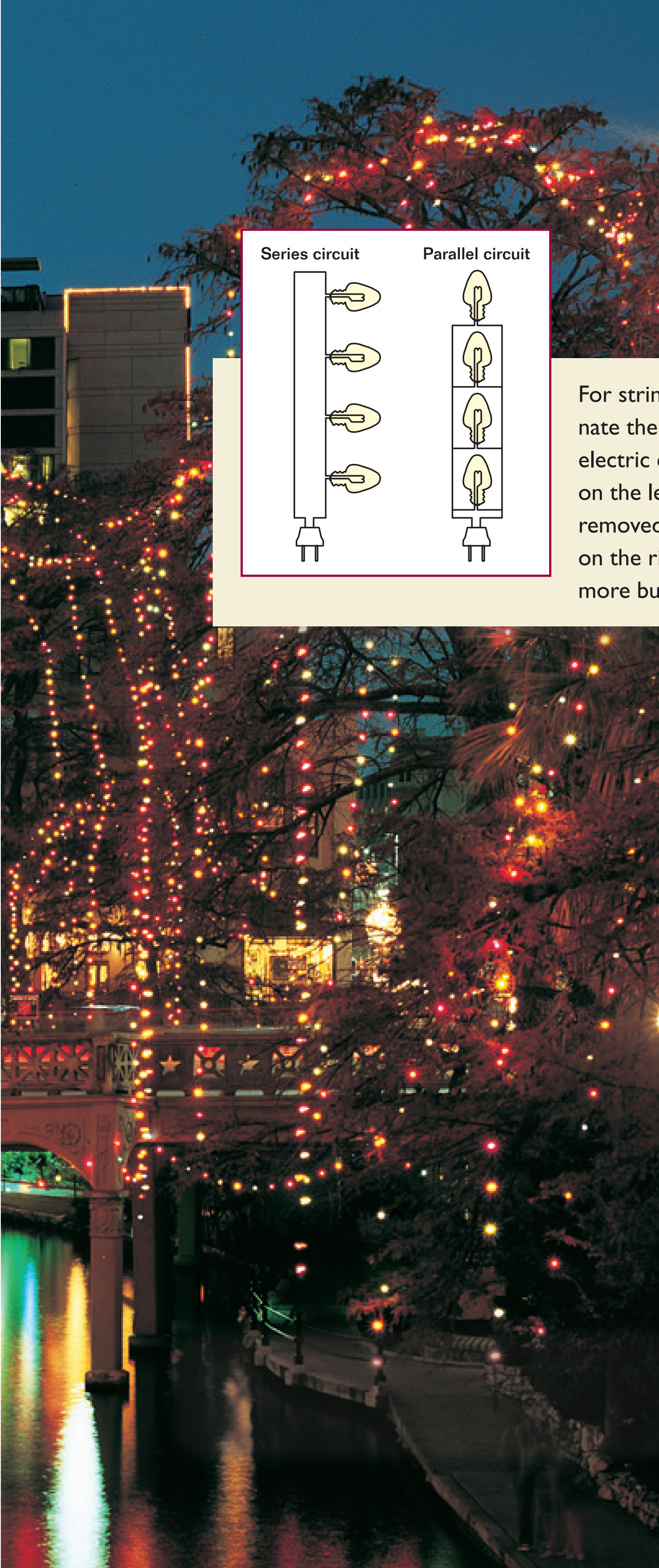

Casa Rio
MEXICAN FOOD



CHAPTER 18

Circuits and Circuit Elements

For strings of decorative lights—such as these that illuminate the Riverwalk in San Antonio, Texas—two types of electric circuits can be used. In a series circuit, illustrated on the left, the entire set goes dark when one bulb is removed from the circuit. In a parallel circuit, illustrated on the right, other bulbs remain lighted even when one or more bulbs are removed.

WHAT TO EXPECT

In this chapter, you will explore the basic properties of series and parallel circuits.

WHY IT MATTERS

All electric circuits are wired in series, parallel, or a combination. The type of circuit affects the current and potential difference of elements connected to the circuit, such as decorative light bulbs on strands or appliances in your home.

CHAPTER PREVIEW

SECTION 1

Schematic Diagrams and Circuits

SECTION OBJECTIVES

- Interpret and construct circuit diagrams.
- Identify circuits as open or closed.
- Deduce the potential difference across the circuit load, given the potential difference across the battery's terminals.

schematic diagram

a representation of a circuit that uses lines to represent wires and different symbols to represent components

SCHEMATIC DIAGRAMS

Take a few minutes to examine the battery and light bulb in **Figure 1(a);** then draw a diagram of each element in the photograph and its connection. How easily could your diagram be interpreted by someone else? Could the elements in your diagram be used to depict a string of decorative lights, such as those draped over the trees of the San Antonio Riverwalk?

A diagram that depicts the construction of an electrical apparatus is called a **schematic diagram.** The schematic diagram shown in **Figure 1(b)** uses symbols to represent the bulb, battery, and wire from **Figure 1(a).** Note that these same symbols can be used to describe these elements in any electrical apparatus. This way, schematic diagrams can be read by anyone familiar with the standard set of symbols.

Reading schematic diagrams allows us to determine how the parts in an electrical device are arranged. In this chapter, you will see how the arrangement of resistors in an electrical device can affect the current in and potential difference across the other elements in the device. The ability to interpret schematic diagrams for complicated electrical equipment is an essential skill for solving problems involving electricity.

As shown in **Table 1,** each element used in a piece of electrical equipment is represented by a symbol in schematic diagrams that reflects the element's construction or function. For example, the schematic-diagram symbol that represents an open switch resembles the open knife switch that is shown in the corresponding photograph. Note that **Table 1** also includes other forms of schematic-diagram symbols; these alternative symbols will not be used in this book.

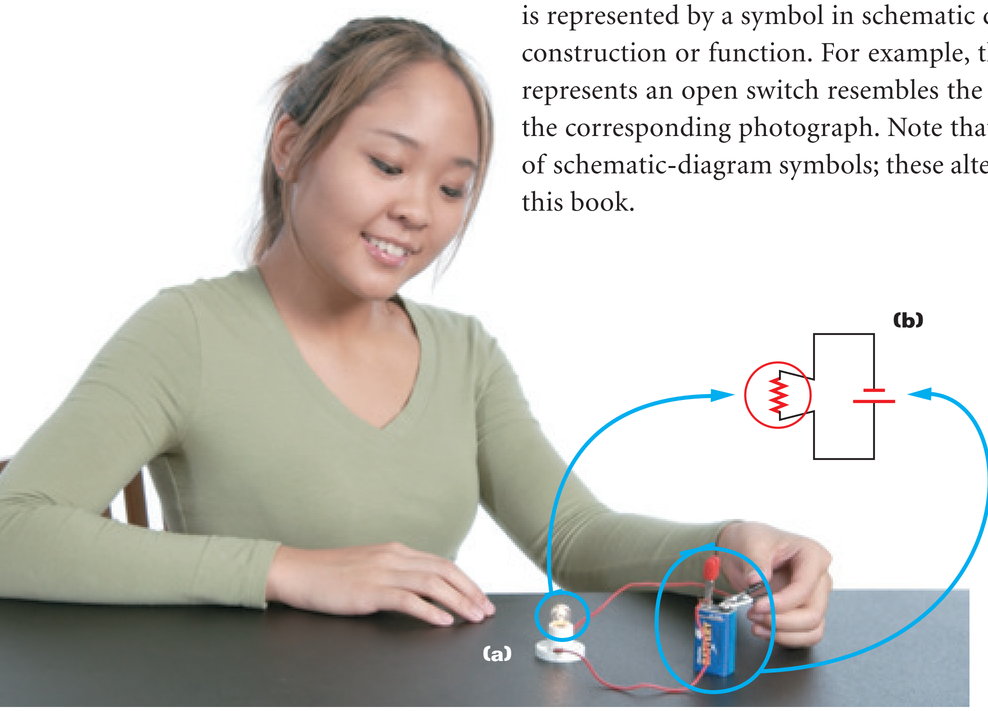
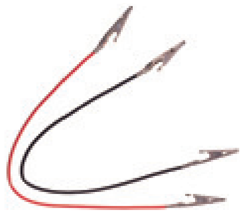
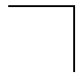
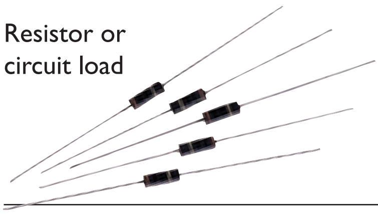
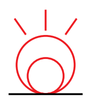
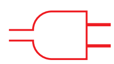
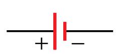
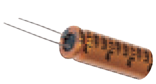
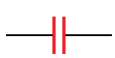


Figure 1
(a) When this battery is connected to a light bulb, the potential difference across the battery generates a current that illuminates the bulb. **(b)** The connections between the light bulb and battery can be represented in a schematic diagram.

Table 1 Schematic-Diagram Symbols

Component		Symbol used in this book	Other forms of this symbol	Explanation
Wire or conductor				• Wires that connect elements are conductors. • Because wires offer negligible resistance, they are represented by straight lines.
Resistor or circuit load				• Resistors are shown having multiple bends, illustrating resistance to the movement of charges.
Bulb or lamp				• The multiple bends of the filament indicate that the light bulb behaves as a resistor. • The symbol for the filament of the bulb is often enclosed in a circle to emphasize the enclosure of a resistor in a bulb.
Plug				• The plug symbol looks like a container for two prongs. • The emf between the two prongs of a plug is symbolized by lines of unequal length.
Battery			 Multiple cells	• Differences in line length indicate a potential difference between positive and negative terminals of the battery. • The longer line represents the positive terminal of the battery.
Switch	 Open  Closed	 Open  Closed		• The small circles indicate the two places where the switch makes contact with the wires. Most switches work by breaking only one of the contacts, not both.
Capacitor				• The two parallel plates of a capacitor are symbolized by two parallel lines of equal length. • One curved line indicates that the capacitor can be used with only direct current sources with the polarity as shown.

ELECTRIC CIRCUITS

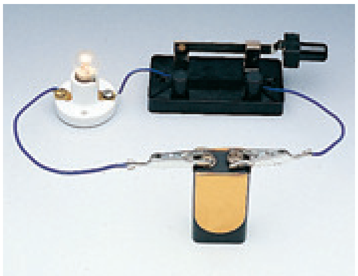


Figure 2
When all electrical components are connected, charges can move freely in a circuit. The movement of charges in a circuit can be halted by opening the switch.

electric circuit

a set of electrical components connected such that they provide one or more complete paths for the movement of charges

Think about how you get the bulb in **Figure 2** to light up. Will the bulb stay lit if the switch is opened? Is there any way to light the bulb without connecting the wires to the battery?

The filament of the light bulb acts as a resistor. When a wire connects the terminals of the battery to the light bulb, as shown in **Figure 2,** charges built up on one terminal of the battery have a path to follow to reach the opposite charges on the other terminal. Because there are charges moving through the wire, a current exists. This current causes the filament to heat up and glow.

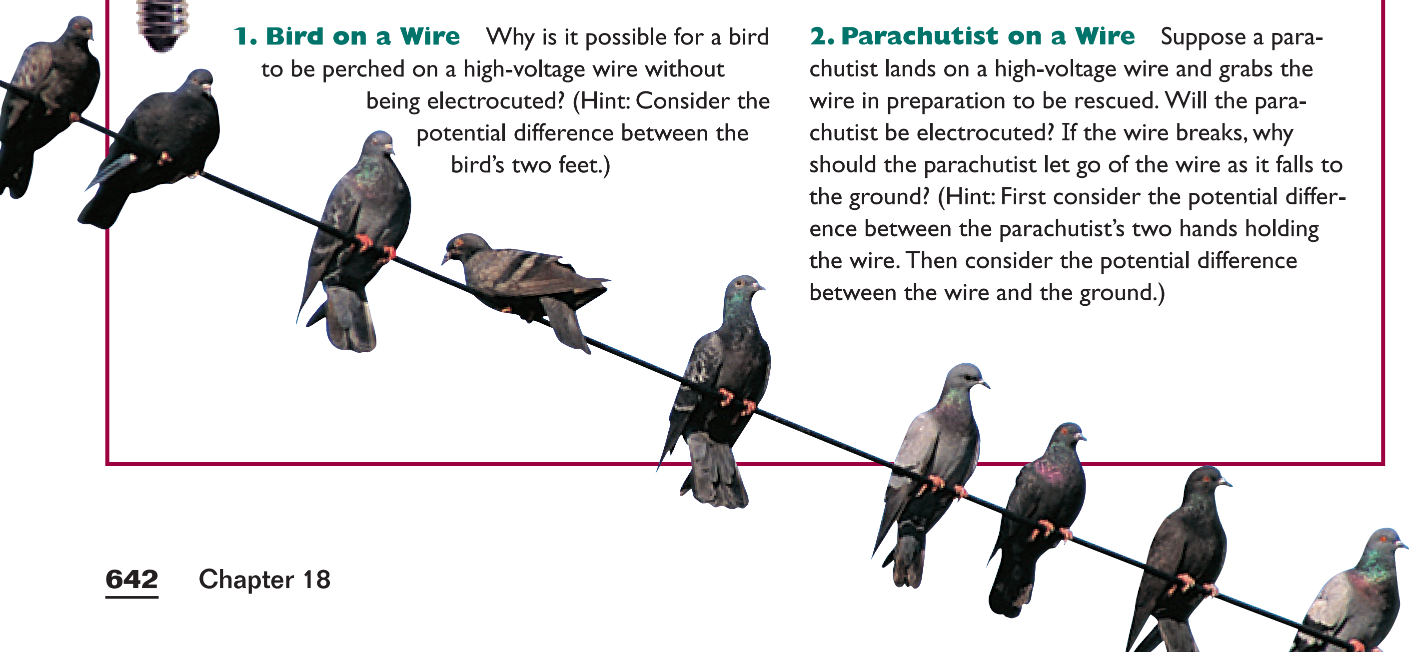
Together, the bulb, battery, switch, and wire form an **electric circuit.** An electric circuit is a path through which charges can flow. A schematic diagram for a circuit is sometimes called a *circuit diagram.*

Any element or group of elements in a circuit that dissipates energy is called a *load.* A simple circuit consists of a source of potential difference and electrical energy, such as a battery, and a load, such as a bulb or group of bulbs. Because the connecting wire and switch have negligible resistance, we will not consider these elements as part of the load.

In **Figure 2,** the path from one battery terminal to the other is complete, a potential difference exists, and electrons move from one terminal to the other. In other words, there is a closed-loop path for electrons to follow. This is called a *closed circuit.* The switch in the circuit in **Figure 2** must be closed in order for a steady current to exist.

Without a complete path, there is no charge flow and therefore no current. This situation is an *open circuit.* If the switch in **Figure 2** were open, as shown in **Table 1,** the circuit would be open, the current would be zero, and the bulb would not light up.

Conceptual Challenge



1. Bird on a Wire Why is it possible for a bird to be perched on a high-voltage wire without being electrocuted? (Hint: Consider the potential difference between the bird's two feet.)

2. Parachutist on a Wire Suppose a parachutist lands on a high-voltage wire and grabs the wire in preparation to be rescued. Will the parachutist be electrocuted? If the wire breaks, why should the parachutist let go of the wire as it falls to the ground? (Hint: First consider the potential difference between the parachutist's two hands holding the wire. Then consider the potential difference between the wire and the ground.)

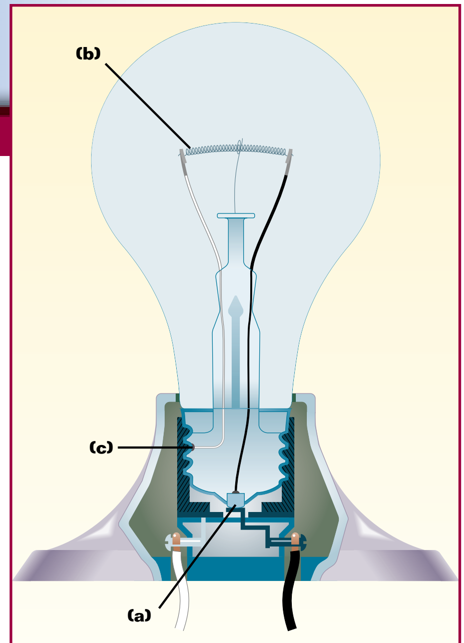
The Inside Story on Light Bulbs

How does a light bulb contain a complete conducting path? When you look at a clear light bulb, you can see the twisted filament inside that provides a portion of the conducting path for the circuit. However, the bulb screws into a single socket; it seems to have only a single contact, the rounded part at the bulb's base.

Closer examination of the socket reveals that it has two contacts inside. One contact, in the bottom of the socket, is connected to the wire going to one side of the filament. The other contact is in the side of the socket, and it is connected to the wire going to the other side of the filament.

The placement of the contacts within the socket indicates how the bulb completes the circuit, as shown on the right. Within the bulb, one side of the filament is connected with wires to the contact at the light bulb's base, **(a).** The other side of the filament is connected to the side of the metal base, **(c).** Insulating material between the side of the base and the contact on the bottom prevents the wires from being connected to each other with a conducting material. In this way, charges have only one path to follow when passing through a light bulb—through the filament, **(b).**

When a light bulb is screwed in, the contact on one side of the socket touches the threads on the side of the bulb's base. The contact on the bottom of the socket touches the contact on the bottom of the bulb's base. Charges then enter through the bulb's base, move through the bulb to the filament, and exit the bulb through the threads. For most light bulbs, the bulb will glow regardless of which direction the charges move. Thus, the positive terminal of a battery can be connected to either the base of the bulb or the threads of the bulb, as long as the negative terminal is connected to the threads or base, respectively. All that matters is that there is a complete conducting path for the charges to move through the circuit.



Light bulbs contain a complete conducting path. When a light bulb is screwed in, charges can enter through the base **(a),** move along the wire to the filament **(b),** and exit the bulb through the threads **(c).**

Short circuits can be hazardous

Without a load, such as a bulb or other resistor, the circuit contains little resistance to the movement of charges. This situation is called a *short circuit.* For example, a short circuit occurs when a wire is connected from one terminal of a battery to the other by a wire with little resistance. This commonly occurs when uninsulated wires connected to different terminals come into contact with each other.

When short circuits occur in the wiring of your home, the increase in current can become unsafe. Most wires cannot withstand the increased current, and they begin to overheat. The wire's insulation may even melt or cause a fire.

extension

Integrating Technology

Visit go.hrw.com for the activity "Incandescent Light Bulbs."

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The source of potential difference and electrical energy is the circuit's emf

Will a bulb in a circuit light up if you remove the battery? Without a potential difference, there is no charge flow and no current. The battery is necessary because the battery is the source of potential difference and electrical energy for the circuit. So, the bulb must be connected to the battery to be lit.

Any device that increases the potential energy of charges circulating in a circuit is a source of *emf*. The emf is the energy per unit charge supplied by a source of electric current. Think of such a source as a "charge pump" that forces electrons to move in a certain direction. Batteries and generators are examples of emf sources.

For conventional current, the terminal voltage is less than the emf

Look at the battery attached to the light bulb in the circuit shown in **Figure 3.** As shown in the inset, instead of behaving only like a source of emf, the battery behaves as if it contains both an emf source and a resistor. The battery's internal resistance to current is the result of moving charges colliding with atoms inside the battery while the charges are traveling from one terminal to the other. Thus, when charges move conventionally in a battery, the potential difference across the battery's terminals, the *terminal voltage,* is actually slightly less than the emf.

Unless otherwise stated, any reference in this book to the potential difference across a battery should be thought of as the potential difference measured across the battery's terminals rather than as the emf of the battery. In other words, all examples and end-of-chapter problems will disregard the internal resistance of the battery.

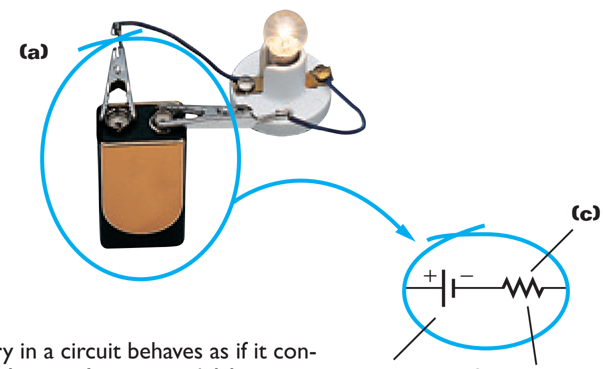


Figure 3
(a) A battery in a circuit behaves as if it contains both **(b)** an emf source and **(c)** an internal resistance. For simplicity's sake, in problem solving it will be assumed that this internal resistance is insignificant.

Quick Lab

Simple Circuits

MATERIALS LIST

- 1 miniature light bulb
- 1 D-cell battery
- wires
- rubber band or tape

SAFETY CAUTION

Do not perform this lab with any batteries or electrical devices other than those listed here.

Never work with electricity near water. Be sure the floor and all work surfaces are dry.

Connect the bulb to the battery using two wires, using a rubber band or tape to hold the wire to the battery. Once you have gotten the bulb to light, try different arrangements to see whether there is more than one way to get the bulb to light. Can you make the bulb light using just one wire? Diagram each arrangement that you try, and note whether it produces light.

Explain exactly which parts of the bulb, battery, and wire must be connected for the light bulb to produce light.

Potential difference across a load equals the terminal voltage

When charges move within a battery from one terminal to the other, the chemical energy of the battery is converted to the electrical potential energy of the charges. As charges move through the circuit, their electrical potential energy is converted to other forms of energy. For instance, when the load is a resistor, the electrical potential energy of the charges is converted to the internal energy of the resistor and dissipated as thermal energy and light energy.

Because energy is conserved, the energy gained and the energy lost must be equal for one complete trip around the circuit (starting and ending at the same place). Thus, the electrical potential energy gained in the battery must equal the energy dissipated by the load. Because the potential difference is the measurement of potential energy per amount of charge, the potential increase across the battery must equal the potential decrease across the load.

SECTION REVIEW

1. Identify the types of elements in the schematic diagram illustrated in **Figure 4** and the number of each type.

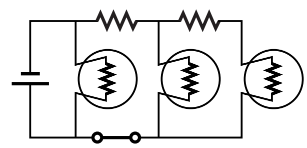


Figure 4

2. Using the symbols listed in **Table 1,** draw a schematic diagram of a working circuit that contains two resistors, an emf source, and a closed switch.
3. In which of the circuits pictured below will there be no current?

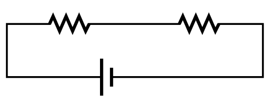


Figure 5

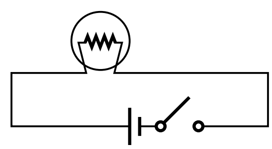


Figure 6

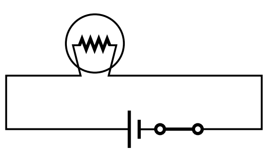


Figure 7

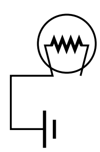
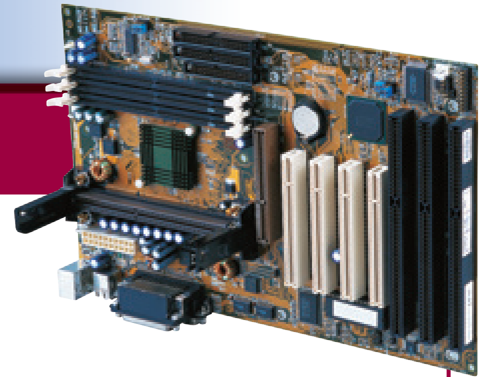


Figure 8

4. If the potential difference across the bulb in a certain flashlight is 3.0 V, what is the potential difference across the combination of batteries used to power it?
5. **Critical Thinking** In what forms is the electrical energy that is supplied to a string of decorative lights dissipated?

THE INSIDE STORY ON TRANSISTORS AND INTEGRATED CIRCUITS



A computer motherboard is a multi-layered collection of integrated circuits containing millions of transistors and other circuit elements.

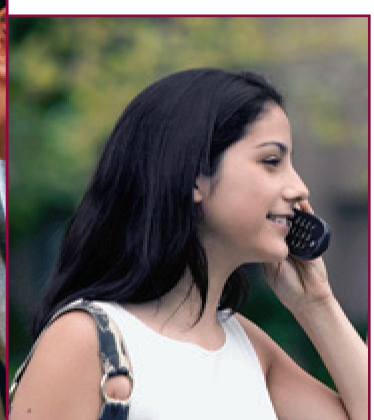
In the chapter "Electrical Energy and Current," you learned about a class of materials called *semiconductors,* which have properties between those of insulators and conductors. Semiconductors play many important roles in today's world, as they are the foundation of circuits found in virtually every electronic device.

Most commercial semiconductors are made primarily of either silicon or germanium. The conductive properties of semiconductors can be enhanced by adding impurities to the base material in a process called *doping.* Depending on how a semiconductor is doped, it can be either an n-type semiconductor or a p-type semiconductor. N-type semiconductors carry negative charges (in the form of electrons), and p-type semiconductors carry positive charges. The positive charges in a p-type semiconductor are not actually positively charged particles. They are "holes" created by the absence of electrons.

The most interesting and useful properties of semiconductors emerge when more than one type of semiconductor is used in a device. One such device is a *diode,* which is made by placing a p-type semiconductor next to an n-type semiconductor. The junction where the two types meet is called a *p-n junction.* A diode has almost infinite resistance in one direction and nearly zero resistance in the other direction. One useful application of diodes is the conversion of alternating current to direct current.

A *transistor* is a device that contains three layers of semiconductors. Transistors can be either *pnp transistors* or *npn transistors,* depending on the order of the layers.

A transistor is like two diodes placed back-to-back. You might think this would mean that no current exists in a transistor, as there is infinite resistance at one or the other of the p-n junctions. However, if a small voltage is applied to the middle layer of the transistor, the p-n junctions are altered in such a way that a large amount of current can be in the transistor. As a result, transistors can be used as switches, allowing a small current to turn a larger current on or off. Transistor-based switches are the building blocks of computers. A single switch turned on or off can represent a binary digit, or *bit,* which is always either a one or a zero.



An *integrated circuit* is a collection of transistors, diodes, capacitors, and resistors embedded in a single piece of silicon, known as a *chip.* Much of the rapid progress in the computer and electronics industries in the past few decades has been a result of improvements in semiconductor technologies. These improvements allow smaller and smaller transistors and other circuit elements to be placed on chips. A typical computer motherboard, such as the one shown here, contains several integrated circuits, each one containing several million transistors.

Resistors in Series or in Parallel

SECTION 2

SECTION OBJECTIVES

- **Calculate the equivalent resistance for a circuit of resistors in series, and find the current in and potential difference across each resistor in the circuit.**
- **Calculate the equivalent resistance for a circuit of resistors in parallel, and find the current in and potential difference across each resistor in the circuit.**

RESISTORS IN SERIES

In a circuit that consists of a single bulb and a battery, the potential difference across the bulb equals the terminal voltage. The total current in the circuit can be found using the equation $\Delta V = IR$.

What happens when a second bulb is added to such a circuit, as shown in **Figure 9**? When moving through this circuit, charges that pass through one bulb must also move through the second bulb. Because all charges in the circuit must follow the same conducting path, these bulbs are said to be connected in **series.**

series

describes two or more components of a circuit that provide a single path for current

Resistors in series carry the same current

Light-bulb filaments are resistors; thus, **Figure 9(b)** represents the two bulbs in **Figure 9(a)** as resistors. Because charge is conserved, charges cannot build up or disappear at a point. For this reason, the amount of charge that enters one bulb in a given time interval equals the amount of charge that exits that bulb in the same amount of time. Because there is only one path for a charge to follow, the amount of charge entering and exiting the first bulb must equal the amount of charge that enters and exits the second bulb in the same time interval.

Because the current is the amount of charge moving past a point per unit of time, the current in the first bulb must equal the current in the second bulb. This is true for any number of resistors arranged in series. *When many resistors are connected in series, the current in each resistor is the same.*

The total current in a series circuit depends on how many resistors are present and on how much resistance each offers. Thus, to find the total current, first use the individual resistance values to find the total resistance of the circuit, called the *equivalent resistance.* Then the equivalent resistance can be used to find the current.

Figure 9
These two light bulbs are connected in series. Because light-bulb filaments are resistors, **(a)** the two bulbs in this series circuit can be represented by **(b)** two resistors in the schematic diagram shown on the right.

The equivalent resistance in a series circuit is the sum of the circuit's resistances

As described in Section 1, the potential difference across the battery, ΔV, must equal the potential difference across the load, $\Delta V_1 + \Delta V_2$, where ΔV_1 is the potential difference across R_1 and ΔV_2 is the potential difference across R_2.

$$\Delta V = \Delta V_1 + \Delta V_2$$

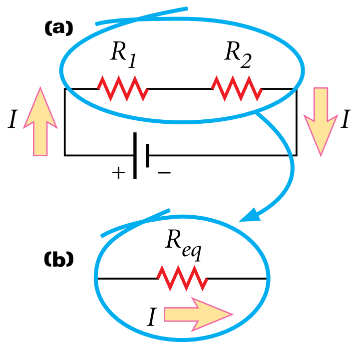


Figure 10
(a) The two resistors in the actual circuit have the same effect on the current in the circuit as **(b)** the equivalent resistor.

According to $\Delta V = IR$, the potential difference across each resistor is equal to the current in that resistor multiplied by the resistance.

$$\Delta V = I_1R_1 + I_2R_2$$

Because the resistors are in series, the current in each is the same. For this reason, I_1 and I_2 can be replaced with a single variable for the current, I.

$$\Delta V = I(R_1 + R_2)$$

Finding a value for the equivalent resistance of the circuit is now possible. If you imagine the equivalent resistance replacing the original two resistors, as shown in **Figure 10,** you can treat the circuit as if it contains only one resistor and use $\Delta V = IR$ to relate the total potential difference, current, and equivalent resistance.

$$\Delta V = I(R_{eq})$$

Now set the last two equations for ΔV equal to each other, and divide by the current.

$$\Delta V = I(R_{eq}) = I(R_1 + R_2)$$

$$R_{eq} = R_1 + R_2$$

Thus, the equivalent resistance of the series combination is the sum of the individual resistances. An extension of this analysis shows that the equivalent resistance of two or more resistors connected in series can be calculated using the following equation.

RESISTORS IN SERIES

$$R_{eq} = R_1 + R_2 + R_3 \ldots$$

Equivalent resistance equals the total of individual resistances in series.

Because R_{eq} represents the sum of the individual resistances that have been connected in series, *the equivalent resistance of a series combination of resistors is always greater than any individual resistance.*

To find the total current in a series circuit, first simplify the circuit to a single equivalent resistance using the boxed equation above; then use $\Delta V = IR$ to calculate the current.

$$I = \frac{\Delta V}{R_{eq}}$$

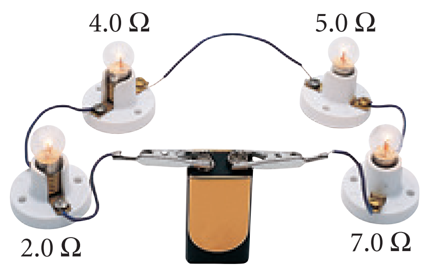
Because the current in each bulb is equal to the total current, you can also use $\Delta V = IR$ to calculate the potential difference across each resistor.

$$\Delta V_1 = IR_1 \quad \text{and} \quad \Delta V_2 = IR_2$$

The method described above can be used to find the potential difference across resistors in a series circuit containing any number of resistors.

SAMPLE PROBLEM A

Resistors in Series



PROBLEM

A 9.0 V battery is connected to four light bulbs, as shown at right. Find the equivalent resistance for the circuit and the current in the circuit.

SOLUTION

1. DEFINE

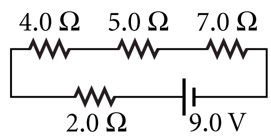
Given: $\Delta V = 9.0$ V $\quad R_1 = 2.0\ \Omega$

$R_2 = 4.0\ \Omega \quad R_3 = 5.0\ \Omega$

$R_4 = 7.0\ \Omega$

Unknown: $R_{eq} = ? \quad I = ?$

Diagram:



2. PLAN

Choose an equation or situation:
Because the resistors are connected end to end, they are in series. Thus, the equivalent resistance can be calculated with the equation for resistors in series.

$$R_{eq} = R_1 + R_2 + R_3 \ldots$$

The following equation can be used to calculate the current.

$$\Delta V = IR_{eq}$$

Rearrange the equation to isolate the unknown:
No rearrangement is necessary to calculate R_{eq}, but $\Delta V = IR_{eq}$ must be rearranged to calculate current.

$$I = \frac{\Delta V}{R_{eq}}$$

3. CALCULATE

Substitute the values into the equation and solve:

$$R_{eq} = 2.0\ \Omega + 4.0\ \Omega + 5.0\ \Omega + 7.0\ \Omega$$

$$\boxed{R_{eq} = 18.0\ \Omega}$$

continued on next page

Substitute the equivalent resistance value into the equation for current.

$$I = \frac{\Delta V}{R_{eq}} = \frac{9.0\ \text{V}}{18.0\ \Omega}$$

$$\boxed{I = 0.50\ \text{A}}$$

4. EVALUATE For resistors connected in series, the equivalent resistance should be greater than the largest resistance in the circuit.

$$18.0\ \Omega > 7.0\ \Omega$$

PRACTICE A

Resistors in Series

1. A 12.0 V storage battery is connected to three resistors, 6.75 Ω, 15.3 Ω, and 21.6 Ω, respectively. The resistors are joined in series.

a. Calculate the equivalent resistance.

b. What is the current in the circuit?

2. A 4.0 Ω resistor, an 8.0 Ω resistor, and a 12.0 Ω resistor are connected in series with a 24.0 V battery.

a. Calculate the equivalent resistance.

b. Calculate the current in the circuit.

c. What is the current in each resistor?

3. Because the current in the equivalent resistor of Sample Problem A is 0.50 A, it must also be the current in each resistor of the original circuit. Find the potential difference across each resistor.

4. A series combination of two resistors, 7.25 Ω and 4.03 Ω, is connected to a 9.00 V battery.

a. Calculate the equivalent resistance of the circuit and the current.

b. What is the potential difference across each resistor?

5. A 7.0 Ω resistor is connected in series with another resistor and a 4.5 V battery. The current in the circuit is 0.60 A. Calculate the value of the unknown resistance.

6. Several light bulbs are connected in series across a 115 V source of emf.

a. What is the equivalent resistance if the current in the circuit is 1.70 A?

b. If each light bulb has a resistance of 1.50 Ω, how many light bulbs are in the circuit?

Series circuits require all elements to conduct

What happens to a series circuit when a single bulb burns out? Consider what a circuit diagram for a string of lights with one broken filament would look like. As the schematic diagram in **Figure 11** shows, the broken filament means that there is a gap in the conducting pathway used to make up the circuit. Because the circuit is no longer closed, there is no current in it and all of the bulbs go dark.

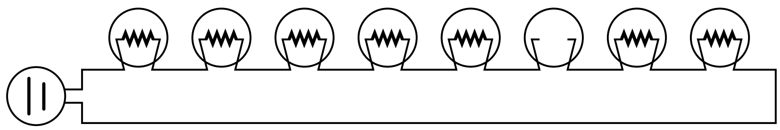


Figure 11
A burned-out filament in a bulb has the same effect as an open switch. Because this series circuit is no longer complete, there is no current in the circuit.

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Topic: Resistors
SciLinks Code: HF61302

Why, then, would anyone arrange resistors in series? Resistors can be placed in series with a device in order to regulate the current in that device. In the case of decorative lights, adding an additional bulb will decrease the current in each bulb. Thus, the filament of each bulb need not withstand such a high current. Another advantage to placing resistors in series is that several lesser resistances can be used to add up to a single greater resistance that is unavailable. Finally, in some cases, it is important to have a circuit that will have no current if any one of its component parts fails. This technique is used in a variety of contexts, including some burglar alarm systems.

RESISTORS IN PARALLEL

As discussed above, when a single bulb in a series light set burns out, the entire string of lights goes dark because the circuit is no longer closed. What would happen if there were alternative pathways for the movement of charge, as shown in **Figure 12**?

A wiring arrangement that provides alternative pathways for the movement of a charge is a **parallel** arrangement. The bulbs of the decorative light set shown in the schematic diagram in **Figure 12** are arranged in parallel with each other.

parallel

describes two or more components of a circuit that provide separate conducting paths for current because the components are connected across common points or junctions

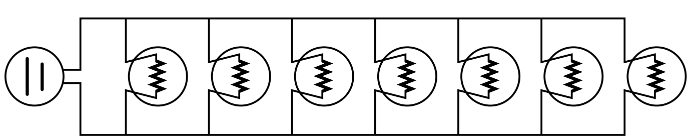


Figure 12
These decorative lights are wired in parallel. Notice that in a parallel arrangement there is more than one path for current.

Resistors in parallel have the same potential differences across them

To explore the consequences of arranging resistors in parallel, consider the two bulbs connected to a battery in **Figure 13(a).** In this arrangement, the left side of each bulb is connected to the positive terminal of the battery, and the right side of each bulb is connected to the negative terminal. Because the sides of each bulb are connected to common points, the potential difference across each bulb is the same. If the common points are the battery's terminals, as they are in the figure, the potential difference across each resistor is also equal to the terminal voltage of the battery. The current in each bulb, however, is not always the same.

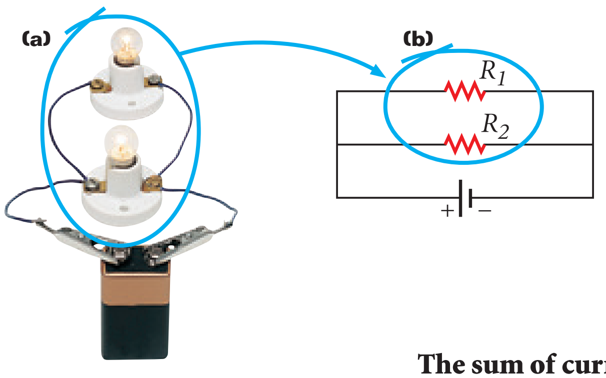


Figure 13
(a) This simple parallel circuit with two bulbs connected to a battery can be represented by **(b)** the schematic diagram shown on the right.

The sum of currents in parallel resistors equals the total current

In **Figure 13,** when a certain amount of charge leaves the positive terminal and reaches the branch on the left side of the circuit, some of the charge moves through the top bulb and some moves through the bottom bulb. If one of the bulbs has less resistance, more charge moves through that bulb because the bulb offers less opposition to the flow of charges.

Because charge is conserved, the sum of the currents in each bulb equals the current I delivered by the battery. This is true for all resistors in parallel.

$$I = I_1 + I_2 + I_3 \ldots$$

The parallel circuit shown in **Figure 13** can be simplified to an equivalent resistance with a method similar to the one used for series circuits. To do this, first show the relationship among the currents.

$$I = I_1 + I_2$$

Then substitute the equivalents for current according to $\Delta V = IR$.

$$\frac{\Delta V}{R_{eq}} = \frac{\Delta V_1}{R_1} + \frac{\Delta V_2}{R_2}$$

Quick Lab

Series and Parallel Circuits

MATERIALS LIST

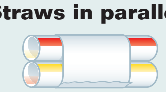
- 4 regular drinking straws
- 4 stirring straws or coffee stirrers
- tape

Cut the regular drinking straws and thin stirring straws into equal lengths. Tape them end to end in long tubes to form series combinations. Form parallel combinations by taping the straws together side by side.

Try several combinations of like and unlike straws. Blow through each combination of tubes, holding your fingers in front of the opening(s) to compare the airflow (or current) that you achieve with each combination.

Straws in series

Straws in parallel



Rank the combinations according to how much resistance they offer. Classify them according to the amount of current created in each.

Because the potential difference across each bulb in a parallel arrangement equals the terminal voltage ($\Delta V = \Delta V_1 = \Delta V_2$), you can divide each side of the equation by ΔV to get the following equation.

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2}$$

An extension of this analysis shows that the equivalent resistance of two or more resistors connected in parallel can be calculated using the following equation.

RESISTORS IN PARALLEL

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \ldots$$

The equivalent resistance of resistors in parallel can be calculated using a reciprocal relationship.

Notice that this equation does not give the value of the equivalent resistance directly. You must take the reciprocal of your answer to obtain the value of the equivalent resistance.

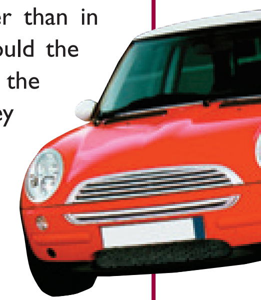
Because of the reciprocal relationship, *the equivalent resistance for a parallel arrangement of resistors must always be less than the smallest resistance in the group of resistors.*

The conclusions made about both series and parallel circuits are summarized in **Table 2.**

Conceptual Challenge

1. Car Headlights

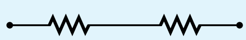
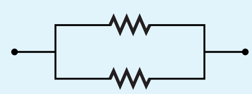
How can you tell that the headlights on a car are wired in parallel rather than in series? How would the brightness of the bulbs differ if they were wired in series across the same 12 V battery instead of in parallel?



2. Simple Circuits

Sketch as many different circuits as you can using three light bulbs—each of which has the same resistance—and a battery.

Table 2 Resistors in Series or in Parallel

	Series	Parallel
schematic diagram		
current	$I = I_1 = I_2 = I_3 \ldots$ = same for each resistor	$I = I_1 + I_2 + I_3 \ldots$ = sum of currents
potential difference	$\Delta V = \Delta V_1 + \Delta V_2 + \Delta V_3 \ldots$ = sum of potential differences	$\Delta V = \Delta V_1 = \Delta V_2 = \Delta V_3 \ldots$ = same for each resistor
equivalent resistance	$R_{eq} = R_1 + R_2 + R_3 \ldots$ = sum of individual resistances	$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \ldots$ = reciprocal sum of resistances

SAMPLE PROBLEM B

Resistors in Parallel

PROBLEM

A 9.0 V battery is connected to four resistors, as shown at right. Find the equivalent resistance for the circuit and the total current in the circuit.

SOLUTION

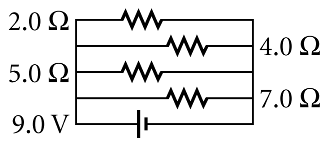
1. DEFINE **Given:** $\Delta V = 9.0\ \text{V}$ $\quad R_1 = 2.0\ \Omega$

$R_2 = 4.0\ \Omega$ $\quad R_3 = 5.0\ \Omega$

$R_4 = 7.0\ \Omega$

Unknown: $R_{eq} = ?\quad I = ?$

Diagram:



2. PLAN **Choose an equation or situation:**

Because both sides of each resistor are connected to common points, they are in parallel. Thus, the equivalent resistance can be calculated with the equation for resistors in parallel.

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \ldots \text{ for parallel}$$

The following equation can be used to calculate the total current.

$$\Delta V = IR_{eq}$$

Rearrange the equation to isolate the unknown:

No rearrangement is necessary to calculate R_{eq}; rearrange $\Delta V = IR_{eq}$ to calculate the total current delivered by the battery.

$$I = \frac{\Delta V}{R_{eq}}$$

3. CALCULATE **Substitute the values into the equation and solve:**

$$\frac{1}{R_{eq}} = \frac{1}{2.0\ \Omega} + \frac{1}{4.0\ \Omega} + \frac{1}{5.0\ \Omega} + \frac{1}{7.0\ \Omega}$$

$$\frac{1}{R_{eq}} = \frac{0.50}{1\ \Omega} + \frac{0.25}{1\ \Omega} + \frac{0.20}{1\ \Omega} + \frac{0.14}{1\ \Omega} = \frac{1.09}{1\ \Omega}$$

$$R_{eq} = \frac{1\ \Omega}{1.09}$$

$$\boxed{R_{eq} = 0.917\ \Omega}$$

TIP *The equation for resistors in parallel gives you the reciprocal of the equivalent resistance. Be sure to take the reciprocal of this value in the final step to find the equivalent resistance.*

Substitute that equivalent resistance value in the equation for current.

$$I = \frac{\Delta V_{tot}}{R_{eq}} = \frac{9.0\ \text{V}}{0.917\ \Omega}$$

$$\boxed{I = 9.8\ \text{A}}$$

CALCULATOR SOLUTION

The calculator answer is 9.814612868, but because the potential difference, 9.0 V, has only two significant digits, the answer is reported as 9.8 A.

4. EVALUATE For resistors connected in parallel, the equivalent resistance should be less than the smallest resistance.

$$0.917\ \Omega < 2.0\ \Omega$$

PRACTICE B

Resistors in Parallel

1. The potential difference across the equivalent resistance in Sample Problem B equals the potential difference across each of the individual parallel resistors. Calculate the value for the current in each resistor.

2. A length of wire is cut into five equal pieces. The five pieces are then connected in parallel, with the resulting resistance being 2.00 Ω. What was the resistance of the original length of wire before it was cut up?

3. A 4.0 Ω resistor, an 8.0 Ω resistor, and a 12.0 Ω resistor are connected in parallel across a 24.0 V battery.

a. What is the equivalent resistance of the circuit?
b. What is the current in each resistor?

4. An 18.0 Ω, 9.00 Ω, and 6.00 Ω resistor are connected in parallel to an emf source. A current of 4.00 A is in the 9.00 Ω resistor.

a. Calculate the equivalent resistance of the circuit.
b. What is the potential difference across the source?
c. Calculate the current in the other resistors.

Parallel circuits do not require all elements to conduct

What happens when a bulb burns out in a string of decorative lights that is wired in parallel? There is no current in that branch of the circuit, but each of the parallel branches provides a separate alternative pathway for current. Thus, the potential difference supplied to the other branches and the current in these branches remain the same, and the bulbs in these branches remain lit.

Did you know?

Because the potential difference provided by a wall outlet in a home in North America is not the same as the potential difference that is standard on other continents, appliances made in North America are not always compatible with wall outlets in homes on other continents.

When resistors are wired in parallel with an emf source, the potential difference across each resistor always equals the potential difference across the source. Because household circuits are arranged in parallel, appliance manufacturers are able to standardize their design, producing devices that all operate at the same potential difference. As a result, manufacturers can choose the resistance to ensure that the current will be neither too high nor too low for the internal wiring and other components that make up the device.

Additionally, the equivalent resistance of several parallel resistors is less than the resistance of any of the individual resistors. Thus, a low equivalent resistance can be created with a group of resistors of higher resistances.

SECTION REVIEW

1. Two resistors are wired in series. In another circuit, the same two resistors are wired in parallel. In which circuit is the equivalent resistance greater?

2. A 5 Ω, a 10 Ω, and a 15 Ω resistor are connected in series.

a. Which resistor has the most current in it?

b. Which resistor has the largest potential difference across it?

3. A 5 Ω, a 10 Ω, and a 15 Ω resistor are connected in parallel.

a. Which resistor has the most current in it?

b. Which resistor has the largest potential difference across it?

4. Find the current in and potential difference across each of the resistors in the following circuits:

a. a 2.0 Ω and a 4.0 Ω resistor wired in series with a 12 V source

b. a 2.0 Ω and a 4.0 Ω resistor wired in parallel with a 12 V source

5. **Interpreting Graphics** The brightness of a bulb depends only on the bulb's resistance and on the potential difference across it. A bulb with a greater potential difference dissipates more power and thus is brighter. The five bulbs shown in **Figure 14** are identical, and so are the three batteries. Rank the bulbs in order of brightness from greatest to least, indicating if any are equal. Explain your reasoning. (Disregard the resistance of the wires.)

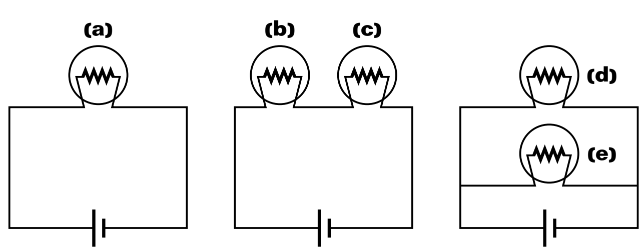


Figure 14

Complex Resistor Combinations

SECTION 3

SECTION OBJECTIVES

- **Calculate the equivalent resistance for a complex circuit involving both series and parallel portions.**
- **Calculate the current in and potential difference across individual elements within a complex circuit.**

RESISTORS COMBINED BOTH IN PARALLEL AND IN SERIES

Series and parallel circuits are not often encountered independent of one another. Most circuits today employ both series and parallel wiring to utilize the advantages of each type.

A common example of a complex circuit is the electrical wiring typical in a home. In a home, a fuse or circuit breaker is connected in series to numerous outlets, which are wired to one another in parallel. An example of a typical household circuit is shown in **Figure 15.**

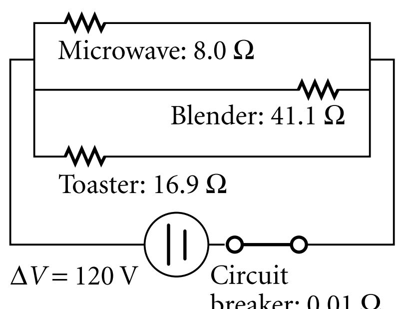
As a result of the outlets being wired in parallel, all the appliances operate independently; if one is switched off, any others remain on. Wiring the outlets in parallel ensures that an identical potential difference exists across any appliance. This way, appliance manufacturers can produce appliances that all use the same standard potential difference.

To prevent excessive current, a fuse or circuit breaker must be placed in series with all of the outlets. Fuses and circuit breakers open the circuit when the current becomes too high. A fuse is a small metallic strip that melts if the current exceeds a certain value. After a fuse has melted, it must be replaced. A circuit breaker, a more modern device, triggers a switch when current reaches a certain value. The switch must be reset, rather than replaced, after the circuit overload has been removed. Both fuses and circuit breakers must be in series with the entire load to prevent excessive current from reaching any appliance. In fact, if all the devices in **Figure 15** were used at once, the circuit would be overloaded. The circuit breaker would interrupt the current.

Fuses and circuit breakers are carefully selected to meet the demands of a circuit. If the circuit is to carry currents as large as 30 A, an appropriate fuse or circuit breaker must be used. Because the fuse or circuit breaker is placed in series with the rest of the circuit, the current in the fuse or circuit breaker is the same as the total current in the circuit. To find this current, one must determine the equivalent resistance.

When determining the equivalent resistance for a complex circuit, you must simplify the circuit into groups of series and parallel resistors and then find the equivalent resistance for each group by using the rules for finding the equivalent resistance of series and parallel resistors.

(a)



(b)

Figure 15
(a) When all of these devices are plugged into the same household circuit, **(b)** the result is a parallel combination of resistors in series with a circuit breaker.

SAMPLE PROBLEM C

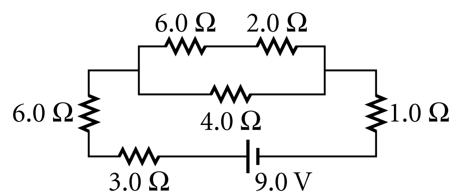
STRATEGY Equivalent Resistance

PROBLEM

Determine the equivalent resistance of the complex circuit shown below.

REASONING

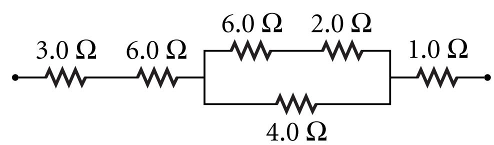
The best approach is to divide the circuit into groups of series and parallel resistors. This way, the methods presented in Sample Problems A and B can be used to calculate the equivalent resistance for each group.



SOLUTION

1. Redraw the circuit as a group of resistors along one side of the circuit.

Because bends in a wire do not affect the circuit, they do not need to be represented in a schematic diagram. Redraw the circuit without the corners, keeping the arrangement of the circuit elements the same, as shown at right.



TIP *For now, disregard the emf source, and work only with the resistances.*

2. Identify components in series, and calculate their equivalent resistance.

Resistors in groups **(a)** and **(b)** are in series.

For group **(a):** $R_{eq} = 3.0\ \Omega + 6.0\ \Omega = 9.0\ \Omega$

For group **(b):** $R_{eq} = 6.0\ \Omega + 2.0\ \Omega = 8.0\ \Omega$

3. Identify components in parallel, and calculate their equivalent resistance.

Resistors in group **(c)** are in parallel.

For group **(c):**

$$\frac{1}{R_{eq}} = \frac{1}{8.0\ \Omega} + \frac{1}{4.0\ \Omega} = \frac{0.12}{1\ \Omega} + \frac{0.25}{1\ \Omega} = \frac{0.37}{1\ \Omega}$$

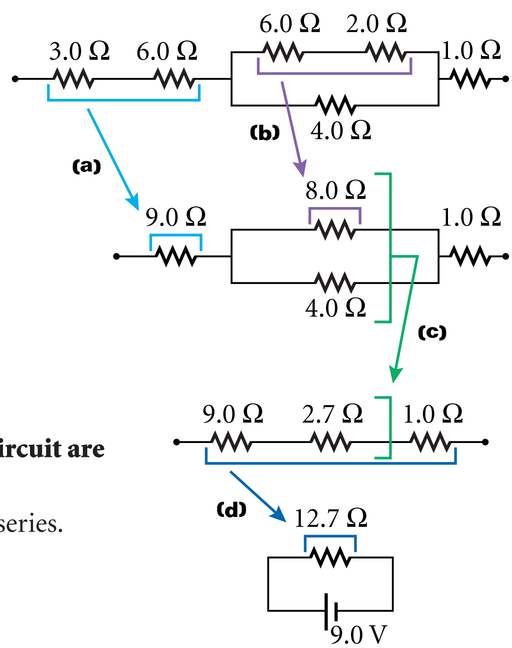
$R_{eq} = 2.7\ \Omega$

4. Repeat steps 2 and 3 until the resistors in the circuit are reduced to a single equivalent resistance.

The remainder of the resistors, group **(d)**, are in series.

For group **(d):** $R_{eq} = 9.0\ \Omega + 2.7\ \Omega + 1.0\ \Omega$

$$\boxed{R_{eq} = 12.7\ \Omega}$$



TIP *It doesn't matter in what order the operations of simplifying the circuit are done, as long as the simpler equivalent circuits still have the same current in and potential difference across the load.*

PRACTICE C

Equivalent Resistance

1. For each of the following sets of values, determine the equivalent resistance for the circuit shown in **Figure 16.**

a. $R_a = 25.0\ \Omega$ $R_b = 3.0\ \Omega$ $R_c = 40.0\ \Omega$
b. $R_a = 12.0\ \Omega$ $R_b = 35.0\ \Omega$ $R_c = 25.0\ \Omega$
c. $R_a = 15.0\ \Omega$ $R_b = 28.0\ \Omega$ $R_c = 12.0\ \Omega$

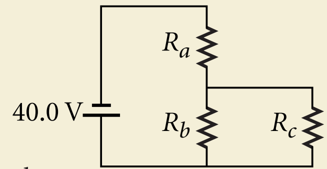


Figure 16

2. For each of the following sets of values, determine the equivalent resistance for the circuit shown in **Figure 17.**

a. $R_a = 25.0\ \Omega$ $R_b = 3.0\ \Omega$ $R_c = 40.0\ \Omega$
$R_d = 15.0\ \Omega$ $R_e = 18.0\ \Omega$

b. $R_a = 12.0\ \Omega$ $R_b = 35.0\ \Omega$ $R_c = 25.0\ \Omega$
$R_d = 50.0\ \Omega$ $R_e = 45.0\ \Omega$

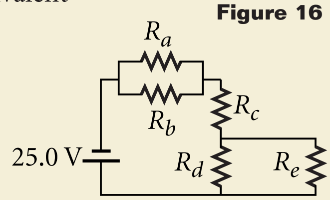


Figure 17

Work backward to find the current in and potential difference across a part of a circuit

Now that the equivalent resistance for a complex circuit has been determined, you can work backward to find the current in and potential difference across any resistor in that circuit. In the household example, substitute potential difference and equivalent resistance in $\Delta V = IR$ to find the total current in the circuit. Because the fuse or circuit breaker is in series with the load, the current in it is equal to the total current. Once this total current is determined, $\Delta V = IR$ can again be used to find the potential difference across the fuse or circuit breaker.

There is no single formula for finding the current in and potential difference across a resistor buried inside a complex circuit. Instead, $\Delta V = IR$ and the rules reviewed in **Table 3** must be applied to smaller pieces of the circuit until the desired values are found.

Table 3 Series and Parallel Resistors

	Series	Parallel
current	same as total	add to find total
potential difference	add to find total	same as total

PHYSICS INTERACTIVE TUTOR

Module 17
"Electrical Circuits"
provides an interactive lesson with guided problem-solving practice to teach you about many kinds of electric circuits, including complex combinations of resistors.

SAMPLE PROBLEM D

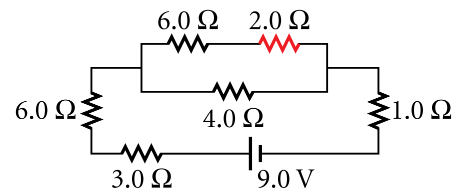
STRATEGY Current in and Potential Difference Across a Resistor

PROBLEM

Determine the current in and potential difference across the 2.0 Ω resistor highlighted in the figure below.

REASONING

First determine the total circuit current by reducing the resistors to a single equivalent resistance. Then rebuild the circuit in steps, calculating the current and potential difference for the equivalent resistance of each group until the current in and potential difference across the 2.0 Ω resistor are known.



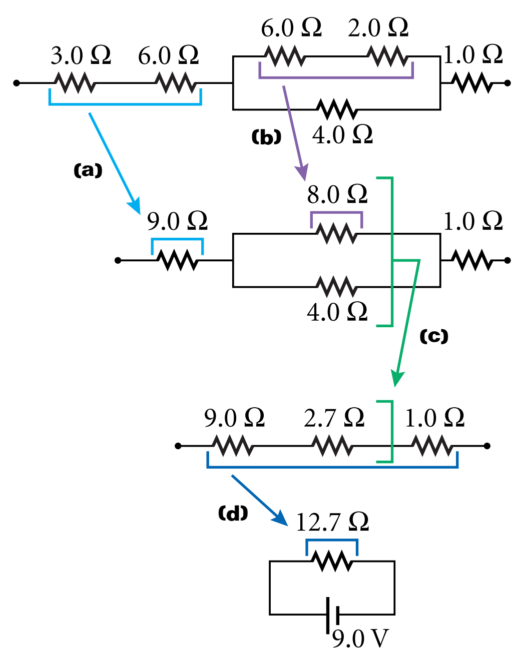
SOLUTION

1. Determine the equivalent resistance of the circuit.
The equivalent resistance of the circuit is 12.7 Ω; this value is calculated in Sample Problem C.

2. Calculate the total current in the circuit.
Substitute the potential difference and equivalent resistance in $\Delta V = IR$, and rearrange the equation to find the current delivered by the battery.

$$I = \frac{\Delta V}{R_{eq}} = \frac{9.0\ \text{V}}{12.7\ \Omega} = 0.71\ \text{A}$$

3. Determine a path from the equivalent resistance found in step 1 to the 2.0 Ω resistor.
Review the path taken to find the equivalent resistance in the figure at right, and work backward through this path. The equivalent resistance for the entire circuit is the same as the equivalent resistance for group **(d).** The center resistor in group **(d)** in turn is the equivalent resistance for group **(c).** The top resistor in group **(c)** is the equivalent resistance for group **(b),** and the right resistor in group **(b)** is the 2.0 Ω resistor.



TIP *It is not necessary to solve for R_{eq} first and then work backward to find current in or potential difference across a particular resistor, as shown in this Sample Problem, but working through these steps keeps the mathematical operations at each step simpler.*

4. Follow the path determined in step 3, and calculate the current in and potential difference across each equivalent resistance. Repeat this process until the desired values are found.

A. Regroup, evaluate, and calculate.

Replace the circuit's equivalent resistance with group **(d).** The resistors in group **(d)** are in series; therefore, the current in each resistor is the same as the current in the equivalent resistance, which equals 0.71 A. The potential difference across the 2.7 Ω resistor in group **(d)** can be calculated using $\Delta V = IR$.

Given: $I = 0.71\ \text{A}$ $\quad R = 2.7\ \Omega$

Unknown: $\Delta V = ?$

$$\Delta V = IR = (0.71\ \text{A})(2.7\ \Omega) = 1.9\ \text{V}$$

B. Regroup, evaluate, and calculate.

Replace the center resistor with group **(c).**

The resistors in group **(c)** are in parallel; therefore, the potential difference across each resistor is the same as the potential difference across the 2.7 Ω equivalent resistance, which equals 1.9 V. The current in the 8.0 Ω resistor in group **(c)** can be calculated using $\Delta V = IR$.

Given: $\Delta V = 1.9\ \text{V}$ $\quad R = 8.0\ \Omega$

Unknown: $I = ?$

$$I = \frac{\Delta V}{R} = \frac{1.9\ \text{V}}{8.0\ \Omega} = 0.24\ \text{A}$$

C. Regroup, evaluate, and calculate.

Replace the 8.0 Ω resistor with group **(b).**

The resistors in group **(b)** are in series; therefore, the current in each resistor is the same as the current in the 8.0 Ω equivalent resistance, which equals 0.24 A.

$$\boxed{I = 0.24\ \text{A}}$$

The potential difference across the 2.0 Ω resistor can be calculated using $\Delta V = IR$.

Given: $I = 0.24\ \text{A}$ $\quad R = 2.0\ \Omega$

Unknown: $\Delta V = ?$

$$\Delta V = IR = (0.24\ \text{A})\ (2.0\ \Omega) = 0.48\ \text{V}$$

$$\boxed{\Delta V = 0.48\ \text{V}}$$

TIP *You can check each step in problems like Sample Problem D by using $\Delta V = IR$ for each resistor in a set. You can also check the sum of ΔV for series circuits and the sum of I for parallel circuits.*

PRACTICE D

Current in and Potential Difference Across a Resistor

Calculate the current in and potential difference across each of the resistors shown in the schematic diagram in **Figure 18.**

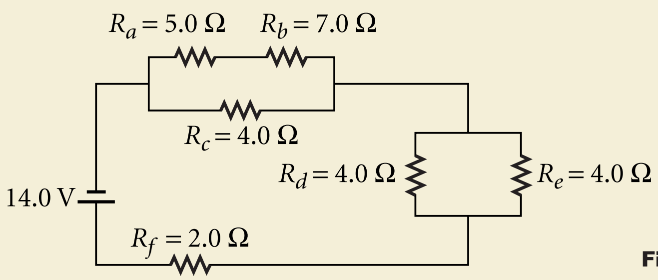


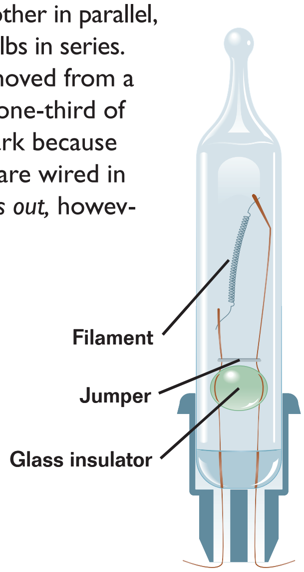
Figure 18

THE INSIDE STORY ON DECORATIVE LIGHTS AND BULBS

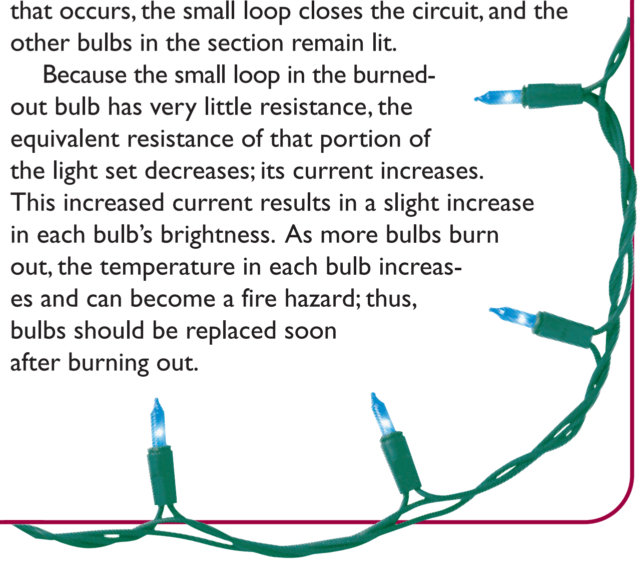
Light sets arranged in series cannot remain lit if a bulb burns out. Wiring in parallel can eliminate this problem, but each bulb must then be able to withstand 120 V. To eliminate the drawbacks of either approach, modern light sets typically contain two or three sections connected to each other in parallel, each of which contains bulbs in series.

When one bulb is removed from a modern light set, half or one-third of the lights in the set go dark because the bulbs in that section are wired in series. When a bulb *burns out,* however, all of the other bulbs in the set remain lit. How is this possible?

Modern decorative bulbs have a short loop of insulated wire, called the *jumper,* that is wrapped around the wires connected to the filament, as shown at left. There is no current in the insulated wire when the bulb is functioning properly. When the filament breaks, however, the current in the section is zero and the potential difference across the two wires connected to the broken filament is then 120 V. This large potential difference creates a spark across the two wires that burns the insulation off the small loop of wire. Once that occurs, the small loop closes the circuit, and the other bulbs in the section remain lit.



Because the small loop in the burned-out bulb has very little resistance, the equivalent resistance of that portion of the light set decreases; its current increases. This increased current results in a slight increase in each bulb's brightness. As more bulbs burn out, the temperature in each bulb increases and can become a fire hazard; thus, bulbs should be replaced soon after burning out.



SECTION REVIEW

1. Find the equivalent resistance of the complex circuit shown in **Figure 19.**

2. What is the current in the 1.5 Ω resistor in the complex circuit shown in **Figure 19**?

3. What is the potential difference across the 1.5 Ω resistor in the circuit shown in **Figure 19**?

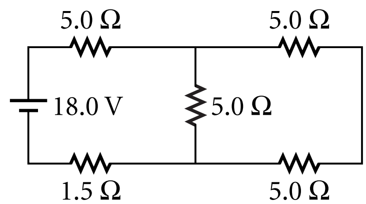


Figure 19

4. A certain strand of miniature lights contains 35 bulbs wired in series, with each bulb having a resistance of 15.0 Ω. What is the equivalent resistance when three such strands are connected in parallel across a potential difference of 120.0 V?

5. What is the current in and potential difference across each of the bulbs in the strands of lights described in item 4?

6. If one of the bulbs in one of the three strands of lights in item 4 goes out while the other bulbs in that strand remain lit, what is the current in and potential difference across each of the lit bulbs in that strand?

7. **Interpreting Graphics** **Figure 20** depicts a household circuit containing several appliances and a circuit breaker attached to a 120 V source of potential difference.

a. Is the current in the toaster equal to the current in the microwave?

b. Is the potential difference across the microwave equal to the potential difference across the popcorn popper?

c. Is the current in the circuit breaker equal to the total current in all of the appliances combined?

d. Determine the equivalent resistance for the circuit.

e. Determine how much current is in the toaster.

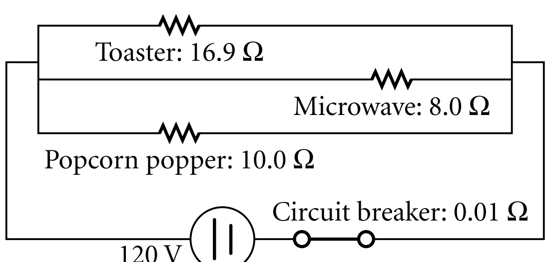


Figure 20

extension

Integrating Health

Visit go.hrw.com for the activity "Recording Electricity in the Brain."

Keyword HF6CIRX

PHYSICS CAREERS

Semiconductor Technician

Brad Baker is creating a recipe on the plasma etch tool to test a new process.

Electronic chips are used in a wide variety of devices, from toys to phones to computers. To learn more about chip making as a career, read the interview with Etch Process Engineering Technician Brad Baker, who works for Motorola.

What training did you receive in order to become a semiconductor technician?

My experience is fairly unique. My degree is in psychology. You have to have an associate's degree in some sort of electrical or engineering field or an undergraduate degree in any field.

What about semiconductor manufacturing made it more interesting than other fields?

While attending college, I worked at an airline. There was not a lot of opportunity to advance, which helped point me in other directions. Circuitry has a lot of parallels to the biological aspects of the brain, which is what I studied in school. We use the scientific method a lot.

What is the nature of your work?

I work on the etch process team. Device engineers design the actual semiconductor. Our job is to figure out how to make what they have requested. It's sort of like being a chef. Once you have experience, you know which ingredient to add.

What is your favorite thing about your job?

I feel like a scientist. My company gives us the freedom to try new things and develop new processes.

Has your job changed since you started it?

Each generation of device is smaller, so we have to do more in less space. As the devices get smaller, it becomes more challenging to get a design process that is powerful enough but doesn't etch too much or too little.

What advice do you have for students who are interested in semiconductor engineering?

The field is very science oriented, so choose chemical engineering, electrical engineering, or material science as majors. Other strengths are the ability to understand and meet challenges, knowledge of troubleshooting techniques, patience, and analytical skills. Also, everything is computer automated, so you have to know how to use computers.

CHAPTER 18 Highlights

KEY IDEAS

Section 1 Schematic Diagrams and Circuits

- Schematic diagrams use standardized symbols to summarize the contents of electric circuits.
- A circuit is a set of electrical components connected so that they provide one or more complete paths for the movement of charges.
- Any device that transforms nonelectrical energy into electrical energy, such as a battery or a generator, is a source of emf.
- If the internal resistance of a battery is neglected, the emf can be considered equal to the terminal voltage, the potential difference across the source's two terminals.

Section 2 Resistors in Series or in Parallel

- Resistors in series have the same current.
- The equivalent resistance of a set of resistors connected in series is the sum of the individual resistances.
- The sum of currents in parallel resistors equals the total current.
- The equivalent resistance of a set of resistors connected in parallel is calculated using an inverse relationship.

Section 3 Complex Resistor Combinations

- Many complex circuits can be understood by isolating segments that are in series or in parallel and simplifying them to their equivalent resistances.

Variable Symbols

Quantities	Units	Conversions
I current	A amperes	= C/s = coulombs of charge per second
R resistance	Ω ohms	=V/A = volts per ampere of current
ΔV potential difference	V volts	= J/C = joules of energy per coulomb of charge

KEY TERMS

schematic diagram (p. 640)

electric circuit (p. 642)

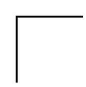
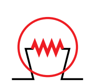
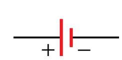
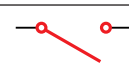
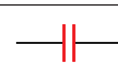
series (p. 647)

parallel (p. 651)

PROBLEM SOLVING

See **Appendix D: Equations** for a summary of the equations introduced in this chapter. If you need more problem-solving practice, see **Appendix I: Additional Problems.**

Diagram Symbols

Wire or conductor	
Resistor or circuit load	
Bulb or lamp	
Plug	
Battery/ direct-current emf source	
Switch	
Capacitor	

CHAPTER 18 Review

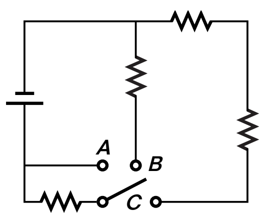
SCHEMATIC DIAGRAMS AND CIRCUITS

Review Questions

1. Why are schematic diagrams useful?

2. Draw a circuit diagram for a circuit containing three 5.0 Ω resistors, a 6.0 V battery, and a switch.

3. The switch in the circuit shown at right can be set to connect to points *A*, *B*, or *C*. Which of these connections will provide a complete circuit?



4. If the batteries in a cassette recorder provide a terminal voltage of 12.0 V, what is the potential difference across the entire recorder?

5. In a case in which the internal resistance of a battery is significant, which is greater?

a. the terminal voltage
b. the emf of the battery

Conceptual Questions

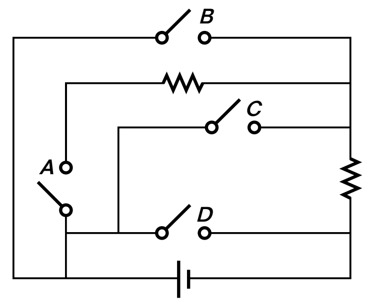
6. Do charges move from a source of potential difference into a load or through both the source and the load?

7. Assuming that you want to create a circuit that has current in it, why should there be no openings in the circuit?

8. Suppose a 9 V battery is connected across a light bulb. In what form is the electrical energy supplied by the battery dissipated by the light bulb?

9. Why is it dangerous to use an electrical appliance when you are in the bathtub?

10. Which of the switches in the circuit below will complete a circuit when closed? Which will cause a short circuit?



RESISTORS IN SERIES OR IN PARALLEL

Review Questions

11. If four resistors in a circuit are connected in series, which of the following is the same for the resistors in the circuit?

a. potential difference across the resistors
b. current in the resistors

12. If four resistors in a circuit are in parallel, which of the following is the same for the resistors in the circuit?

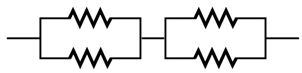
a. potential difference across the resistors
b. current in the resistors

Conceptual Questions

13. A short circuit is a circuit containing a path of very low resistance in parallel with some other part of the circuit. Discuss the effect of a short circuit on the current within the portion of the circuit that has very low resistance.

14. Fuses protect electrical devices by opening a circuit if the current in the circuit is too high. Would a fuse work successfully if it were connected in parallel with the device that it is supposed to protect?

15. What might be an advantage of using two identical resistors in parallel that are connected in series with another identical parallel pair, as shown below, instead of using a single resistor?



Practice Problems

For problems 16–17, see Sample Problem A.

16. A length of wire is cut into five equal pieces. If each piece has a resistance of 0.15 Ω, what was the resistance of the original length of wire?

17. A 4.0 Ω resistor, an 8.0 Ω resistor, and a 12 Ω resistor are connected in series with a 24 V battery. Determine the following:

a. the equivalent resistance for the circuit
b. the current in the circuit

For problems 18–19, see Sample Problem B.

18. The resistors in item 17 are connected in parallel across a 24 V battery. Determine the following:

a. the equivalent resistance for the circuit
b. the current delivered by the battery

19. An 18.0 Ω resistor, 9.00 Ω resistor, and 6.00 Ω resistor are connected in parallel across a 12 V battery. Determine the following:

a. the equivalent resistance for the circuit
b. the current delivered by the battery

COMPLEX RESISTOR COMBINATIONS

Conceptual Questions

20. A technician has two resistors, each of which has the same resistance, *R*.

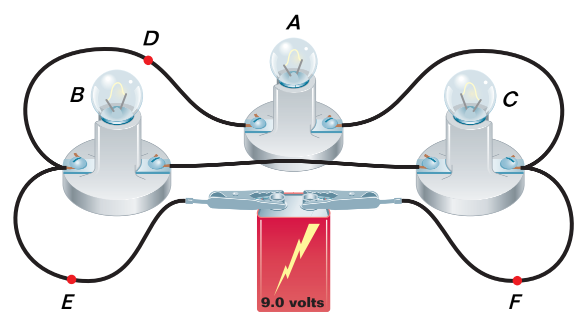
a. How many different resistances can the technician achieve?
b. Express the effective resistance of each possibility in terms of *R*.

21. The technician in item 20 finds another resistor, so now there are three resistors with the same resistance.

a. How many different resistances can the technician achieve?
b. Express the effective resistance of each possibility in terms of *R*.

22. Three identical light bulbs are connected in circuit to a battery, as shown below. Compare the level of brightness of each bulb when all the bulbs are illuminated. What happens to the brightness of each bulb if the following changes are made to the circuit?

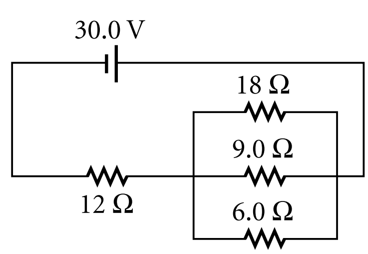
a. Bulb *A* is removed from its socket.
b. Bulb *C* is removed from its socket.
c. A wire is connected directly between points *D* and *E*.
d. A wire is connected directly between points *D* and *F*.



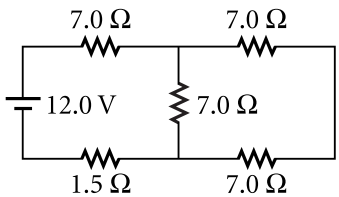
Practice Problems

For problems 23–24, see Sample Problem C.

23. Find the equivalent resistance of the circuit shown in the figure below.

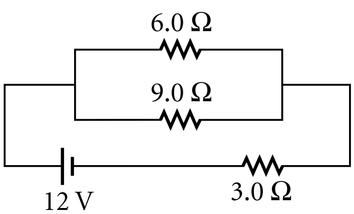


24. Find the equivalent resistance of the circuit shown in the figure below.



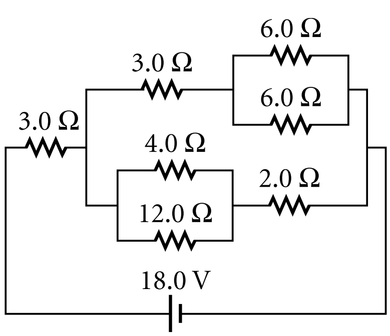
For problems 25–26, see Sample Problem D.

25. For the circuit shown below, determine the current in each resistor and the potential difference across each resistor.



26. For the circuit shown in the figure below, determine the following:

a. the current in the 2.0 Ω resistor
b. the potential difference across the 2.0 Ω resistor
c. the potential difference across the 12.0 Ω resistor
d. the current in the 12.0 Ω resistor



MIXED REVIEW

27. An 8.0 Ω resistor and a 6.0 Ω resistor are connected in series with a battery. The potential difference across the 6.0 Ω resistor is measured as 12 V. Find the potential difference across the battery.

28. A 9.0 Ω resistor and a 6.0 Ω resistor are connected in parallel to a battery, and the current in the 9.0 Ω resistor is found to be 0.25 A. Find the potential difference across the battery.

29. A 9.0 Ω resistor and a 6.0 Ω resistor are connected in series to a battery, and the current through the 9.0 Ω resistor is 0.25 A. What is the potential difference across the battery?

30. A 9.0 Ω resistor and a 6.0 Ω resistor are connected in series with an emf source. The potential difference across the 6.0 Ω resistor is measured with a voltmeter to be 12 V. Find the potential difference across the emf source.

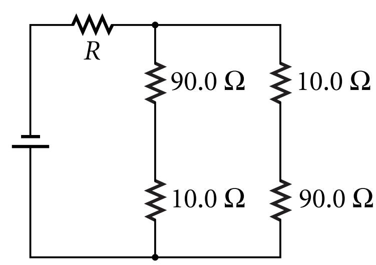
31. An 18.0 Ω, 9.00 Ω, and 6.00 Ω resistor are connected in series with an emf source. The current in the 9.00 Ω resistor is measured to be 4.00 A.

a. Calculate the equivalent resistance of the three resistors in the circuit.
b. Find the potential difference across the emf source.
c. Find the current in the other resistors.

32. The stockroom has only 20 Ω and 50 Ω resistors.

a. You need a resistance of 45 Ω. How can this resistance be achieved using three resistors?
b. Describe two ways to achieve a resistance of 35 Ω using four resistors.

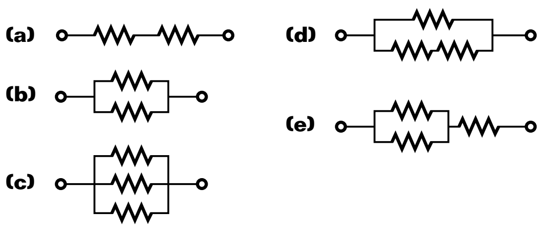
33. The equivalent resistance of the circuit shown below is 60.0 Ω. Use the diagram to determine the value of R.



34. Two identical parallel-wired strings of 25 bulbs are connected to each other in series. If the equivalent resistance of the combination is 150.0 Ω and it is connected across a potential difference of 120.0 V, what is the resistance of each individual bulb?

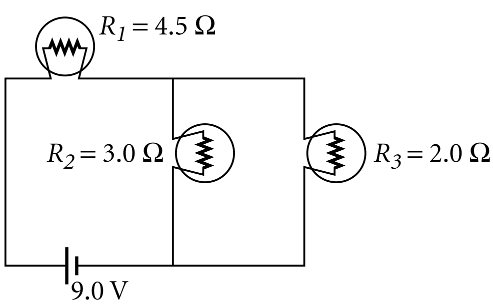
35. The figures **(a)–(e)** below depict five resistance diagrams. Each individual resistance is 6.0 Ω .

a. Which resistance combination has the largest equivalent resistance?
b. Which resistance combination has the smallest equivalent resistance?
c. Which resistance combination has an equivalent resistance of 4.0 Ω ?
d. Which resistance combination has an equivalent resistance of 9.0 Ω ?



36. Three small lamps are connected to a 9.0 V battery, as shown below.

a. What is the equivalent resistance of this circuit?
b. What is the current in the battery?
c. What is the current in each bulb?
d. What is the potential difference across each bulb?



37. An 18.0 Ω resistor and a 6.0 Ω resistor are connected in series to an 18.0 V battery. Find the current in and the potential difference across each resistor.

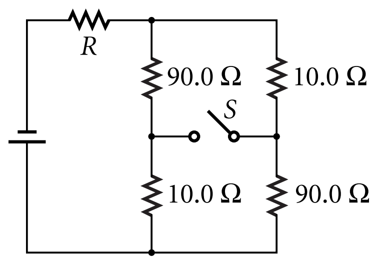
38. A 30.0 Ω resistor is connected in parallel to a 15.0 Ω resistor. These are joined in series to a 5.00 Ω resistor and a source with a potential difference of 30.0 V.

a. Draw a schematic diagram for this circuit.
b. Calculate the equivalent resistance.
c. Calculate the current in each resistor.
d. Calculate the potential difference across each resistor.

39. A resistor with an unknown resistance is connected in parallel to a 12 Ω resistor. When both resistors are connected to an emf source of 12 V, the current in the unknown resistor is measured with an ammeter to be 3.0 A. What is the resistance of the unknown resistor?

40. The resistors described in item 37 are reconnected in parallel to the same 18.0 V battery. Find the current in each resistor and the potential difference across each resistor.

41. The equivalent resistance for the circuit shown below drops to one-half its original value when the switch, *S*, is closed. Determine the value of *R*.



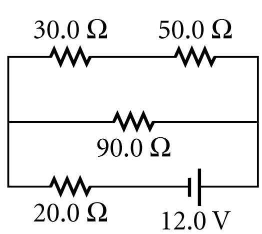
42. You can obtain only four 20.0 Ω resistors from the stockroom.

a. How can you achieve a resistance of 50.0 Ω under these circumstances?
b. What can you do if you need a 5.0 Ω resistor?

43. Four resistors are connected to a battery with a terminal voltage of 12.0 V, as shown below. Determine the following:

a. the equivalent resistance for the circuit
b. the current in the battery
c. the current in the 30.0 Ω resistor
d. the power dissipated by the 50.0 Ω resistor
e. the power dissipated by the 20.0 Ω resistor

(Hint: Remember that $P = \frac{(\Delta V)^2}{R} = I\Delta V$.)



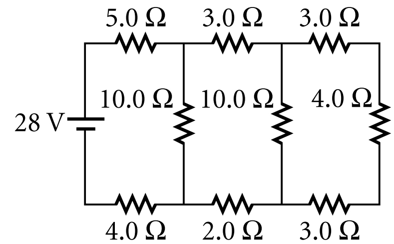
44. Two resistors, *A* and *B*, are connected in series to a 6.0 V battery. A voltmeter connected across resistor *A* measures a potential difference of 4.0 V. When the two resistors are connected in parallel across the 6.0 V battery, the current in *B* is found to be 2.0 A. Find the resistances of *A* and *B*.

45. Draw a schematic diagram of nine 100 Ω resistors arranged in a series-parallel network so that the total resistance of the network is also 100 Ω. All nine resistors must be used.

46. For the circuit below, find the following:

a. the equivalent resistance of the circuit

b. the current in the 5.0 Ω resistor



Graphing Calculator Practice

Parallel Resistors

Electric circuits are often composed of combinations of series and parallel circuits. The overall resistance of a circuit is determined by dividing the circuit into groups of series and parallel resistors and determining the equivalent resistance of each group. As you learned earlier in this chapter, the equivalent resistance of parallel resistors is given by the following equation:

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \cdots$$

One interesting consequence of this equation is that the equivalent resistance for resistors in parallel will always be less than the smallest resistor in the group.

In this graphing calculator activity, you will determine the equivalent resistance for various resistors in parallel. You will confirm that the equivalent resistance is always less than the smallest resistor, and you will relate the number of resistors and changes in resistance to the equivalent resistance.

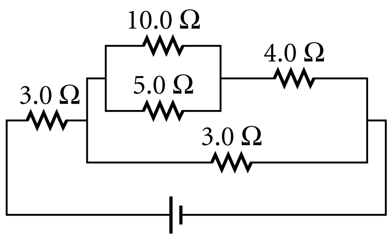
Visit go.hrw.com and type in the keyword **HF6CIRX** to find this graphing calculator activity. Refer to **Appendix B** for instructions on downloading the program for this activity.

47. The power supplied to the circuit shown below is 4.00 W. Use the information in the diagram to determine the following:

a. the equivalent resistance of the circuit

b. the potential difference across the battery

(Hint: Remember that $P = \frac{(\Delta V)^2}{R}$.)



48. Your toaster oven and coffee maker each dissipate 1200 W of power. Can you operate both of these appliances at the same time if the 120 V line you use in your kitchen has a circuit breaker rated at 15 A? Explain.
(Hint: Recall that $P = I\Delta V$.)

49. An electric heater is rated at 1300 W, a toaster is rated at 1100 W, and an electric grill is rated at 1500 W. The three appliances are connected in parallel across a 120 V emf source.

a. Find the current in each appliance.

b. Is a 30.0 A circuit breaker sufficient in this situation? Explain.

Alternative Assessment

1. How many ways can two or more batteries be connected in a circuit with a light bulb? How will the current change depending on the arrangement? First draw diagrams of the circuits you want to test. Then identify the measurements you need to make to answer the question. If your teacher approves your plan, obtain the necessary equipment and perform the experiment.

2. Research the career of an electrical engineer or technician. Prepare materials for people interested in this career field. Include information on where people in this career field work, which tools and equipment they use, and the challenges of their field. Indicate what training is typically necessary to enter the field.

3. The manager of an automotive repair shop has been contacted by two competing firms that are selling ammeters to be used in testing automobile electrical systems. One firm has published claims that its ammeter is better because it has high internal resistance. The other firm has published claims that its ammeter is better because it has low resistance. Write a report with your recommendation to the manager of the automotive repair shop. Include diagrams and calculations that explain how you reached your conclusion.

4. You and your friend want to start a business exporting small electrical appliances. You have found people willing to be your partners to distribute these appliances in Germany. Write a letter to these potential partners that describes your product line and that asks for the information you will need about the electric power, sources, consumption, and distribution in Germany.

5. Contact an electrician, builder, or contractor, and ask to see a house electrical plan. Study the diagram to identify the circuit breakers, their connections to different appliances in the home, and the limitations they impose on the circuit's design. Find out how much current, on average, is in each appliance in the house. Draw a diagram of the house, showing which circuit breakers control which appliances. Your diagram should also keep the current in each of these appliances under the performance and safety limits.

Standardized Test Prep

MULTIPLE CHOICE

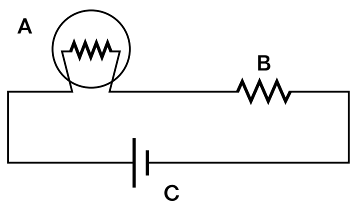
1. Which of the following is the correct term for a circuit that does not have a closed-loop path for electron flow?

A. closed circuit
B. dead circuit
C. open circuit
D. short circuit

2. Which of the following is the correct term for a circuit in which the load has been unintentionally bypassed?

F. closed circuit
G. dead circuit
H. open circuit
J. short circuit

Use the diagram below to answer questions 3–5.



3. Which of the circuit elements contribute to the load of the circuit?

A. Only A
B. A and B, but not C
C. Only C
D. A, B, and C

4. Which of the following is the correct equation for the equivalent resistance of the circuit?

F. $R_{eq} = R_A + R_B$

G. $\frac{1}{R_{eq}} = \frac{1}{R_A} + \frac{1}{R_B}$

H. $R_{eq} = I\Delta V$

J. $\frac{1}{R_{eq}} = \frac{1}{R_A} + \frac{1}{R_B} + \frac{1}{R_C}$

5. Which of the following is the correct equation for the current in the resistor?

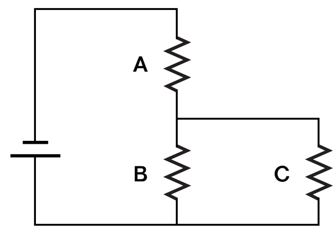
A. $I = I_A + I_B + I_C$

B. $I_B = \frac{\Delta V}{R_{eq}}$

C. $I_B = I_{total} + I_A$

D. $I_B = \frac{\Delta V}{R_B}$

Use the diagram below to answer questions 6–7.



6. Which of the following is the correct equation for the equivalent resistance of the circuit?

F. $R_{eq} = R_A + R_B + R_C$

G. $\frac{1}{R_{eq}} = \frac{1}{R_A} + \frac{1}{R_B} + \frac{1}{R_C}$

H. $R_{eq} = I\Delta V$

J. $R_{eq} = R_A + \left(\frac{1}{R_B} + \frac{1}{R_C}\right)^{-1}$

7. Which of the following is the correct equation for the current in resistor B?

A. $I = I_A + I_B + I_C$

B. $I_B = \frac{\Delta V}{R_{eq}}$

C. $I_B = I_{total} + I_A$

D. $I_B = \frac{\Delta V_B}{R_B}$

8. Three 2.0 Ω resistors are connected in series to a 12 V battery. What is the potential difference across each resistor?

F. 2.0 V
G. 4.0 V
H. 12 V
J. 36 V

Use the following passage to answer questions 9–11.

Six light bulbs are connected in parallel to a 9.0 V battery. Each bulb has a resistance of 3.0 Ω.

9. What is the potential difference across each bulb?

A. 1.5 V
B. 3.0 V
C. 9.0 V
D. 27 V

10. What is the current in each bulb?

F. 0.5 A
G. 3.0 A
H. 4.5 A
J. 18 A

11. What is the total current in the circuit?

A. 0.5 A
B. 3.0 A
C. 4.5 A
D. 18 A

SHORT RESPONSE

12. Which is greater, a battery's terminal voltage or the same battery's emf? Explain why these two quantities are not equal.

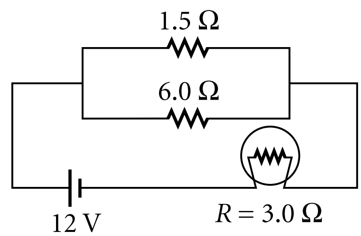
13. Describe how a short circuit could lead to a fire.

14. Explain the advantage of wiring the bulbs in a string of decorative lights in parallel rather than in series.

EXTENDED RESPONSE

15. Using standard symbols for circuit elements, draw a diagram of a circuit that contains a battery, an open switch, and a light bulb in parallel with a resistor. Add an arrow to indicate the direction of current if the switch were closed.

Use the diagram below to answer questions 16–17.



16. For the circuit shown, calculate the following:

a. the equivalent resistance of the circuit
b. the current in the light bulb.

Show all your work for both calculations.

17. After a period of time, the 6.0 Ω resistor fails and breaks. Describe what happens to the brightness of the bulb. Support your answer.

18. Find the current in and potential difference across each of the resistors in the following circuits:

a. a 4.0 Ω and a 12.0 Ω resistor wired in series with a 4.0 V source.
b. a 4.0 Ω and a 12.0 Ω resistor wired in parallel with a 4.0 V source.

Show all your work for each calculation.

19. Find the current in and potential difference across each of the resistors in the following circuits:

a. a 150 Ω and a 180 Ω resistor wired in series with a 12 V source.
b. a 150 Ω and a 180 Ω resistor wired in parallel with a 12 V source.

Show all your work for each calculation.

Test TIP Prepare yourself for taking an important test by getting plenty of sleep the night before and by eating a healthy breakfast on the day of the test.

CHAPTER 18

Inquiry Lab

Design Your Own

Resistors in Series and in Parallel

OBJECTIVES

- **Measure** current in and potential difference across resistors in series and in parallel.
- **Find** the unknown resistances of two resistors.
- **Calculate** equivalent resistances.
- **Analyze** the relationships between potential difference, current, and resistance in a circuit.

MATERIALS LIST

- **2 multimeters, or 1 dc ammeter and 1 voltmeter**
- **2 resistors**
- **insulated connecting wire**
- **power supply**
- **switch**

In this lab, you will design an experiment to compare the circuits created by wiring two unknown resistors first in series and then in parallel. By taking measurements of the current in and the potential difference (voltage) across the resistors, and the potential difference across the whole circuit, you will find the value of the resistance of each resistor and the equivalent resistance for both resistors to compare the total current in each of the two circuits.

SAFETY

- **Never close a circuit until it has been approved by your teacher.**
- **Never rewire or adjust any element of a closed circuit.**
- **Never work with electricity near water; be sure the floor and all work surfaces are dry.**
- **If the pointer on any kind of meter moves off scale, open the circuit immediately by opening the switch.**
- **Do not attempt this exercise with any batteries or electrical devices other than those provided by your teacher for this purpose.**
- **Use a hot mitt to handle resistors, light sources, and other equipment that may be hot. Allow all equipment to cool before storing it.**

PROCEDURE

1. Study the materials provided, and design an experiment to meet the goals stated above. If you are not certain how to use the power supply, the meters, or any of the other materials, ask your teacher for help.
2. Write out your lab procedure, including a detailed description of the measurements to take during each step. You may use **Figure 1** and **Figure 2** as guides to possible setups. The dc power supplies should be set to about 5.0 V when you are taking measurements.
3. Ask your teacher to approve your procedure.
4. Follow all steps of your procedure. **IMPORTANT: Your teacher must approve your circuit before you turn on the power supply in any step. Always open the switch immediately after you have taken measurements. Do not change the circuit or any of the meter connections**

while the switch is closed. Any time you change your circuit, including the points of connection for any of the meters, your teacher must approve the circuit again before you close the switch.

5. Clean up your work area. Put equipment away safely so that it is ready to be used again.

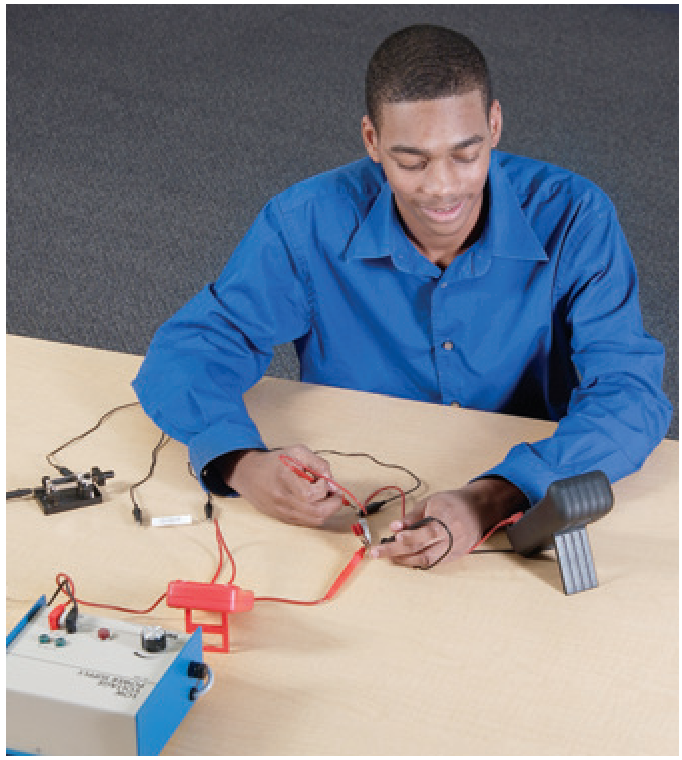


Figure 1

- Use the voltage meter to measure potential difference across the resistors.

ANALYSIS

1. **Organizing Data** Using your measurements for potential difference and current, compute the resistance values of R_1 and R_2 in each circuit.
2. **Analyzing Results** Compare your results from item 1 for the different circuits.
   - **a.** Do R_1 and R_2 have the same values in each circuit?
   - **b.** Did you expect R_1 and R_2 to have the same values? Explain. If the results are different, suggest a possible reason.
3. **Organizing Data** Compute the equivalent resistance R_{eq} using the values found in item 1 for each circuit.
4. **Analyzing Results** Based on your calculations in item 3, did the two resistors provide the same equivalent resistance in both circuits? If not, which combination had the greater resistance? Explain how the combination of resistors affects the total resistance in the circuit.
5. **Organizing Data** Compute the total current in each circuit using the calculated value for R_{eq} and the measured value for ΔV_T.
6. **Analyzing Results** Do both circuits have the same total current? If not, which circuit has the greater current? Explain how the combination of resistors affects the total current in the circuit.

CONCLUSIONS

7. **Drawing Conclusions** Compare the total current in each circuit with the current in each resistor. What is the relationship between the current in an individual resistor and the total current in the circuit?
8. **Drawing Conclusions** For each circuit, compare the potential difference across each resistor with ΔV_T. What is the relationship?