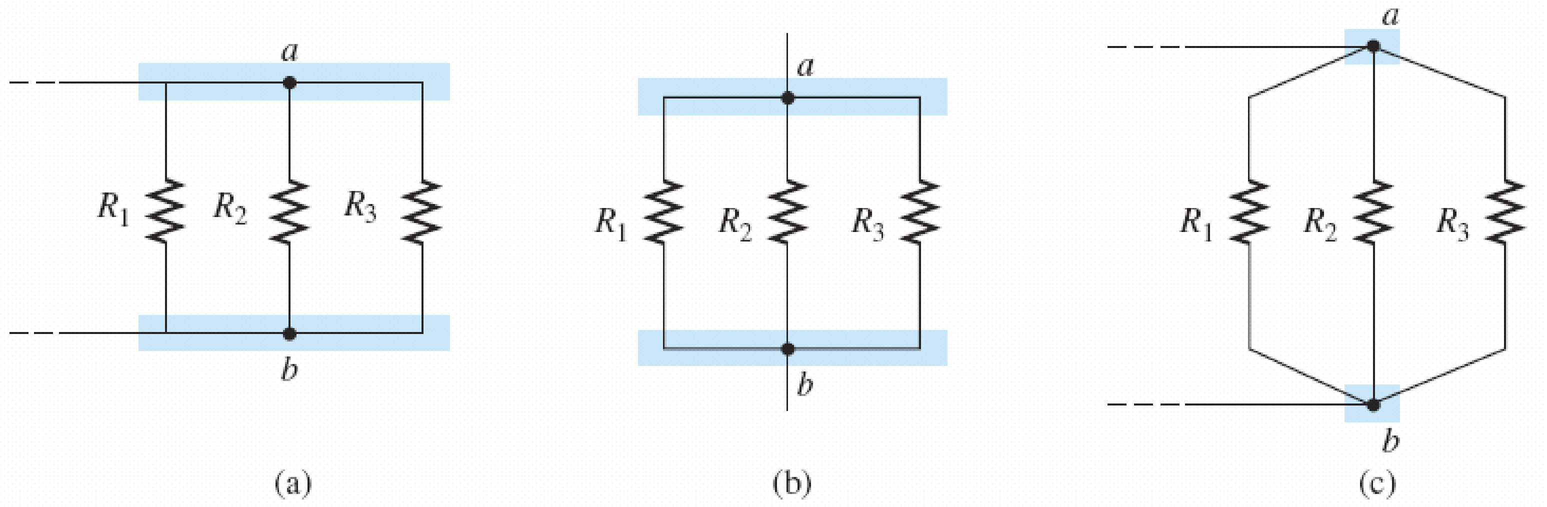


FIG. 6.2 *Schematic representations of three parallel resistors.*

LOGO

PARALLEL RESISTORS

- For resistors in parallel as shown in Fig. 6.3, the total resistance is determined from the following equation:

$$\boxed{\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \cdots + \frac{1}{R_N}}$$

PARALLEL RESISTORS

- Since $G = 1/R$, the equation can also be written in terms of conductance levels as follows:

$$\boxed{G_T = G_1 + G_2 + G_3 + \cdots + G_N}$$

PARALLEL RESISTORS

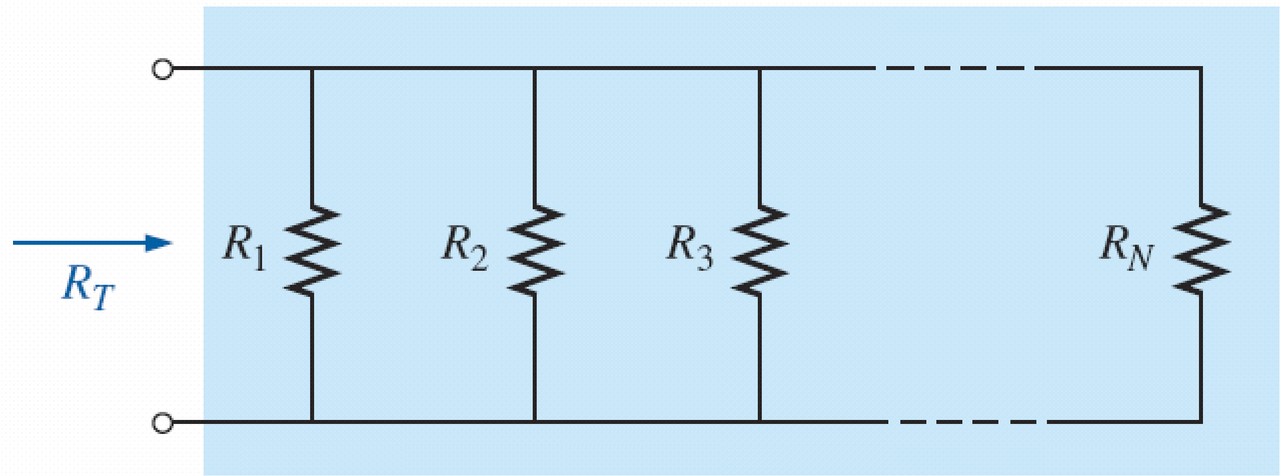


FIG. 6.3 *Parallel combination of resistors.*

PARALLEL RESISTORS

- In general, however, when the total resistance is desired, the following format is applied:

$$\boxed{R_T = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \cdots + \frac{1}{R_N}}}$$

PARALLEL RESISTORS

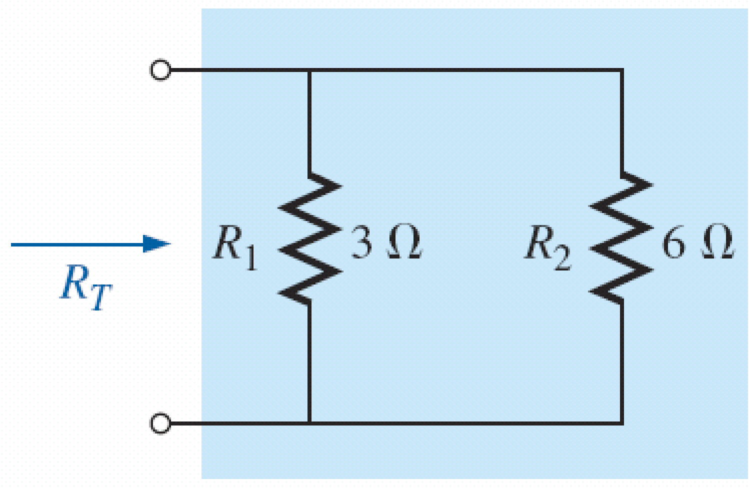


FIG. 6.4 *Parallel resistors for Example 6.1.*

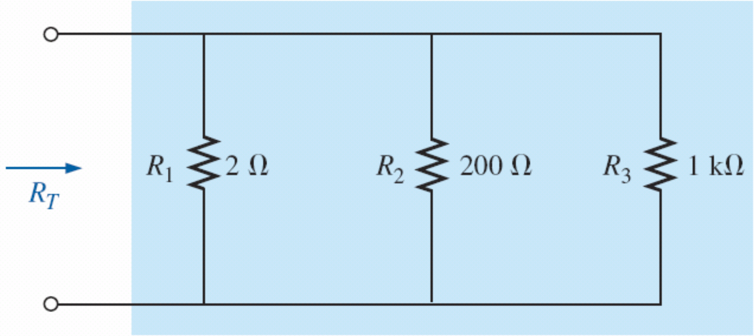


FIG. 6.5 *Parallel resistors for Example 6.2.*

PARALLEL RESISTORS

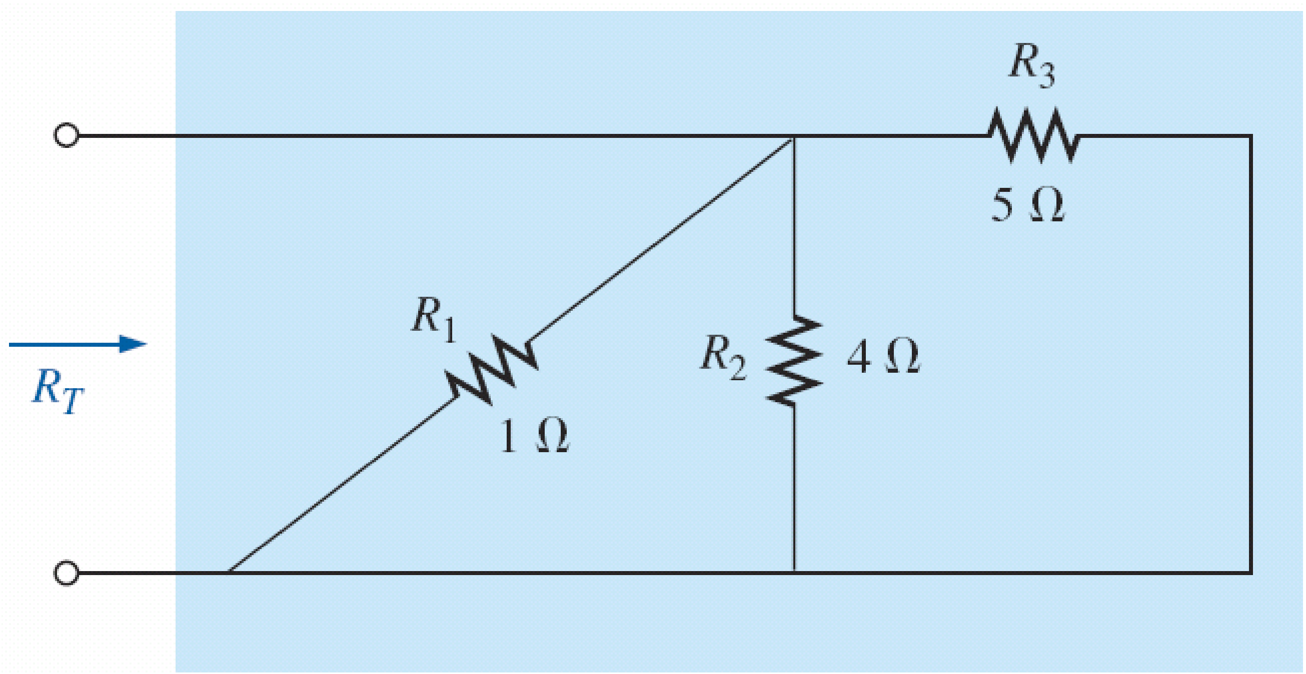


FIG. 6.6 *Network to be investigated in Example 6.3.*

PARALLEL RESISTORS

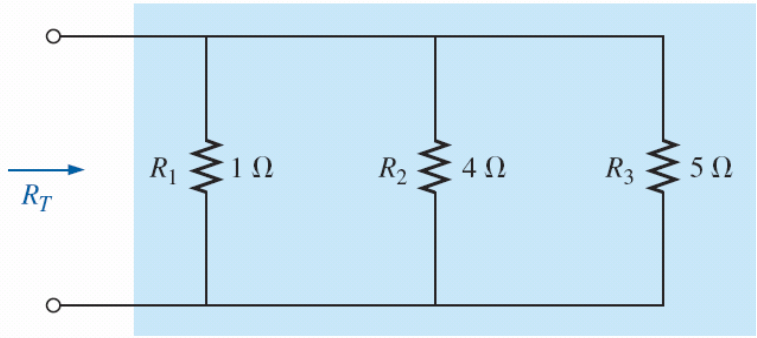


FIG. 6.7 *Network in Fig. 6.6 redrawn.*

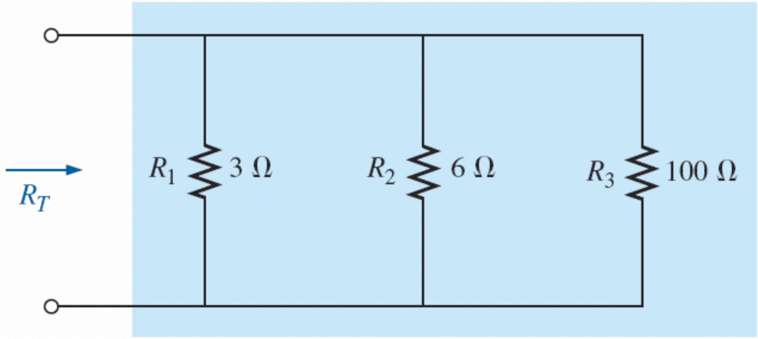


FIG. 6.8 *Adding a parallel 100 resistor to the network in Fig. 6.4.*

LOGO

PARALLEL RESISTORS

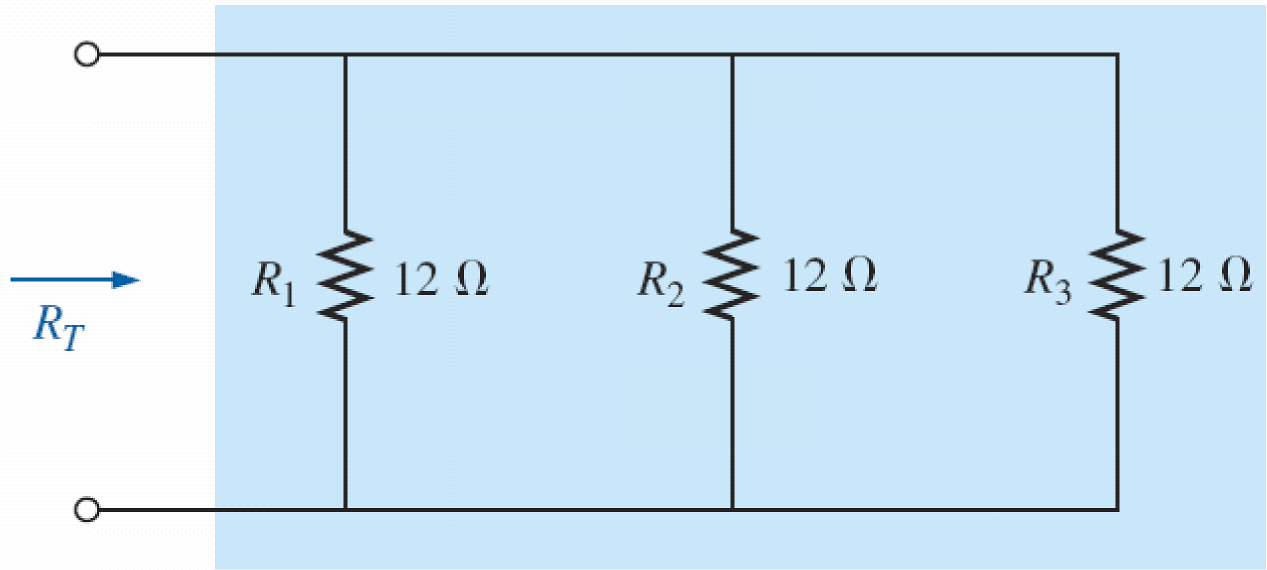


FIG. 6.9 *Three equal parallel resistors to be investigated in Example 6.5.*

LOGO

PARALLEL RESISTORS

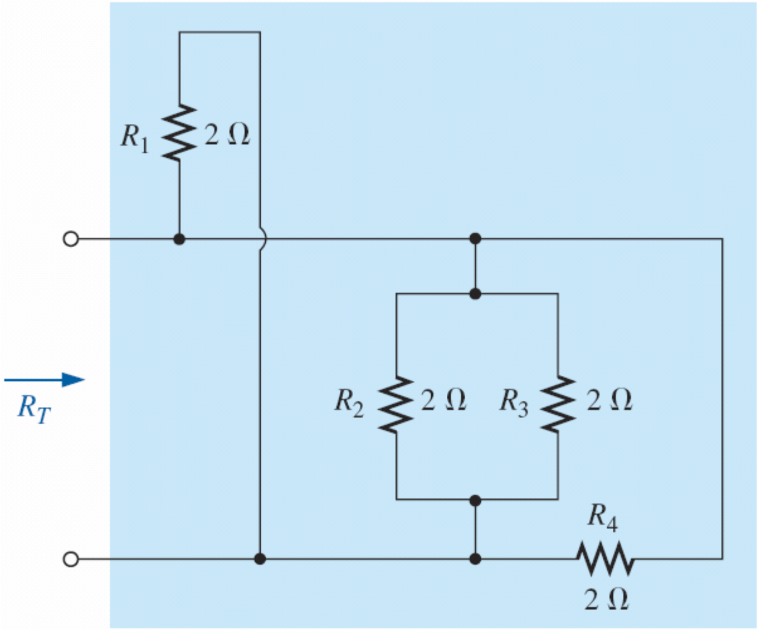


FIG. 6.10 *Parallel configuration for Example 6.6.*

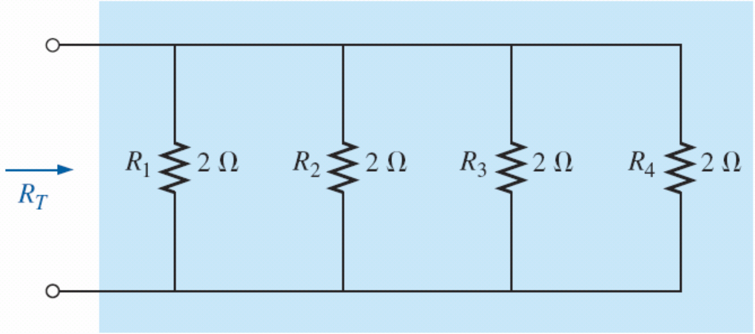


FIG. 6.11 *Network in Fig. 6.10 redrawn.*

LOGO

PARALLEL RESISTORS

Special Case: Two Parallel Resistors

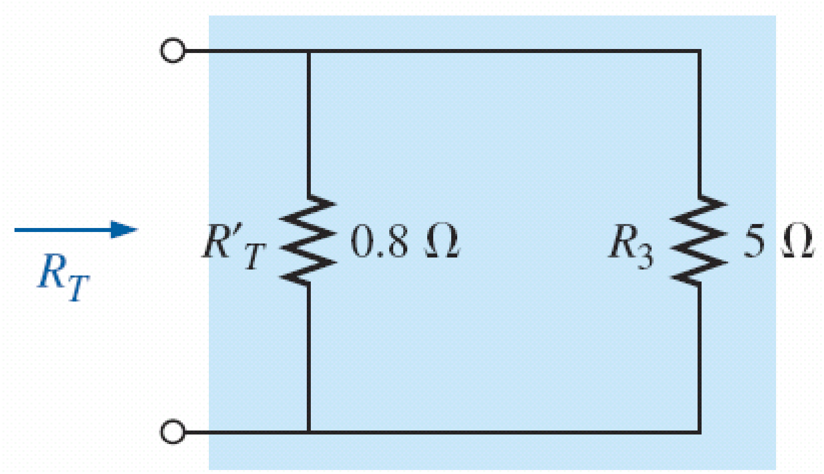


FIG. 6.12 *Reduced equivalent in Fig. 6.7.*

PARALLEL RESISTORS

Special Case: Two Parallel Resistors

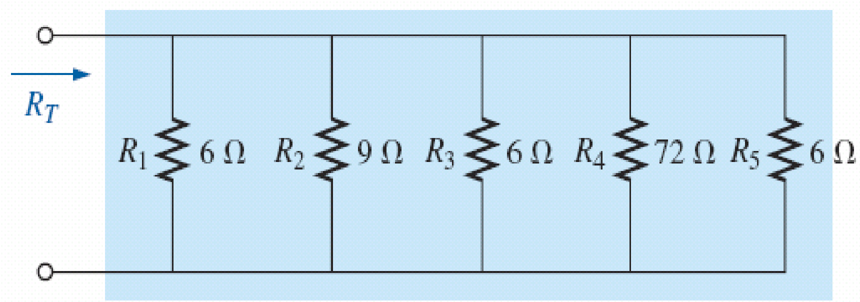


FIG. 6.13 *Parallel network for Example 6.9.*

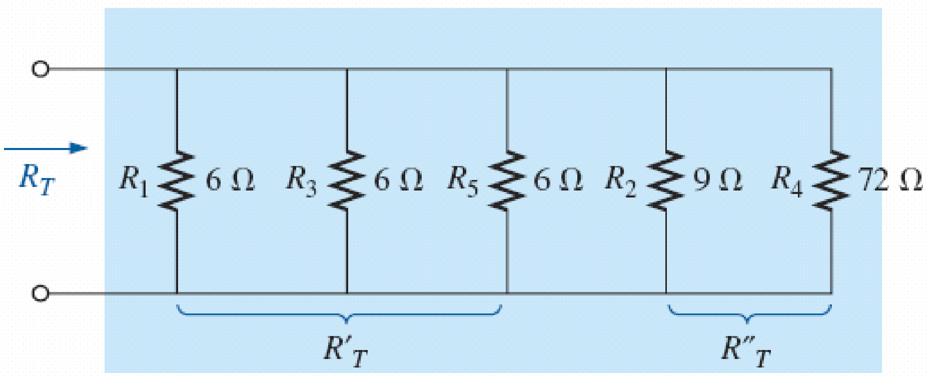


FIG. 6.14 *Redrawn network in Fig. 6.13 (Example 6.9).*

LOGO

PARALLEL RESISTORS

Special Case: Two Parallel Resistors

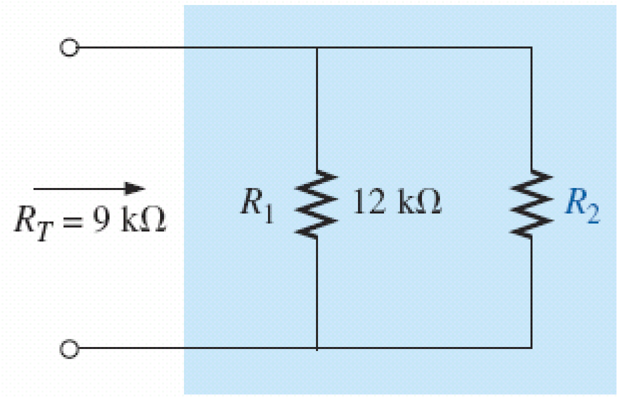


FIG. 6.15 *Parallel network for Example 6.10.*

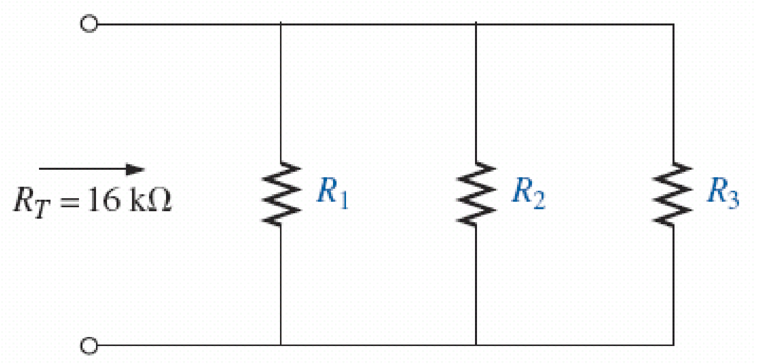


FIG. 6.16 *Parallel network for Example 6.11.*

PARALLEL RESISTORS

Instrumentation

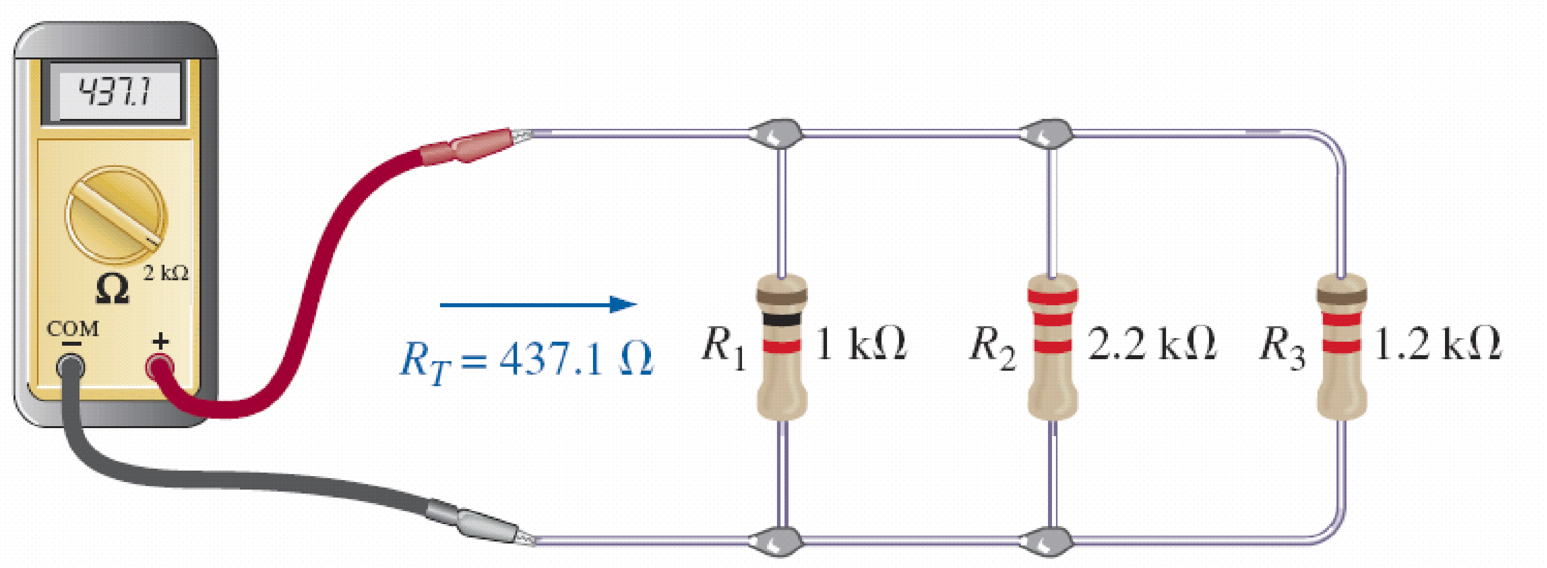


FIG. 6.17 *Using an ohmmeter to measure the total resistance of a parallel network.*

LOGO

PARALLEL CIRCUITS

- A **parallel circuit** can now be established by connecting a supply across a set of parallel resistors as shown in Fig. 6.18.
- The positive terminal of the supply is directly connected to the top of each resistor, while the negative terminal is connected to the bottom of each resistor.

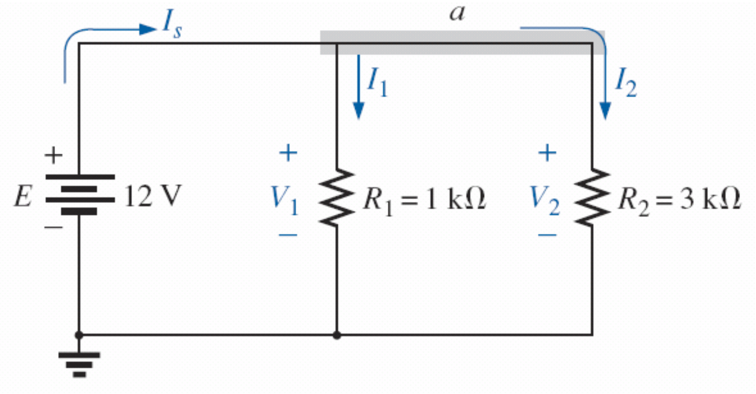


FIG. 6.18 *Parallel network.*

PARALLEL CIRCUITS

- In general, ***the voltage is always the same across parallel elements.***
    - Therefore, remember that ***if two elements are in parallel, the voltage across them must be the same. However, if the voltage across two neighboring elements is the same, the two elements may or may not be in parallel.***

PARALLEL CIRCUITS

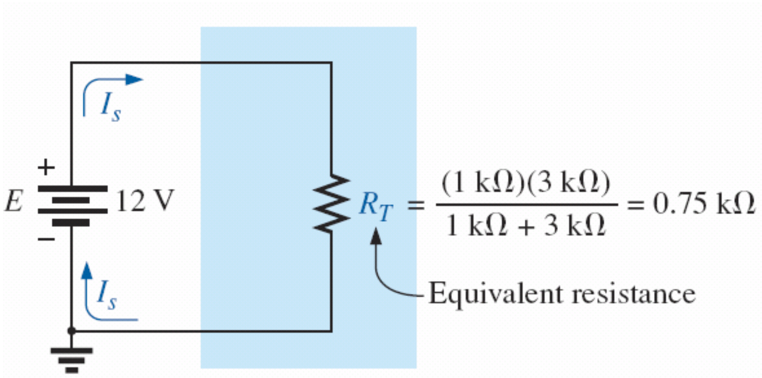


FIG. 6.19 *Replacing the parallel resistors in Fig. 6.18 with the equivalent total resistance.*

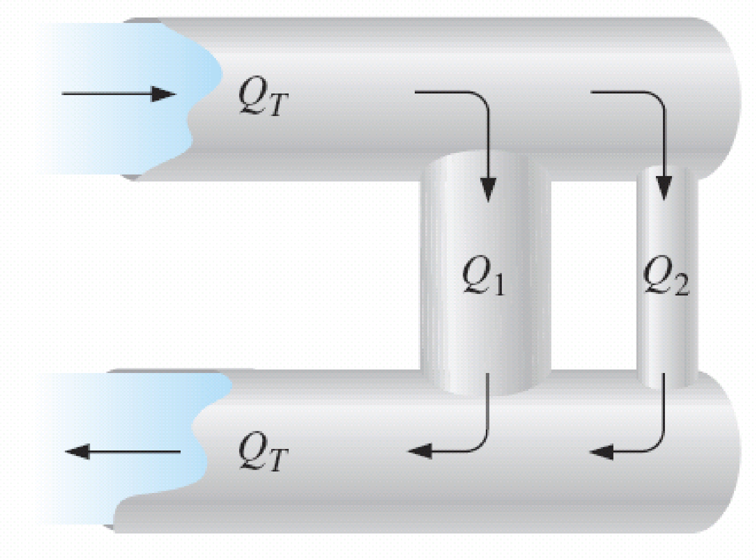


FIG. 6.20 *Mechanical analogy for Fig. 6.18.*

LOGO

PARALLEL CIRCUITS

- ***For single-source parallel networks, the source current (Is) is always equal to the sum of the individual branch currents.***

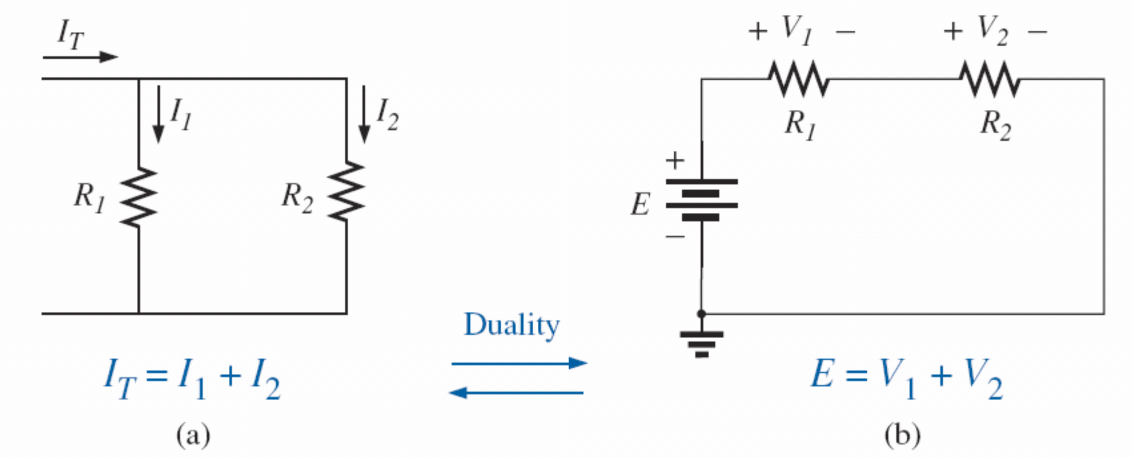


FIG. 6.21 *Demonstrating the duality that exists between series and parallel circuits.*

LOGO

PARALLEL CIRCUITS

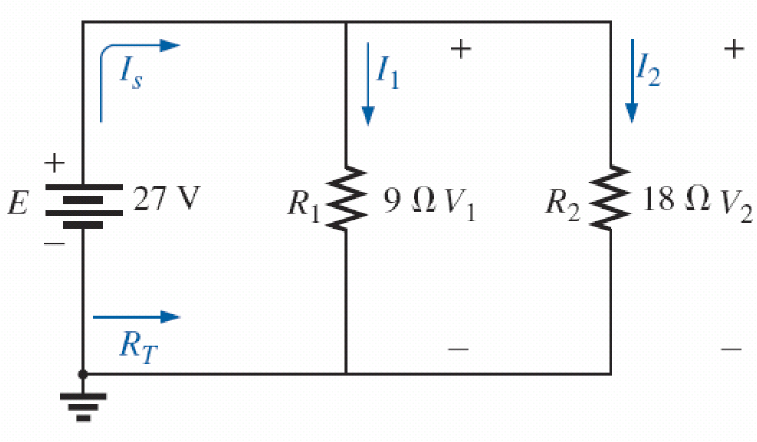


FIG. 6.22 *Parallel network for Example 6.12.*

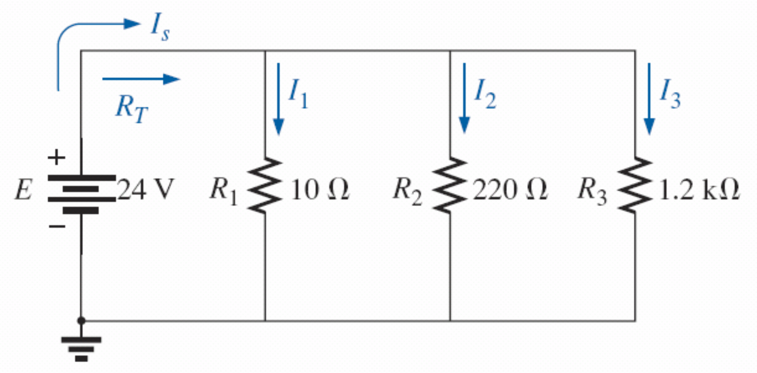


FIG. 6.23 *Parallel network for Example 6.13.*

LOGO

PARALLEL CIRCUITS

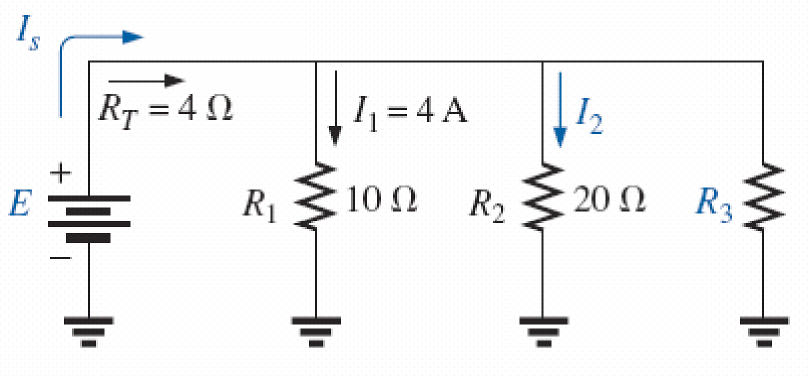


FIG. 6.24 *Parallel network for Example 6.14.*

PARALLEL CIRCUITS

Instrumentation

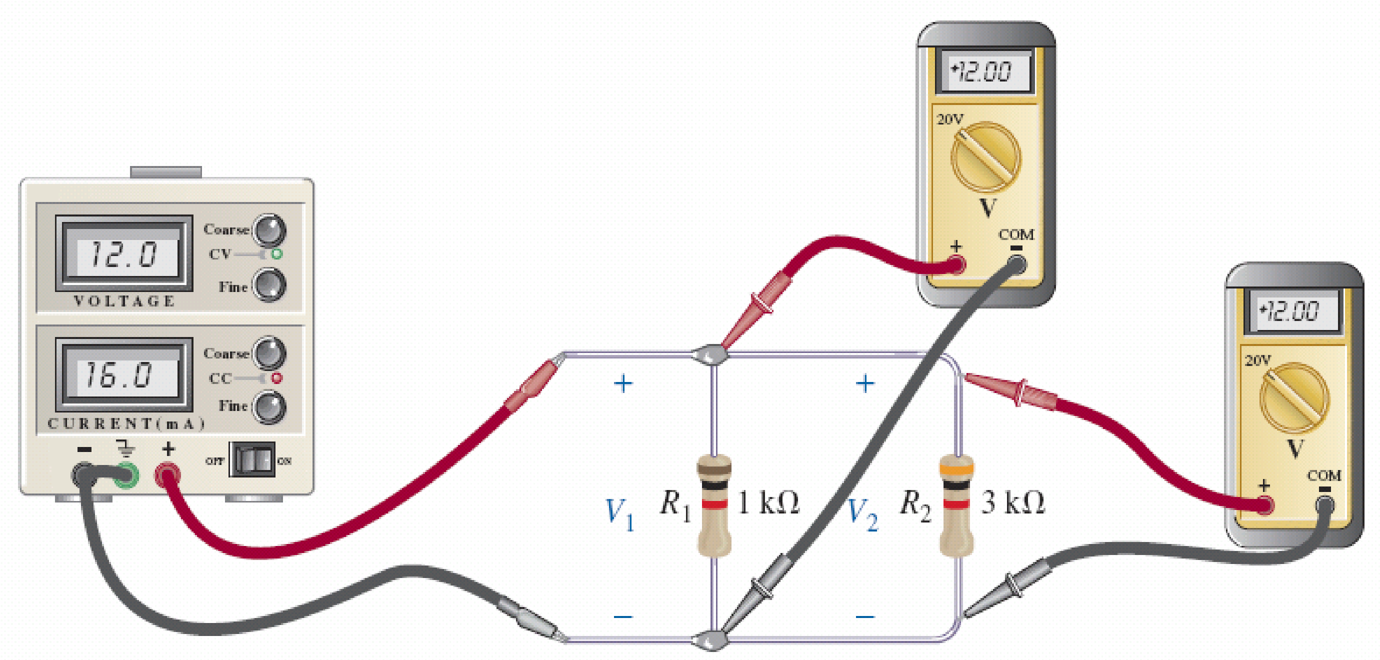


FIG. 6.25 *Measuring the voltages of a parallel dc network.*

LOGO

PARALLEL CIRCUITS

Instrumentation

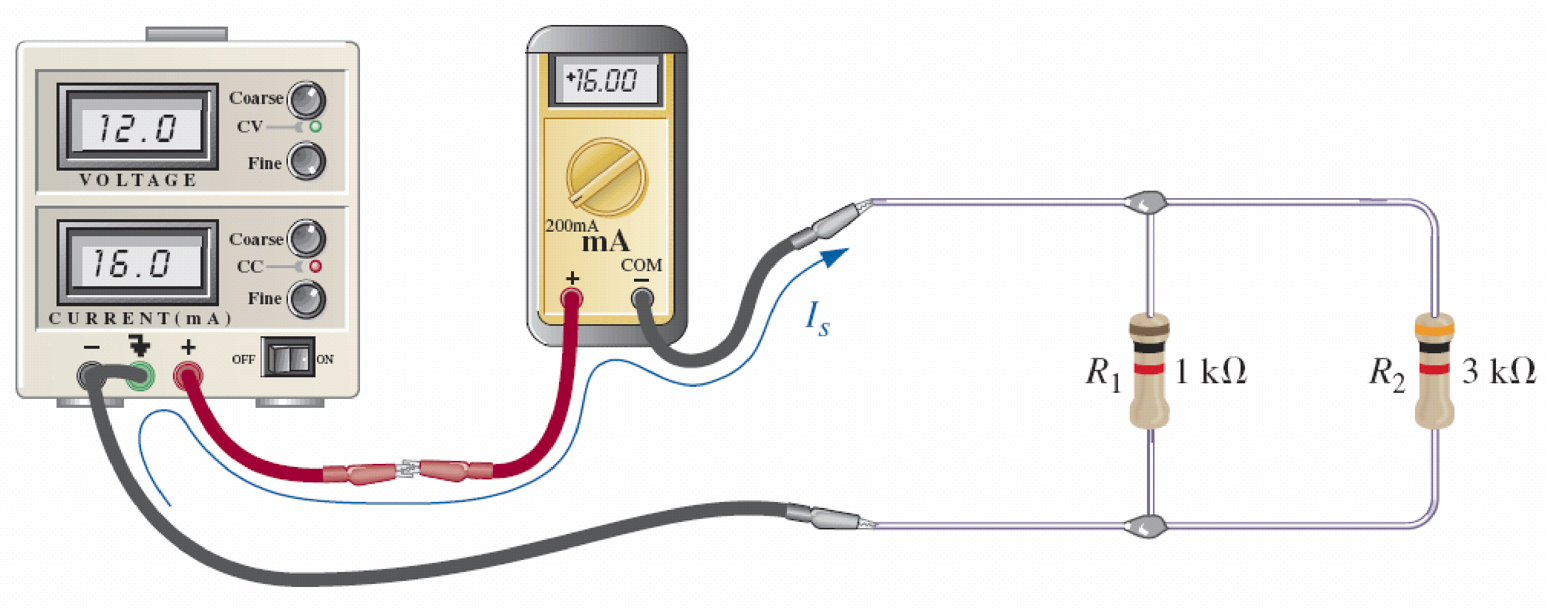


FIG. 6.26 *Measuring the source current of a parallel network.*

PARALLEL CIRCUITS

Instrumentation

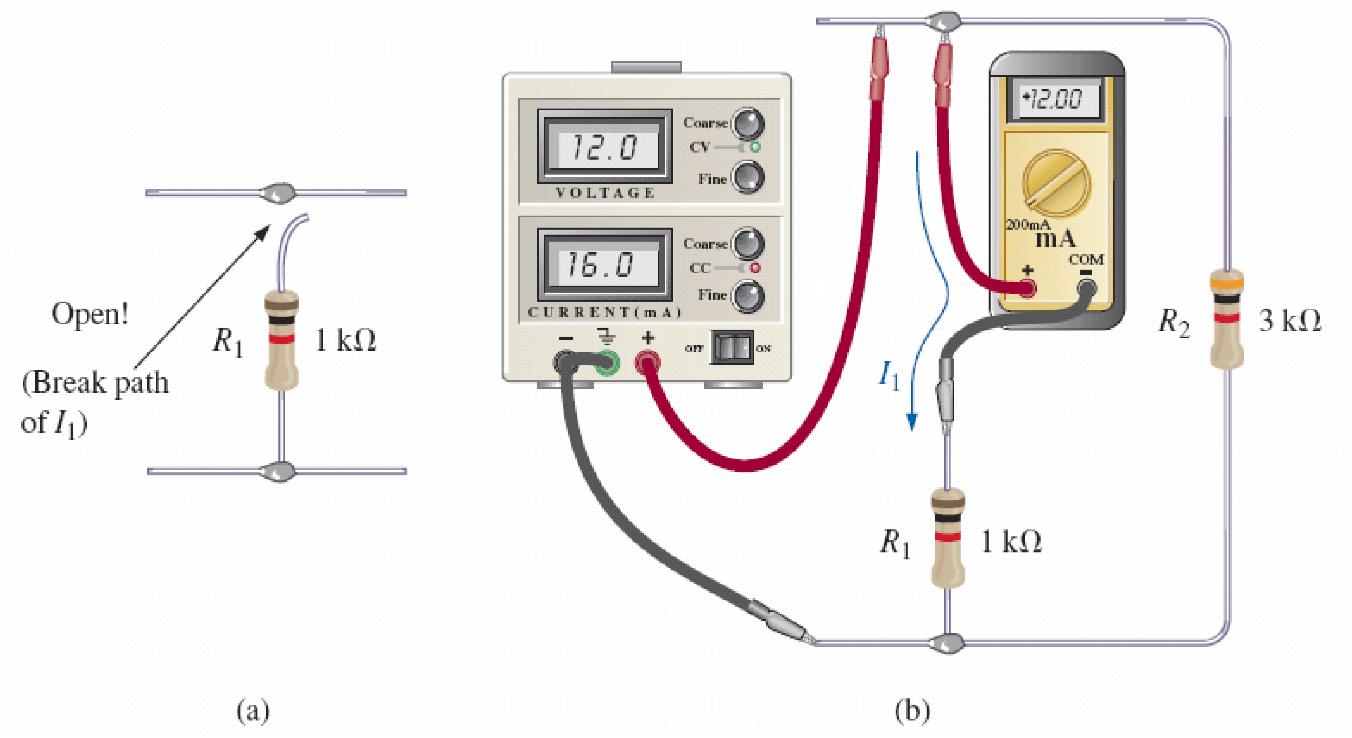


FIG. 6.27 *Measuring the current through resistor R_1.*

LOGO

POWER DISTRIBUTION IN A PARALLEL CIRCUIT

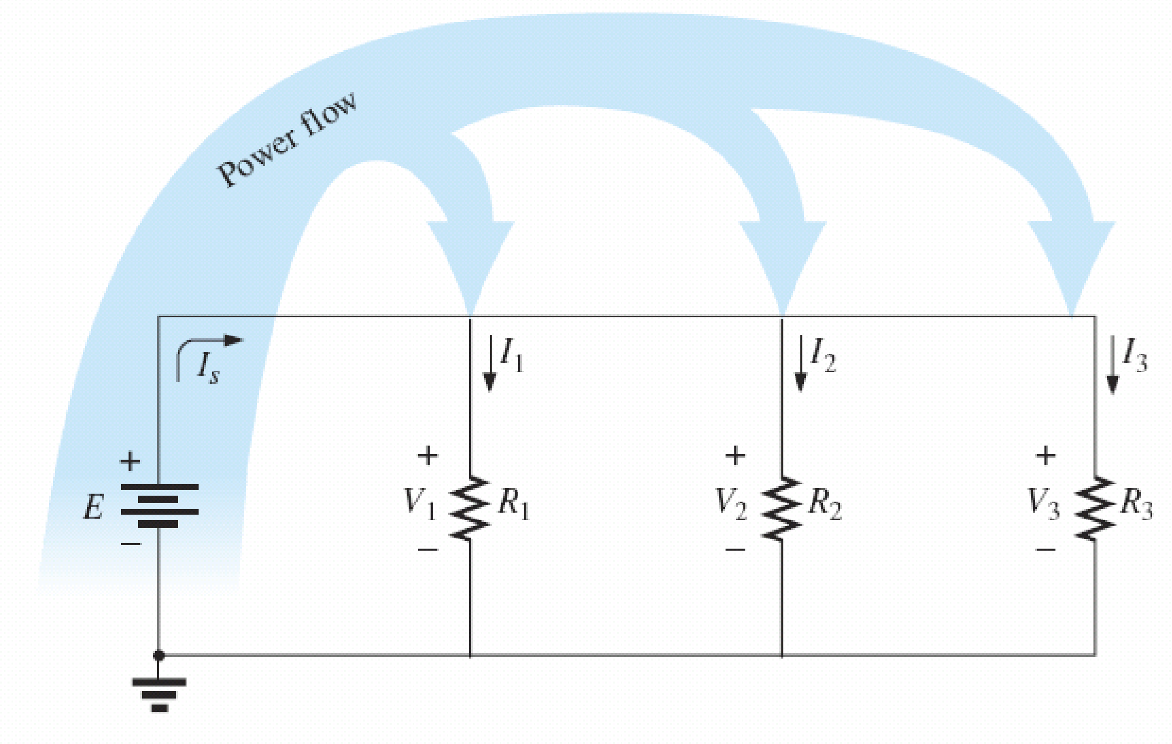


FIG. 6.28 *Power flow in a dc parallel network.*

LOGO

POWER DISTRIBUTION IN A PARALLEL CIRCUIT

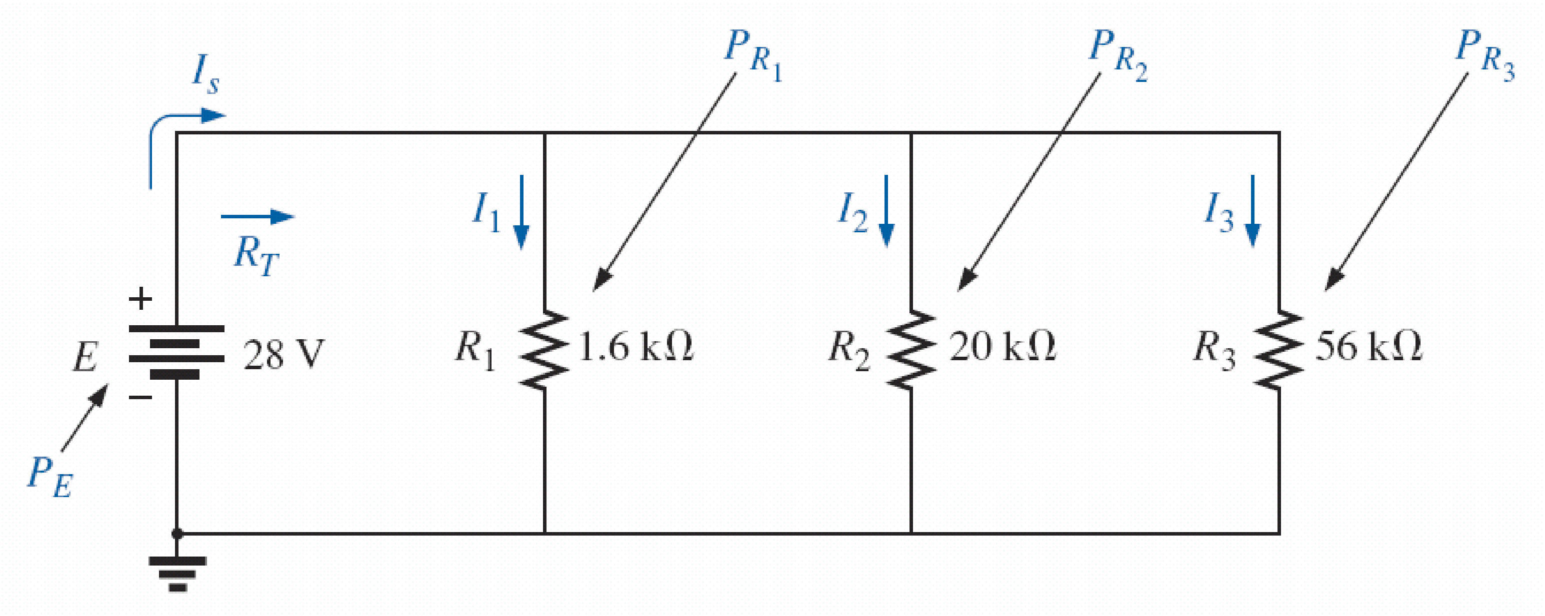


FIG. 6.29 *Parallel network for Example 6.15.*

KIRCHHOFF’S CURRENT LAW

- In the previous chapter, Kirchhoff’s voltage law was introduced, providing a very important relationship among the voltages of a closed path.
- Kirchhoff is also credited with developing the following equally important relationship between the currents of a network, called **Kirchhoff’s current law (KCL):**
  - ***The algebraic sum of the currents entering and leaving a junction (or region) of a network is zero.***

KIRCHHOFF’S CURRENT LAW

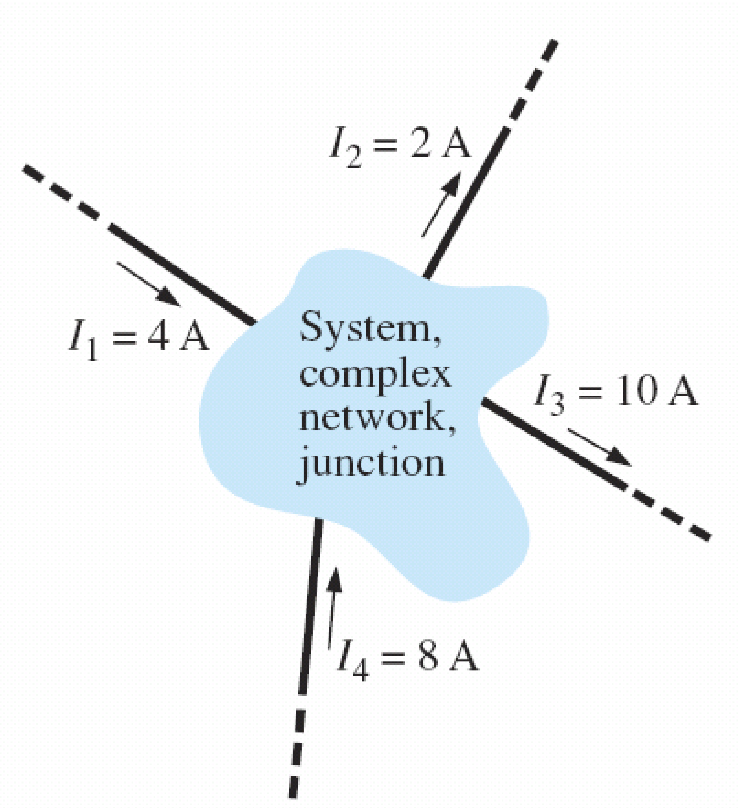


FIG. 6.30 *Introducing Kirchhoff ’s current law.*

LOGO

KIRCHHOFF’S CURRENT LAW

FIG. 6.31 *(a) Demonstrating Kirchhoff ’s current law; (b) the water analogy for the junction in (a).*

KIRCHHOFF'S CURRENT LAW

- In technology, the term **node** is commonly used to refer to a junction of two or more branches.

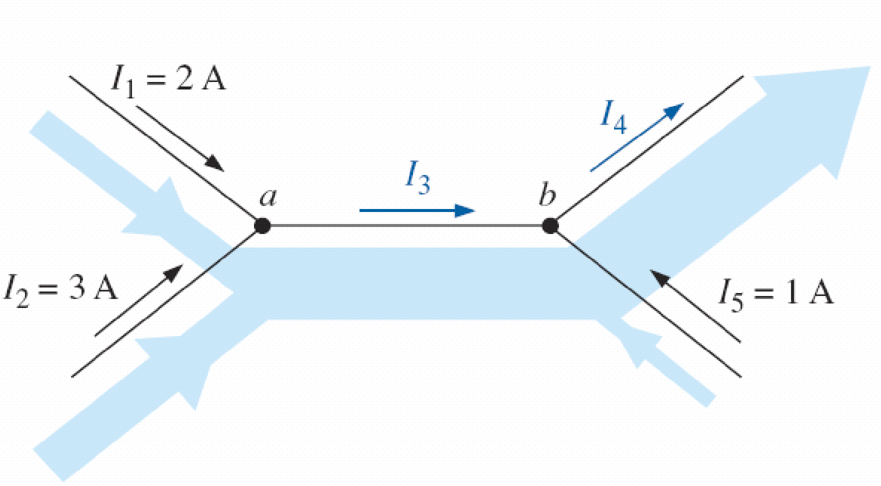


FIG. 6.32 *Two-node configuration for Example 6.16.*

KIRCHHOFF’S CURRENT LAW

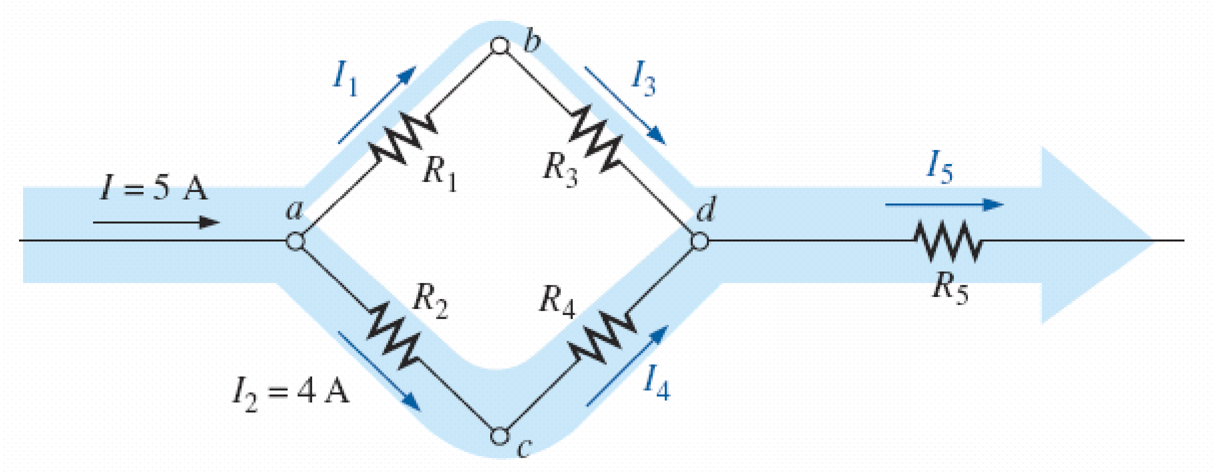


FIG. 6.33 *Four-node configuration for Example 6.17.*

LOGO

KIRCHHOFF'S CURRENT LAW

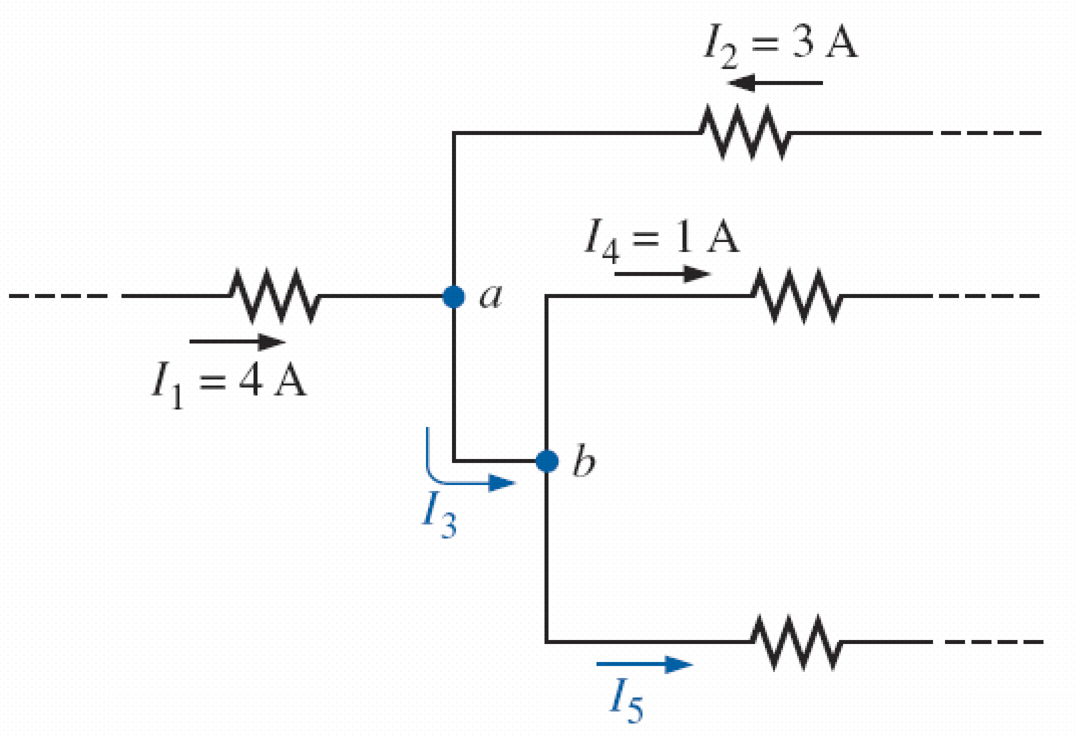


FIG. 6.34 *Network for Example 6.18.*

LOGO

KIRCHHOFF'S CURRENT LAW

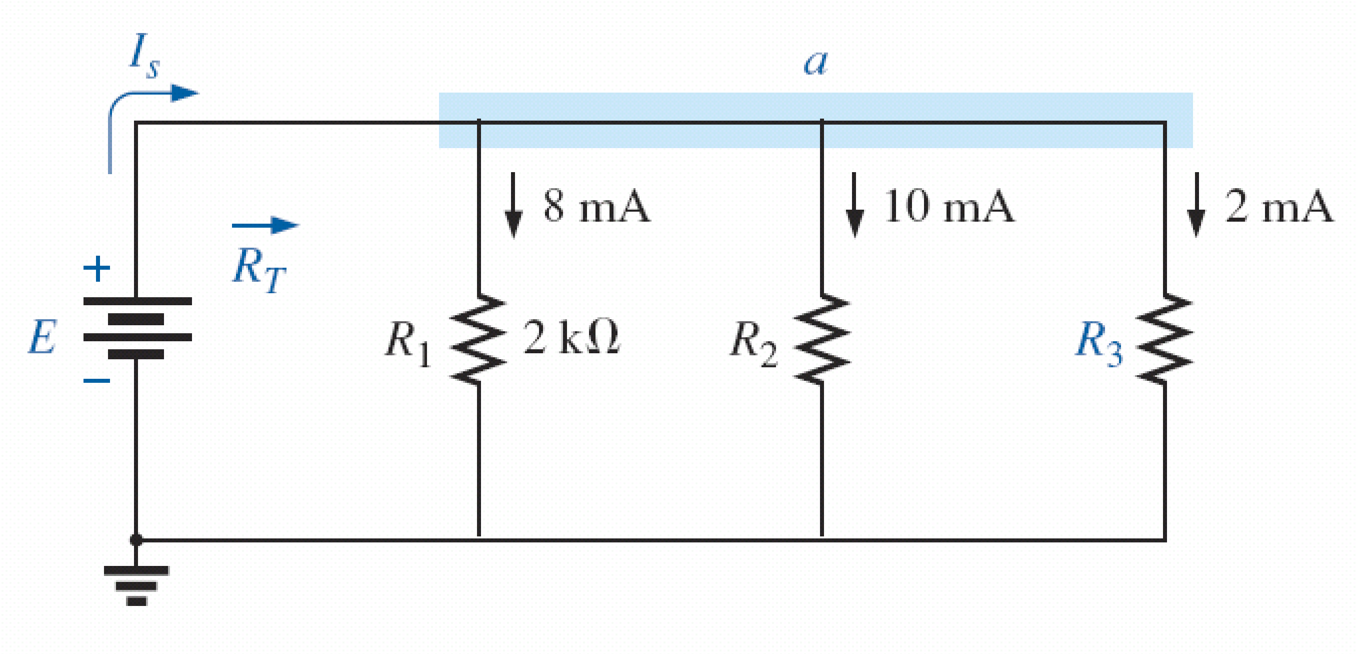


FIG. 6.35 *Parallel network for Example 6.19.*

KIRCHHOFF'S CURRENT LAW

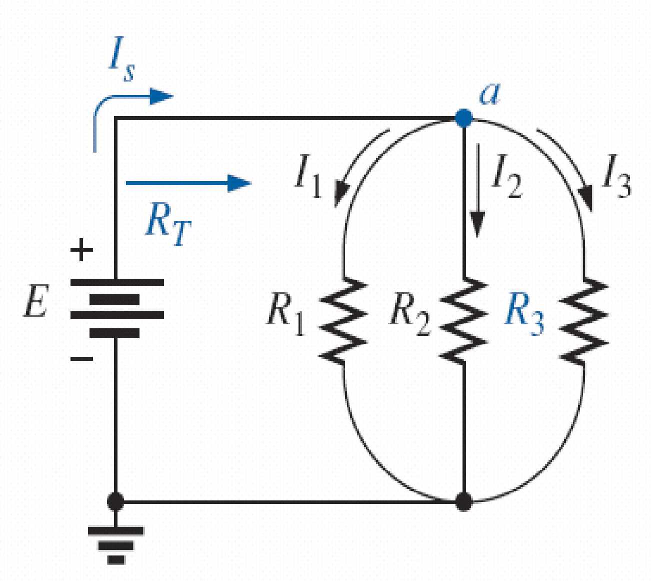


FIG. 6.36 *Redrawn network in Fig. 6.35.*

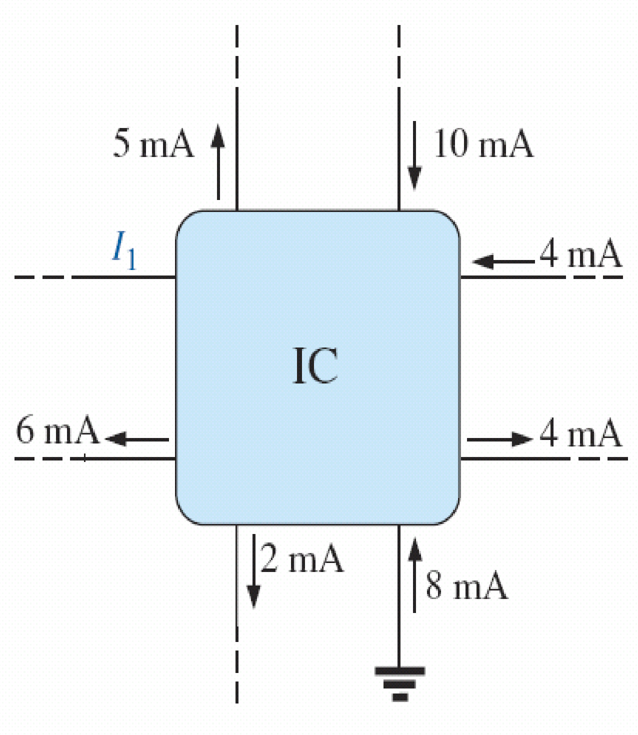


FIG. 6.37 *Integrated circuit for Example 6.20.*

LOGO

CURRENT DIVIDER RULE

- For series circuits we have the powerful voltage divider rule for finding the voltage across a resistor in a series circuit.
- We now introduce the equally powerful **current divider rule (CDR)** for finding the current through a resistor in a parallel circuit.

CURRENT DIVIDER RULE

- In general:
  - *For two parallel elements of equal value, the current will divide equally.*
  - *For parallel elements with different values, the smaller the resistance, the greater is the share of input current.*
  - *For parallel elements of different values, the current will split with a ratio equal to the inverse of their resistance values.*

LOGO

CURRENT DIVIDER RULE

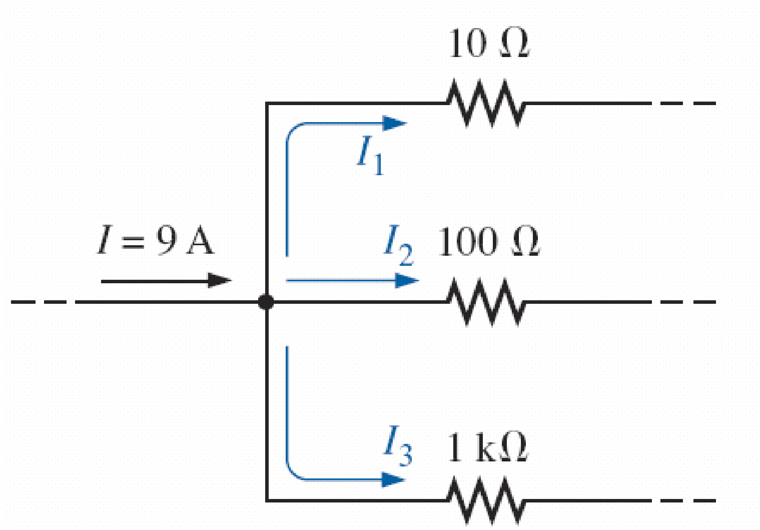


FIG. 6.38 *Discussing the manner in which the current will split between three parallel branches of different resistive value.*

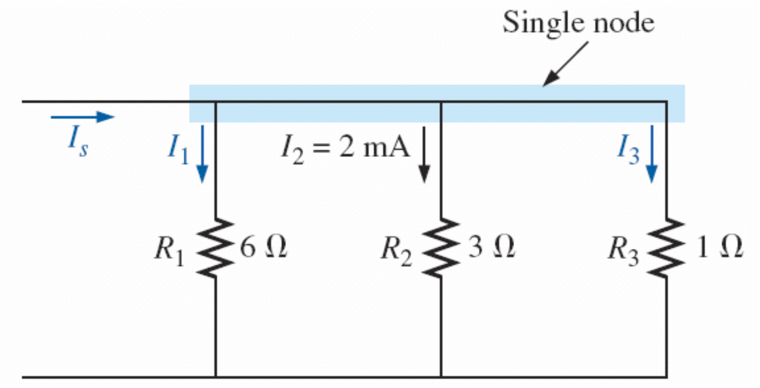


FIG. 6.39 *Parallel network for Example 6.21.*

LOGO

CURRENT DIVIDER RULE

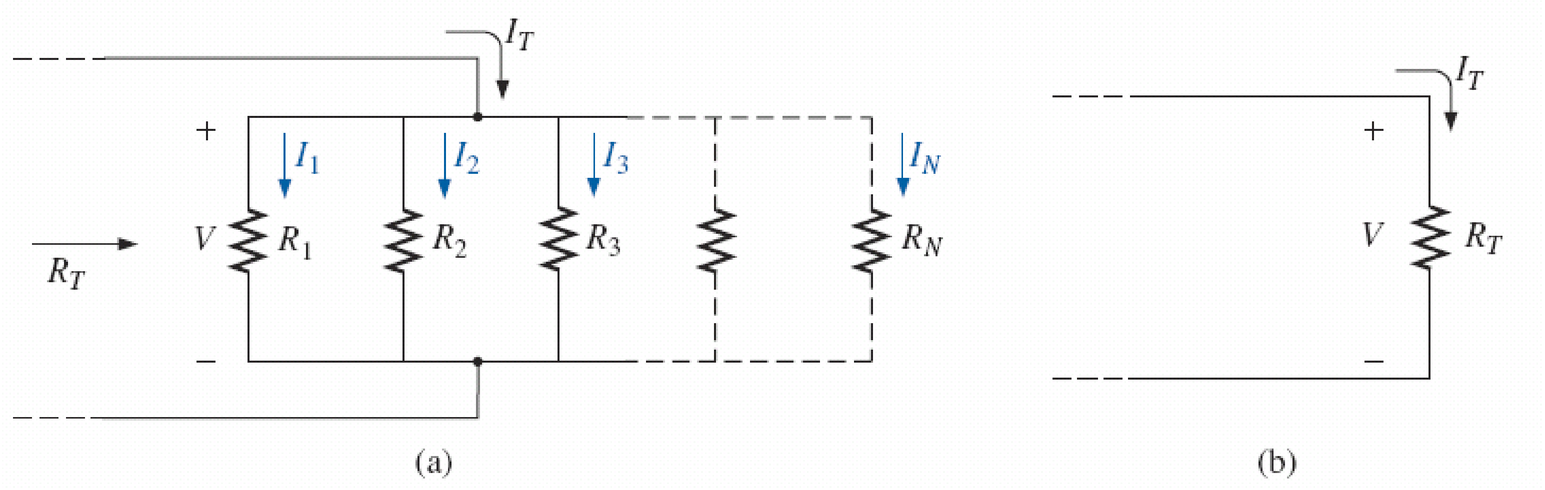


FIG. 6.40 *Deriving the current divider rule: (a) parallel network of N parallel resistors; (b) reduced equivalent of part (a).*

LOGO

CURRENT DIVIDER RULE

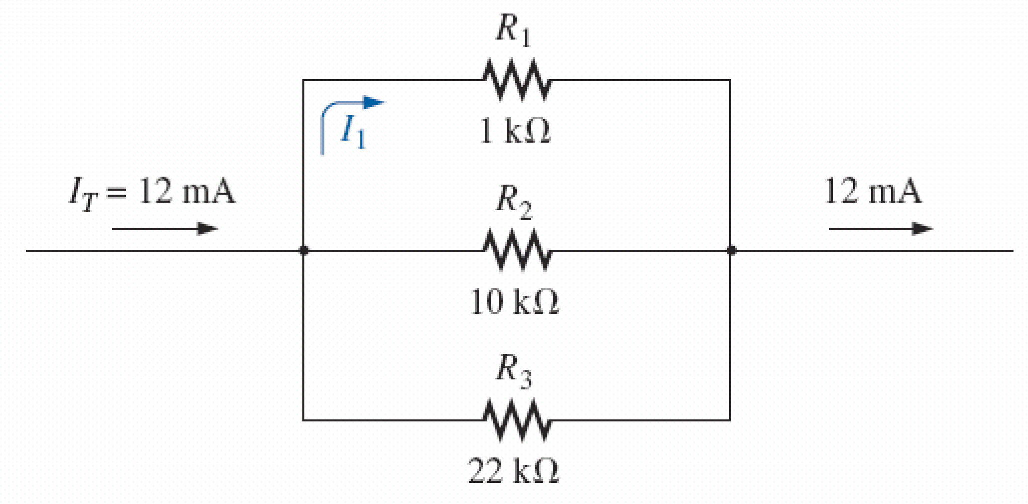


FIG. 6.41 *Using the current divider rule to calculate current I1 in Example 6.22.*

LOGO

CURRENT DIVIDER RULE

- Note also that ***for a parallel network, the current through the smallest resistor will be very close to the total entering current if the other parallel elements of the configuration are much larger in magnitude.***

CURRENT DIVIDER RULE

Special Case: Two Parallel Resistors

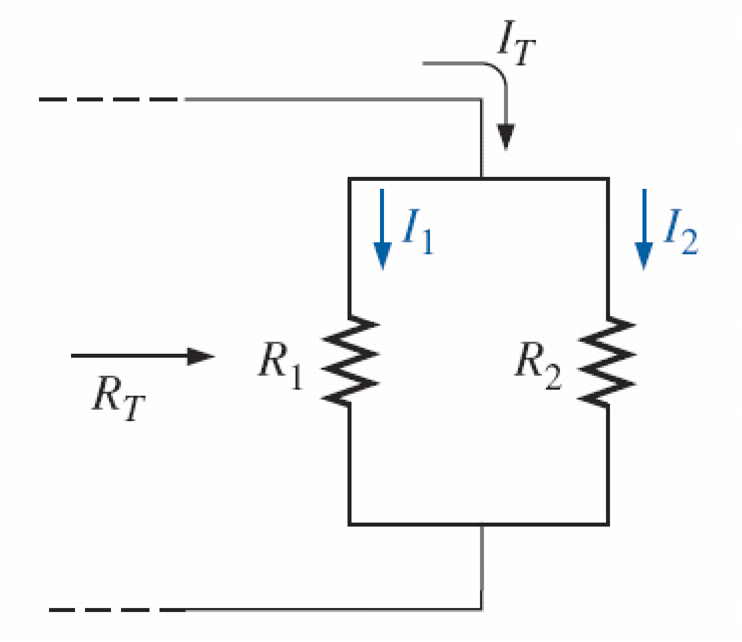


FIG. 6.42 *Deriving the current divider rule for the special case of only two parallel resistors.*

LOGO

CURRENT DIVIDER RULE

Special Case: Two Parallel Resistors

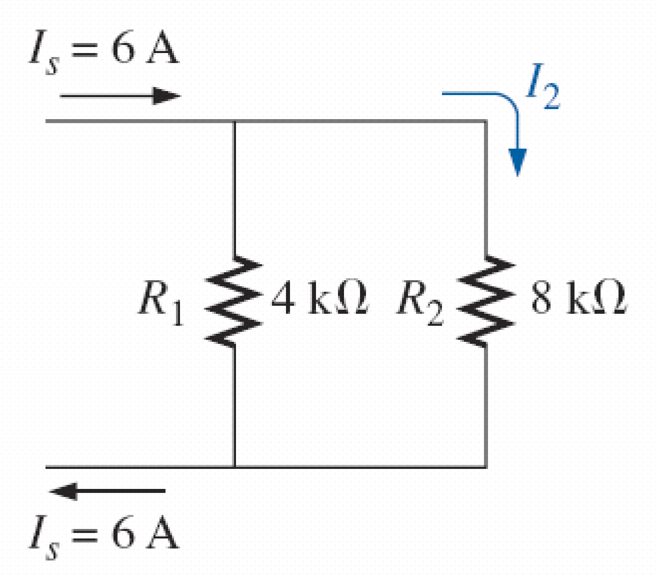


FIG. 6.43 *Using the current divider rule to determine current I_2 in Example 6.23.*

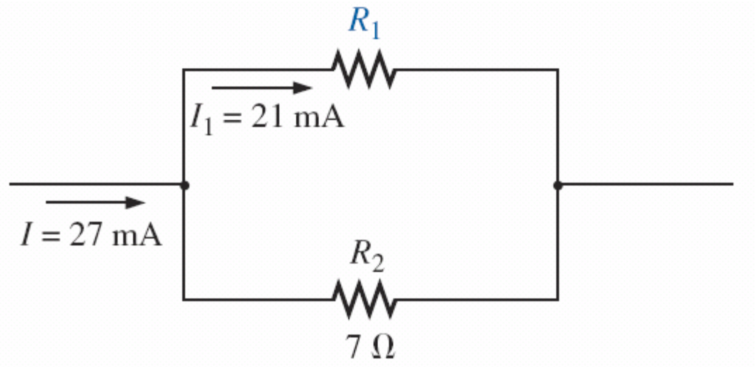
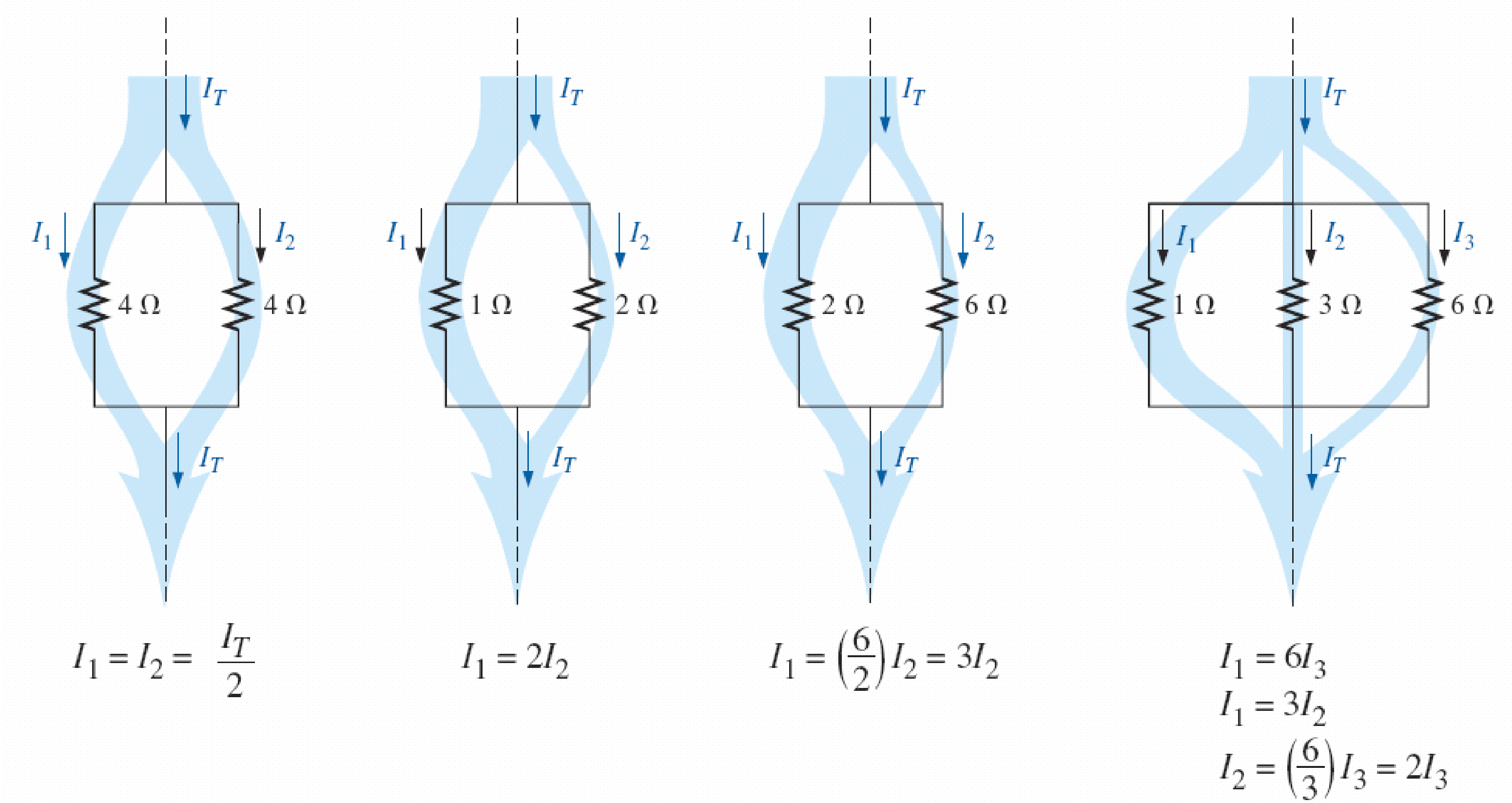


FIG. 6.44 *A design-type problem for two parallel resistors (Example 6.24).*

LOGO

CURRENT DIVIDER RULE

Special Case: Two Parallel Resistors



$$I_1 = I_2 = \frac{I_T}{2}$$

$$I_1 = 2I_2$$

$$I_1 = \left(\frac{6}{2}\right) I_2 = 3I_2$$

$$I_1 = 6I_3$$
$$I_1 = 3I_2$$
$$I_2 = \left(\frac{6}{3}\right) I_3 = 2I_3$$

FIG. 6.45 *Demonstrating how current divides through equal and unequal parallel resistors.*

VOLTAGE SOURCES IN PARALLEL

- Because the voltage is the same across parallel elements, ***voltage sources can be placed in parallel only if they have the same voltage.***
- The primary reason for placing two or more batteries or supplies in parallel is to increase the current rating above that of a single supply.

LOGO

VOLTAGE SOURCES IN PARALLEL

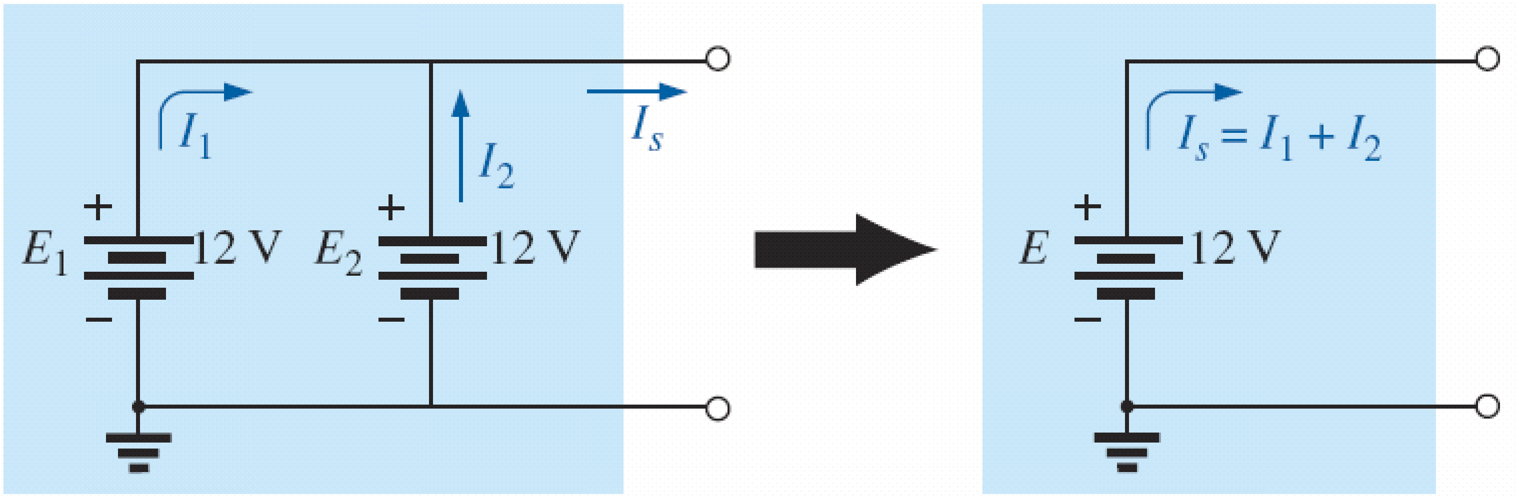


FIG. 6.46 *Demonstrating the effect of placing two ideal supplies of the same voltage in parallel.*

LOGO

VOLTAGE SOURCES IN PARALLEL

- If for some reason two batteries of different voltages are placed in parallel, both will become ineffective or damaged because the battery with the larger voltage will rapidly discharge through the battery with the smaller terminal voltage.

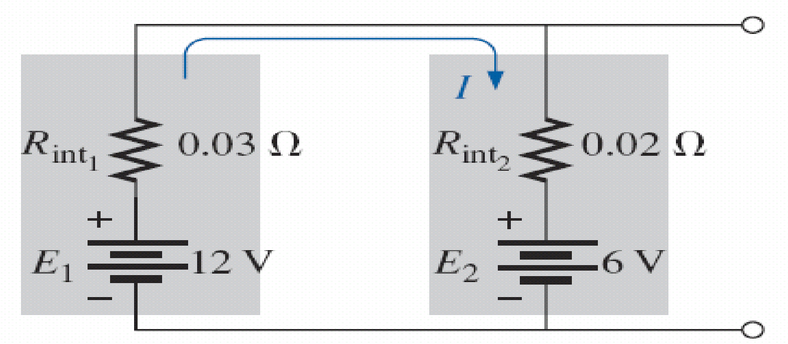


FIG. 6.47 *Examining the impact of placing two lead-acid batteries of different terminal voltages in parallel.*

VOLTAGE SOURCES IN PARALLEL

- In general, ***it is always recommended that when you are replacing batteries in series or parallel, replace all the batteries.***

LOGO

OPEN AND SHORT CIRCUITS

- Open circuits and short circuits can often cause more confusion and difficulty in the analysis of a system than standard series or parallel configurations.
- An **open circuit** is two isolated terminals not connected by an element of any kind, as shown in Fig. 6.48(a).

OPEN AND SHORT CIRCUITS

- Since a path for conduction does not exist, the current associated with an open circuit must always be zero.
- The voltage across the open circuit, however, can be any value, as determined by the system it is connected to.
  - In summary, therefore, ***an open circuit can have a potential difference (voltage) across its terminals, but the current is always zero amperes.***

OPEN AND SHORT CIRCUITS

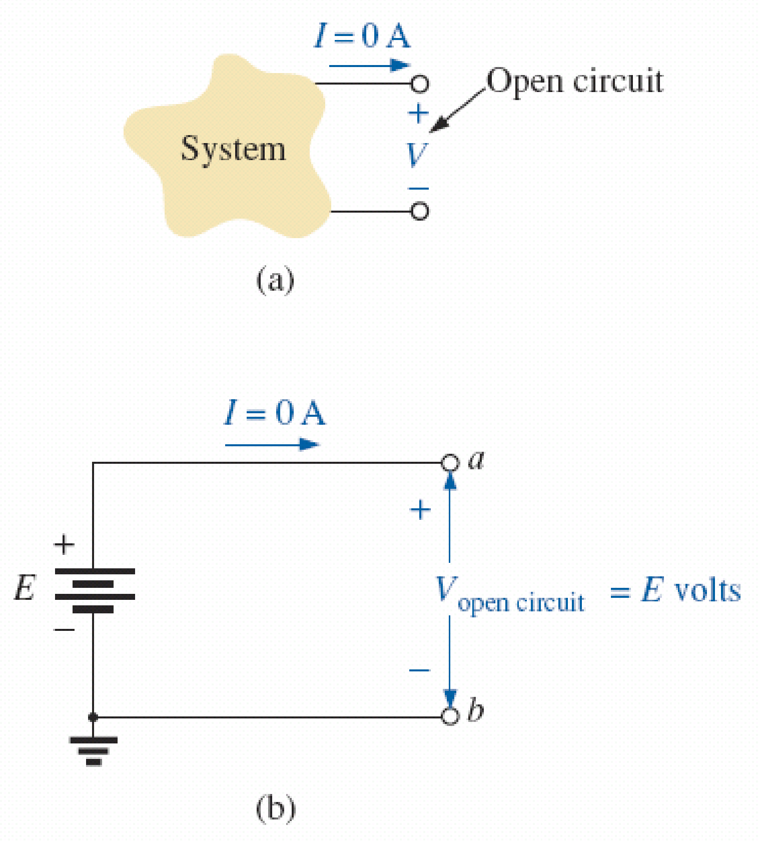


FIG. 6.48 *Defining an open circuit.*

OPEN AND SHORT CIRCUITS

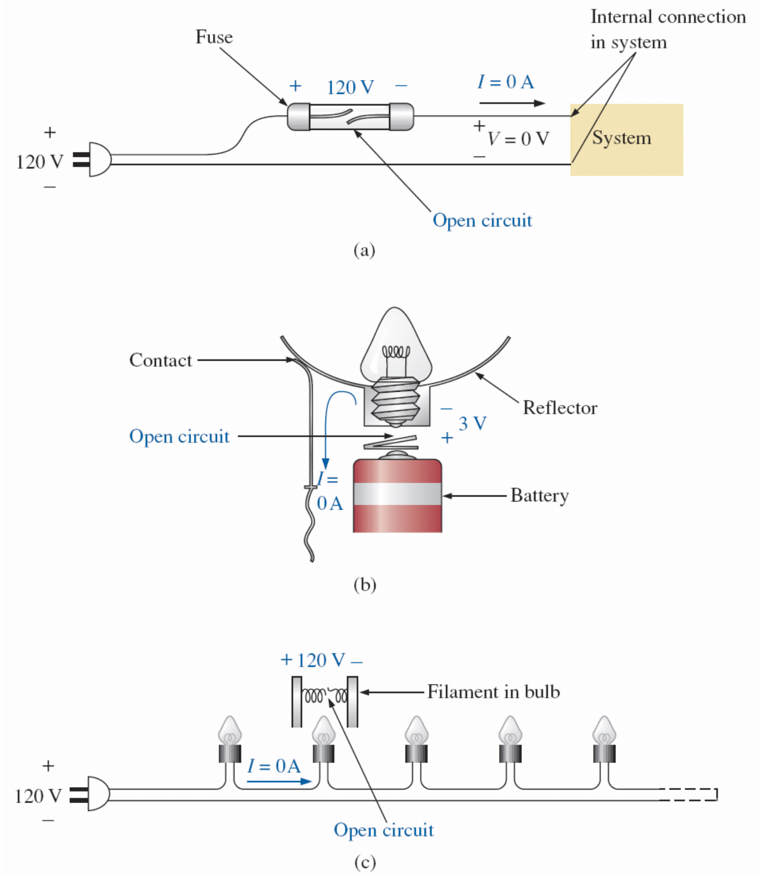


FIG. 6.49 *Examples of open circuits.*

OPEN AND SHORT CIRCUITS

- A **short circuit** is a very low resistance, direct connection between two terminals of a network.

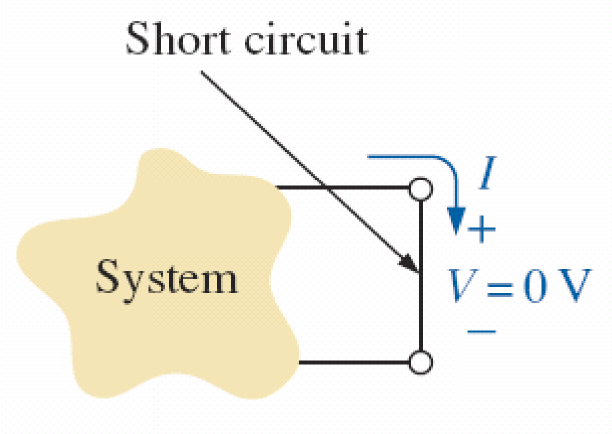


FIG. 6.50 *Defining a short circuit.*

OPEN AND SHORT CIRCUITS

- In summary, therefore, ***a short circuit can carry a current of a level determined by the external circuit, but the potential difference (voltage) across its terminals is always zero volts.***

LOGO

OPEN AND SHORT CIRCUITS

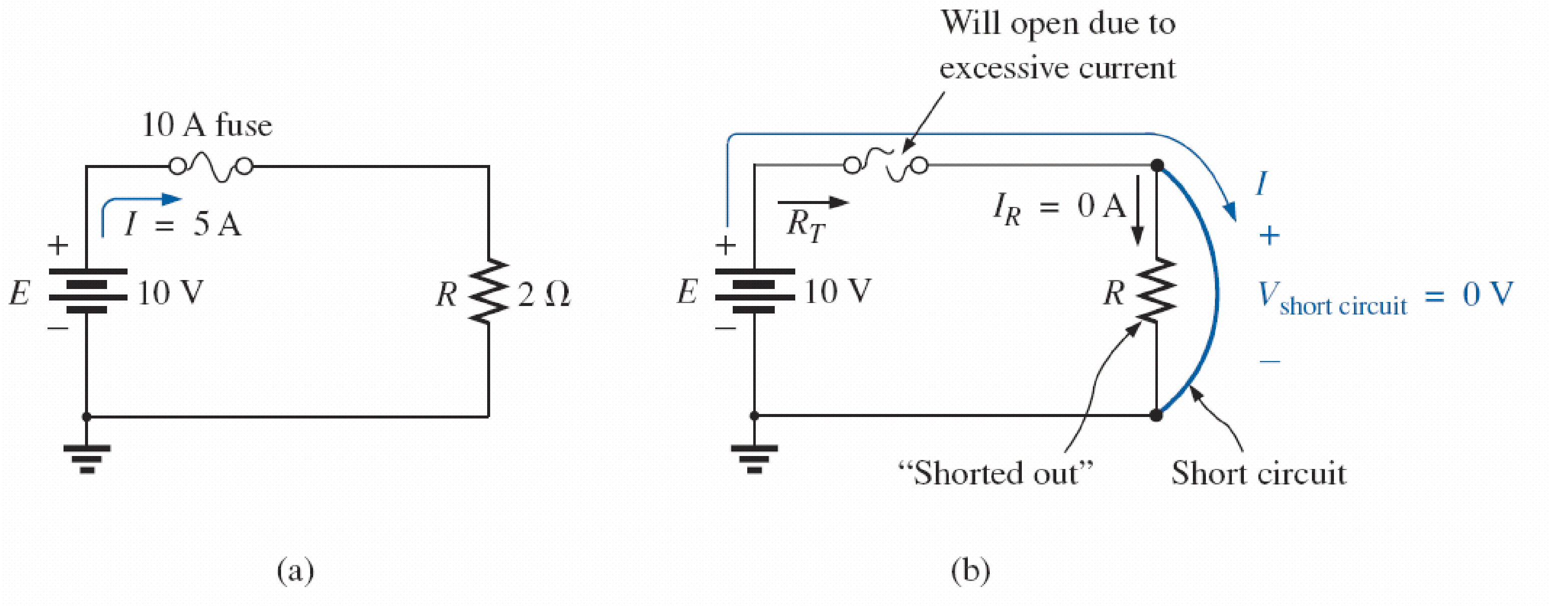
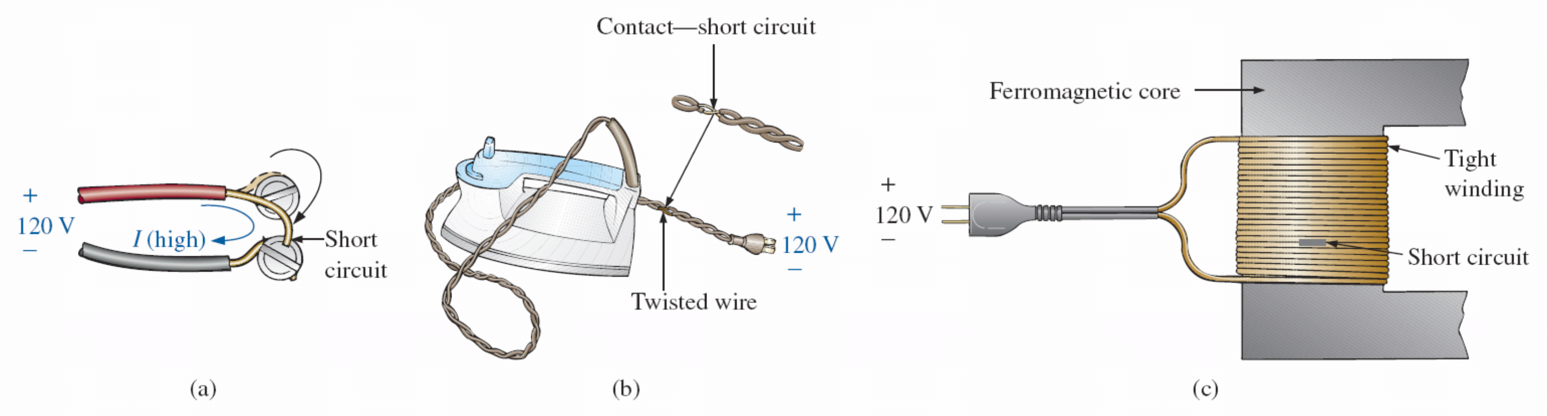


FIG. 6.51 *Demonstrating the effect of a short circuit on current levels.*

OPEN AND SHORT CIRCUITS



(a) (b) (c)

FIG. 6.52 *Examples of short circuits.*

LOGO

OPEN AND SHORT CIRCUITS

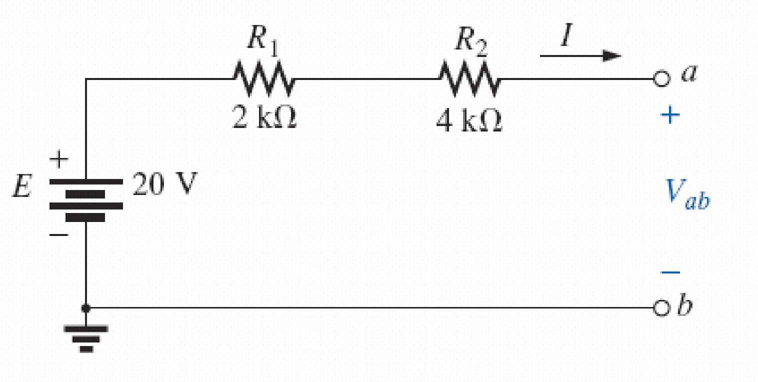


FIG. 6.53 *Network for Example 6.25.*

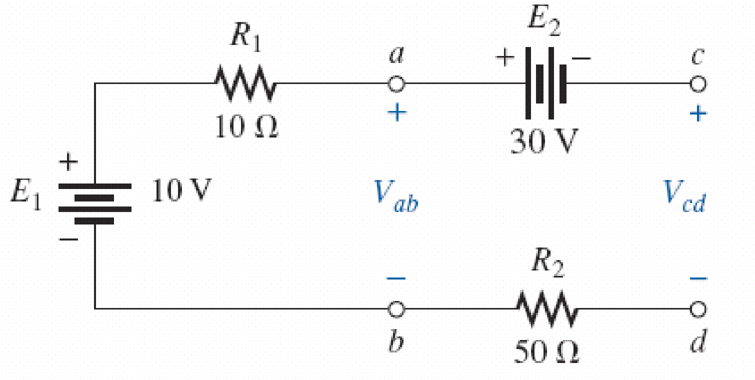


FIG. 6.54 *Network for Example 6.26.*

OPEN AND SHORT CIRCUITS

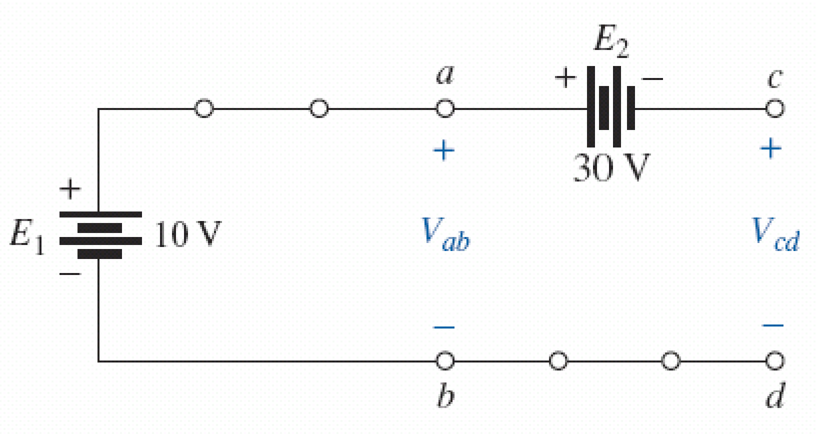
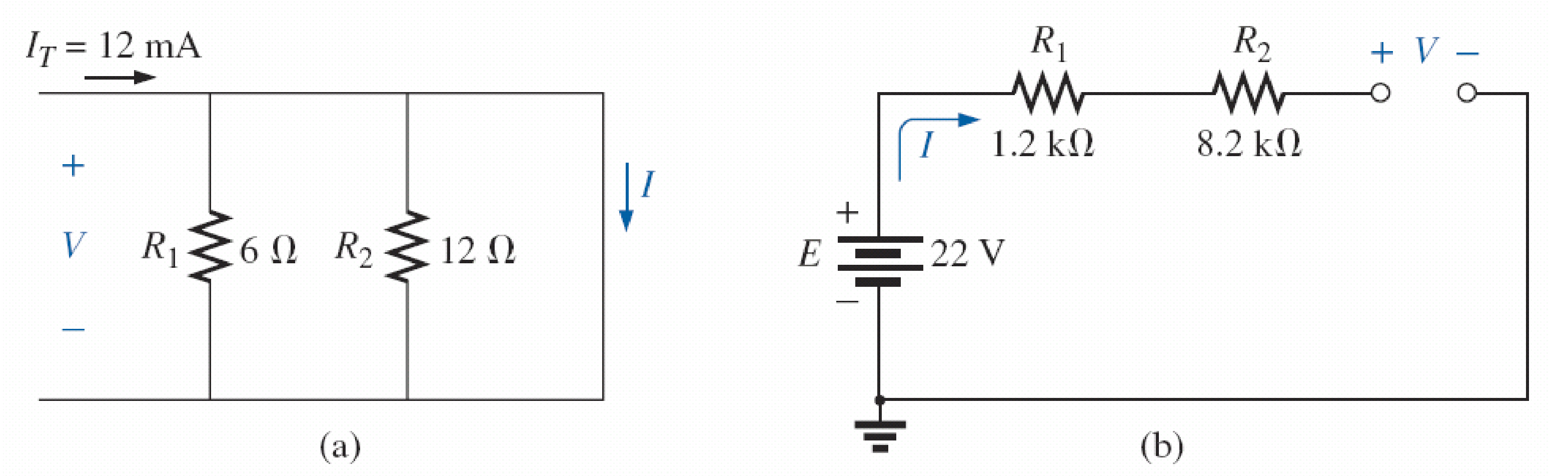


FIG. 6.55 *Circuit in Fig. 6.54 redrawn.*

OPEN AND SHORT CIRCUITS



(a) (b)

FIG. 6.56 *Networks for Example 6.27.*

OPEN AND SHORT CIRCUITS

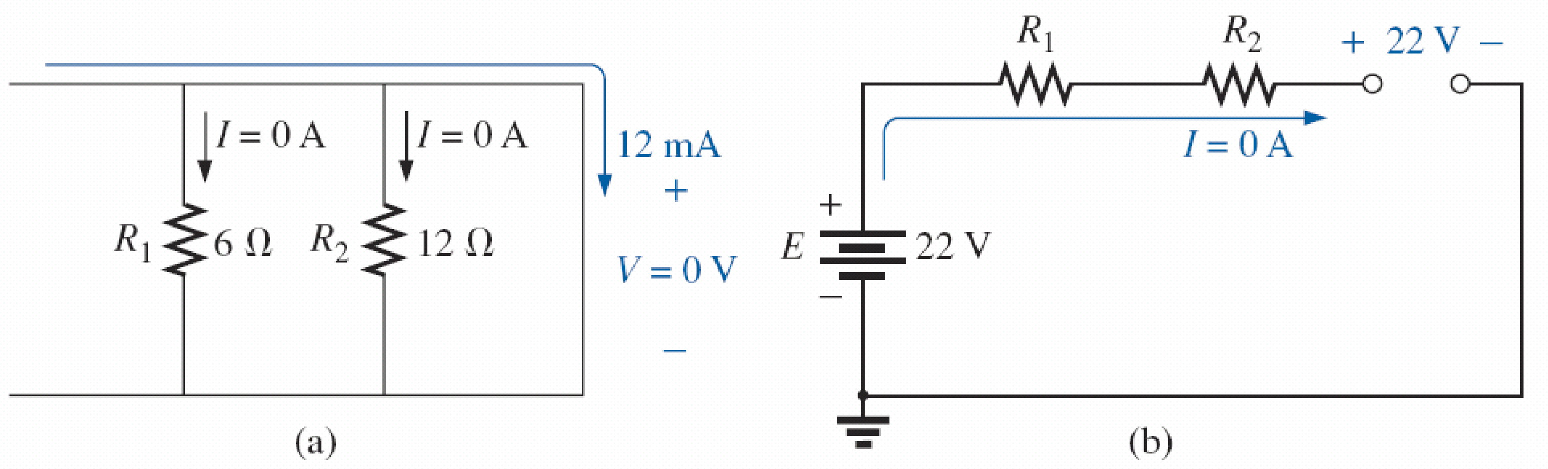


FIG. 6.57 *Solutions to Example 6.27.*

OPEN AND SHORT CIRCUITS

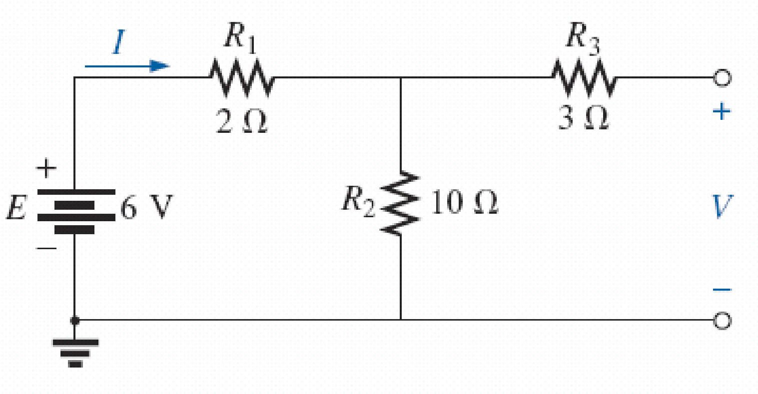


FIG. 6.58 *Network for Example 6.28.*

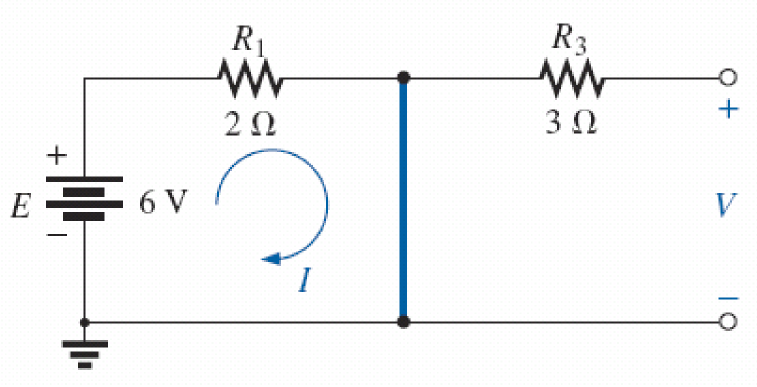


FIG. 6.59 *Network in Fig. 6.58 with R_2 replaced by a jumper.*

LOGO

VOLTMETER LOADING EFFECTS

- When you insert an ammeter, you actually introduce an additional resistance in series with the branch in which you are measuring the current.
- Generally, this is not a serious problem, but it can have a troubling effect on your readings, so it is important to be aware of it.

VOLTMETER LOADING EFFECTS

- Voltmeters also have an internal resistance that appears between the two terminals of interest when a measurement is being made.
- While an ammeter places an additional resistance in series with the branch of interest, a voltmeter places an additional resistance *across* the element.

VOLTMETER LOADING EFFECTS

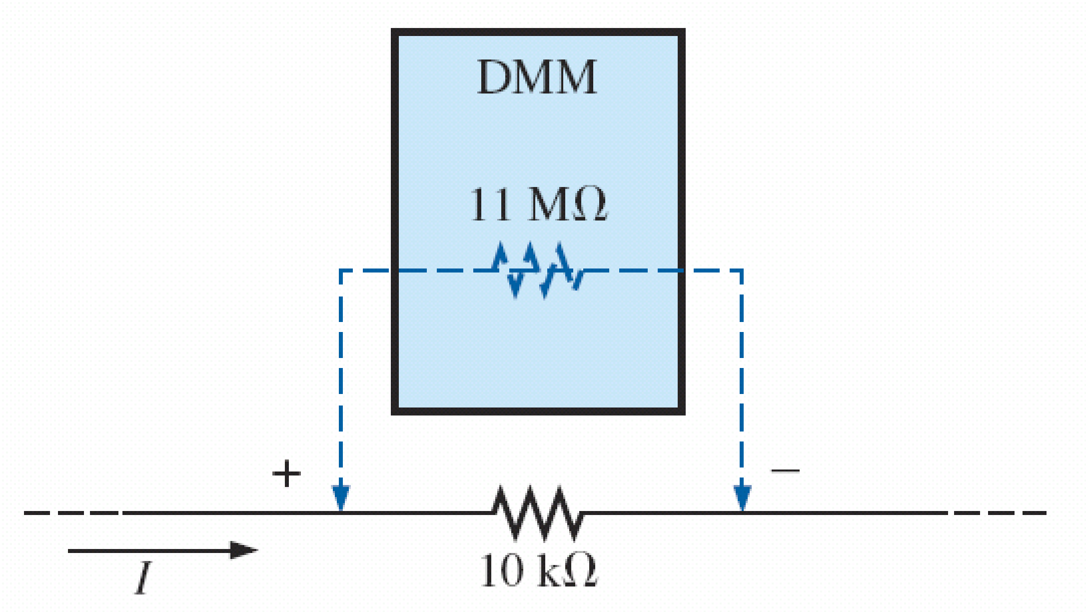


FIG. 6.60 *Voltmeter loading.*

VOLTMETER LOADING EFFECTS

- Since it appears in parallel with the element of interest, *the ideal level for the internal resistance of a voltmeter would be infinite ohms, just as zero ohms would be ideal for an ammeter.*
- Unfortunately, the internal resistance of any voltmeter is not infinite and changes from one type of meter to another.
    - ***Most digital voltmeters can be used in circuits with resistances up to the high-kilohm range without concern for the effect of the internal resistance on the reading.***

LOGO

VOLTMETER LOADING EFFECTS

- To determine the resistance R_m of any scale of a VOM, simply multiply the **maximum voltage** of the chosen scale by the **ohm/volt (Ω/V) rating** normally appearing at the bottom of the face of the meter.

LOGO

VOLTMETER LOADING EFFECTS

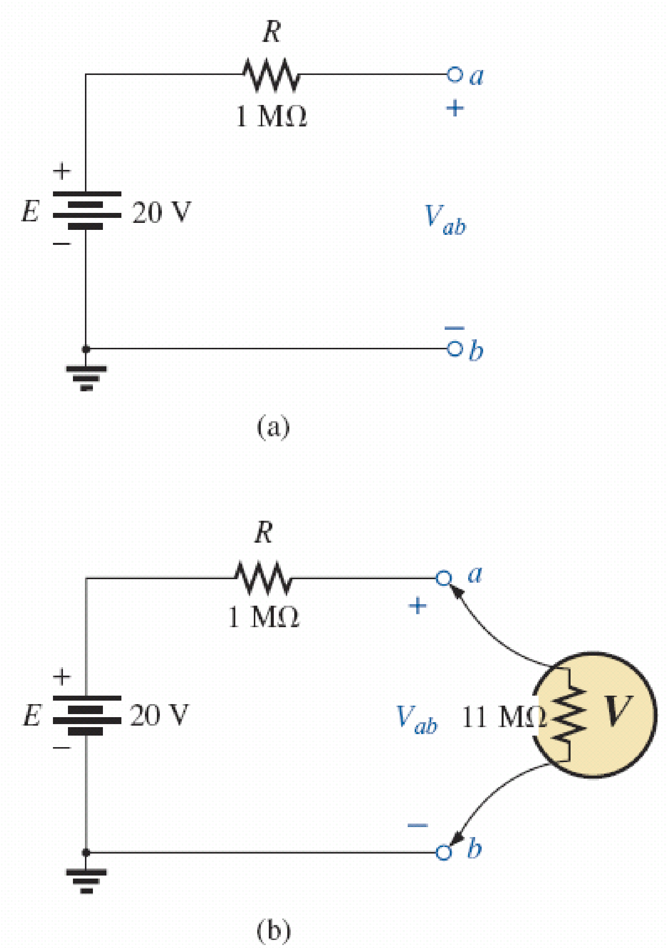


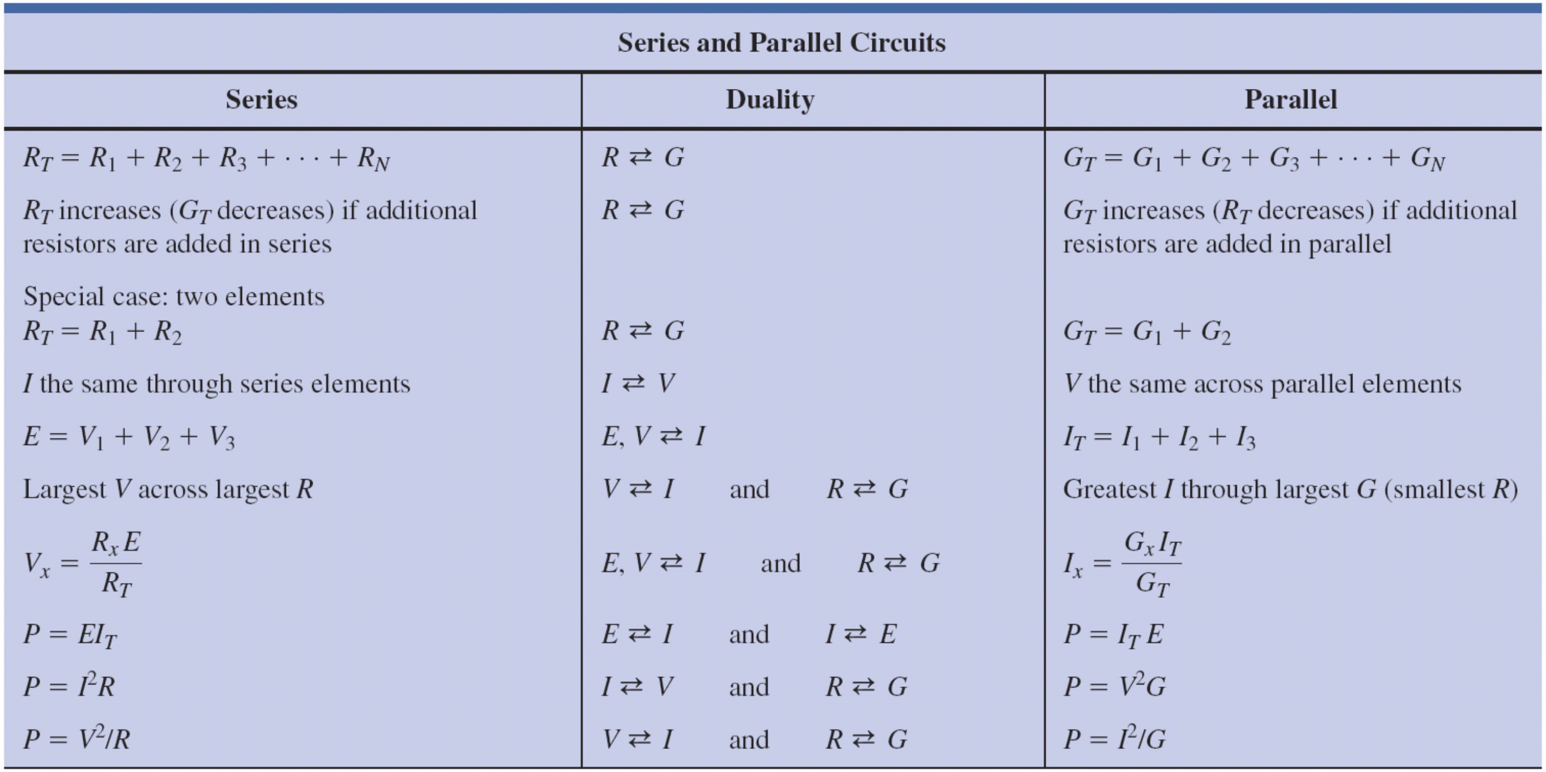
FIG. 6.61 *(a) Measuring an open-circuit voltage with a voltmeter; (b) determining the effect of using a digital voltmeter with an internal resistance of 11 MΩ on measuring an open-circuit voltage (Example 6.29).*

SUMMARY TABLE

- Now that the series and parallel configurations have been covered in detail, we will review the salient equations and characteristics of each.
- The equations for one can often be obtained directly from the other by simply applying the **duality** principle.
- Duality between equations means that the format for an equation can be applied to two different situations by just changing the variable of interest.

LOGO

SUMMARY TABLE



Series and Parallel Circuits

Series	Duality	Parallel
$R_T = R_1 + R_2 + R_3 + \cdots + R_N$	$R \rightleftarrows G$	$G_T = G_1 + G_2 + G_3 + \cdots + G_N$
R_T increases (G_T decreases) if additional resistors are added in series	$R \rightleftarrows G$	G_T increases (R_T decreases) if additional resistors are added in parallel
Special case: two elements $R_T = R_1 + R_2$	$R \rightleftarrows G$	$G_T = G_1 + G_2$
I the same through series elements	$I \rightleftarrows V$	V the same across parallel elements
$E = V_1 + V_2 + V_3$	$E, V \rightleftarrows I$	$I_T = I_1 + I_2 + I_3$
Largest V across largest R	$V \rightleftarrows I$ and $R \rightleftarrows G$	Greatest I through largest G (smallest R)
$V_x = \dfrac{R_x E}{R_T}$	$E, V \rightleftarrows I$ and $R \rightleftarrows G$	$I_x = \dfrac{G_x I_T}{G_T}$
$P = EI_T$	$E \rightleftarrows I$ and $I \rightleftarrows E$	$P = I_T E$
$P = I^2R$	$I \rightleftarrows V$ and $R \rightleftarrows G$	$P = V^2G$
$P = V^2/R$	$V \rightleftarrows I$ and $R \rightleftarrows G$	$P = I^2/G$

TABLE 6.1 *Summary table.*

LOGO

TROUBLESHOOTING TECHNIQUES

- The art of *troubleshooting* is not limited solely to electrical or electronic systems.
  - In the broad sense, ***troubleshooting is a process by which acquired knowledge and experience are used to localize a problem and offer or implement a solution.***

TROUBLESHOOTING TECHNIQUES

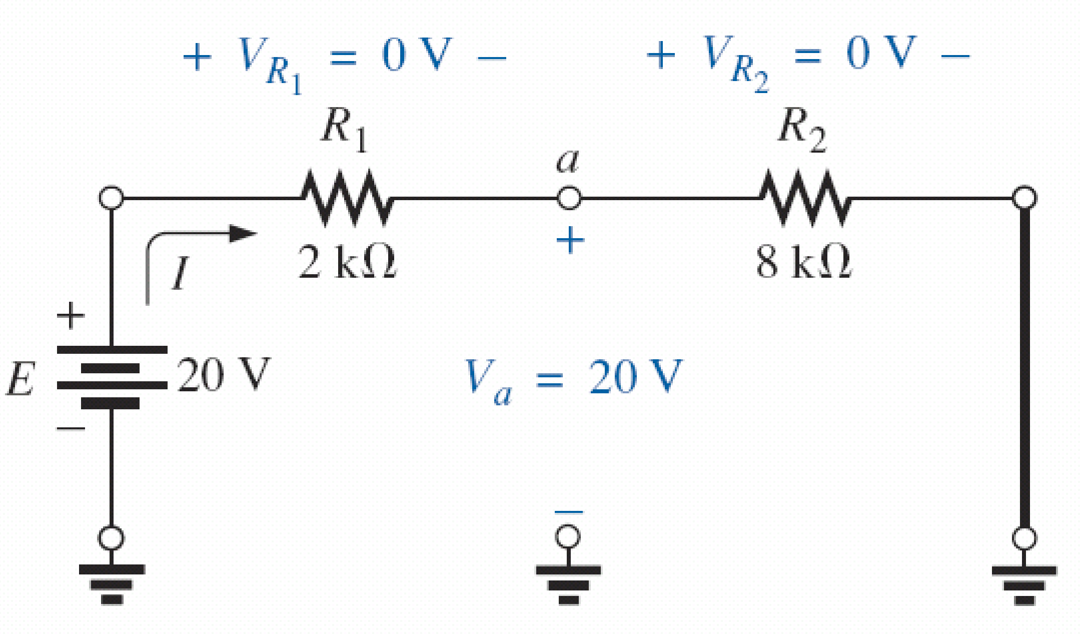
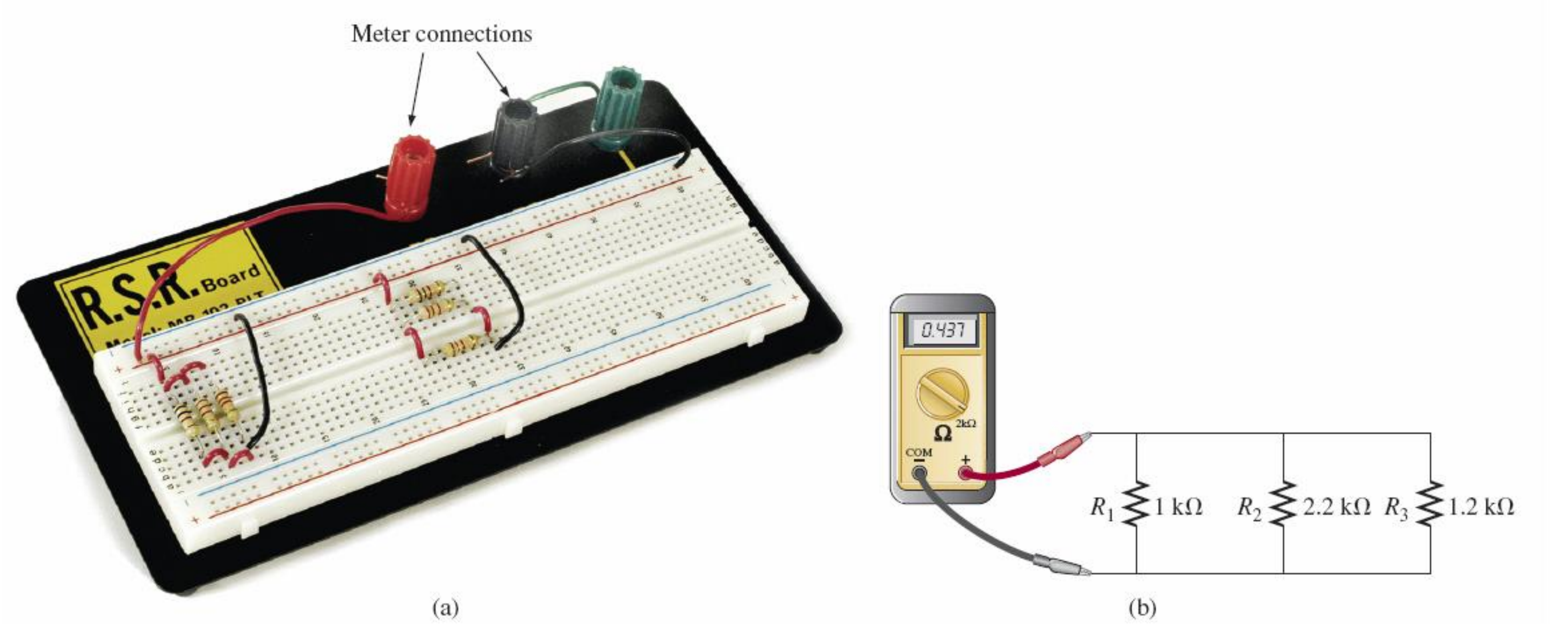


FIG. 6.62 *A malfunctioning network.*

PROTOBOARDS (BREADBOARDS)



(a) (b)

FIG. 6.63 *Using a protoboard to set up the circuit in Fig. 6.17.*

COMPUTER ANALYSIS

PSpice

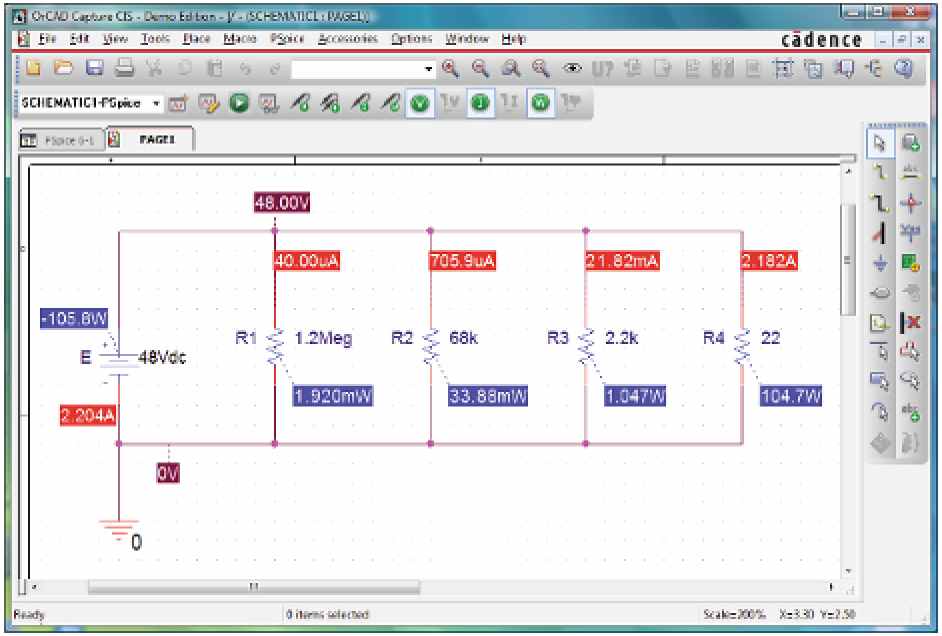


FIG. 6.69 *Applying PSpice to a parallel network.*

COMPUTER ANALYSIS

Multisim

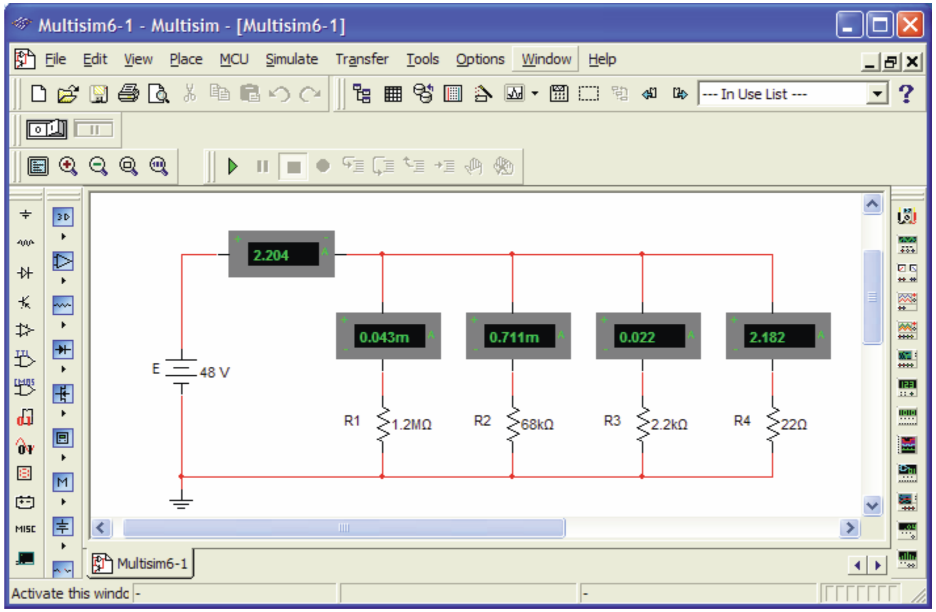


FIG. 6.70 *Using the indicators of Multisim to display the currents of a parallel dc network.*

LOGO

Series-Parallel Circuits

INTRODUCTION

- *A series-parallel configuration is one that is formed by a combination of series and parallel elements.*
- *A complex configuration is one in which none of the elements are in series or parallel.*

LOGO

SERIES-PARALLEL NETWORKS

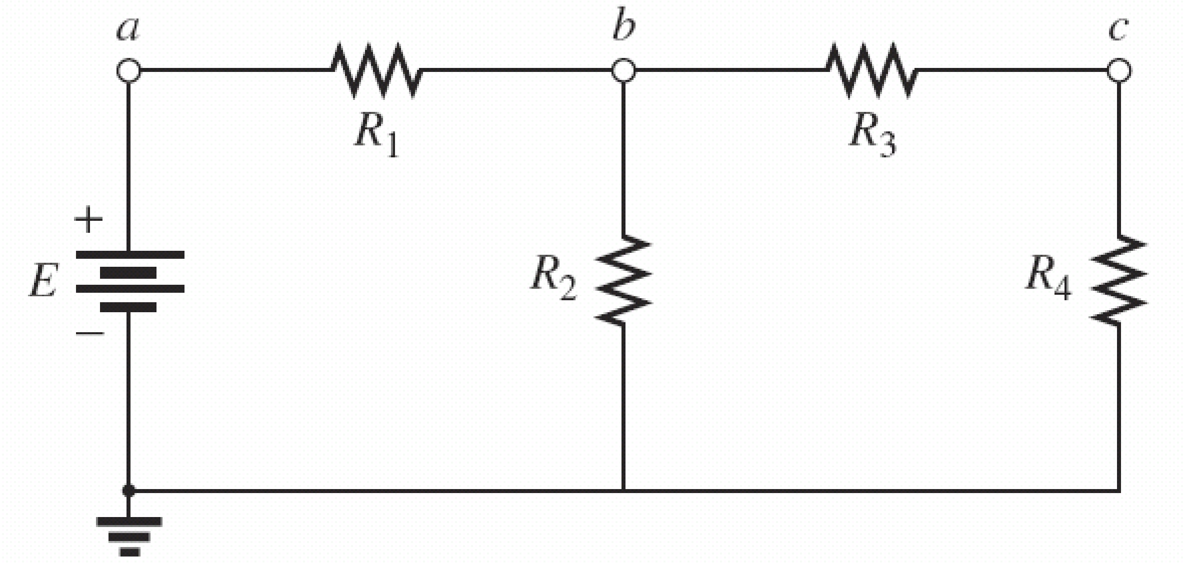


FIG. 7.1 *Series-parallel dc network.*

LOGO

REDUCE AND RETURN APPROACH

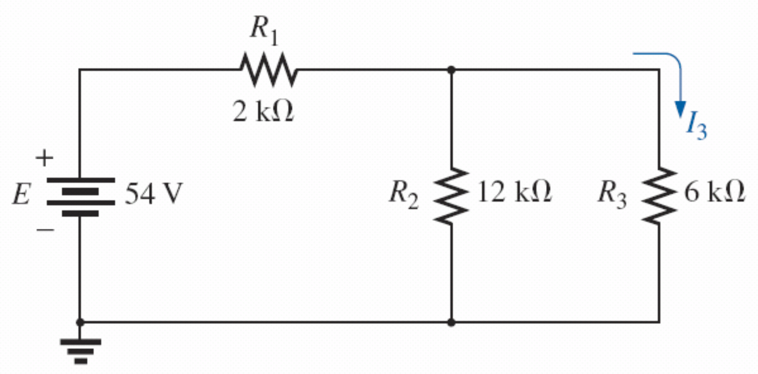


FIG. 7.3 *Series-parallel network for Example 7.1.*

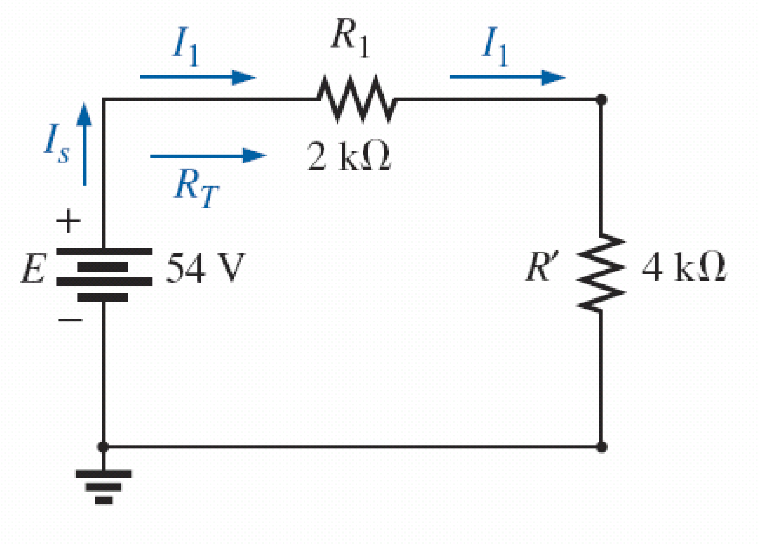


FIG. 7.4 *Substituting the parallel equivalent resistance for resistors R_2 and R_3 in Fig. 7.3.*

REDUCE AND RETURN APPROACH

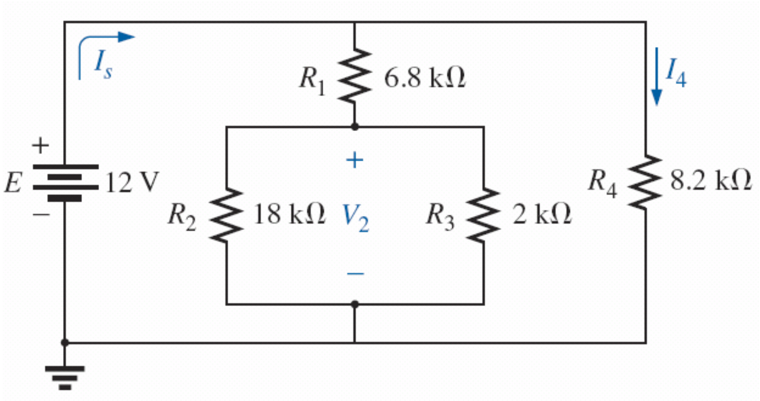


FIG. 7.5 *Series-parallel network for Example 7.2.*

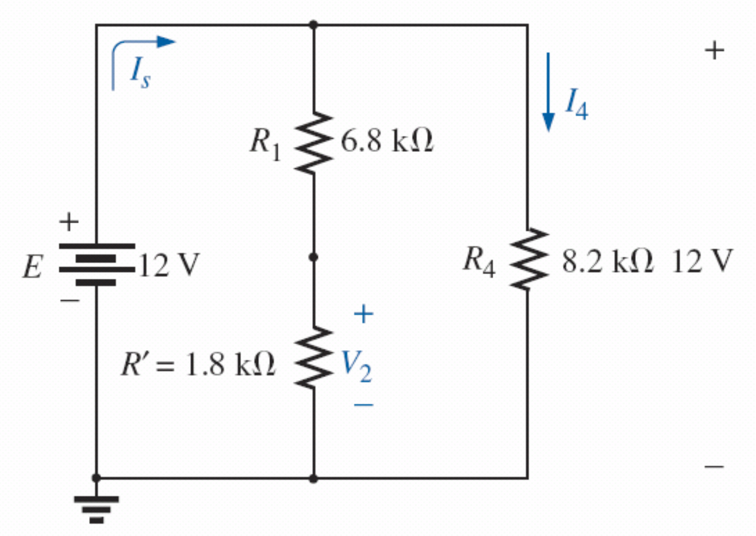


FIG. 7.6 *Schematic representation of the network in Fig. 7.5 after substituting the equivalent resistance R for the parallel combination of R_2 and R_3.*

REDUCE AND RETURN APPROACH

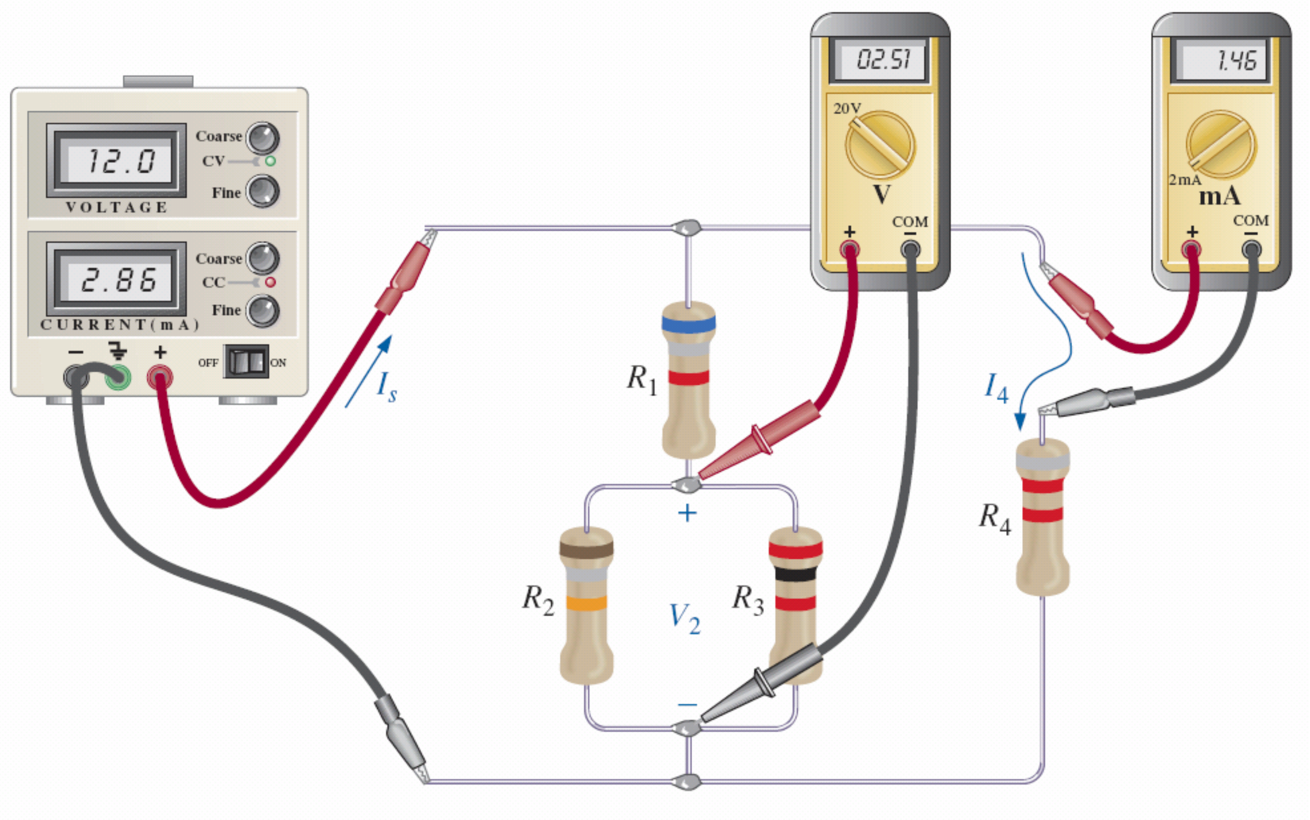


FIG. 7.7 *Inserting an ammeter and a voltmeter to measure I_4 and V_2, respectively.*

LOGO

BLOCK DIAGRAM APPROACH

- Once the grouping of elements reveals the most direct approach, you can examine the impact of the individual components in each group.
- This grouping of elements is called the *block diagram approach*

BLOCK DIAGRAM APPROACH

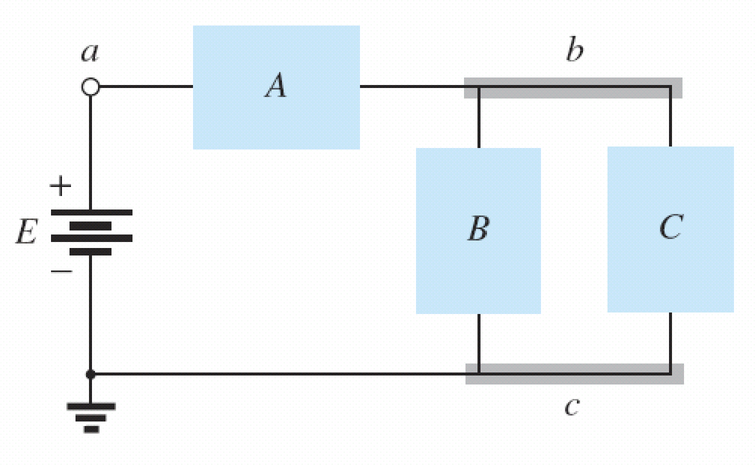


FIG. 7.8 *Introducing the block diagram approach.*

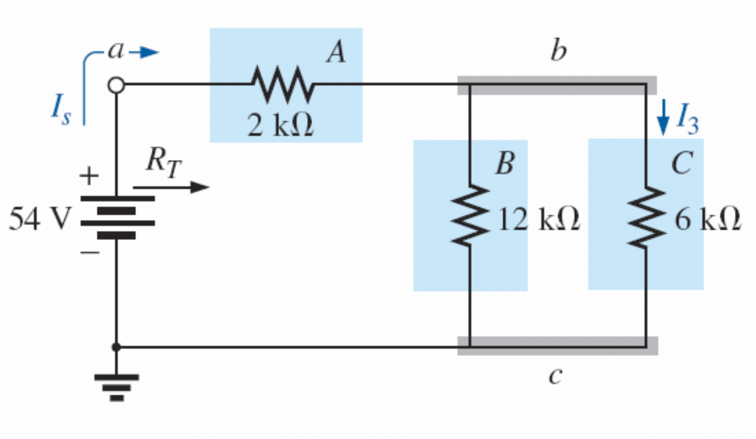


FIG. 7.9 *Block diagram format of Fig. 7.3.*

LOGO

BLOCK DIAGRAM APPROACH

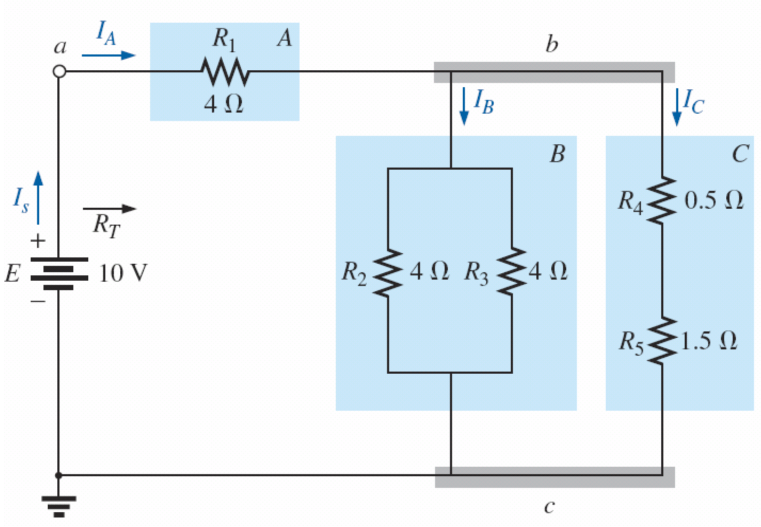


FIG. 7.10 *Example 7.3.*

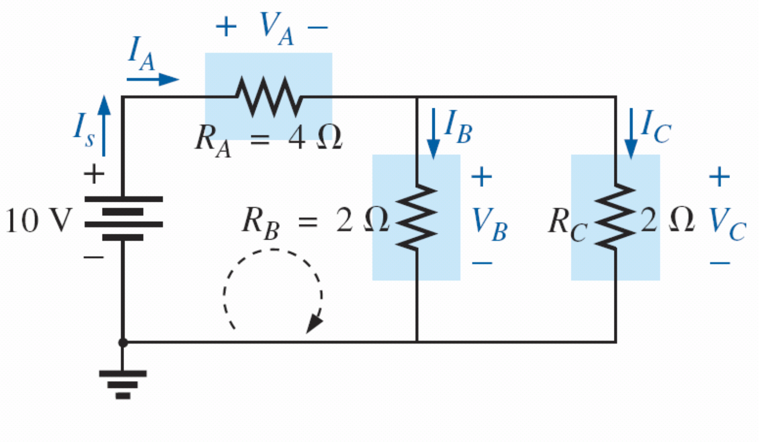


FIG. 7.11 *Reduced equivalent of Fig. 7.10.*

LOGO

BLOCK DIAGRAM APPROACH

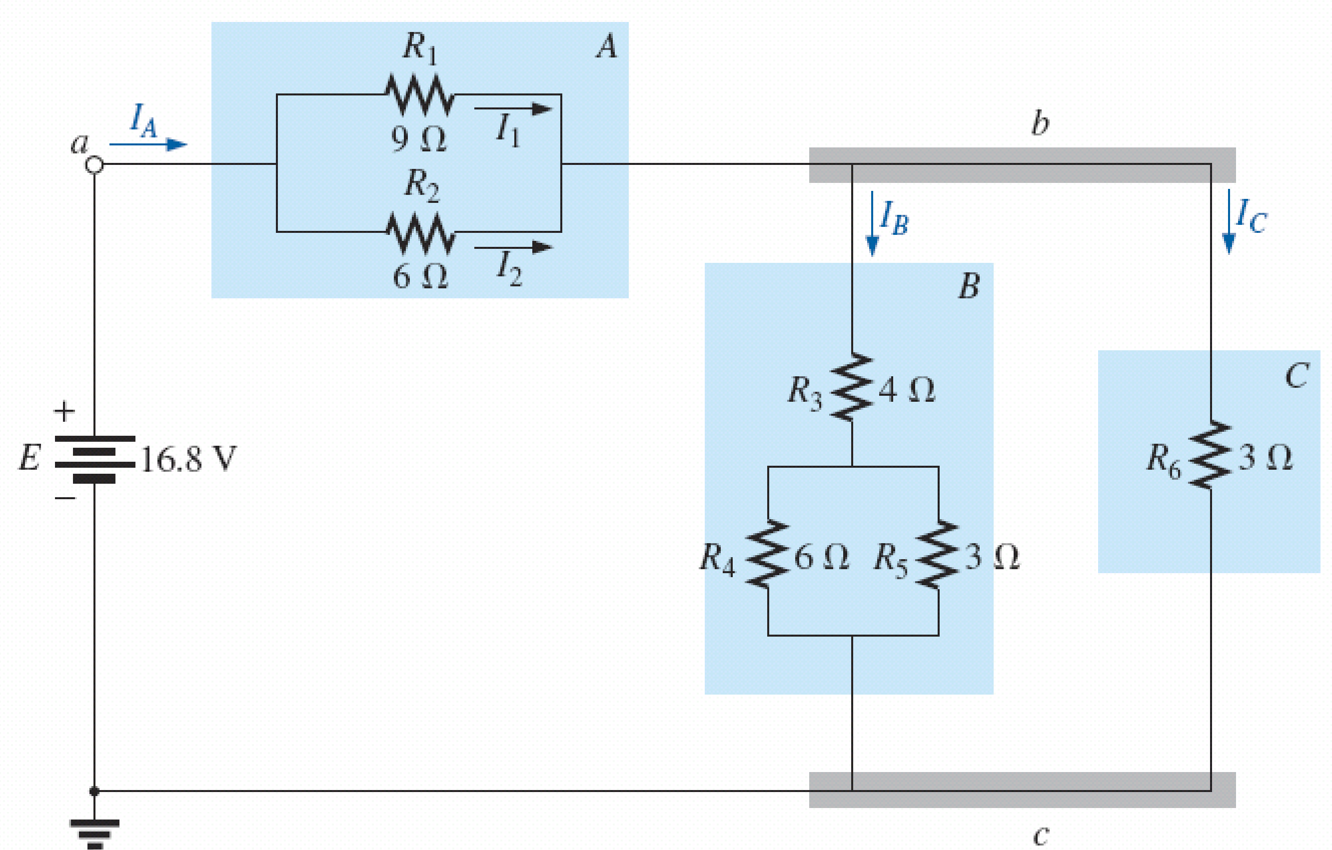


FIG. 7.12 *Example 7.4.*

LOGO

BLOCK DIAGRAM APPROACH

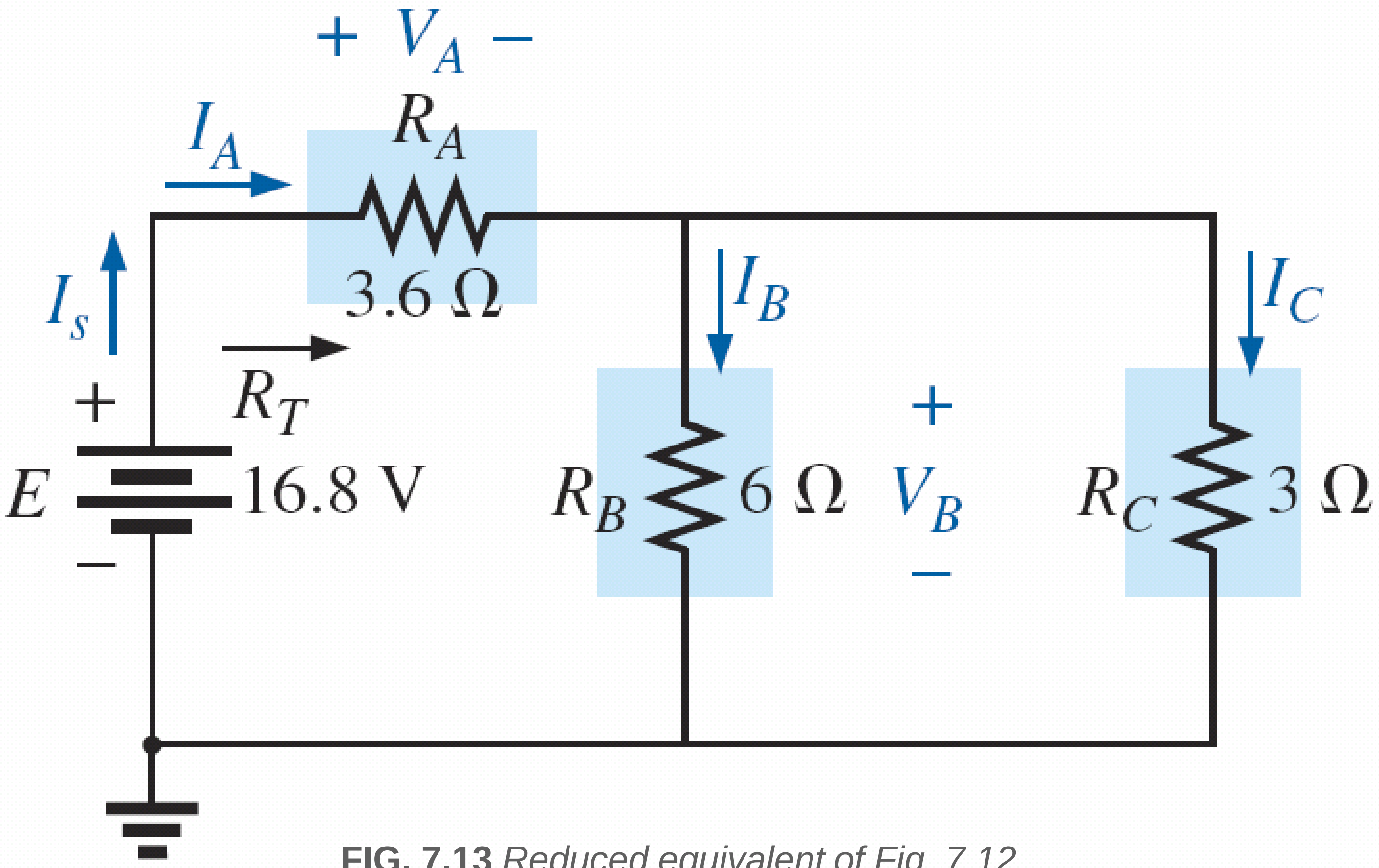


FIG. 7.13 *Reduced equivalent of Fig. 7.12.*

LOGO

DESCRIPTIVE EXAMPLES

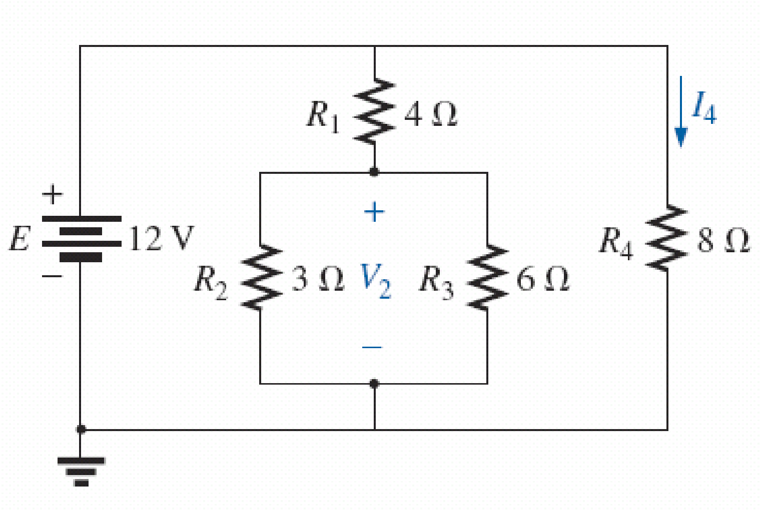


FIG. 7.14 *Example 7.5.*

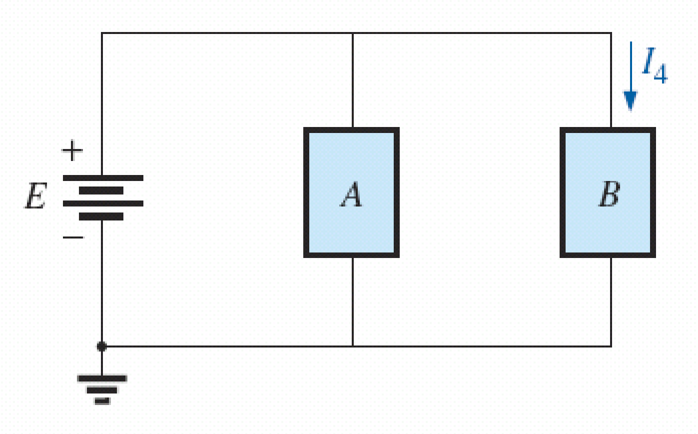


FIG. 7.15 *Block diagram of Fig. 7.14.*

LOGO

DESCRIPTIVE EXAMPLES

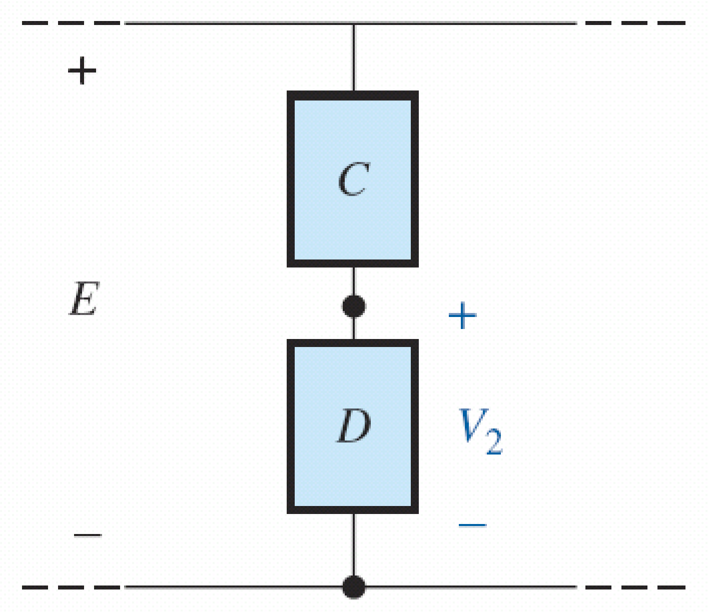


FIG. 7.16 *Alternative block diagram for the first parallel branch in Fig. 7.14.*

DESCRIPTIVE EXAMPLES

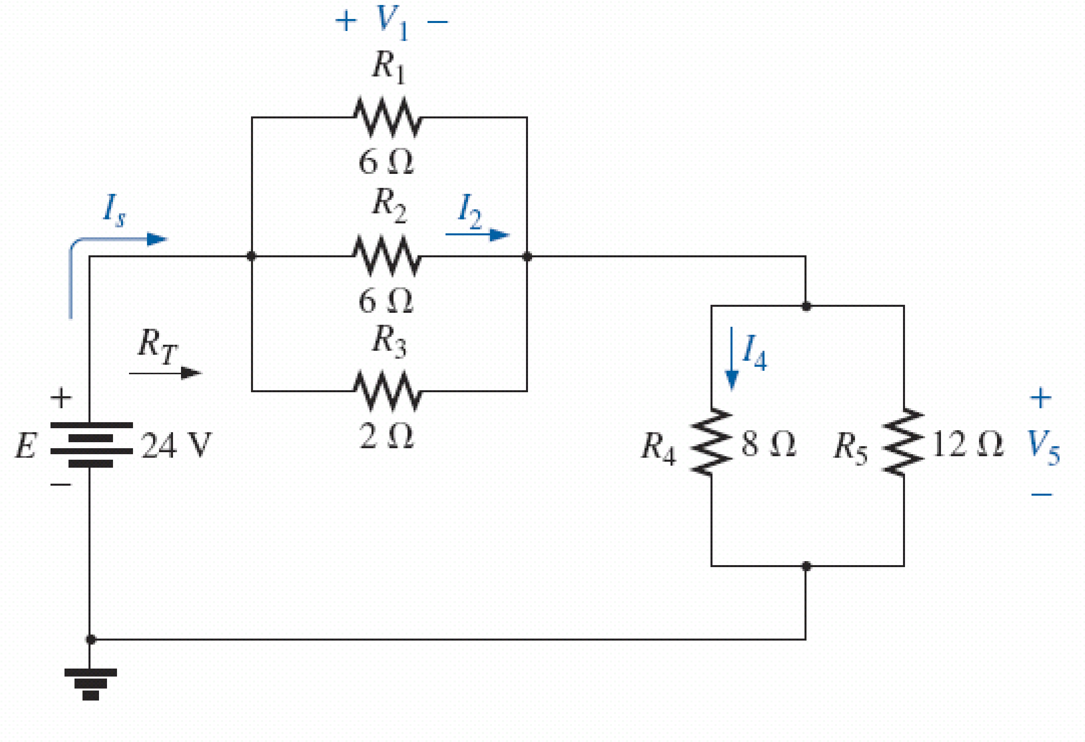


FIG. 7.17 *Example 7.6.*

LOGO

DESCRIPTIVE EXAMPLES

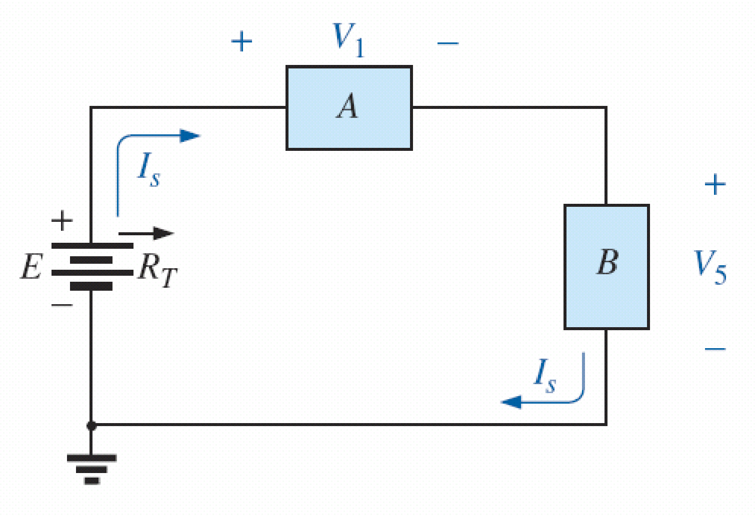


FIG. 7.18 *Block diagram for Fig. 7.17.*

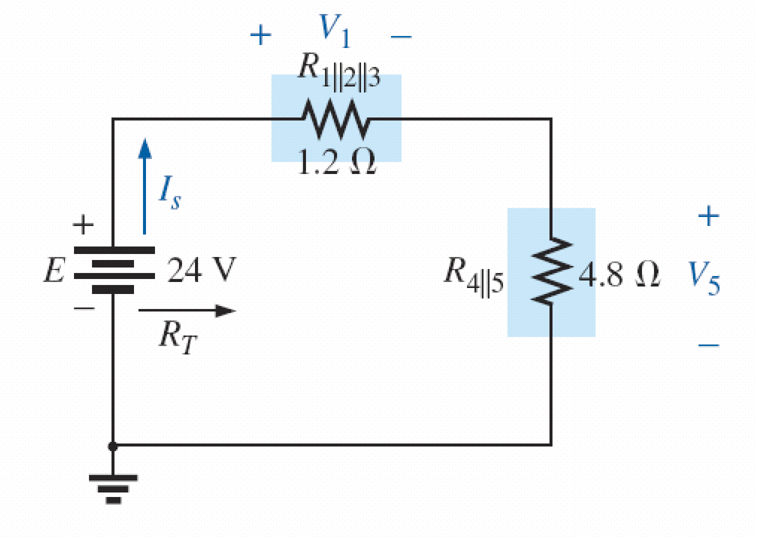


FIG. 7.19 *Reduced form of Fig. 7.17.*

LOGO

DESCRIPTIVE EXAMPLES

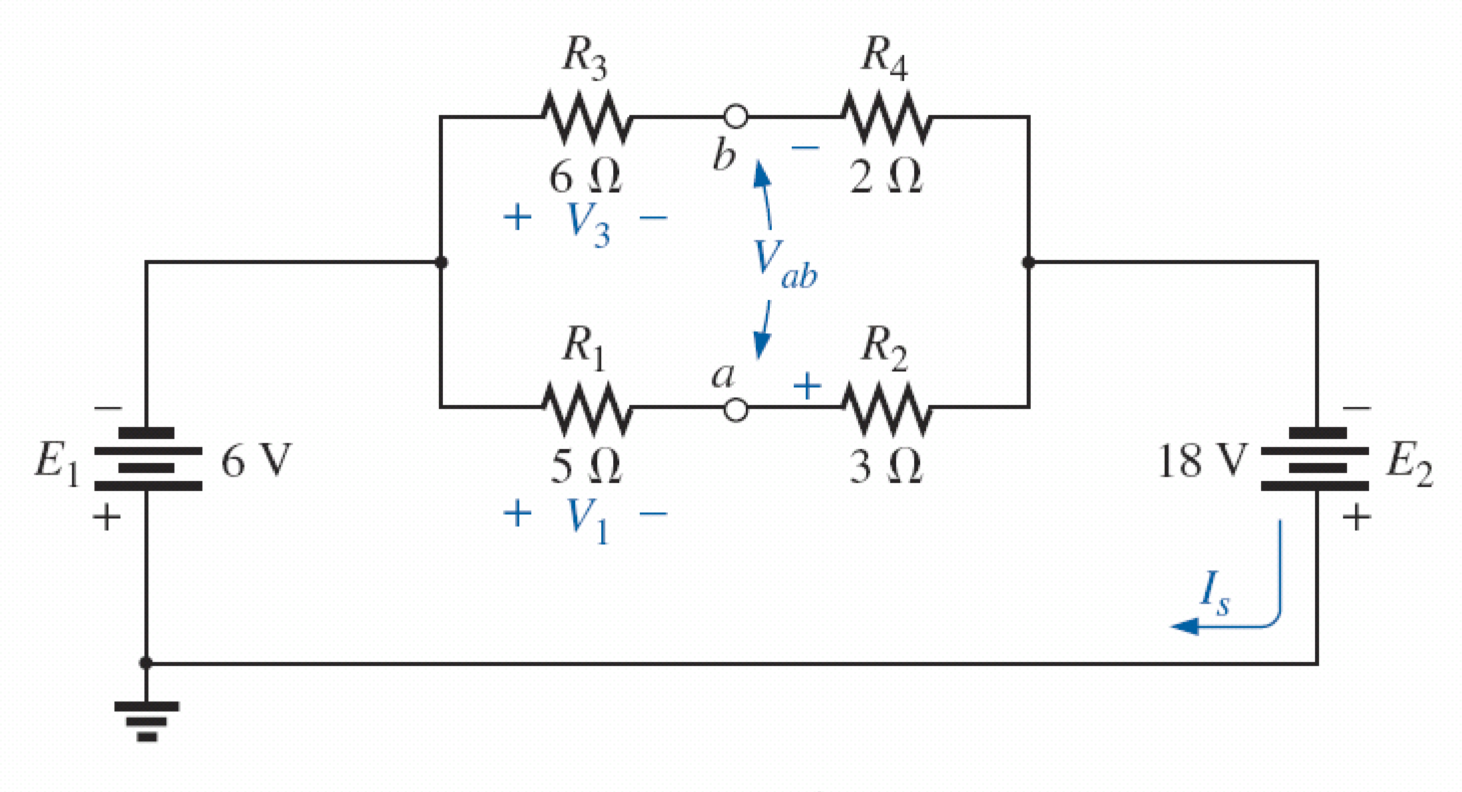


FIG. 7.20 *Example 7.7.*

LOGO

DESCRIPTIVE EXAMPLES

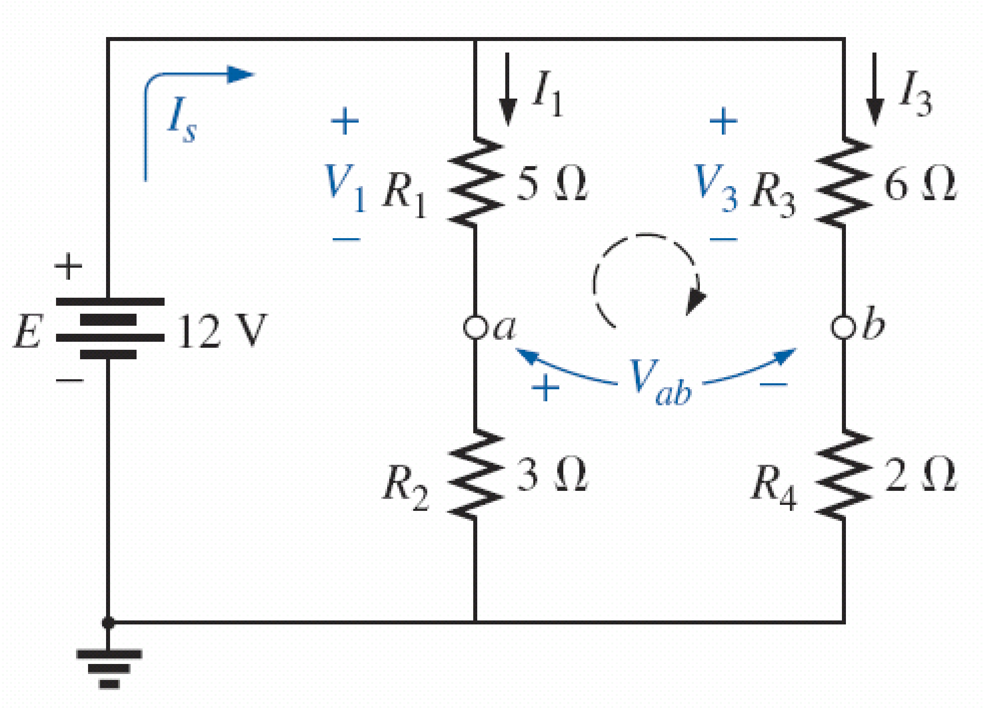


FIG. 7.21 *Network in Fig. 7.20 redrawn.*

LOGO

DESCRIPTIVE EXAMPLES

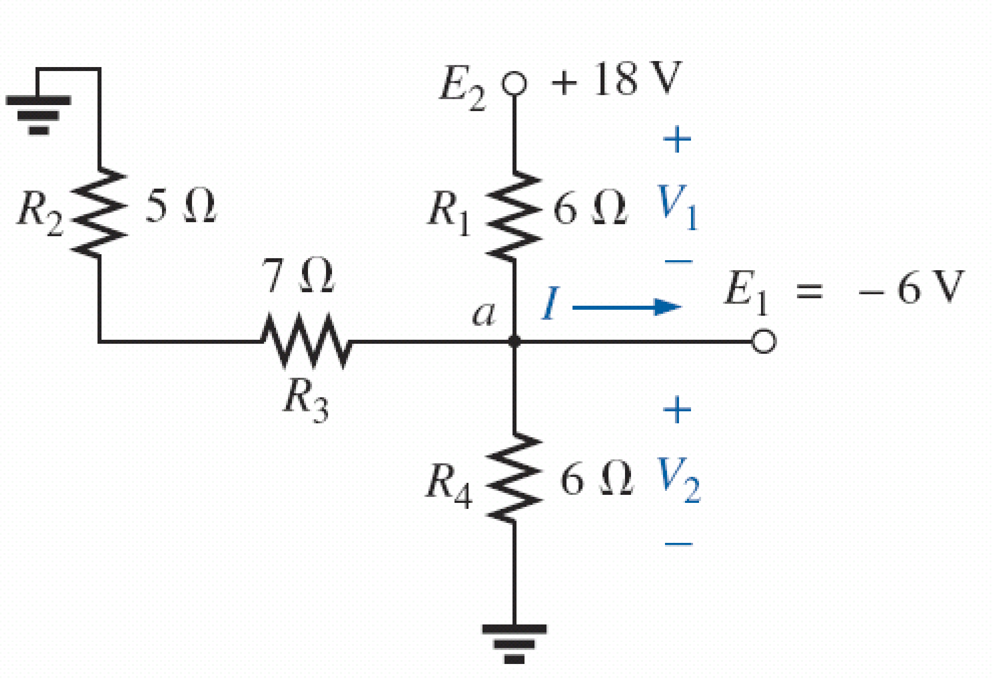


FIG. 7.22 *Example 7.8.*

LOGO

DESCRIPTIVE EXAMPLES

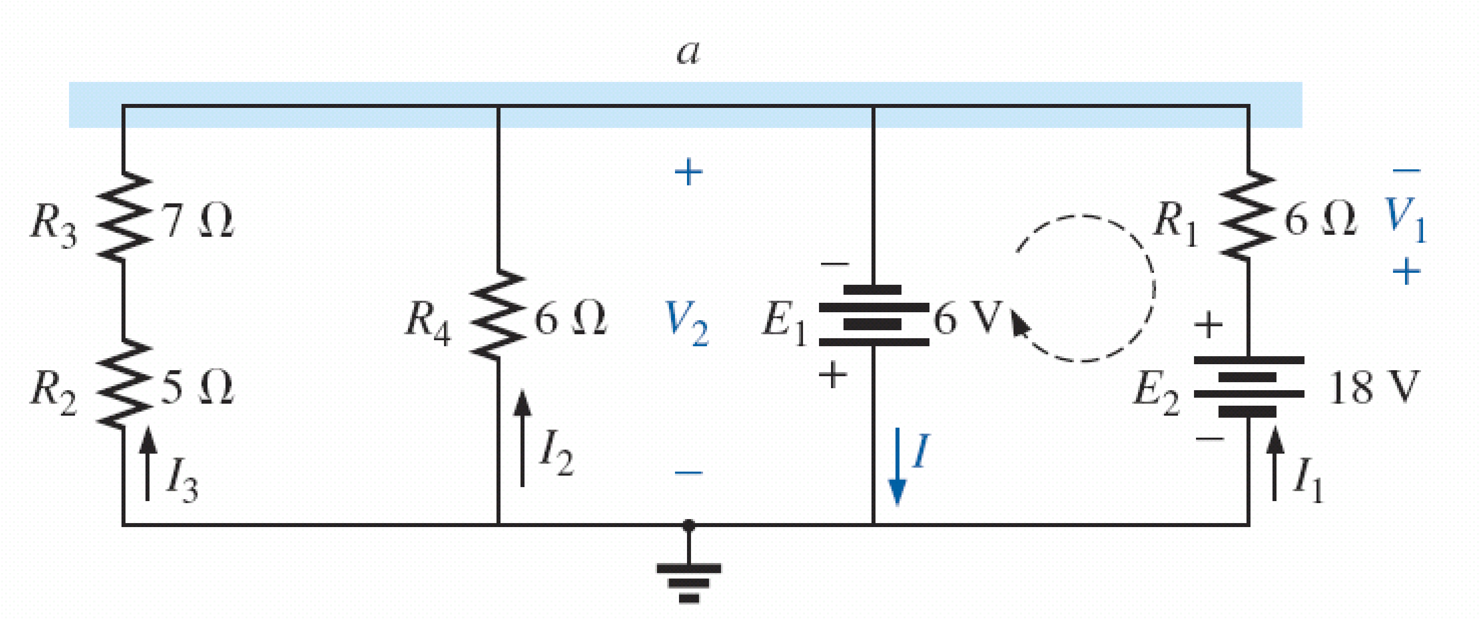


FIG. 7.23 *Network in Fig. 7.22 redrawn.*

DESCRIPTIVE EXAMPLES

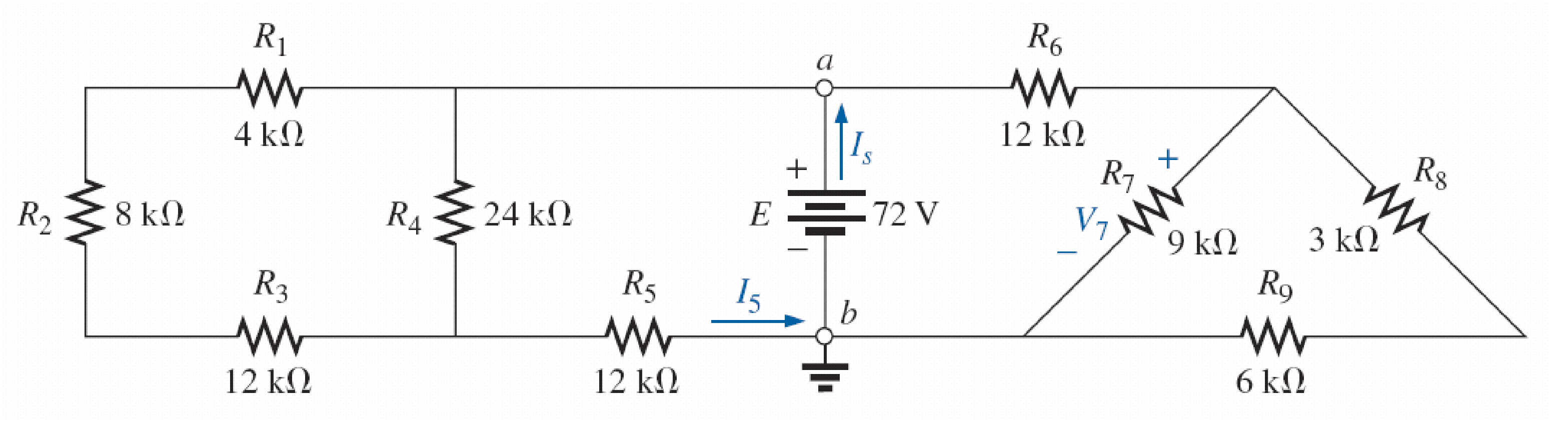


FIG. 7.26 *Example 7.10.*

LOGO

DESCRIPTIVE EXAMPLES

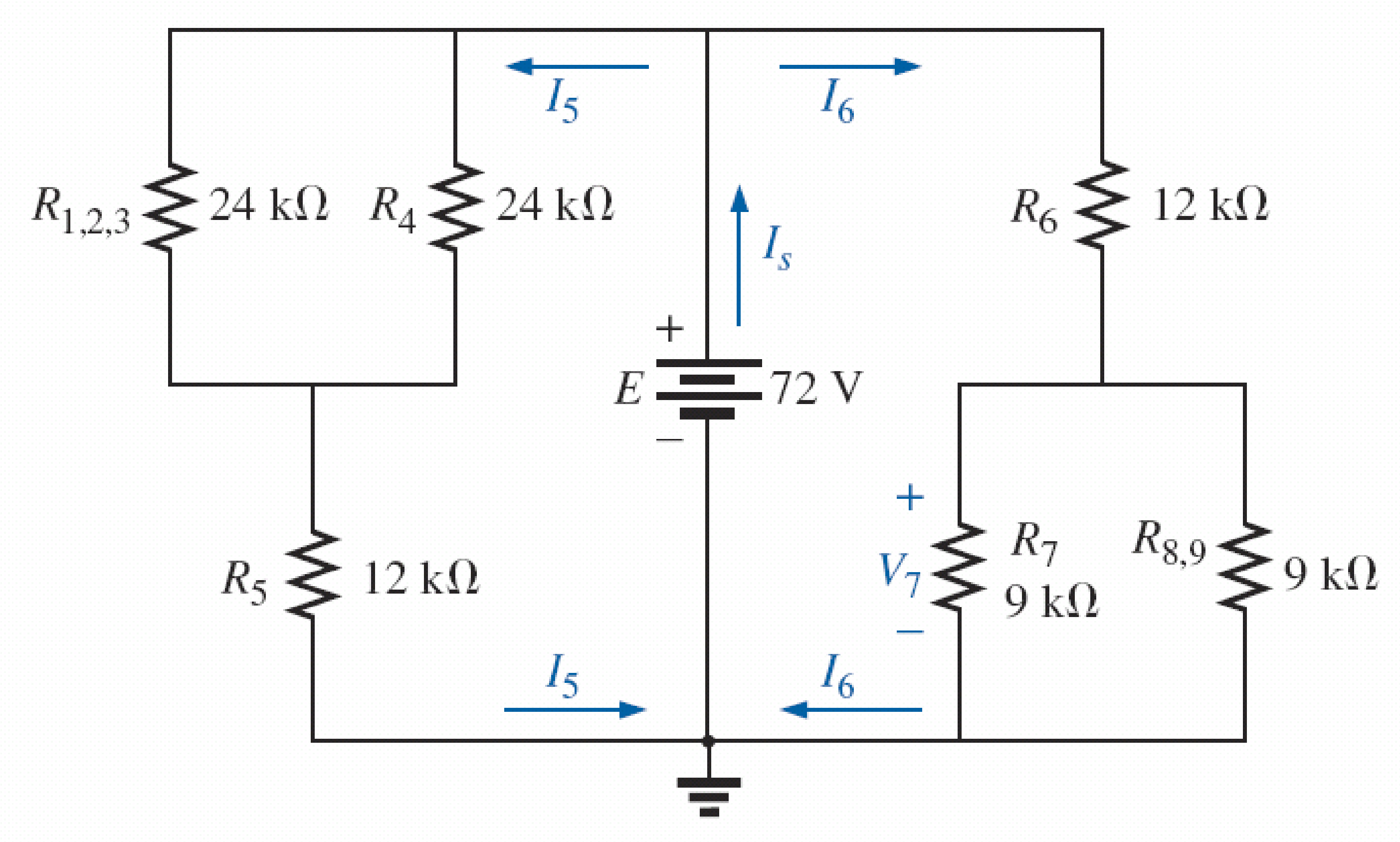


FIG. 7.27 *Network in Fig. 7.26 redrawn.*

LOGO

DESCRIPTIVE EXAMPLES

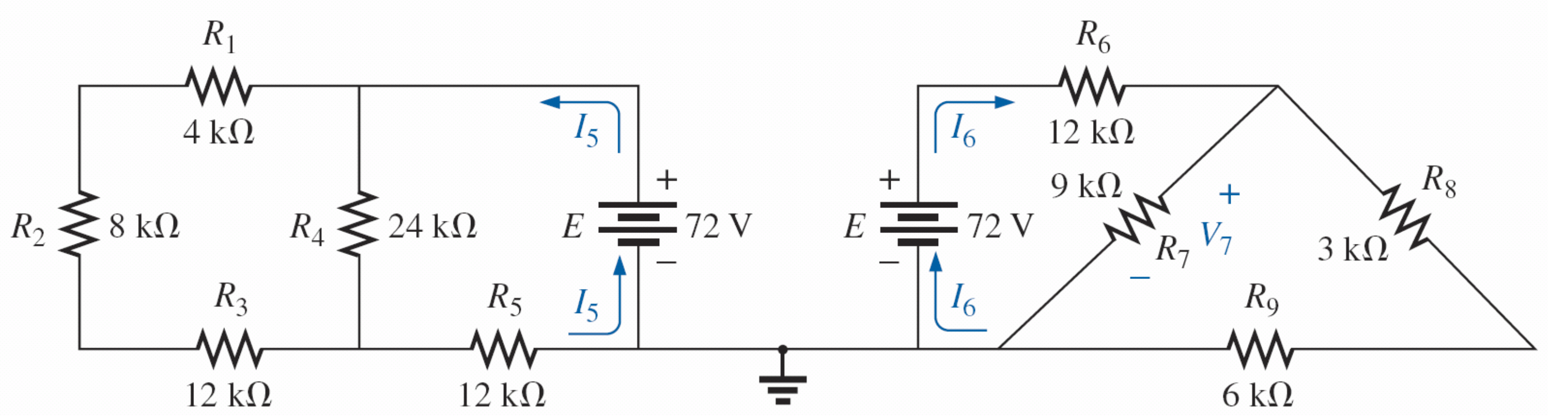


FIG. 7.28 *An alternative approach to Example 7.10.*

DESCRIPTIVE EXAMPLES

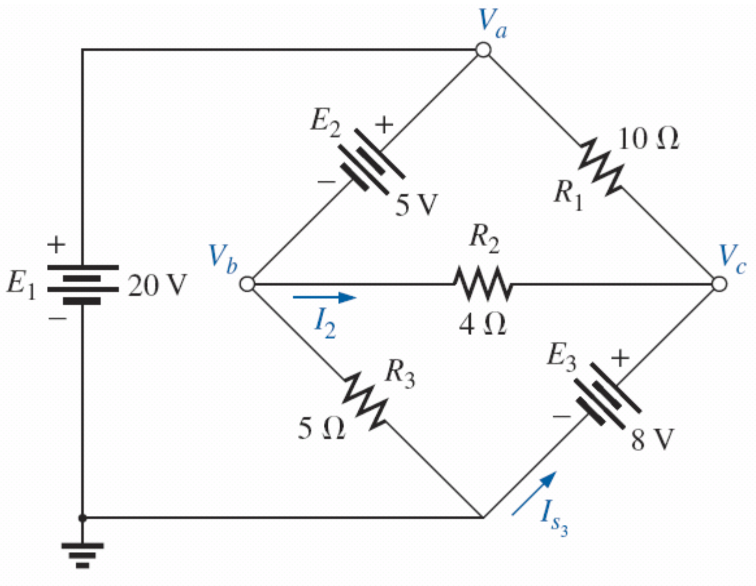


FIG. 7.29 *Example 7.11.*

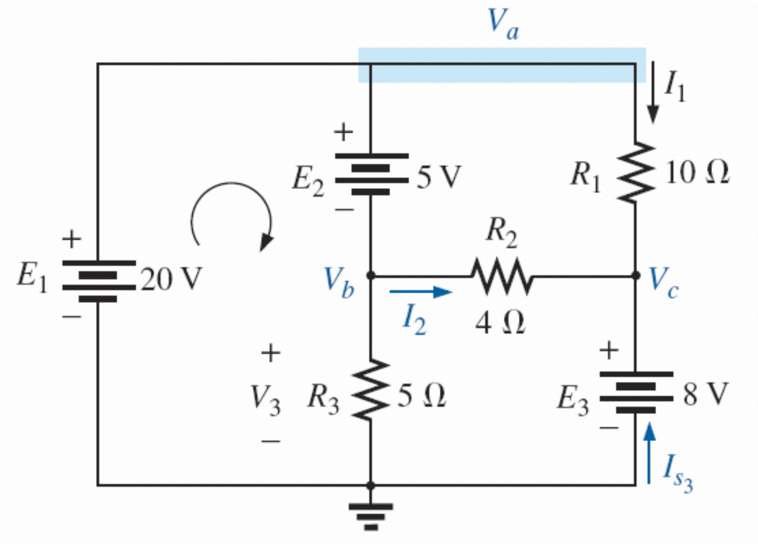


FIG. 7.30 *Network in Fig. 7.29 redrawn to better define a path toward the desired unknowns.*

LOGO

DESCRIPTIVE EXAMPLES

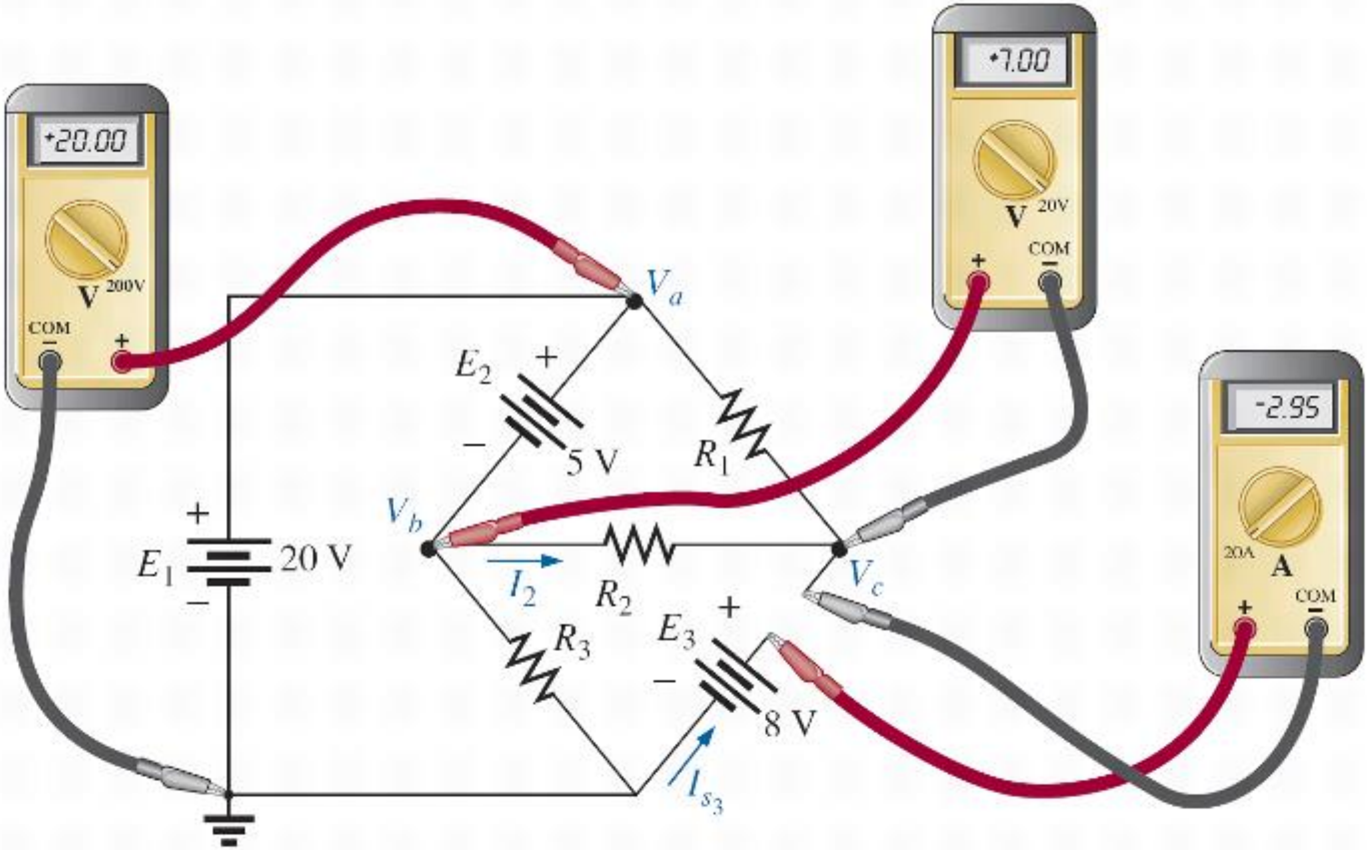


FIG. 7.31 *Complex network for Example 7.11.*

LADDER NETWORKS

- A three-section **ladder network** appears in Fig. 7.32.
- The reason for the terminology is quite obvious for the repetitive structure.
- Basically two approaches are used to solve networks of this type.

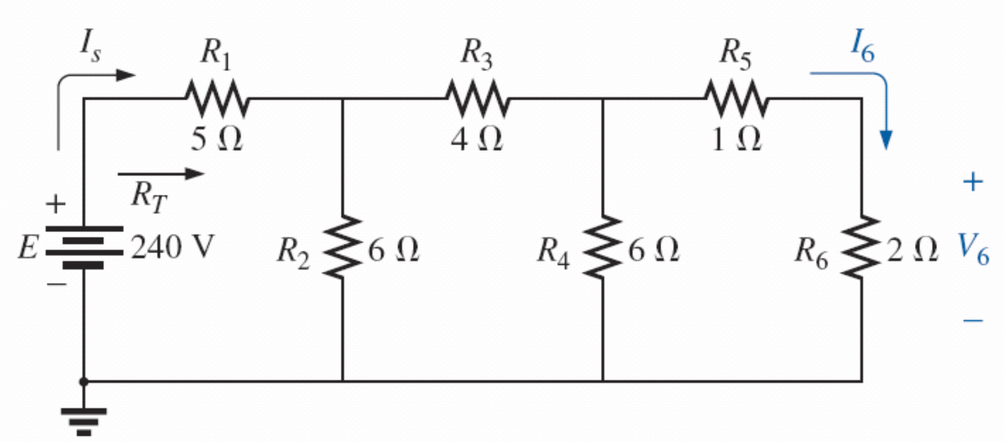


FIG. 7.32 *Ladder network.*

LOGO

LADDER NETWORKS

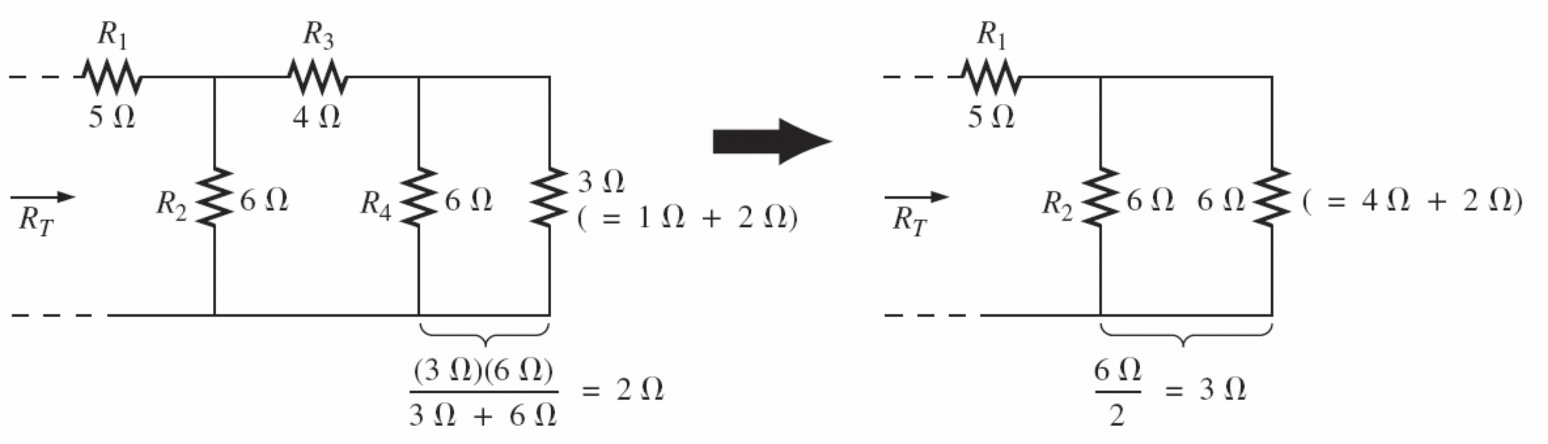


FIG. 7.33 *Working back to the source to determine R_T for the network in Fig. 7.32.*

LOGO

LADDER NETWORKS

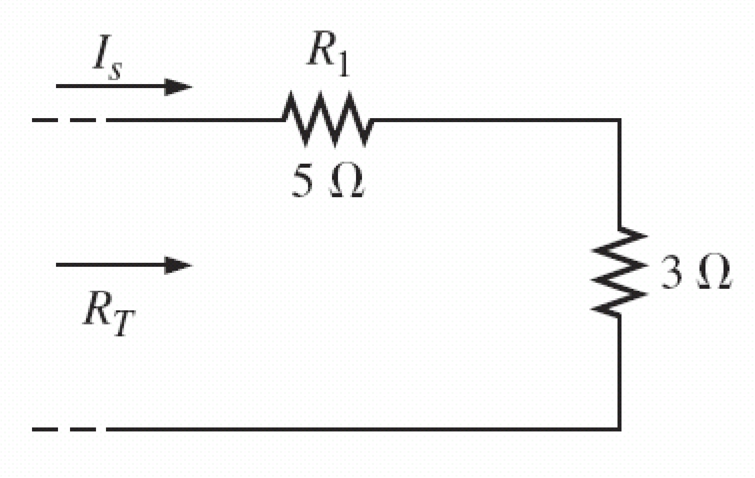


FIG. 7.34 *Calculating R_T and I_s.*

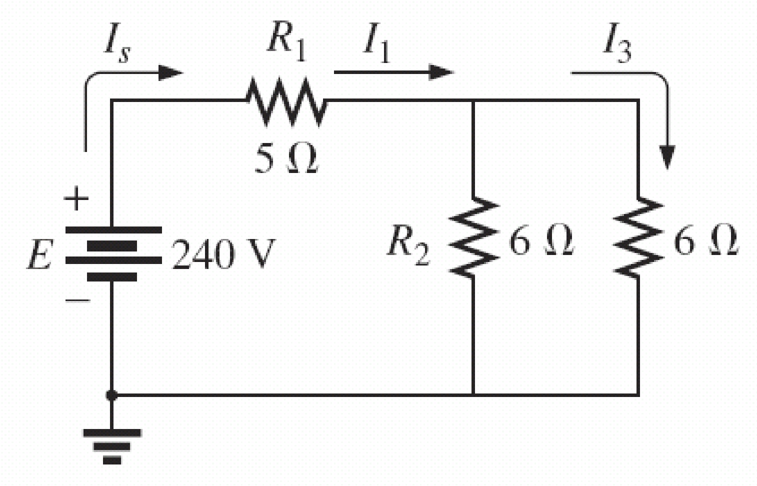


FIG. 7.35 *Working back toward I_6.*

LADDER NETWORKS

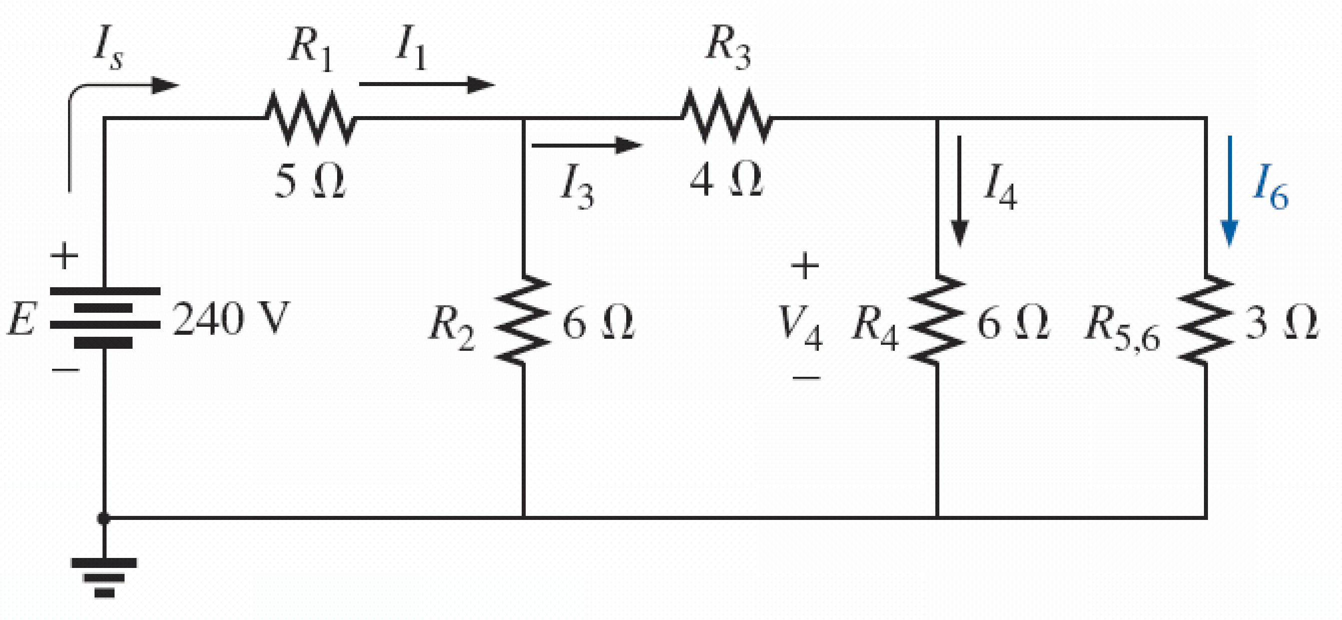


FIG. 7.36 *Calculating I_6.*

LOGO

LADDER NETWORKS

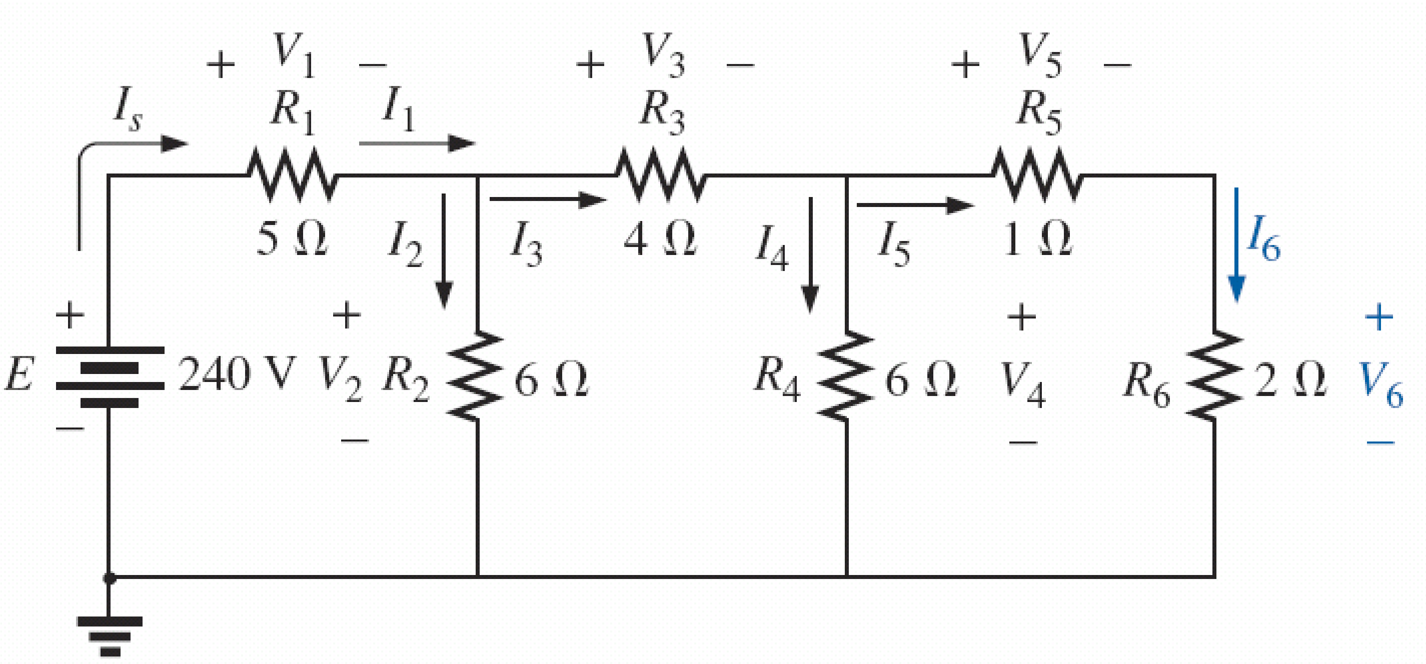


FIG. 7.37 *An alternative approach for ladder networks.*

AMMETER, VOLTMETER, AND OHMMETER DESIGN

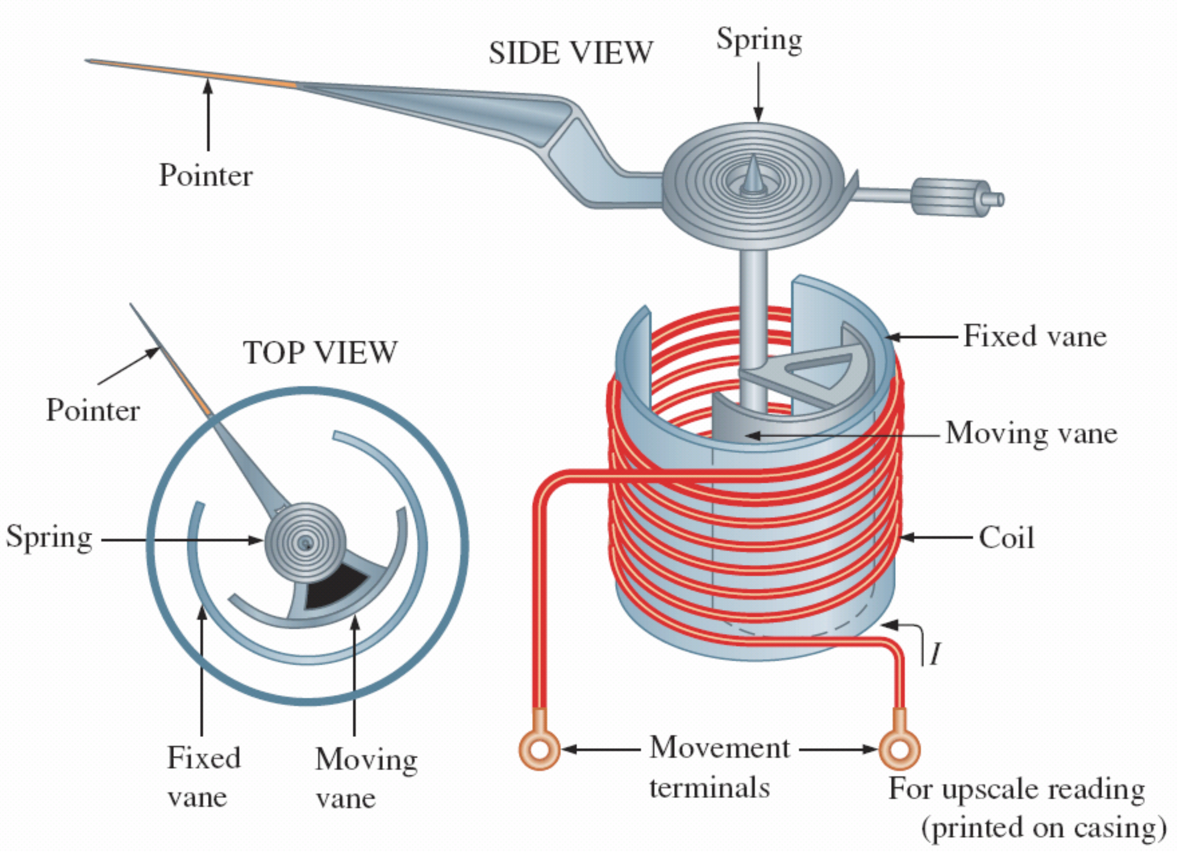


FIG. 7.46 *Iron-vane movement.*

AMMETER, VOLTMETER, AND OHMMETER DESIGN

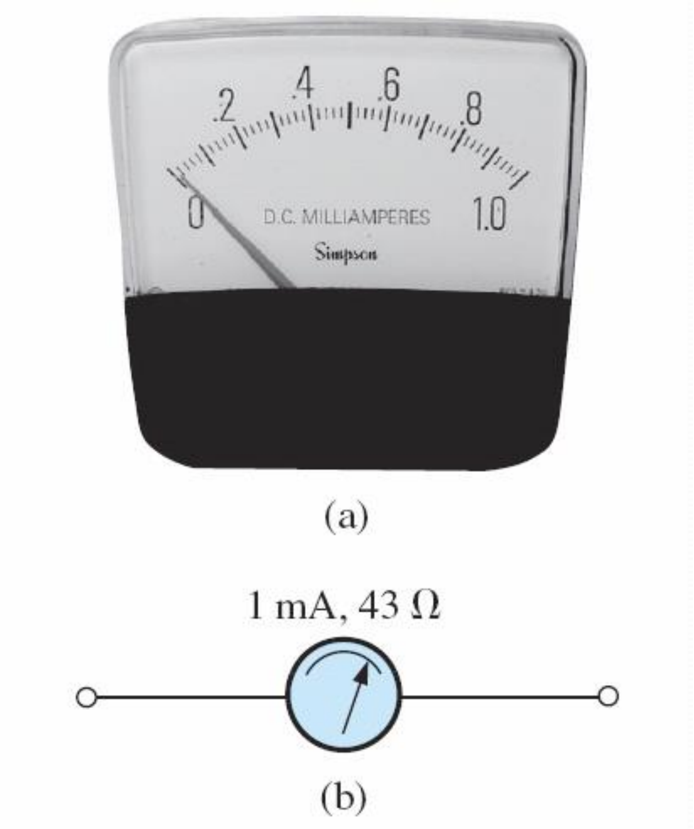


FIG. 7.47 *Iron-vane movement; (a) photo, (b) symbol and ratings.*

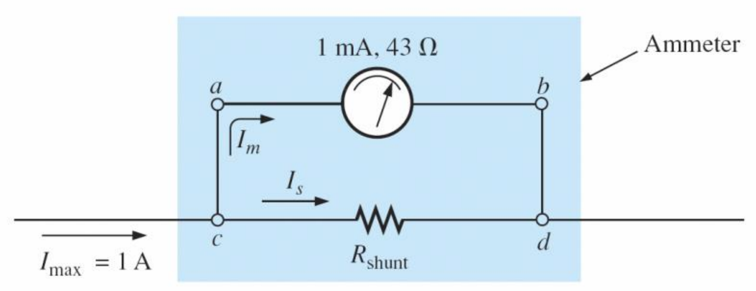


FIG. 7.48 *Basic ammeter.*

LOGO

AMMETER, VOLTMETER, AND OHMMETER DESIGN

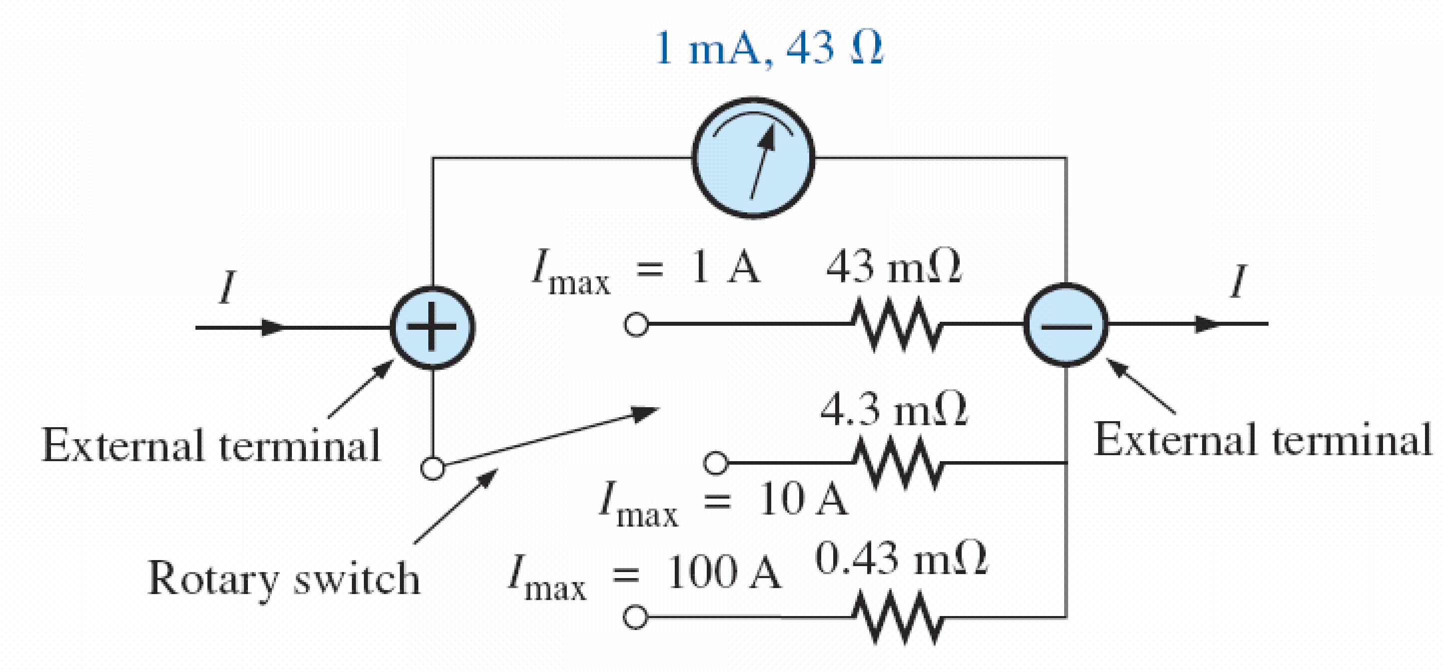


FIG. 7.49 *Multirange ammeter.*

AMMETER, VOLTMETER, AND OHMMETER DESIGN

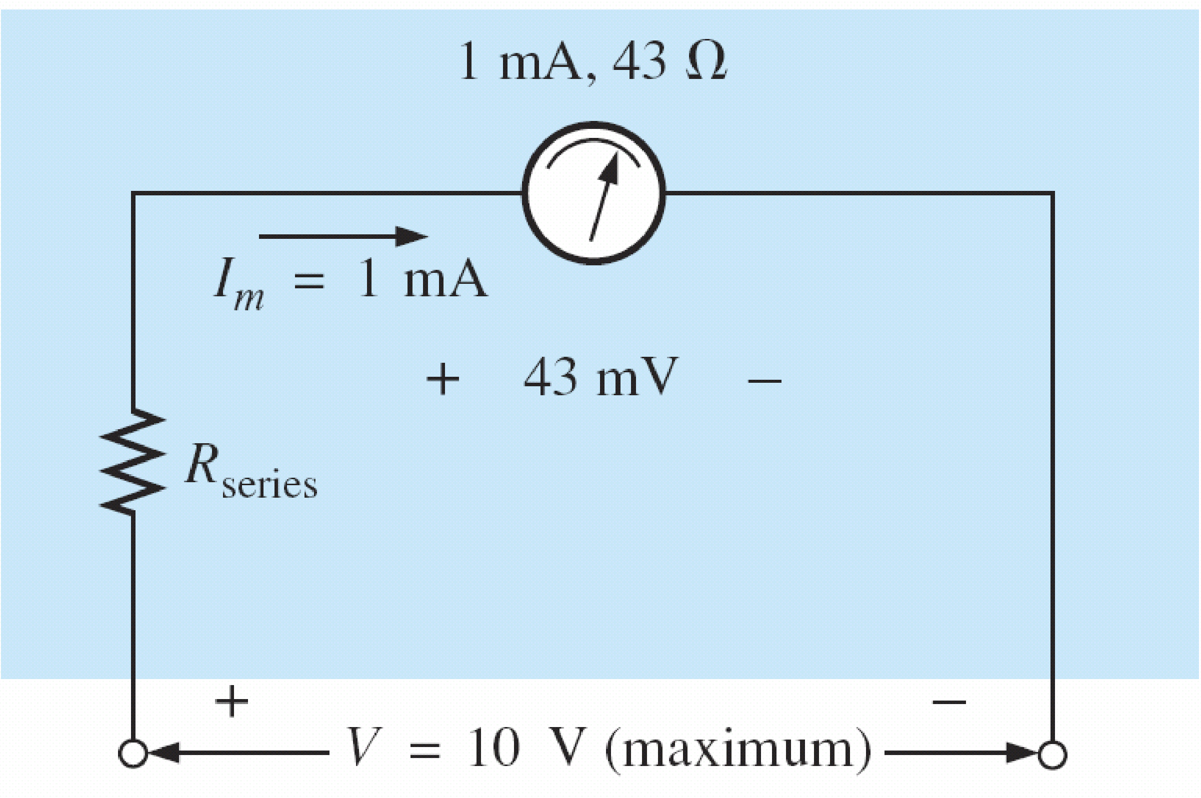


FIG. 7.50 *Basic voltmeter.*

LOGO

AMMETER, VOLTMETER, AND OHMMETER DESIGN (The Voltmeter)

- A variation in the additional circuitry permits the use of the iron-vane movement in the design of a voltmeter.
- The 1 mA, 43 Ω movement can also be rated as a 43 mV (1 mA x 43 Ω), 43 movement, indicating that the maximum voltage that the movement can measure independently is 43 mV.
- The millivolt rating is sometimes referred to as the *voltage sensitivity (VS)*.

AMMETER, VOLTMETER, AND OHMMETER

DESIGN (The Voltmeter)

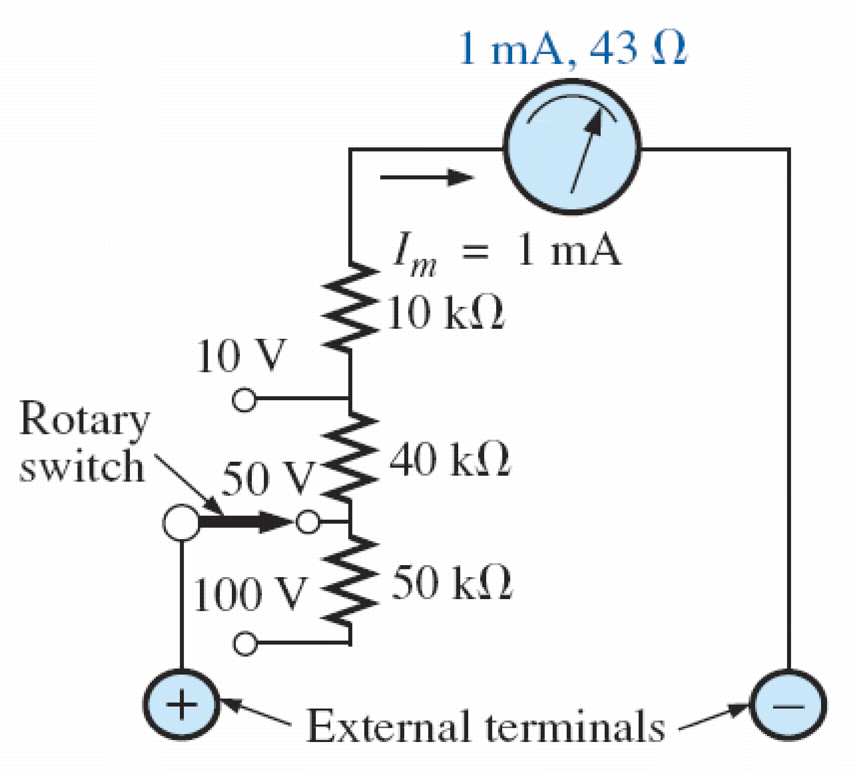


FIG. 7.51 *Multirange voltmeter.*

LOGO

AMMETER, VOLTMETER, AND OHMMETER DESIGN (The Ohmmeter)

- In general, ohmmeters are designed to measure resistance in the low, middle, or high range.
- The most common is the **series ohmmeter,** designed to read resistance levels in the midrange.

AMMETER, VOLTMETER, AND OHMMETER DESIGN (The Ohmmeter)

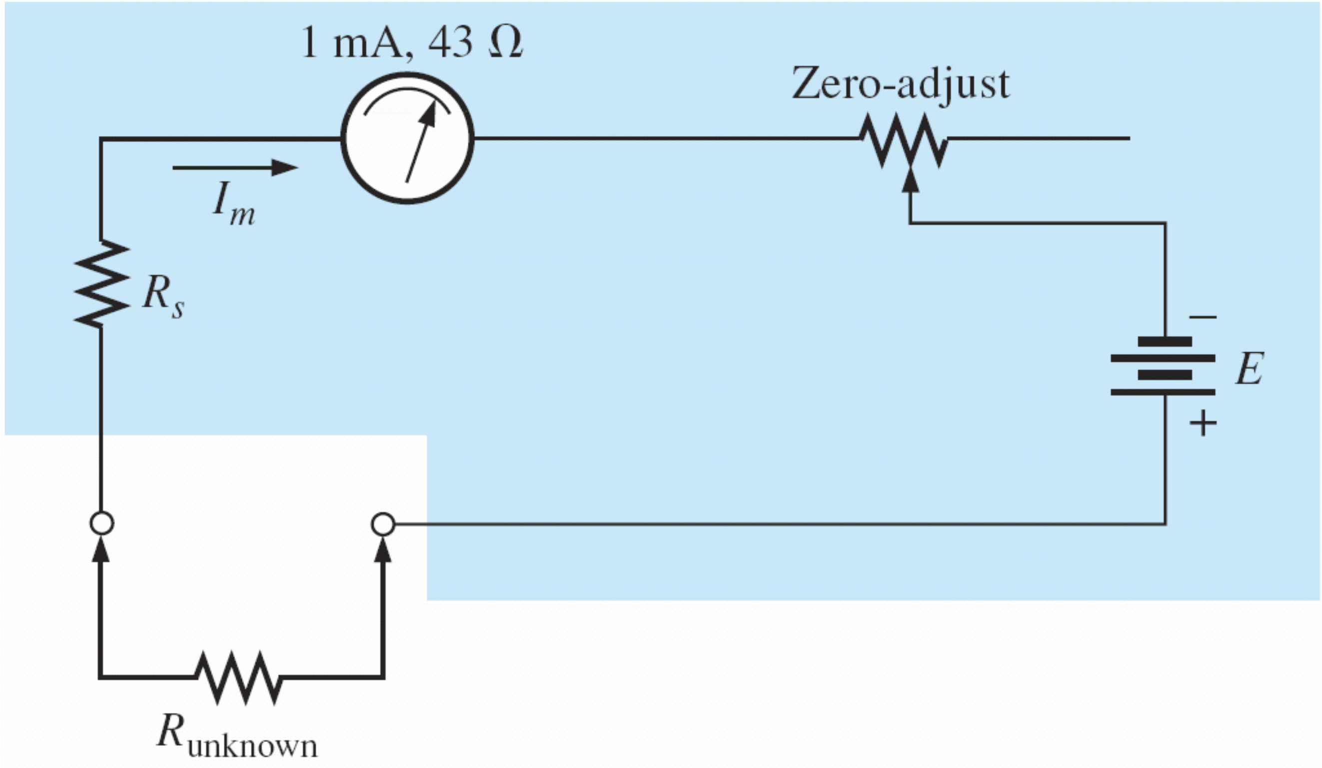


FIG. 7.52 *Series ohmmeter.*

LOGO

AMMETER, VOLTMETER, AND OHMMETER DESIGN (The Ohmmeter)

FIG. 7.53 *Nanovoltmeter.*

AMMETER, VOLTMETER, AND OHMMETER DESIGN (The Ohmmeter)

- The **megohmmeter** (often called a *megger*) is an instrument for measuring very high resistance values.
- Its primary function is to test the insulation found in power transmission systems, electrical machinery, transformers, and so on.

  To measure the high-resistance values, a high dc voltage is established by a hand-driven generator.

AMMETER, VOLTMETER, AND OHMMETER DESIGN (The Ohmmeter)

FIG. 7.54 *Megohmmeter.*

APPLICATIONS

Boosting a Car Battery

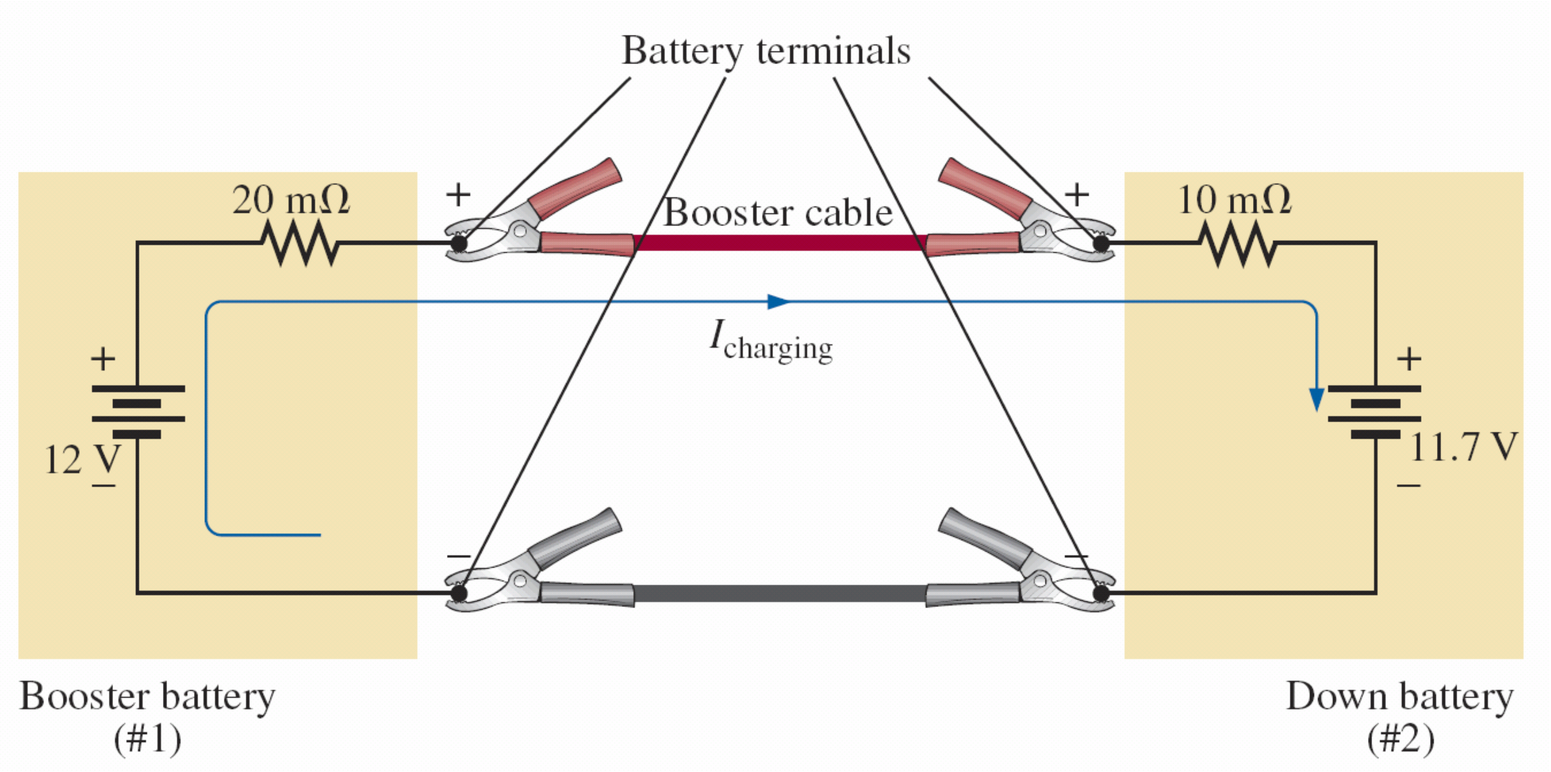


FIG. 7.55 *Boosting a car battery.*

APPLICATIONS

Electronic Circuits

- The operation of most electronic systems requires a distribution of dc voltages throughout the design.
- Although a full explanation of why the dc level is required (since it is an ac signal to be amplified) will have to wait for the introductory courses in electronic circuits, the dc analysis will proceed in much the same manner as described in this chapter.

LOGO

APPLICATIONS

Electronic Circuits

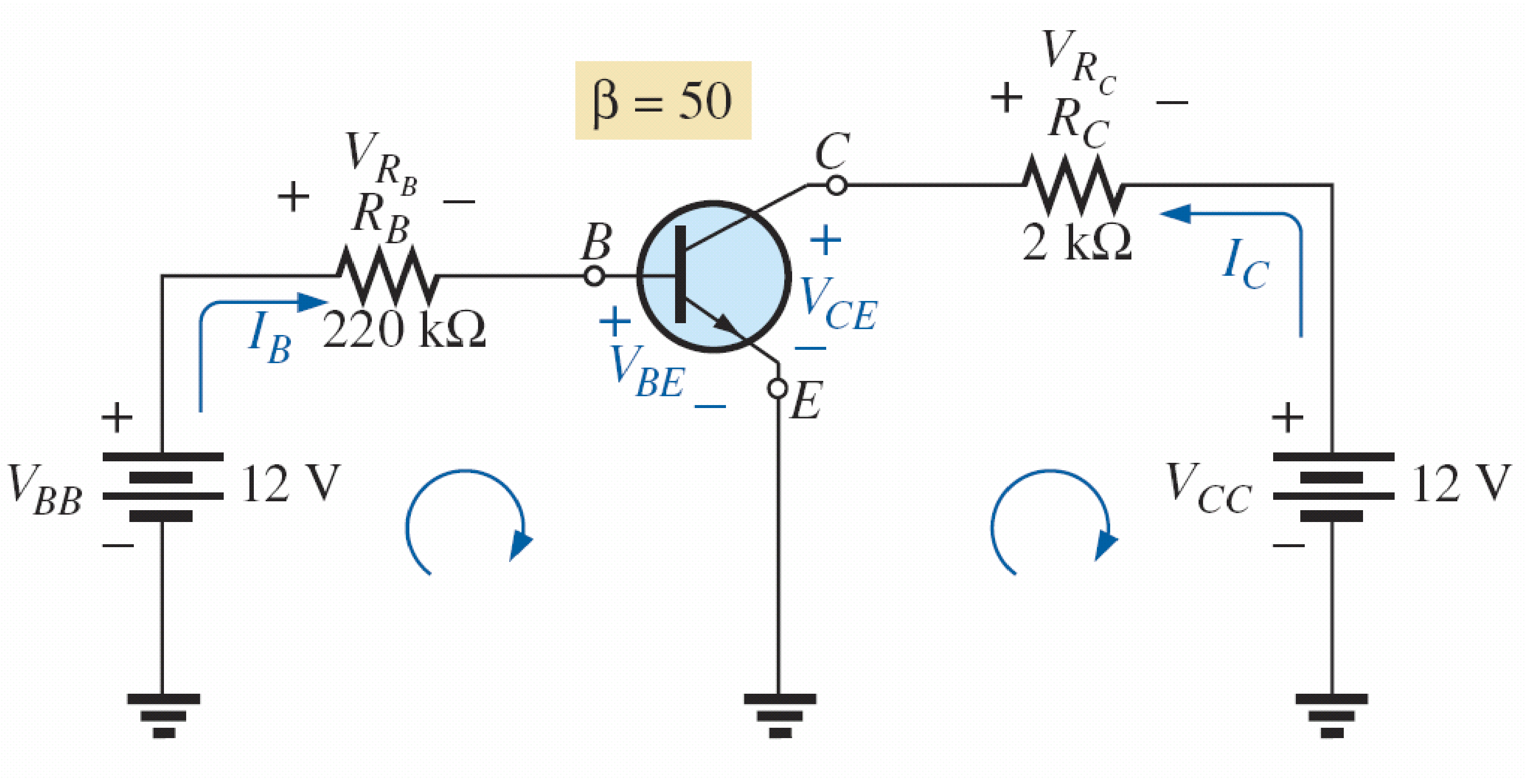


FIG. 7.58 *The dc bias levels of a transistor amplifier.*

COMPUTER ANALYSIS

PSpice

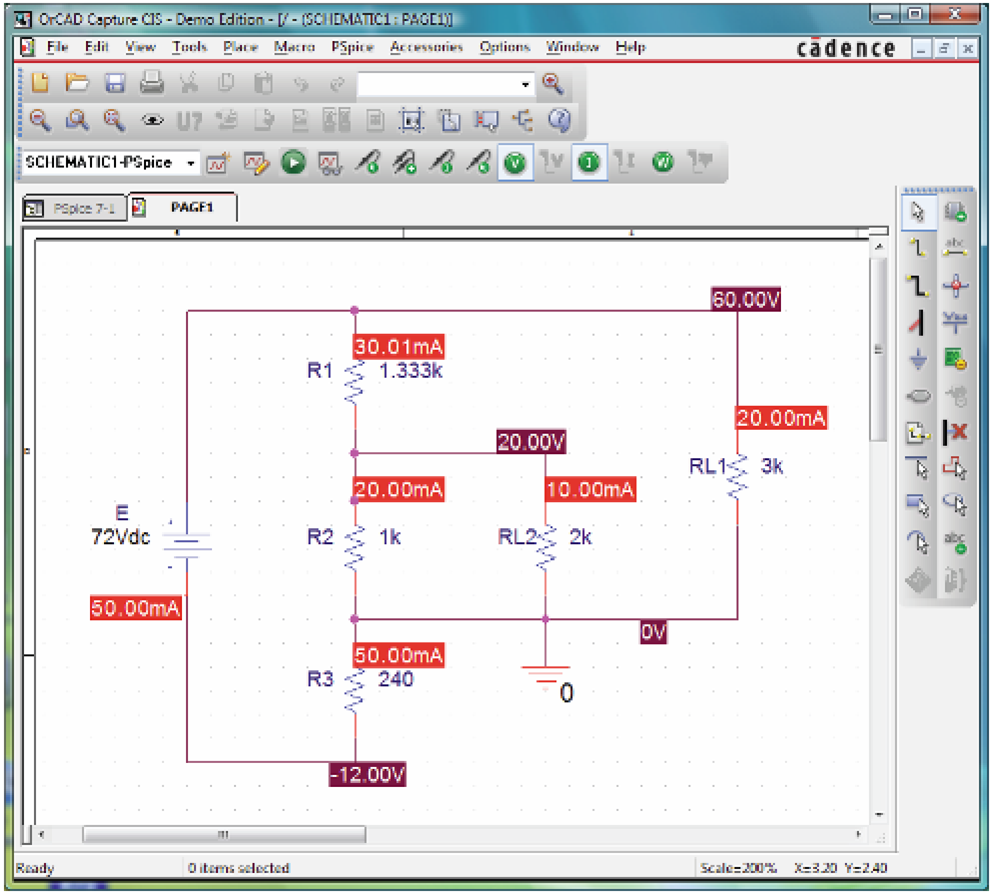


FIG. 7.59 *Using PSpice to verify the results of Example 7.12.*

Thank You !