

# Chapter 23

# Series and Parallel Circuits

## What You'll Learn

- You will distinguish among series circuits, parallel circuits, and series-parallel combinations, and solve problems involving them.
- You will explain the function of fuses, circuit breakers, and ground-fault interrupters, and describe how ammeters and voltmeters are used in circuits.

## Why It's Important

Electric circuits are the basis of every electric device, from electric lights to microwave ovens to computers. Learning how circuits work will help you understand how countless electric devices function.

### Electric Load Centers

Electric load centers form the link between the utility company and the circuits in a building. Each circuit breaker protects an individual circuit, which has the various loads connected in parallel.

## Think About This ►

Why are the building loads connected in parallel?  
How are the circuit breakers connected?



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## How do fuses protect electric circuits?

### Question

How does a fuse prevent an electric circuit from drawing too much current and creating a safety hazard?

### Procedure

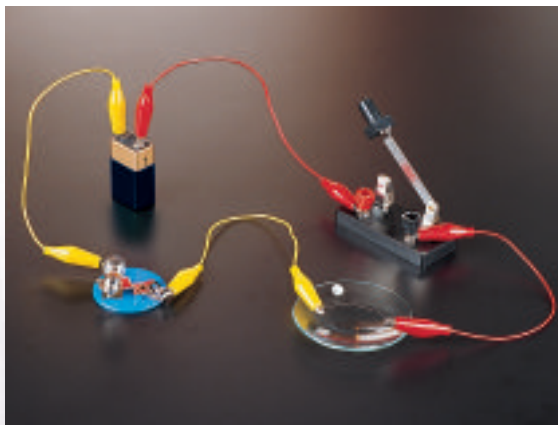


1. Connect the negative terminal of a 9-V battery to one terminal of a flashlight-bulb socket using a copper wire. **CAUTION: Wire ends may be sharp and could cause cuts.**
2. Connect the other terminal of the bulb socket to a single strand of steel wool using copper wire. Make sure the strand of steel wool is suspended over a small glass container.
3. Connect the other end of the single strand of steel wool to a switch using another piece of copper wire. Make sure the switch is open (turned off).
4. Connect the other terminal of the switch to the positive terminal of a power supply or a battery.
5. **Hypothesize** Predict what will happen when the switch is closed (turned on).
6. **Observe** Close the switch and make observations of the strand of steel wool.
7. Repeat steps 1–6 using a thicker strand of steel wool, or twist several strands together to form a single, thicker strand.

### Analysis

Explain how the thickness of a wire is related to how fast the wire will overheat and break apart. Why have circuit breakers replaced fuses in the electric circuit boxes of new homes?

**Critical Thinking** Why is it important to replace a burned-out fuse in a house or car electric circuit with one that has the correct rating?



## 23.1 Simple Circuits

**A**lthough the connection may not immediately be clear to you, a mountain river can be used to model an electric circuit. From its source high in the mountains, the river flows downhill to the plains below. No matter which path the river takes, its change in elevation, from the mountaintop to the plain, is the same. Some rivers flow downhill in a single stream. Other rivers may split into two or more smaller streams as they flow over a waterfall or through a series of rapids. In this case, part of the river follows one path, while other parts of the river follow different paths. No matter how many paths the river takes, however, the total amount of water flowing down the mountain remains unchanged. In other words, the amount of water flowing downhill is not affected by the path it takes.

### ▶ Objectives

- **Describe** series and parallel circuits.
- **Calculate** currents, voltage drops, and equivalent resistances in series and parallel circuits.

### ▶ Vocabulary

series circuit  
equivalent resistance  
voltage divider  
parallel circuit



■ **Figure 23-1** No matter what path a river or a stream takes down a mountain, the amount of water and the drop in elevation are the same.

How does the river shown in **Figure 23-1** model an electric circuit? The distance that the river drops is similar to the potential difference in a circuit. The amount of water flowing in the river is similar to current in a circuit. Narrow rapids create resistance and are similar to resistors in a circuit. What part of a river is similar to a battery or a generator in an electric circuit? The energy source needed to raise water to the top of the mountain is the Sun. Solar energy evaporates water from lakes and seas leading to the formation of clouds that release rain or snow that falls on the mountain-tops. Continue to think about the mountain river model as you read about the current in electric circuits.

## Series Circuits

Three students are connecting two identical lamps to a battery, as illustrated in **Figure 23-2**. Before they make the final connection to the battery, their teacher asks them to predict the brightnesses of the two lamps.

Each student knows that the brightness of a lamp depends on the current through it. The first student predicts that only the lamp close to the positive (+) terminal of the battery will light because all the current will be used up as thermal and light energy. The second student predicts that only part of the current will be used up, and the second lamp will glow, but more brightly than the first. The third student predicts that the lamps will be of equal brightness because current is a flow of charge and the charge leaving the first lamp has nowhere else to go in the circuit except through the second lamp. The third student reasons that because the current will be the same in each lamp, the brightness also will be the same. How do you predict the lights will behave?

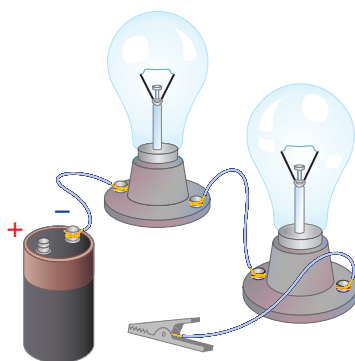
If you consider the mountain river model for this circuit, you will realize that the third student is correct. Recall from Chapter 20 that charge cannot be created or destroyed. Because the charge in the circuit has only one path to follow and cannot be destroyed, the same amount of charge must leave a circuit as enters the circuit. This means that the current is the same everywhere in the circuit. If you connect three ammeters in the circuit, as shown in **Figure 23-3**, they all will show the same current. A circuit such as this, in which all current travels through each device, is called a **series circuit**.

If the current is the same throughout the circuit, what is used by the lamp to produce the thermal and light energy? Recall that power, the rate at which electric energy is converted, is represented by  $P = IV$ . Thus, if there is a potential difference, or voltage drop, across the lamp, then electric energy is being converted into another form. The resistance of the lamp is defined as  $R = V/I$ . Thus, the potential difference, also called the voltage drop, is  $V = IR$ .

**Current and resistance in a series circuit** From the river model, you know that the sum of the drops in height is equal to the total drop from the top of the mountain to sea level. In an electric circuit, the increase in voltage provided by the generator or other energy source,  $V_{\text{source}}$  is equal to the sum of voltage drops across lamps A and B, and is represented by the following equation:

$$V_{\text{source}} = V_A + V_B$$

■ **Figure 23-2** What is your prediction about the brightnesses of the two lightbulbs after the circuit is connected?



To find the potential drop across a resistor, multiply the current in the circuit by the resistance of the individual resistor. Because the current through the lamps is the same,  $V_A = IR_A$  and  $V_B = IR_B$ . Therefore,  $V_{\text{source}} = IR_A + IR_B$ , or  $V_{\text{source}} = I(R_A + R_B)$ . The current through the circuit is represented by the following equation:

$$I = \frac{V_{\text{source}}}{R_A + R_B}$$

The same idea can be extended to any number of resistances in series, not just two. The same current would exist in the circuit with a single resistor,  $R$ , that has a resistance equal to the sum of the resistances of the two lamps. Such a resistance is called the **equivalent resistance** of the circuit. For resistors in series, the equivalent resistance is the sum of all the individual resistances, as expressed by the following equation.

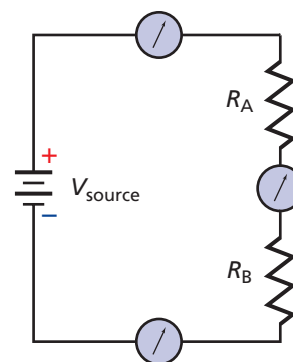
**Equivalent Resistance for Resistors in Series**  $R = R_A + R_B + \dots$

The equivalent resistance of resistors in series equals the sum of the individual resistances of the resistors.

Notice that the equivalent resistance is greater than that of any individual resistor. Therefore, if the battery voltage does not change, adding more devices in series always decreases the current. To find the current through a series circuit, first calculate the equivalent resistance and then use the following equation.

**Current**  $I = \frac{V_{\text{source}}}{R}$

Current in a series circuit is equal to the potential difference of the source divided by the equivalent resistance.

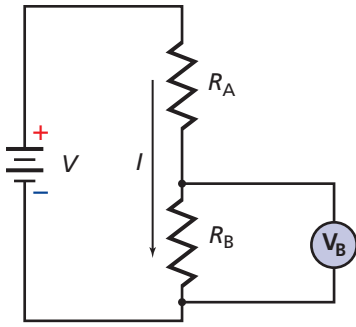


■ **Figure 23-3** The ammeters show that the current is the same everywhere in a series circuit.

## ▶ PRACTICE Problems

## Additional Problems, Appendix B

- Three  $20\text{-}\Omega$  resistors are connected in series across a  $120\text{-V}$  generator. What is the equivalent resistance of the circuit? What is the current in the circuit?
- A  $10\text{-}\Omega$ ,  $15\text{-}\Omega$ , and  $5\text{-}\Omega$  resistor are connected in a series circuit with a  $90\text{-V}$  battery. What is the equivalent resistance of the circuit? What is the current in the circuit?
- A  $9\text{-V}$  battery is in a circuit with three resistors connected in series.
  - If the resistance of one of the resistors increases, how will the equivalent resistance change?
  - What will happen to the current?
  - Will there be any change in the battery voltage?
- A string of holiday lights has ten bulbs with equal resistances connected in series. When the string of lights is connected to a  $120\text{-V}$  outlet, the current through the bulbs is  $0.06\text{ A}$ .
  - What is the equivalent resistance of the circuit?
  - What is the resistance of each bulb?
- Calculate the voltage drops across the three resistors in problem 2, and verify that their sum equals the voltage of the battery.



■ **Figure 23-4** In this voltage-divider circuit, the values of  $R_A$  and  $R_B$  are chosen such that the voltage drop across  $R_B$  is the desired voltage.

**Voltage drops in a series circuit** As current moves through any circuit, the net change in potential must be zero. This is because the circuit's electric energy source, the battery or generator, raises the potential an amount equal to the potential drop produced when the current passes through the resistors. Therefore, the net change is zero.

An important application of series resistors is a circuit called a voltage divider. A **voltage divider** is a series circuit used to produce a voltage source of desired magnitude from a higher-voltage battery. For example, suppose you have a 9-V battery but need a 5-V potential source. Consider the circuit shown in **Figure 23-4**. Two resistors,  $R_A$  and  $R_B$ , are connected in series across a battery of magnitude  $V$ . The equivalent resistance of the circuit is  $R = R_A + R_B$ . The current is represented by the following equation:

$$I = \frac{V}{R}$$

$$= \frac{V}{R_A + R_B}$$

The desired voltage, 5 V, is the voltage drop,  $V_B$ , across resistor  $R_B$ :  $V_B = IR_B$ . Into this equation, the earlier equation for current is substituted.

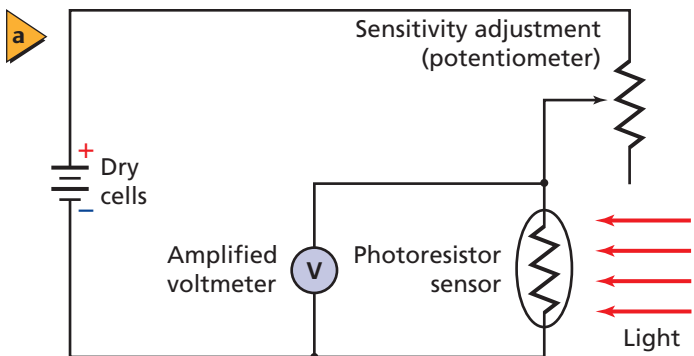
$$V_B = IR_B$$

$$= \left( \frac{V}{R_A + R_B} \right) R_B$$

$$= \frac{VR_B}{R_A + R_B}$$

Voltage dividers often are used with sensors, such as photoresistors. The resistance of a photoresistor depends upon the amount of light that strikes it. Photoresistors are made of semiconductors, such as silicon, selenium, or cadmium sulfide. A typical photoresistor can have a resistance of  $400 \Omega$  when light is striking it compared with a resistance of  $400,000 \Omega$  when the photoresistor is in the dark. The voltage output of a voltage divider that uses a photoresistor depends upon the amount of light striking the photoresistor sensor. This circuit can be used as a light meter, such as the one shown in **Figure 23-5**. In this device, an electronic circuit detects the potential difference and converts it to a measurement of illuminance that can be read on the digital display. The amplified voltmeter reading will drop as illuminance increases.

■ **Figure 23-5** The voltage output of this voltage divider depends upon the amount of light striking the photoresistor sensor **(a)**. Light meters used in photography make use of a voltage divider **(b)**.



## ▶ EXAMPLE Problem 1

**Voltage Drops in a Series Circuit** Two resistors,  $47.0\ \Omega$  and  $82.0\ \Omega$ , are connected in series across a  $45.0\text{-V}$  battery.

- What is the current in the circuit?
- What is the voltage drop across each resistor?
- If the  $47.0\text{-}\Omega$  resistor is replaced by a  $39.0\text{-}\Omega$  resistor, will the current increase, decrease, or remain the same?
- What is the new voltage drop across the  $82.0\text{-}\Omega$  resistor?

### 1 Analyze and Sketch the Problem

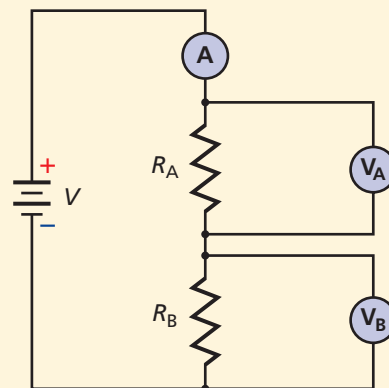
- Draw a schematic of the circuit.

**Known:** **Unknown:**

$$V_{\text{source}} = 45.0\ \text{V} \quad I = ?$$

$$R_A = 47.0\ \Omega \quad V_A = ?$$

$$R_B = 82.0\ \Omega \quad V_B = ?$$



### 2 Solve for the Unknown

- To determine the current, first find the equivalent resistance.

$$I = \frac{V_{\text{source}}}{R} \quad \text{and} \quad R = R_A + R_B$$

$$= \frac{V_{\text{source}}}{R_A + R_B} \quad \text{Substitute } R = R_A + R_B$$

$$= \frac{45.0\ \text{V}}{47.0\ \Omega + 82.0\ \Omega} \quad \text{Substitute } V_{\text{source}} = 45.0\ \text{V}, R_A = 47.0\ \Omega, R_B = 82.0\ \Omega$$

$$= 0.349\ \text{A}$$

- Use  $V = IR$  for each resistor.

$$\begin{aligned} V_A &= IR_A \\ &= (0.349\ \text{A})(47.0\ \Omega) \quad \text{Substitute } I = 0.349\ \text{A}, R_A = 47.0\ \Omega \\ &= 16.4\ \text{V} \end{aligned}$$

$$\begin{aligned} V_B &= IR_B \\ &= (0.349\ \text{A})(82.0\ \Omega) \quad \text{Substitute } I = 0.349\ \text{A}, R_B = 82.0\ \Omega \\ &= 28.6\ \text{V} \end{aligned}$$

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- Calculate current, this time using  $39.0\ \Omega$  as  $R_A$ .

$$\begin{aligned} I &= \frac{V_{\text{source}}}{R_A + R_B} \\ &= \frac{45.0\ \text{V}}{39.0\ \Omega + 82.0\ \Omega} \quad \text{Substitute } V_{\text{source}} = 45.0\ \text{V}, R_A = 39.0\ \Omega, R_B = 82.0\ \Omega \\ &= 0.372\ \text{A} \end{aligned}$$

The current will increase.

- Determine the new voltage drop in  $R_B$ .

$$\begin{aligned} V_B &= IR_B \\ &= (0.372\ \text{A})(82.0\ \Omega) \quad \text{Substitute } I = 0.372\ \text{A}, R_B = 82.0\ \Omega \\ &= 30.5\ \text{V} \end{aligned}$$

### 3 Evaluate the Answer

- Are the units correct?** Current is  $\text{A} = \text{V}/\Omega$ ; voltage is  $\text{V} = \text{A} \cdot \Omega$ .
- Is the magnitude realistic?** For current, if  $R > V$ ,  $I < 1$ . The voltage drop across any one resistor must be less than the voltage of the circuit. Both values of  $V_B$  are less than  $V_{\text{source}}$ , which is  $45\ \text{V}$ .

6. The circuit shown in Example Problem 1 is producing these symptoms: the ammeter reads 0 A,  $V_A$  reads 0 V, and  $V_B$  reads 45 V. What has happened?
7. Suppose the circuit shown in Example Problem 1 has these values:  $R_A = 255 \Omega$ ,  $R_B = 292 \Omega$ , and  $V_A = 17.0$  V. No other information is available.
  - a. What is the current in the circuit?
  - b. What is the battery voltage?
  - c. What are the total power dissipation and the individual power dissipations?
  - d. Does the sum of the individual power dissipations in the circuit equal the total power dissipation in the circuit? Explain.
8. Holiday lights often are connected in series and use special lamps that short out when the voltage across a lamp increases to the line voltage. Explain why. Also explain why these light sets might blow their fuses after many bulbs have failed.
9. The circuit in Example Problem 1 has unequal resistors. Explain why the resistor with the lower resistance will operate at a lower temperature.
10. A series circuit is made up of a 12.0-V battery and three resistors. The voltage across one resistor is 1.21 V, and the voltage across another resistor is 3.33 V. What is the voltage across the third resistor?

▶ EXAMPLE Problem 2

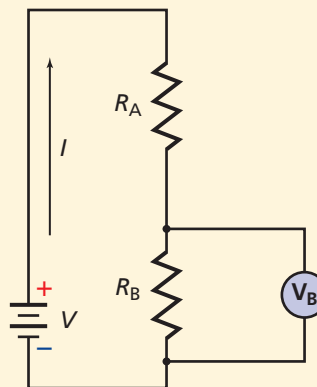
**Voltage Divider** A 9.0-V battery and two resistors,  $390 \Omega$  and  $470 \Omega$ , are connected as a voltage divider. What is the voltage across the  $470\text{-}\Omega$  resistor?

**1 Analyze and Sketch the Problem**

- Draw the battery and resistors in a series circuit.

**Known:**  $V_{\text{source}} = 9.0$  V  
 $R_A = 390 \Omega$   
 $R_B = 470 \Omega$

**Unknown:**  $V_B = ?$



**2 Solve for the Unknown**

$$R = R_A + R_B$$

$$I = \frac{V_{\text{source}}}{R}$$

$$= \frac{V_{\text{source}}}{R_A + R_B}$$

Substitute  $R = R_A + R_B$

$$V_B = IR_B$$

$$= \frac{V_{\text{source}} R_B}{R_A + R_B}$$

$$= \frac{(9.0 \text{ V})(470 \Omega)}{390 \Omega + 470 \Omega}$$

$$= 4.9 \text{ V}$$

Substitute  $I = \frac{V_{\text{source}}}{R_A + R_B}$

Substitute  $V_{\text{source}} = 9.0$  V,  $R_A = 390 \Omega$ ,  $R_B = 470 \Omega$

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**3 Evaluate the Answer**

- **Are the units correct?** The voltage is  $V = \text{V}\Omega/\Omega$ . The ohms cancel, leaving volts.
- **Is the magnitude realistic?** The voltage drop is less than the battery voltage. Because  $470 \Omega$  is more than half of the equivalent resistance, the voltage drop is more than half of the battery voltage.

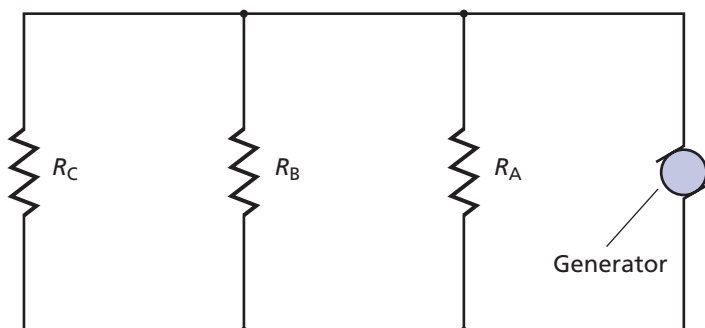


11. A  $22\text{-}\Omega$  resistor and a  $33\text{-}\Omega$  resistor are connected in series and placed across a  $120\text{-V}$  potential difference.
  - a. What is the equivalent resistance of the circuit?
  - b. What is the current in the circuit?
  - c. What is the voltage drop across each resistor?
  - d. What is the voltage drop across the two resistors together?
12. Three resistors of  $3.3\text{ k}\Omega$ ,  $4.7\text{ k}\Omega$ , and  $3.9\text{ k}\Omega$  are connected in series across a  $12\text{-V}$  battery.
  - a. What is the equivalent resistance?
  - b. What is the current through the resistors?
  - c. What is the voltage drop across each resistor?
  - d. Find the total voltage drop across the three resistors.
13. A student makes a voltage divider from a  $45\text{-V}$  battery, a  $475\text{-k}\Omega$  resistor, and a  $235\text{-k}\Omega$  resistor. The output is measured across the smaller resistor. What is the voltage?
14. Select a resistor to be used as part of a voltage divider along with a  $1.2\text{-k}\Omega$  resistor. The drop across the  $1.2\text{-k}\Omega$  resistor is to be  $2.2\text{ V}$  when the supply is  $12\text{ V}$ .

## Parallel Circuits

Look at the circuit shown in **Figure 23-6**. How many current paths are there? The current from the generator can go through any of the three resistors. A circuit in which there are several current paths is called a **parallel circuit**. The three resistors are connected in parallel; both ends of the three paths are connected together. In the mountain river model, such a circuit is illustrated by three paths for the water over a waterfall. Some paths might have a large flow of water, while others might have a small flow. The sum of the flows, however, is equal to the total flow of water over the falls. In addition, regardless of which channel the water flows through, the drop in height is the same. Similarly, in a parallel electric circuit, the total current is the sum of the currents through each path, and the potential difference across each path is the same.

■ **Figure 23-6** The parallel paths for current in this diagram are analogous to multiple paths that a river might take down a mountain.



## MINI LAB

### Parallel Resistance

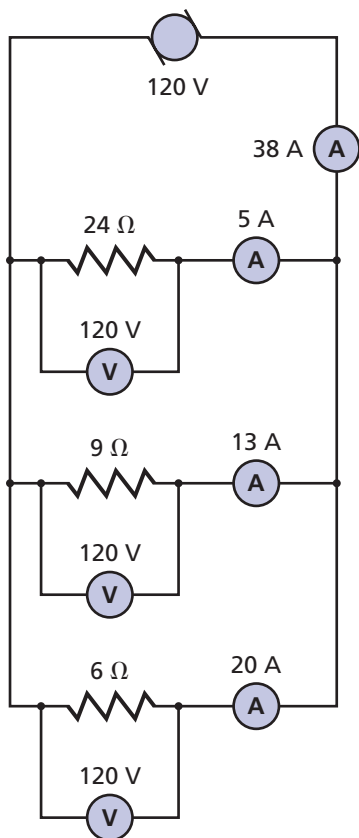


Hook up a power supply, a resistor, and an ammeter in a series circuit.

1. **Predict** what will happen to the current in the circuit when a second, identical resistor is added in parallel to the first.
2. **Test** your prediction.
3. **Predict** the new currents when the circuit contains three and four identical resistors in parallel.
4. **Test** your prediction.

### Analyze and Conclude

5. **Make** a data table to show your results.
6. **Explain** your results. (*Hint: Include the idea of resistance.*)



■ **Figure 23-7** In a parallel circuit, the total current is equal to the sum of the currents in the individual paths.

What is the current through each resistor in a parallel electric circuit? It depends upon the individual resistances. For example, in **Figure 23-7**, the potential difference across each resistor is 120 V. The current through a resistor is given by  $I = V/R$ , so you can calculate the current through the 24-Ω resistor as  $I = (120 \text{ V})/(24 \text{ } \Omega) = 5.0 \text{ A}$  and then calculate the currents through the other two resistors. The total current through the generator is the sum of the currents through the three paths, in this case, 38 A.

What would happen if the 6-Ω resistor were removed from the circuit? Would the current through the 24-Ω resistor change? That current depends only upon the potential difference across it and its resistance; because neither has changed, the current also is unchanged. The same is true for the current through the 9-Ω resistor. The branches of a parallel circuit are independent of each other. The total current through the generator, however, would change. The sum of the currents in the branches would be 18 A if the 6-Ω resistor were removed.

**Resistance in a parallel circuit** How can you find the equivalent resistance of a parallel circuit? In Figure 23-7, the total current through the generator is 38 A. Thus, the value of a single resistor that results in a 38-A current when a 120-V potential difference is placed across it can easily be calculated by using the following equation:

$$\begin{aligned} R &= \frac{V}{I} \\ &= \frac{120 \text{ V}}{38 \text{ A}} \\ &= 3.2 \text{ } \Omega \end{aligned}$$

Notice that this resistance is smaller than that of any of the three resistors in parallel. Placing two or more resistors in parallel always decreases the equivalent resistance of a circuit. The resistance decreases because each new resistor provides an additional path for current, thereby increasing the total current while the potential difference remains unchanged.

To calculate the equivalent resistance of a parallel circuit, first note that the total current is the sum of the currents through the branches. If  $I_A$ ,  $I_B$ , and  $I_C$  are the currents through the branches and  $I$  is the total current, then  $I = I_A + I_B + I_C$ . The potential difference across each resistor is the same, so the current through each resistor, for example,  $R_A$ , can be found from  $I_A = V/R_A$ . Therefore, the equation for the sum of the currents is as follows:

$$\frac{V}{R} = \frac{V}{R_A} + \frac{V}{R_B} + \frac{V}{R_C}$$

Dividing both sides of the equation by  $V$  provides an equation for the equivalent resistance of the three parallel resistors.

#### Equivalent Resistance for Resistors in Parallel

$$\frac{1}{R} = \frac{1}{R_A} + \frac{1}{R_B} + \frac{1}{R_C} \dots$$

The reciprocal of the equivalent resistance is equal to the sum of the reciprocals of the individual resistances.

This equation can be used for any number of resistors in parallel.

## APPLYING PHYSICS

### ► Testing Resistance

Ohmmeters, which are used to measure resistance, work by passing a known voltage across a resistor and measuring the current. The resistance is then displayed. Some ohmmeters use potentials of less than 1 V to avoid damaging delicate electronic components, whereas others may use hundreds of volts to check the integrity of insulating materials. ◀



## ▶ EXAMPLE Problem 3

**Equivalent Resistance and Current in a Parallel Circuit** Three resistors,  $60.0\ \Omega$ ,  $30.0\ \Omega$ , and  $20.0\ \Omega$ , are connected in parallel across a  $90.0\text{-V}$  battery.

- Find the current through each branch of the circuit.
- Find the equivalent resistance of the circuit.
- Find the current through the battery.

### 1 Analyze and Sketch the Problem

- Draw a schematic of the circuit.
- Include ammeters to show where you would measure each of the currents.

**Known:**

$$R_A = 60.0\ \Omega$$

$$R_B = 30.0\ \Omega$$

$$R_C = 20.0\ \Omega$$

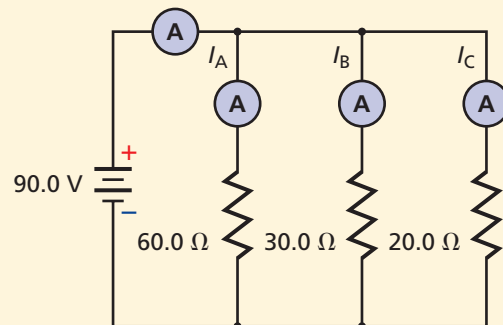
$$V = 90.0\ \text{V}$$

**Unknown:**

$$I_A = ? \quad I = ?$$

$$I_B = ? \quad R = ?$$

$$I_C = ?$$



### 2 Solve for the Unknown

- Because the voltage across each resistor is the same, use  $I = \frac{V}{R}$  for each branch.

$$\begin{aligned} I_A &= \frac{V}{R_A} \\ &= \frac{90.0\ \text{V}}{60.0\ \Omega} \\ &= 1.50\ \text{A} \end{aligned}$$

Substitute  $V = 90.0\ \text{V}$ ,  $R_A = 60.0\ \Omega$

$$\begin{aligned} I_B &= \frac{V}{R_B} \\ &= \frac{90.0\ \text{V}}{30.0\ \Omega} \\ &= 3.00\ \text{A} \end{aligned}$$

Substitute  $V = 90.0\ \text{V}$ ,  $R_B = 30.0\ \Omega$

$$\begin{aligned} I_C &= \frac{V}{R_C} \\ &= \frac{90.0\ \text{V}}{20.0\ \Omega} \\ &= 4.50\ \text{A} \end{aligned}$$

Substitute  $V = 90.0\ \text{V}$ ,  $R_C = 20.0\ \Omega$

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- Use the equivalent resistance equation for parallel circuits.

$$\begin{aligned} \frac{1}{R} &= \frac{1}{R_A} + \frac{1}{R_B} + \frac{1}{R_C} \\ &= \frac{1}{60.0\ \Omega} + \frac{1}{30.0\ \Omega} + \frac{1}{20.0\ \Omega} \\ &= \frac{1}{10.0\ \Omega} \\ R &= 10.0\ \Omega \end{aligned}$$

Substitute  $R_A = 60.0\ \Omega$ ,  $R_B = 30.0\ \Omega$ ,  $R_C = 20.0\ \Omega$

- Use  $I = \frac{V}{R}$  to find the total current.

$$\begin{aligned} I &= \frac{V}{R} \\ &= \frac{90.0\ \text{V}}{10.0\ \Omega} \\ &= 9.00\ \text{A} \end{aligned}$$

Substitute  $V = 90.0\ \text{V}$ ,  $R = 10.0\ \Omega$

### 3 Evaluate the Answer

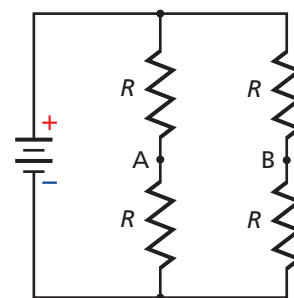
- Are the units correct?** Current is measured in amps; resistance is measured in ohms.
- Is the magnitude realistic?** The equivalent resistance is less than any single resistor. The current for the circuit,  $I$ , equals the sum of the current found for each resistor,  $I_A + I_B + I_C$ .

15. Three  $15.0\text{-}\Omega$  resistors are connected in parallel and placed across a  $30.0\text{-V}$  battery.
  - a. What is the equivalent resistance of the parallel circuit?
  - b. What is the current through the entire circuit?
  - c. What is the current through each branch of the circuit?
16. A  $120.0\text{-}\Omega$  resistor, a  $60.0\text{-}\Omega$  resistor, and a  $40.0\text{-}\Omega$  resistor are connected in parallel and placed across a  $12.0\text{-V}$  battery.
  - a. What is the equivalent resistance of the parallel circuit?
  - b. What is the current through the entire circuit?
  - c. What is the current through each branch of the circuit?
17. Suppose that one of the  $15.0\text{-}\Omega$  resistors in problem 15 is replaced by a  $10.0\text{-}\Omega$  resistor.
  - a. Does the equivalent resistance change? If so, how?
  - b. Does the amount of current through the entire circuit change? If so, in what way?
  - c. Does the amount of current through the other  $15.0\text{-}\Omega$  resistors change? If so, how?
18. A  $150\text{-}\Omega$  branch in a circuit must be reduced to  $93\ \Omega$ . A resistor will be added to this branch of the circuit to make this change. What value of resistance should be used and how must the resistor be connected?
19. A  $12\text{-}\Omega$ ,  $2\text{-W}$  resistor is connected in parallel with a  $6.0\text{-}\Omega$ ,  $4\text{-W}$  resistor. Which will become hotter if the voltage across them keeps increasing?

Series and parallel connections differ in how they affect a lighting circuit. Imagine a  $60\text{-W}$  and a  $100\text{-W}$  bulb are used in a lighting circuit. Recall that the brightness of a lightbulb is proportional to the power it dissipates, and that  $P = I^2R$ . When the bulbs are connected in parallel, each is connected across  $120\text{ V}$  and the  $100\text{-W}$  bulb glows more brightly. When connected in series, the current through each bulb is the same. Because the resistance of the  $60\text{-W}$  bulb is greater than that of the  $100\text{-W}$  bulb, the higher-resistance  $60\text{-W}$  bulb dissipates more power and glows more brightly.

## 23.1 Section Review

20. **Circuit Types** Compare and contrast the voltages and the currents in series and parallel circuits.
21. **Total Current** A parallel circuit has four branch currents:  $120\text{ mA}$ ,  $250\text{ mA}$ ,  $380\text{ mA}$ , and  $2.1\text{ A}$ . How much current is supplied by the source?
22. **Total Current** A series circuit has four resistors. The current through one resistor is  $810\text{ mA}$ . How much current is supplied by the source?
23. **Circuits** A switch is connected in series with a  $75\text{-W}$  bulb to a source of  $120\text{ V}$ .
  - a. What is the potential difference across the switch when it is closed (turned on)?
  - b. What is the potential difference across the switch if another  $75\text{-W}$  bulb is added in series?
24. **Critical Thinking** The circuit in **Figure 23-8** has four identical resistors. Suppose that a wire is added to connect points A and B. Answer the following questions, and explain your reasoning.
  - a. What is the current through the wire?
  - b. What happens to the current through each resistor?
  - c. What happens to the current drawn from the battery?
  - d. What happens to the potential difference across each resistor?



■ Figure 23-8



## 23.2 Applications of Circuits

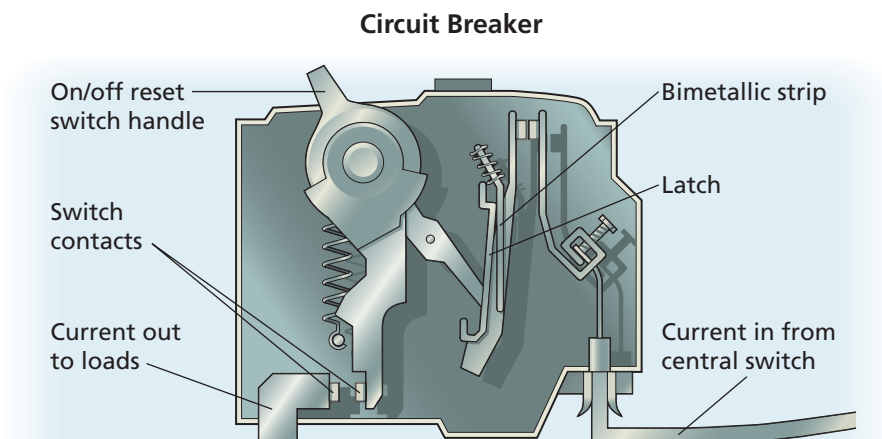
You have learned about some of the elements of household wiring circuits. It is important to understand the requirements and limitations of these systems. Above all, you need to be aware of the safety measures that must be followed to prevent accidents and injuries.

### Safety Devices

In an electric circuit, fuses and circuit breakers act as safety devices. They prevent circuit overloads that can occur when too many appliances are turned on at the same time or when a short circuit occurs in one appliance. A **short circuit** occurs when a circuit with a very low resistance is formed. The low resistance causes the current to be very large. When appliances are connected in parallel, each additional appliance placed in operation reduces the equivalent resistance in the circuit and increases the current through the wires. This additional current might produce enough thermal energy to melt the wiring's insulation, cause a short circuit, or even begin a fire.

A **fuse** is a short piece of metal that melts when too large a current passes through it. The thickness of the metal used in the fuse is determined by the amount of current that the circuit is designed to handle safely. If a large, unsafe current passes through the circuit, the fuse melts and breaks the circuit. A **circuit breaker**, shown in **Figure 23-9**, is an automatic switch that opens when the current reaches a threshold value. If there is a current greater than the rated (threshold) value in the circuit, the circuit becomes overloaded. The circuit breaker opens and stops the current.

Current follows a single path from the power source through an electrical appliance and back to the source. Sometimes, a faulty appliance or an accidental drop of the appliance into water might create another current pathway. If this pathway flows through the user, serious injury could result. A current as small as 5 mA flowing through a person could result in electrocution. A **ground-fault interrupter** in an electric outlet prevents such injuries because it contains an electronic circuit that detects small differences in current caused by an extra current path and opens the circuit. Electric codes for buildings often require ground-fault interrupters to be used in bathroom, kitchen, and exterior outlets.



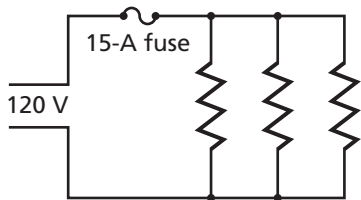
#### ► Objectives

- **Explain** how fuses, circuit breakers, and ground-fault interrupters protect household wiring.
- **Analyze** and solve problems involving combined series-parallel circuits.
- **Explain** how voltmeters and ammeters are used in circuits.

#### ► Vocabulary

short circuit  
fuse  
circuit breaker  
ground-fault interrupter  
combination series-parallel circuit  
ammeter  
voltmeter

■ **Figure 23-9** When too much current flows through the bimetallic strip, the heat that is generated causes the strip to bend and release the latch. The handle moves to the off position, causing the switch to open and break the circuit.



■ **Figure 23-10** The parallel wiring arrangement used in homes allows the simultaneous use of more than one appliance. However, if too many appliances are used at once, the fuse could melt.

**Household applications** **Figure 23-10** diagrams a parallel circuit used in the wiring of homes, and also shows some common appliances that would be connected in parallel. The current in any one circuit does not depend upon the current in the other circuits. Suppose that a 240-W television is plugged into a 120-V outlet. The current is represented by  $I = P/V$ . For the television,  $I = (240 \text{ W})/(120 \text{ V}) = 2.0 \text{ A}$ . When a 720-W curling iron is plugged into the outlet, its current draw is  $I = (720 \text{ W})/(120 \text{ V}) = 6.0 \text{ A}$ . Finally, a 1440-W hair dryer is plugged into the same outlet. The current through the hair dryer is  $I = (1440 \text{ W})/(120 \text{ V}) = 12 \text{ A}$ . The resistance of each appliance can be calculated using the equation  $R = V/I$ . The equivalent resistance of the three appliances is as follows.

$$\begin{aligned} \frac{1}{R} &= \frac{1}{60 \Omega} + \frac{1}{20 \Omega} + \frac{1}{10 \Omega} \\ &= \frac{1}{6 \Omega} \\ R &= 6 \Omega \end{aligned}$$

A fuse is connected in series with the power source so that the entire current passes through it. The current through the fuse is calculated using the equivalent resistance.

$$I = \frac{V}{R} = \frac{120 \text{ V}}{6 \Omega} = 20 \text{ A}$$

If the fuse in the circuit is rated as 15 A, the 20-A current would exceed the rating and cause the fuse to melt, or “blow,” and cut off current.

Fuses and circuit breakers also protect against the large currents created by a short circuit. Without a fuse or a circuit breaker, the current caused by a short circuit easily could start a fire. For example, a short circuit could occur if the insulation on a lamp cord became old and brittle. The two wires in the cord might accidentally touch, resulting in a resistance in the wire of only 0.010  $\Omega$ . This resistance results in a huge current.

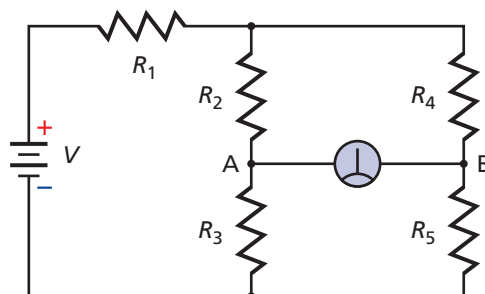
$$I = \frac{V}{R} = \frac{120 \text{ V}}{0.010 \Omega} = 12,000 \text{ A}$$

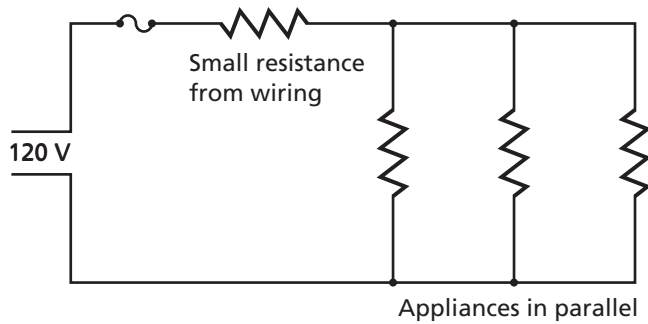
Such a current would cause a fuse or a circuit breaker to open the circuit, thereby preventing the wires from becoming hot enough to start a fire.

## ● CHALLENGE PROBLEM

When the galvanometer, a device used to measure very small currents or voltages, in this circuit measures zero, the circuit is said to be balanced.

1. Your lab partner states that the only way to balance this circuit is to make all the resistors equal. Will this balance the circuit? Is there more than one way to balance this circuit? Explain.
2. Derive a general equation for a balanced circuit using the given labels. *Hint: Treat the circuit as a voltage divider.*
3. Which of the resistors can be replaced with a variable resistor and then used to balance the circuit?
4. Which of the resistors can be replaced with a variable resistor and then used as a sensitivity control? Why would this be necessary? How would it be used in practice?





■ **Figure 23-11** The small resistance inherent in wires is in series with the parallel resistances of household appliances.

## Combined Series-Parallel Circuits

Have you ever noticed the light in your bathroom or bedroom dim when you turned on a hair dryer? The light and the hair dryer are connected in parallel across 120 V. Because of the parallel connection, the current through the light should not have changed when you turned on the hair dryer. Yet the light did dim, so the current must have changed. The dimming occurred because the house wiring had a small resistance. As shown in **Figure 23-11**, this resistance was in series with the parallel circuit. Such a circuit, which includes series and parallel branches, is called a **combination series-parallel circuit**. The following are strategies for analyzing such circuits.

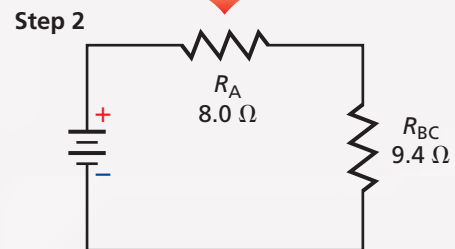
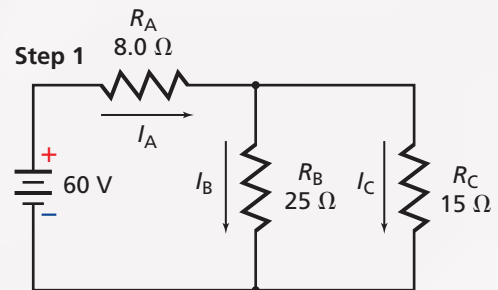
### ► PROBLEM-SOLVING Strategies

#### Series-Parallel Circuits

When analyzing a combination series-parallel circuit, use the following steps to break down the problem.

1. Draw a schematic diagram of the circuit.
2. Find any parallel resistors. Resistors in parallel have separate current paths. They must have the same potential differences across them. Calculate the single equivalent resistance of a resistor that can replace them. Draw a new schematic using that resistor.
3. Are any resistors (including the equivalent resistor) now in series? Resistors in series have one and only one current path through them. Calculate a single new equivalent resistance that can replace them. Draw a new schematic diagram using that resistor.
4. Repeat steps 2 and 3 until you can reduce the circuit to a single resistor. Find the total circuit current. Then go backwards through the circuits to find the currents through and the voltages across individual resistors.

#### Reducing Circuit Diagrams



## ▶ EXAMPLE Problem 4

**Series-Parallel Circuit** A hair dryer with a resistance of  $12.0\ \Omega$  and a lamp with a resistance of  $125\ \Omega$  are connected in parallel to a  $125\text{-V}$  source through a  $1.50\text{-}\Omega$  resistor in series. Find the current through the lamp when the hair dryer is on.

### 1 Analyze and Sketch the Problem

- Draw the series-parallel circuit including the hair dryer and lamp.
- Replace  $R_A$  and  $R_B$  with a single equivalent resistance,  $R_p$ .

**Known:**

$$R_A = 125\ \Omega \quad R_C = 1.50\ \Omega$$

$$R_B = 12.0\ \Omega \quad V_{\text{source}} = 125\ \text{V}$$

**Unknown:**

$$I = ? \quad I_A = ?$$

$$R = ? \quad R_p = ?$$

### 2 Solve for the Unknown

Find the equivalent resistance for the parallel circuit, then find the equivalent resistance for the entire circuit, and then calculate the current.

$$\frac{1}{R_p} = \frac{1}{R_A} + \frac{1}{R_B} = \frac{1}{125\ \Omega} + \frac{1}{12.0\ \Omega} \quad \text{Substitute } R_A = 125\ \Omega, R_B = 12.0\ \Omega$$

$$R_p = 10.9\ \Omega$$

$$R = R_C + R_p = 1.50\ \Omega + 11.0\ \Omega \quad \text{Substitute } R_C = 1.50\ \Omega, R_p = 10.9\ \Omega$$

$$= 12.4\ \Omega$$

$$I = \frac{V_{\text{source}}}{R} = \frac{125\ \text{V}}{12.4\ \Omega} \quad \text{Substitute } V_{\text{source}} = 125\ \text{V}, R = 12.4\ \Omega$$

$$= 10.1\ \text{A}$$

$$V_C = IR_C = (10.1\ \text{A})(1.50\ \Omega) \quad \text{Substitute } I = 10.1\ \text{A}, R_C = 1.50\ \Omega$$

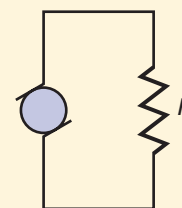
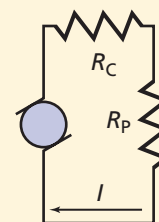
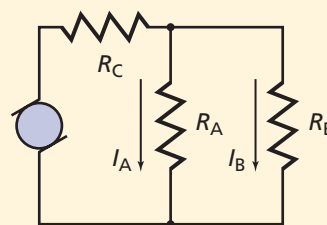
$$= 15.2\ \text{V}$$

$$V_A = V_{\text{source}} - V_C = 125\ \text{V} - 15.2\ \text{V} \quad \text{Substitute } V_{\text{source}} = 125\ \text{V}, V_C = 15.2\ \text{V}$$

$$= 1.10 \times 10^2\ \text{V}$$

$$I_A = \frac{V_A}{R_A} = \frac{1.10 \times 10^2\ \text{V}}{125\ \Omega} \quad \text{Substitute } V_A = 1.10 \times 10^2\ \text{V}, R_A = 125\ \Omega$$

$$= 0.880\ \text{A}$$



#### Math Handbook

Operations with Significant Digits  
pages 835–836

### 3 Evaluate the Answer

- **Are the units correct?** Current is measured in amps, and potential drops are measured in volts.
- **Is the magnitude realistic?** The resistance is greater than the voltage, so the current should be less than  $1\ \text{A}$ .

## ▶ PRACTICE Problems

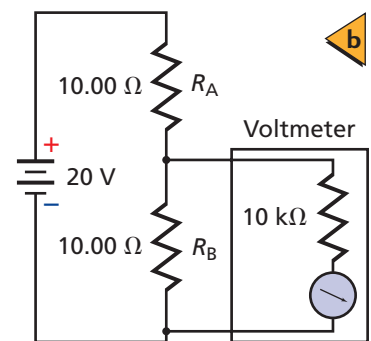
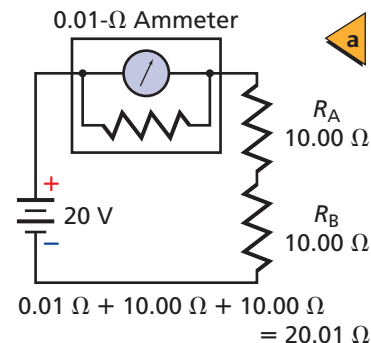
Additional Problems, Appendix B

25. A series-parallel circuit has three resistors: one dissipates  $2.0\ \text{W}$ , the second  $3.0\ \text{W}$ , and the third  $1.5\ \text{W}$ . How much current does the circuit require from a  $12\text{-V}$  battery?
26. There are 11 lights in series, and they are in series with two lights in parallel. If the 13 lights are identical, which of them will burn brightest?
27. What will happen to the circuit in problem 26 if one of the parallel lights burns out?
28. What will happen to the circuit in problem 26 if one of the parallel lights shorts out?

## Ammeters and Voltmeters

An **ammeter** is a device that is used to measure the current in any branch or part of a circuit. If, for example, you wanted to measure the current through a resistor, you would place an ammeter in series with the resistor. This would require opening the current path and inserting an ammeter. Ideally, the use of an ammeter should not change the current in the circuit. Because the current would decrease if the ammeter increased the resistance in the circuit, the resistance of an ammeter is designed to be as low as possible. **Figure 23-12a** shows an ammeter as a meter placed in parallel with a  $0.01\text{-}\Omega$  resistor. Because the resistance of the ammeter is much less than that of the resistors, the current decrease is negligible.

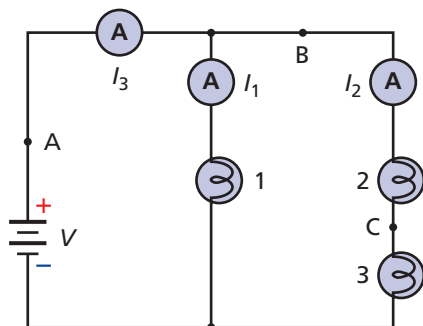
Another instrument, called a **voltmeter**, is used to measure the voltage drop across a portion of a circuit. To measure the potential drop across a resistor, a voltmeter is connected in parallel with the resistor. Voltmeters are designed to have a very high resistance so as to cause the smallest possible change in currents and voltages in the circuit. Consider the circuit shown in **Figure 23-12b**. A voltmeter is shown as a meter in series with a  $10\text{-k}\Omega$  resistor. When the voltmeter is connected in parallel with  $R_B$ , the equivalent resistance of the combination is smaller than  $R_B$  alone. Thus, the total resistance of the circuit decreases, and the current increases. The value of  $R_A$  has not changed, but the current through it has increased, thereby increasing the potential drop across it. The battery, however, holds the potential drop across  $R_A$  and  $R_B$  constant. Thus, the potential drop across  $R_B$  must decrease. The result of connecting a voltmeter across a resistor is to lower the potential drop across it. The higher the resistance of the voltmeter, the smaller the voltage change. Practical meters have resistances of  $10\text{ M}\Omega$ .



■ **Figure 23-12** An ammeter is connected in series with two resistors (a). The small resistance of the ammeter slightly alters the current in the circuit. A voltmeter is connected in parallel with a resistor (b). The high resistance of the voltmeter results in a negligible change in the circuit current and voltage.

## 23.2 Section Review

Refer to **Figure 23-13** for questions 29–33, and 35. The bulbs in the circuit are identical.



■ **Figure 23-13**

**29. Brightness** How do the bulb brightnesses compare?

**30. Current** If  $I_3$  measures  $1.7\text{ A}$  and  $I_1$  measures  $1.1\text{ A}$ , how much current is flowing in bulb 2?

**31. Circuits in Series** The wire at point C is broken and a small resistor is inserted in series with bulbs 2 and 3. What happens to the brightnesses of the two bulbs? Explain.

**32. Battery Voltage** A voltmeter connected across bulb 2 measures  $3.8\text{ V}$ , and a voltmeter connected across bulb 3 measures  $4.2\text{ V}$ . What is the battery voltage?

**33. Circuits** Using the information from problem 32, determine if bulbs 2 and 3 are identical.

**34. Circuit Protection** Describe three common safety devices associated with household wiring.

**35. Critical Thinking** Is there a way to make the three bulbs in Figure 23-13 burn with equal intensity without using any additional resistors? Explain.

## Series and Parallel Circuits

Alternate CBL instructions can be found on the Web site.  
[physicspp.com](http://physicspp.com)

In every circuit there is a relationship among current, potential difference, and resistance in electric circuits. In this experiment, you will investigate how the relationship of current, potential difference, and resistance in series circuits compares to that in parallel circuits.

### QUESTION

**How do relationships among current, potential difference, and resistance compare in series and parallel circuits?**

#### Objectives

- **Describe** the relationship among current, potential difference, and resistance in a series circuit.
- **Summarize** the relationship among current, potential difference, and resistance in a parallel circuit.
- **Collect data** for current and potential difference using electric meters.
- **Calculate** resistance in a lightbulb from current and potential-difference data.

#### Safety Precautions



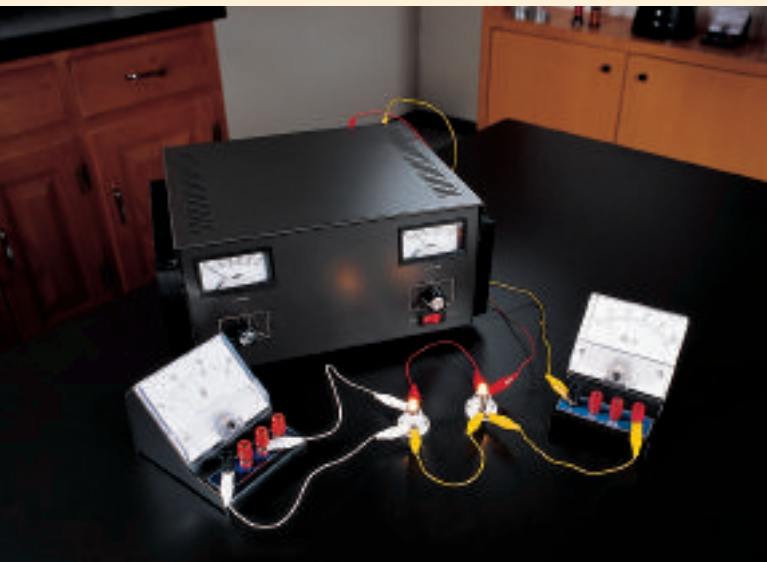
- **Hazard from electric shock is minimal because of the low currents used in this experiment. This experiment should not be carried out using current from an AC circuit, as this current is deadly.**
- **Handle wire ends with care as they may be sharp and could cause cuts.**

#### Materials

low-voltage power supply  
 two light sockets  
 two small lightbulbs  
 ammeter or multimeter (0–500-mA scale)  
 voltmeter or multimeter (0–30-V scale)  
 about ten copper wires with alligator clips

#### Procedure

1. Wire two lightbulb sockets in series with an ammeter and a low-voltage power supply. Observe the correct polarity when wiring the ammeter.
2. Screw the lightbulbs into the sockets. Turn on the power supply. Adjust the power control so that the bulbs are dimly lit.
3. Unscrew one of the bulbs. Record your observations in the data table.
4. Screw in the bulb again and find the potential difference across both sets of bulbs by placing the positive probe of the voltmeter on the positive end of the circuit and the negative probe on the negative end of the circuit. Record your data in the data table.
5. Find the potential difference across each individual lightbulb by placing the positive probe of the voltmeter on the positive end of a bulb and the negative probe on the negative end of the bulb. Record your data in the data table. Repeat for the other bulb in series.
6. Place the ammeter at various locations in the series circuit. Record these currents in the data table.
7. Wire the two lightbulb sockets in parallel with the low-voltage power supply and in series with an ammeter.



Data Table	
Step	Observations
3	
4	
5	
6	
8	
9	
10	
11	

- Screw the lightbulbs into the sockets. Turn on the power supply. Adjust the power control so that the bulbs are dimly lit. Record the current shown on the ammeter in the data table.
- Check the potential difference across the entire circuit and across each lightbulb. Record the values in the data table.
- Place the voltmeter probes across one of the lightbulbs. Now unscrew one of the lightbulbs. Record your observations of both lightbulbs, and record the current and potential difference read by the meters in the data table.
- Return the lightbulb you removed in the previous step to its socket. Now unscrew the other lightbulb. Record your observations of both lightbulbs, and record the current and potential difference read by the meters in the data table.

### Analyze

- Calculate the resistance of the pair of lightbulbs in the series circuit.
- Calculate the resistance of each lightbulb in the series circuit.
- How does the resistance of the pair of lightbulbs compare to the individual resistance of each lightbulb?
- How does the potential difference across the individual lightbulbs compare to the potential difference across the pair of lightbulbs in the series circuit?
- Calculate the resistance of each of the lightbulbs while they are in the parallel circuit. How does this compare to the resistance calculated for the bulbs in the series circuit?

### Conclude and Apply

- Summarize the relationship among current, potential difference, and resistance in a series circuit.
- Summarize the relationship between current and potential difference in a parallel circuit.

### Going Further

Repeat the experiment using lightbulbs of different voltage ratings (for example: 1.5 V, 3.0 V, and 6.0 V).

### Real-World Physics

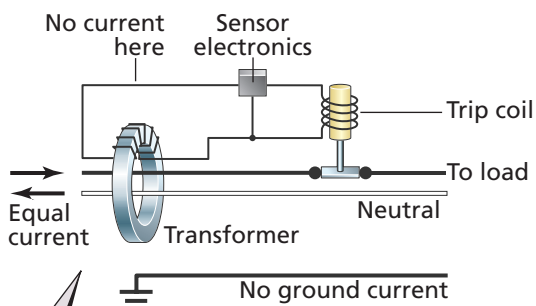
- The lightbulbs in most homes all are rated for 120 V, no matter how many bulbs there are. How is the ability to use any number of same-voltage bulbs affected by the way in which the bulbs are wired (series or parallel)?
- Why do lights in a home dim when a large appliance, such as an air conditioner, is turned on?



To find out more about series and parallel circuits, visit the Web site: [physicspp.com](http://physicspp.com)

## Ground Fault Circuit Interrupters (GFCI)

A ground fault occurs when electricity takes an incorrect path to ground, such as through a person's body. Charles Dalziel, an engineering professor at the University of California, was an expert on the effects of electric shock. When he realized that ground faults were the cause of many electrocutions, he invented a device to prevent such accidents. How does a ground fault circuit interrupter (GFCI) work?



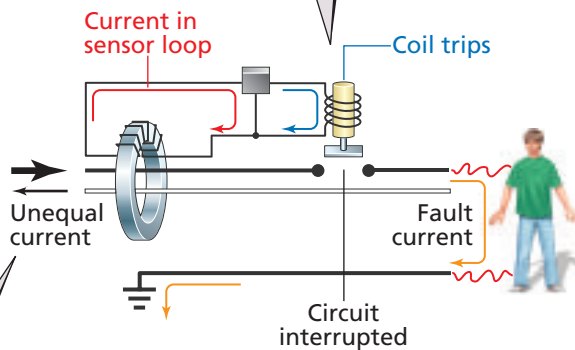
**1** In normal operation, there are equal and opposite currents through the wires, so the net current through the transformer is zero.



**4** A test button on the GFCI connects a small resistor to the circuit, again creating unequal currents in the transformer and opening the circuit.

**2** In a ground fault, there is current from the hot conductor through a person and to the ground. The currents in the two wires are unequal, and a net current passes through the transformer.

**3** The net current induces a changing magnetic field in the transformer core, which induces a current in the loop with the sensor electronics. The sensor detects the current and energizes an electromagnet, called the trip coil, thus breaking the circuit. This process takes 0.025 s.



### Thinking Critically

- Hypothesize** Ground faults can occur when a person standing in water touches an appliance that is plugged in. How is water a factor in creating the ground fault?
- Analyze and Conclude** Will a GFCI protect a person who touches one wire with one hand and the other wire with the other hand? Explain.
- Calculate** In one GFCI, the test resistor is 14.75 kΩ. For a voltage of 115 V, calculate the current through this resistor. Is this a lot of current?

### 23.1 Simple Circuits

#### Vocabulary

- series circuit (p. 618)
- equivalent resistance (p. 619)
- voltage divider (p. 620)
- parallel circuit (p. 623)

#### Key Concepts

- The current is the same everywhere in a simple series circuit.
- The equivalent resistance of a series circuit is the sum of the resistances of its parts.

$$R = R_A + R_B + \dots$$

- The current in a series circuit is equal to the potential difference divided by the equivalent resistance.

$$I = \frac{V_{\text{source}}}{R}$$

- The sum of the voltage drops across resistors that are in series is equal to the potential difference applied across the combination.
- A voltage divider is a series circuit used to produce a voltage source of desired magnitude from a higher-voltage battery.
- The voltage drops across all branches of a parallel circuit are the same.
- In a parallel circuit, the total current is equal to the sum of the currents in the branches.
- The reciprocal of the equivalent resistance of parallel resistors is equal to the sum of the reciprocals of the individual resistances.

$$\frac{1}{R} = \frac{1}{R_A} + \frac{1}{R_B} + \frac{1}{R_C} + \dots$$

- If any branch of a parallel circuit is opened, there is no current in that branch. The current in the other branches is unchanged.

### 23.2 Applications of Circuits

#### Vocabulary

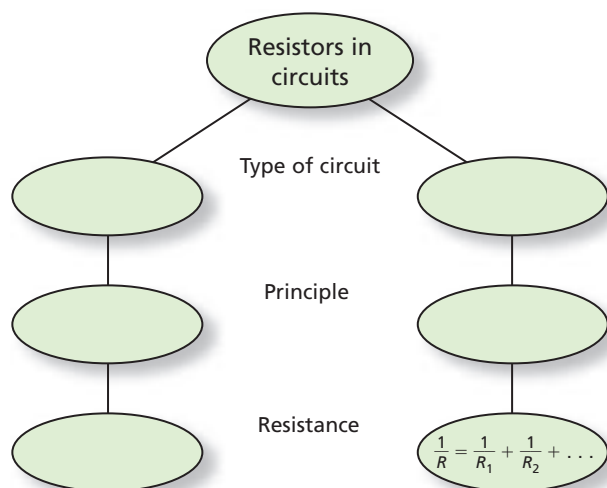
- short circuit (p. 627)
- fuse (p. 627)
- circuit breaker (p. 627)
- ground-fault interrupter (p. 627)
- combination series-parallel circuit (p. 629)
- ammeter (p. 631)
- voltmeter (p. 631)

#### Key Concepts

- A fuse or circuit breaker, placed in series with appliances, creates an open circuit when dangerously high currents flow.
- A complex circuit is a combination of series and parallel branches. Any parallel branch first is reduced to a single equivalent resistance. Then, any resistors in series are replaced by a single resistance.
- An ammeter is used to measure the current in a branch or part of a circuit. An ammeter always has a low resistance and is connected in series.
- A voltmeter measures the potential difference (voltage) across any part or combination of parts of a circuit. A voltmeter always has a high resistance and is connected in parallel with the part of the circuit being measured.

## Concept Mapping

36. Complete the concept map using the following terms: *series circuit*,  $R = R_1 + R_2 + R_3$ , *constant current*, *parallel circuit*, *constant potential*.



## Mastering Concepts

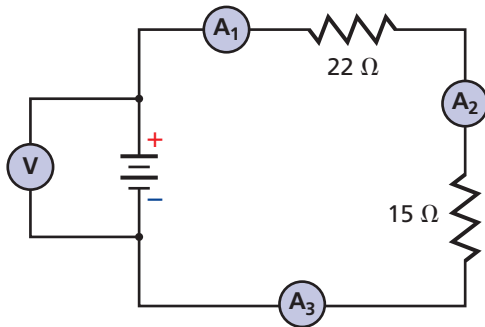
37. Why is it frustrating when one bulb burns out on a string of holiday tree lights connected in series? (23.1)
38. Why does the equivalent resistance decrease as more resistors are added to a parallel circuit? (23.1)
39. Several resistors with different values are connected in parallel. How do the values of the individual resistors compare with the equivalent resistance? (23.1)
40. Why is household wiring constructed in parallel instead of in series? (23.1)
41. Why is there a difference in equivalent resistance between three  $60\text{-}\Omega$  resistors connected in series and three  $60\text{-}\Omega$  resistors connected in parallel? (23.1)
42. Compare the amount of current entering a junction in a parallel circuit with that leaving the junction. (A junction is a point where three or more conductors are joined.) (23.1)
43. Explain how a fuse functions to protect an electric circuit. (23.2)
44. What is a short circuit? Why is a short circuit dangerous? (23.2)
45. Why is an ammeter designed to have a very low resistance? (23.2)
46. Why is a voltmeter designed to have a very high resistance? (23.2)
47. How does the way in which an ammeter is connected in a circuit differ from the way in which a voltmeter is connected? (23.2)
48. What happens to the current in the other two lamps if one lamp in a three-lamp series circuit burns out?
49. Suppose the resistor,  $R_A$ , in the voltage divider in Figure 23-4 is made to be a variable resistor. What happens to the voltage output,  $V_B$ , of the voltage divider if the resistance of the variable resistor is increased?
50. Circuit A contains three  $60\text{-}\Omega$  resistors in series. Circuit B contains three  $60\text{-}\Omega$  resistors in parallel. How does the current in the second  $60\text{-}\Omega$  resistor of each circuit change if a switch cuts off the current to the first  $60\text{-}\Omega$  resistor?
51. What happens to the current in the other two lamps if one lamp in a three-lamp parallel circuit burns out?
52. An engineer needs a  $10\text{-}\Omega$  resistor and a  $15\text{-}\Omega$  resistor, but there are only  $30\text{-}\Omega$  resistors in stock. Must new resistors be purchased? Explain.
53. If you have a 6-V battery and many 1.5-V bulbs, how could you connect them so that they light but do not have more than 1.5 V across each bulb?
54. Two lamps have different resistances, one larger than the other.
  - If the lamps are connected in parallel, which is brighter (dissipates more power)?
  - When the lamps are connected in series, which lamp is brighter?
55. For each of the following, write the form of circuit that applies: series or parallel.
  - The current is the same everywhere throughout the entire circuit.
  - The total resistance is equal to the sum of the individual resistances.
  - The voltage drop across each resistor in the circuit is the same.
  - The voltage drop in the circuit is proportional to the resistance.
  - Adding a resistor to the circuit decreases the total resistance.
  - Adding a resistor to the circuit increases the total resistance.
  - If the current through one resistor in the circuit goes to zero, there is no current in the entire circuit.
  - If the current through one resistor in the circuit goes to zero, the current through all other resistors remains the same.
  - This form is suitable for house wiring.
56. **Household Fuses** Why is it dangerous to replace the 15-A fuse used to protect a household circuit with a fuse that is rated at 30 A?

## Applying Concepts

## Mastering Problems

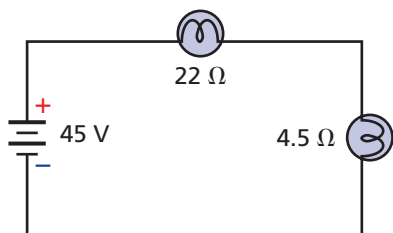
### 23.1 Simple Circuits

57. Ammeter 1 in **Figure 23-14** reads 0.20 A.  
 a. What should ammeter 2 indicate?  
 b. What should ammeter 3 indicate?



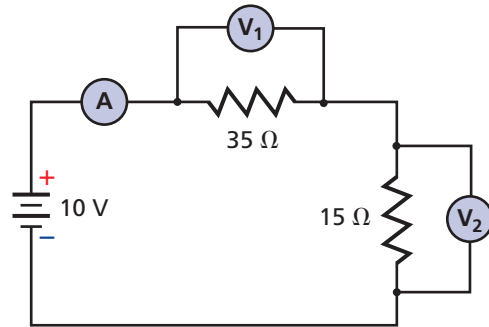
■ Figure 23-14

58. Calculate the equivalent resistance of these series-connected resistors: 680 Ω, 1.1 kΩ, and 10 kΩ.  
 59. Calculate the equivalent resistance of these parallel-connected resistors: 680 Ω, 1.1 kΩ, and 10.2 kΩ.  
 60. A series circuit has two voltage drops: 5.50 V and 6.90 V. What is the supply voltage?  
 61. A parallel circuit has two branch currents: 3.45 A and 1.00 A. What is the current in the energy source?  
 62. Ammeter 1 in **Figure 23-14** reads 0.20 A.  
 a. What is the total resistance of the circuit?  
 b. What is the battery voltage?  
 c. How much power is delivered to the 22-Ω resistor?  
 d. How much power is supplied by the battery?  
 63. Ammeter 2 in **Figure 23-14** reads 0.50 A.  
 a. Find the voltage across the 22-Ω resistor.  
 b. Find the voltage across the 15-Ω resistor.  
 c. What is the battery voltage?  
 64. A 22-Ω lamp and a 4.5-Ω lamp are connected in series and placed across a potential difference of 45 V as shown in **Figure 23-15**.  
 a. What is the equivalent resistance of the circuit?  
 b. What is the current in the circuit?  
 c. What is the voltage drop across each lamp?  
 d. What is the power dissipated in each lamp?



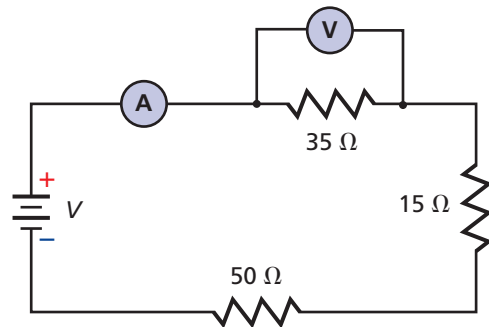
■ Figure 23-15

65. Refer to **Figure 23-16** to answer the following questions.  
 a. What should the ammeter read?  
 b. What should voltmeter 1 read?  
 c. What should voltmeter 2 read?  
 d. How much energy is supplied by the battery per minute?



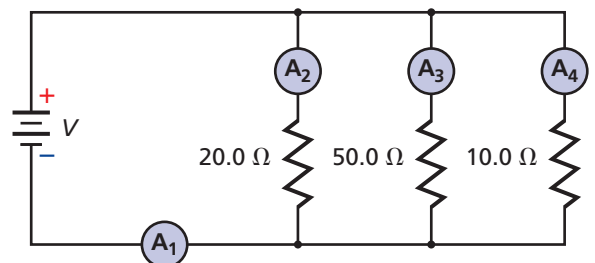
■ Figure 23-16

66. For **Figure 23-17**, the voltmeter reads 70.0 V.  
 a. Which resistor is the hottest?  
 b. Which resistor is the coolest?  
 c. What will the ammeter read?  
 d. What is the power supplied by the battery?



■ Figure 23-17

67. For **Figure 23-18**, the battery develops 110 V.  
 a. Which resistor is the hottest?  
 b. Which resistor is the coolest?  
 c. What will ammeter 1 read?  
 d. What will ammeter 2 read?  
 e. What will ammeter 3 read?  
 f. What will ammeter 4 read?



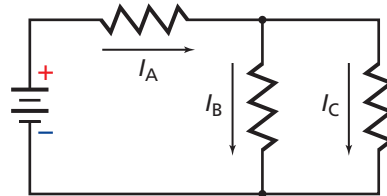
■ Figure 23-18

## Chapter 23 Assessment

68. For Figure 23-18, ammeter 3 reads 0.40 A.
- What is the battery voltage?
  - What will ammeter 1 read?
  - What will ammeter 2 read?
  - What will ammeter 4 read?
69. What is the direction of the conventional current in the 50.0- $\Omega$  resistor in Figure 23-18?
70. The load across a battery consists of two resistors, with values of 15  $\Omega$  and 47  $\Omega$ , connected in series.
- What is the total resistance of the load?
  - What is the voltage of the battery if the current in the circuit is 97 mA?
71. **Holiday Lights** A string of 18 identical holiday tree lights is connected in series to a 120-V source. The string dissipates 64 W.
- What is the equivalent resistance of the light string?
  - What is the resistance of a single light?
  - What power is dissipated by each light?
72. One of the lights in problem 71 burns out. The light shorts out the bulb filament when it burns out. This drops the resistance of the lamp to zero.
- What is the resistance of the light string now?
  - Find the power dissipated by the string.
  - Did the power increase or decrease when the bulb burned out?
73. A 16.0- $\Omega$  and a 20.0- $\Omega$  resistor are connected in parallel. A difference in potential of 40.0 V is applied to the combination.
- Compute the equivalent resistance of the parallel circuit.
  - What is the total current in the circuit?
  - What is the current in the 16.0- $\Omega$  resistor?
74. Amy needs 5.0 V for an integrated-circuit experiment. She uses a 6.0-V battery and two resistors to make a voltage divider. One resistor is 330  $\Omega$ . She decides to make the other resistor smaller. What value should it have?
75. Pete is designing a voltage divider using a 12-V battery and a 82- $\Omega$  resistor as  $R_B$ . What resistor should be used as  $R_A$  if the output voltage across  $R_B$  is to be 4.0 V?
76. **Television** A typical television dissipates 275 W when it is plugged into a 120-V outlet.
- Find the resistance of the television.
  - The television and 2.5- $\Omega$  wires connecting the outlet to the fuse form a series circuit that works like a voltage divider. Find the voltage drop across the television.
  - A 12- $\Omega$  hair dryer is plugged into the same outlet. Find the equivalent resistance of the two appliances.
  - Find the voltage drop across the television and the hair dryer.

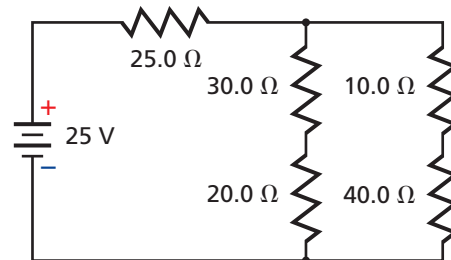
## 23.2 Applications of Circuits

77. Refer to **Figure 23-19** and assume that all the resistors are 30.0  $\Omega$ . Find the equivalent resistance.



■ Figure 23-19

78. Refer to Figure 23-19 and assume that each resistor dissipates 120 mW. Find the total dissipation.
79. Refer to Figure 23-19 and assume that  $I_A = 13$  mA and  $I_B = 1.7$  mA. Find  $I_C$ .
80. Refer to Figure 23-19 and assume that  $I_B = 13$  mA and  $I_C = 1.7$  mA. Find  $I_A$ .
81. Refer to **Figure 23-20** to answer the following questions.
- Determine the total resistance.
  - Determine the current through the 25- $\Omega$  resistor.
  - Which resistor is the hottest? Coolest?



■ Figure 23-20

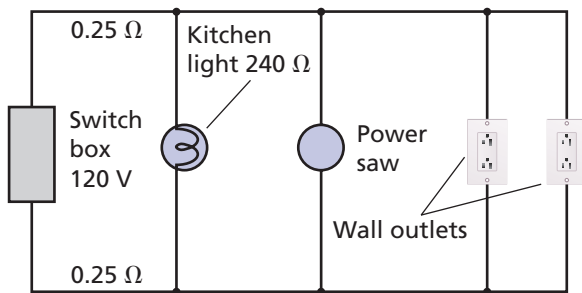
82. A circuit contains six 60-W lamps with a resistance of 240- $\Omega$  each and a 10.0- $\Omega$  heater connected in parallel. The voltage across the circuit is 120 V. Find the current in the circuit for the following situations.
- Four lamps are turned on.
  - All of the lamps are turned on.
  - Six lamps and the heater are operating.
83. If the circuit in problem 82 has a 12-A fuse, will the fuse melt if all the lamps and the heater are on?
84. During a laboratory exercise, you are supplied with a battery of potential difference  $V$ , two heating elements of low resistance that can be placed in water, an ammeter of very small resistance, a voltmeter of extremely high resistance, wires of negligible resistance, a beaker that is well insulated and has negligible heat capacity, and 0.10 kg of water at 25°C. By means of a diagram and standard symbols, show how these components should be connected to heat the water as rapidly as possible.



85. If the voltmeter used in problem 84 holds steady at 45 V and the ammeter reading holds steady at 5.0 A, estimate the time in seconds required to completely vaporize the water in the beaker. Use 4.2 kJ/kg·°C as the specific heat of water and  $2.3 \times 10^6$  J/kg as the heat of vaporization of water.

86. **Home Circuit** A typical home circuit is shown in **Figure 23-21**. The wires to the kitchen lamp each have a resistance of 0.25 Ω. The lamp has a resistance of 0.24 kΩ. Although the circuit is parallel, the lead lines are in series with each of the components of the circuit.

- Compute the equivalent resistance of the circuit consisting of just the lamp and the lead lines to and from the lamp.
- Find the current to the lamp.
- Find the power dissipated in the lamp.



■ Figure 23-21

### Mixed Review

- A series circuit has two voltage drops: 3.50 V and 4.90 V. What is the supply voltage?
- A parallel circuit has two branch currents: 1.45 A and 1.00 A. What is the current in the energy source?
- A series-parallel circuit has three resistors, dissipating 5.50 W, 6.90 W, and 1.05 W, respectively. What is the supply power?
- Determine the maximum safe power in each of three 150-Ω, 5-W resistors connected in series.
- Determine the maximum safe power in each of three 92-Ω, 5-W resistors connected in parallel.
- A voltage divider consists of two 47-kΩ resistors connected across a 12-V battery. Determine the measured output for the following.
  - an ideal voltmeter
  - a voltmeter with a resistance of 85 kΩ
  - a voltmeter with a resistance of  $10 \times 10^6$  Ω

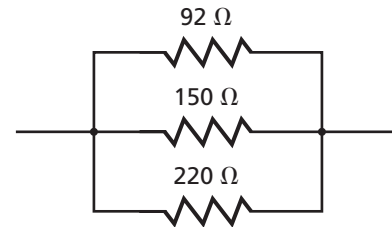
93. Determine the maximum safe voltage that can be applied across the three series resistors in **Figure 23-22** if all three are rated at 5.0 W.



■ Figure 23-22

94. Determine the maximum safe total power for the circuit in problem 93.

95. Determine the maximum safe voltage that can be applied across three parallel resistors of 92 Ω, 150 Ω, and 220 Ω, as shown in **Figure 23-23**, if all three are rated at 5.0 W.



■ Figure 23-23

### Thinking Critically

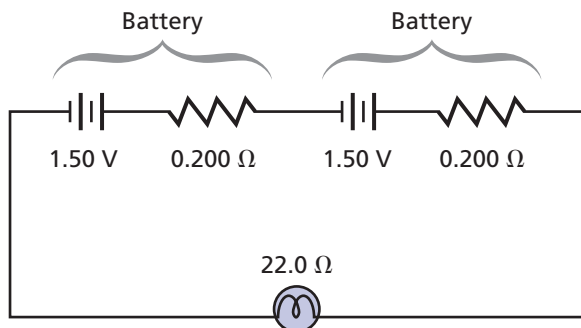
- Apply Mathematics** Derive equations for the resistance of two equal-value resistors in parallel, three equal-value resistors in parallel, and  $N$  equal-value resistors in parallel.
- Apply Concepts** Three-way lamps, of the type in **Figure 23-24**, having a rating of 50 W, 100 W, and 150 W, are common. Draw four partial schematic diagrams that show the lamp filaments and the switch positions for each brightness level, as well as the off position. (You do not need to show the energy source.) Label each diagram.



■ Figure 23-24



- 98. Apply Concepts** Design a circuit that will light one dozen 12-V bulbs, all to the correct (same) intensity, from a 48-V battery.
- Design A requires that should one bulb burn out, all other bulbs continue to produce light.
  - Design B requires that should one bulb burn out, those bulbs that continue working must produce the correct intensity.
  - Design C requires that should one bulb burn out, one other bulb also will go out.
  - Design D requires that should one bulb burn out, either two others will go out or no others will go out.
- 99. Apply Concepts** A battery consists of an ideal source of potential difference in series with a small resistance. The electric energy of the battery is produced by chemical reactions that occur in the battery. However, these reactions also result in a small resistance that, unfortunately, cannot be completely eliminated. A flashlight contains two batteries in series, as shown in **Figure 23-25**. Each has a potential difference of 1.50 V and an internal resistance of  $0.200\ \Omega$ . The bulb has a resistance of  $22.0\ \Omega$ .
- What is the current through the bulb?
  - How much power does the bulb dissipate?
  - How much greater would the power be if the batteries had no internal resistance?



■ **Figure 23-25**

- 100. Apply Concepts** An ohmmeter is made by connecting a 6.0-V battery in series with an adjustable resistor and an ideal ammeter. The ammeter deflects full-scale with a current of 1.0 mA. The two leads are touched together and the resistance is adjusted so that 1.0 mA flows.
- What is the resistance of the adjustable resistor?
  - The leads are now connected to an unknown resistance. What resistance would produce a current of half-scale, 0.50 mA? Quarter-scale, 0.25 mA? Three-quarters-scale, 0.75 mA?
  - Is the ohmmeter scale linear? Explain.

## Writing in Physics

- 101.** Research Gustav Kirchhoff and his laws. Write a one-page summary of how they apply to the three types of circuits presented in this chapter.

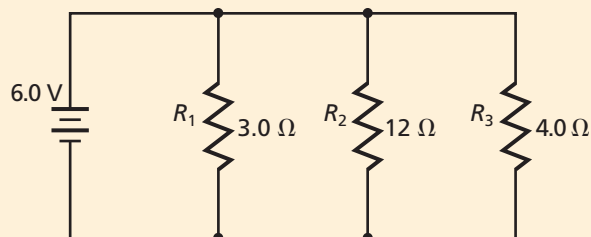
## Cumulative Review

- 102. Airplane** An airplane flying through still air produces sound waves. The wave fronts in front of the plane are spaced 0.50 m apart and those behind the plane are spaced 1.50 m apart. The speed of sound is 340 m/s. (Chapter 15)
- What would be the wavelength of the sound waves if the airplane were not moving?
  - What is the frequency of the sound waves produced by the airplane?
  - What is the speed of the airplane?
  - What is the frequency detected by an observer located directly in front of the airplane?
  - What is the frequency detected by an observer located directly behind the airplane?
- 103.** An object is located 12.6 cm from a convex mirror with a focal length of  $-18.0\text{ cm}$ . What is the location of the object's image? (Chapter 17)
- 104.** The speed of light in a special piece of glass is  $1.75 \times 10^8\text{ m/s}$ . What is its index of refraction? (Chapter 18)
- 105. Monocle** An antireflective coating with an index of refraction of 1.4 is applied to a monocle with an index of refraction of 1.52. If the thickness of the coating is 75 nm, what is/are the wavelength(s) of light for which complete destructive interference will occur? (Chapter 19)
- 106.** Two charges of  $2.0 \times 10^{-5}\text{ C}$  and  $8.0 \times 10^{-6}\text{ C}$  experience a force between them of 9.0 N. How far apart are the two charges? (Chapter 20)
- 107.** A field strength,  $E$ , is measured a distance,  $d$ , from a point charge,  $Q$ . What would happen to the magnitude of  $E$  in the following situations? (Chapter 21)
- $d$  is tripled
  - $Q$  is tripled
  - both  $d$  and  $Q$  are tripled
  - the test charge  $q'$  is tripled
  - all three,  $d$ ,  $Q$ , and  $q'$ , are tripled
- 108.** The current flow in a 12-V circuit drops from 0.55 A to 0.44 A. Calculate the change in resistance. (Chapter 22)

# Standardized Test Practice

## Multiple Choice

Use the following circuit diagram to answer questions 1–3.



1. What is the equivalent resistance of the circuit?

- A  $\frac{1}{19} \Omega$                        C 1.5  $\Omega$   
 B 1.0  $\Omega$                          D 19  $\Omega$

2. What is the current in the circuit?

- A 0.32 A                         C 1.2 A  
 B 0.80 A                         D 4.0 A

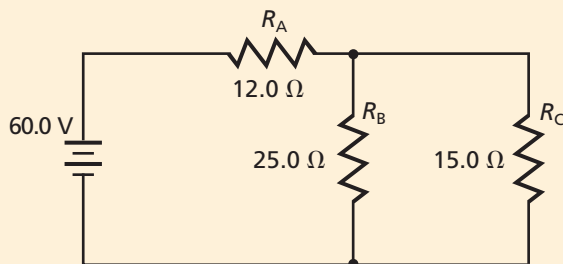
3. How much current is in  $R_3$ ?

- A 0.32 A                         C 2.0 A  
 B 1.5 A                          D 4.0 A

4. What would a voltmeter placed across  $R_2$  read?

- A 0.32 V                         C 3.8 V  
 B 1.5 V                          D 6.0 V

Use the following circuit diagram to answer questions 5 and 6.



5. What is the equivalent resistance of the circuit?

- A 8.42  $\Omega$                        C 21.4  $\Omega$   
 B 10.7  $\Omega$                        D 52.0  $\Omega$

6. What is the current in the circuit?

- A 1.15 A                         C 2.80 A  
 B 2.35 A                         D 5.61 A

7. Nina connects eight 12- $\Omega$  lamps in series. What is the total resistance of the circuit?

- A 0.67  $\Omega$                        C 12  $\Omega$   
 B 1.5  $\Omega$                          D 96  $\Omega$

8. Which statement is true?

- A The resistance of a typical ammeter is very high.  
 B The resistance of a typical voltmeter is very low.  
 C Ammeters have zero resistance.  
 D A voltmeter causes a small change in current.

## Extended Answer

9. Chris is throwing a tailgate party before a nighttime football game. To light the tailgate party, he connects 15 large outdoor lamps to his 12.0-V car battery. Once connected, the lamps do not glow. An ammeter shows that the current through the lamps is 0.350 A. If the lamps require a 0.500-A current in order to work, how many lamps must Chris remove from the circuit?

10. A series circuit has an 8.0-V battery and four resistors,  $R_1 = 4.0 \Omega$ ,  $R_2 = 8.0 \Omega$ ,  $R_3 = 13.0 \Omega$ , and  $R_4 = 15.0 \Omega$ . Calculate the current and the power in the circuit.

## ✓ Test-Taking TIP

### Take a Break

If you have the opportunity to take a break or get up from your desk during a test, take it. Getting up and moving around will give you extra energy and help you clear your mind. During the break, think about something other than the test so you'll be able to begin again with a fresh start.