Chapter 23 Organizer

Section/Objectives	Standards		Lab and Demo Planning
	See page 14T for a key to the standards.		
Chapter Opener	**National**	**State/Local**	
Section 23.1 1. **Describe** series and parallel circuits. 2. **Calculate** currents, voltage drops, and equivalent resistances in series and parallel circuits.	UCP.1, UCP.2, UCP.3, A.1, A.2, B.6		**Student Lab:** **Launch Lab,** p. 617: 9-V battery, small flashlight bulb in socket, four insulated copper wires (20- to 25-cm long), single strands of steel wool, knife switch, small glass container **Mini Lab,** p. 623: power supply; ammeter; wires; four 330-Ω, 0.5-W resistors or four 470-Ω, 0.5-W resistors; (resistors of lower resistance may be used) **Additional Mini Lab,** p. 625: 12-V DC power source, three 12-V lamps, a multimeter or a voltmeter and an ammeter **Teacher Demonstration:** **Quick Demo,** p. 622: variable DC power supply; multimeter; three 100-Ω, 1-W resistors; clip leads
Section 23.2 3. **Explain** how fuses, circuit breakers, and ground-fault interrupters protect household wiring. 4. **Analyze** and **solve** problems involving combined series-parallel circuits. 5. **Explain** how voltmeters and ammeters are used in circuits.	UCP.1, UCP.2, UCP.3, A.1, A.2, B.6, E.1, F.5		**Student Lab:** **Physics Lab,** pp. 632–633: 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 10 copper wires with alligator clips **Teacher Demonstration:** **Quick Demo,** p. 631: power supply, resistors or lamps, multimeter

Differentiated Instruction

L1 Level 1 activities should be appropriate for students with learning difficulties.

L2 Level 2 activities should be within the ability range of all students.

L3 Level 3 activities are designed for above-average students.

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FAST FILE Chapters 21–25 Resources, Chapter 23 Transparency 23-1 Master, p. 89 Transparency 23-2 Master, p. 91 Study Guide, pp. 77–82 Reinforcement, p. 85 Section 23-1 Quiz, p. 83 Mini Lab Worksheet, p. 71 **Teaching Transparency 23-1** **Teaching Transparency 23-2** **Connecting Math to Physics**	**Interactive Chalkboard CD-ROM:** Section 23.1 Presentation **TeacherWorks™ CD-ROM** **Mechanical Universe:** Simple DC Circuits
FAST FILE Chapters 21–25 Resources, Chapter 23 Transparency 23-3 Master, p. 93 Transparency 23-4 Master, p. 95 Study Guide, pp. 77–82 Enrichment, pp. 87–88 Section 23-2 Quiz, p. 84 Physics Lab Worksheet, pp. 73–76 **Teaching Transparency 23-3** **Teaching Transparency 23-4** **Connecting Math to Physics** **Laboratory Manual,** pp. 121–124 **Probeware Laboratory Manual,** pp. 45–48	**Interactive Chalkboard CD-ROM:** Section 23.2 Presentation **TeacherWorks™ CD-ROM** **Problem of the Week at physicspp.com** **Mechanical Universe:** Simple DC Circuits

Assessment Resources

FAST FILE Chapters 21–25 Resources, Chapter 23 Chapter Assessment, pp. 97–102 **Additional Challenge Problems,** p. 23 **Physics Test Prep,** pp. 45–46 **Pre-AP/Critical Thinking,** pp. 45–46 **Supplemental Problems,** pp. 45–46	**Technology** **Interactive Chalkboard CD-ROM:** Chapter 23 Assessment **Exam*View*® Pro Testmaker CD-ROM** **Vocabulary PuzzleMaker** **TeacherWorks™ CD-ROM** **physicspp.com**

Chapter 23 Series and Parallel Circuits

Chapter Overview

This chapter discusses the principles of series and parallel circuits. The first section explains equivalent resistances in series and parallel resistors, circuit currents, voltage drops, and series-parallel circuits. The second section describes how circuits are used, and explains how circuit breakers, fuses, voltmeters, ammeters, and ground-fault interrupters operate.

Think About This

All household devices are connected in parallel because they are designed to operate at the same voltage. The circuit breakers are connected in series so that the circuit will open in case of a dangerously high current. (See page 627.)

Key Terms

series circuit, p. 618
equivalent resistance, p. 619
voltage divider, p. 620
parallel circuit, p. 623
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

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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616
Catherine Karnow/CORBIS, (inset)Horizons Companies

LAUNCH Lab

Purpose to demonstrate how a fuse operates to protect an electric circuit from overheating

Materials 9-volt battery, small flashlight bulb in socket, 4 insulated copper wires about 20-cm to 25-cm long, single strands of steel wool, knife switch, small glass container

Teaching Strategies

- Tell students not to try this lab with a home circuit. The much higher voltage from wall outlets in the home will result in potentially lethal currents.
- You may want to use wires with alligator clips to facilitate making connections.
- Remind students to keep the strand of steel wool over a small container to catch any hot pieces of metal that may result when the metal burns up. Also warn them that some fumes and smoke may be produced.

LAUNCH Lab

How do fuses protect electric circuits?

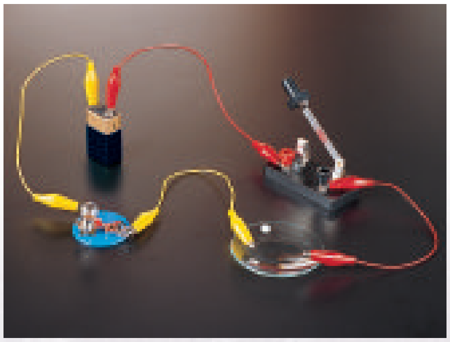
Question
How does a fuse prevent an electric circuit from drawing too much current and creating a safety hazard?

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

Although 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

Expected Results As the current passes through the strand of steel wool, the steel wool will start getting hot, turn red hot, and then burn up.

Analysis The thinner the wire, the faster it will heat up and burn up. A thicker wire can handle more current before it heats up. Circuit breakers are reusable, whereas fuses have to be replaced every time they burn out. Both stop the flow of charges in an electric circuit.

Critical Thinking The correct current rating must be used in a fuse. Using fuses with too high a current rating can be dangerous. For example, when a 20-A fuse is used instead of a recommended 10-A fuse in a house or car circuit, the wires within the circuit could overheat and cause a fire.

1 FOCUS

Bellringer Activity

Series Circuits Connect a variable power supply to a 12-W lightbulb. Use external multimeters to monitor voltage and current. Adjust the supply for 10 V and note the current. Turn off the supply and add a second 12-W bulb in series. Turn on the supply and note the current and the brightness of the two bulbs. Measure the voltage across each bulb. Adjust the supply for 20 V and note the current, brightness, and voltage drops. Discuss the results. **L1 Visual-Spatial**

Tie to Prior Knowledge

Potential Energy Conservation of energy applies to electric circuits. An energy source, such as a battery, raises the potential energy of charges flowing through it. That potential energy drops as the energy is transferred to thermal or light energy by the lamps or resistors. The energy of the charges returns to its original value when the charges reenter the battery. Therefore, the sum of the potential drops must be equal to the potential increase in the battery.

2 TEACH

ACTIVITY

Series Circuits Have students think about and explain how a flashlight is set up. Have a large and small type available to take apart, investigate, and put back together. (Make sure the batteries are working well.) With each battery placed end-to-end, the electricity generated by one battery passes to the next battery or batteries in the series. Discuss how the brightness of a flashlight bulb would change if you could add more batteries, and thus voltage, to the series. **L2 Visual-Spatial**

Identifying Misconceptions

Equivalent Resistance Students sometimes think that the order of the loads in a series can affect the behavior of a series circuit. Explain that changing the order of the loads has no effect on the current or the total power dissipation. In the case of nonequal series resistors, the location of each voltage drop will depend on the location of each resistor, but the total of the drops will always equal the applied voltage. Students might better grasp this point by first constructing a series circuit, measuring the current, and calculating the power. They should then change the order of the loads and measure the current and power again.

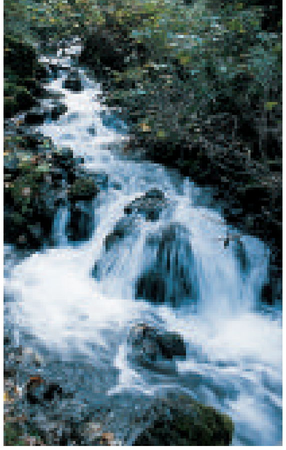


Figure 23-1 No matter what path a river or a stream takes down a mountain, the amount of water and the drop in elevation are the same.

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 mountaintops. Continue to think about the mountain river model as you read about the current in electric circuits.

Series Circuits

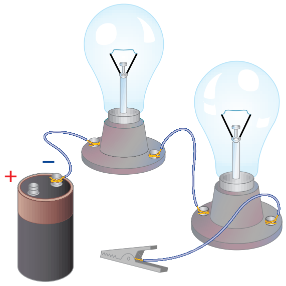
Three students are connecting two identical lamps to a battery, as illustrated in **Figure 23-2.** Before they make the final connection to the battery, their teacher asks them to predict the brightnesses of the two lamps.

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 $V = IR$.

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



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_{source}, is equal to the sum of voltage drops across lamps A and B, and is represented by the following equation:

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

23.1 Resource MANAGER

FAST FILE Chapters 21–25 Resources
- Transparency 23–1 Master, p. 89
- Transparency 23–2 Master, p. 91
- Study Guide, pp. 78–80
- Reinforcement, p. 85
- Section 23–1 Quiz, p. 83
- Mini Lab Worksheet, p. 71

Teaching Transparency 23-1
Teaching Transparency 23-2
Connecting Math to Physics

Technology
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- Interactive Chalkboard CD-ROM
- ExamView® Pro Testmaker CD-ROM
- **physicspp.com**
- **physicspp.com/vocabulary_puzzlemaker**

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, $V_{source} = IR_A + IR_B$, or $V_{source} = I(R_A + R_B)$. The current through the circuit is represented by the following equation:

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

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.

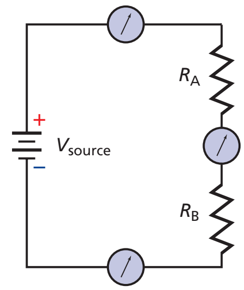


Figure 23-3 The ammeters show that the current is the same everywhere in a series circuit.

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

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

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

PRACTICE Problems

Additional Problems, Appendix B

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

HELPING STRUGGLING STUDENTS Activity

Characteristics of Series Circuits and Equivalent Resistance Have students form several small discussion groups. Have each group prepare lists of the characteristics of series circuits and describe equivalent resistance for a series circuit that contains three resistors. Ask students to include all the appropriate equations, create schematic diagrams, and see if they can think of applications for series circuits. Ask each group to exchange its list with another group for discussion. Later, merge the groups for a broader discussion. **L1 Interpersonal**

Concept Development

Current, Resistance, and Voltage To help students understand the equation $V = IR$, describe a series circuit used to connect an incandescent lamp, which typically operates at relatively high current levels and generates considerable heat. The service life of the lamp filament in the bulb, which produces the light, is often limited. One cause of filament failure is an increase in current to 10 percent above the initial current value. Another cause is a decrease in brightness to 20 percent less than the lamp's initial brightness, which significantly increases the resistance of the bulb. The increased current, the increased resistance, or both subject the filament to excessive voltage, which greatly reduces lamp life.

Discussion

Question Ask students what would be the equivalent resistance of two series resistors where one is quite small and the other quite large.

Answer In a series circuit, the equivalent resistance is the sum of all the resistances in the circuit, no matter how large or small the individual resistances are. So you add the two resistances to get the total. **L2 Logical-Mathematical**

PRACTICE Problems

1. 60 Ω, 2 A
2. 30 Ω, 3 A
3. **a.** It will increase.
   b. It will decrease.
   c. No. It does not depend on the resistance.
4. **a.** 2×10^3 Ω
   b. 2×10^2 Ω
5. $V_1 = 30$ V
   $V_2 = 45$ V
   $V_3 = 15$ V
   $V_1 + V_2 + V_3 = 90$ V, the voltage of the battery

Using Figure 23-4

Ask students how the concept of voltage drop in a voltage divider could be applied as a volume control in a CD player or a radio. A voltage divider circuit in the equipment could act as a sound meter and raise or lower the potential to produce a voltage source for the desired magnitude of sound (volume). **L2 Logical-Mathematical**

Critical Thinking

Voltage Drop in a Series Circuit Holiday light sets are less expensive to manufacture using a series arrangement of bulbs. Yet such sets are not acceptable to many consumers, because when one bulb burns out, the entire set shuts down. Even when consumers know how to troubleshoot this situation (for example, by moving a known good bulb from position to position until the set comes on), they don't want to take the time to do it. Have students investigate and explain what type of bulb holiday light designers have created to deal with this situation. By applying the physical principle that the entire line voltage will drop across a burned-out bulb, designers have developed a special bulb that shorts out when 120 volts appear across its terminals. This type of bulb will no longer light, but the rest will function at a slightly higher voltage. If too many bulbs reach the shorted condition, a series fuse will blow. **L2 Logical-Mathematical**

THE MECHANICAL UNIVERSE
HIGH SCHOOL ADAPTATION

Videotape

Simple DC Circuits

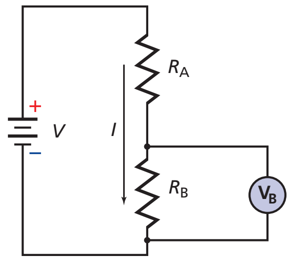


Figure 23-4 In this voltage-divider circuit, the values of R_A and R_B are chosen such that the voltage drop across R_B is the desired voltage.

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.

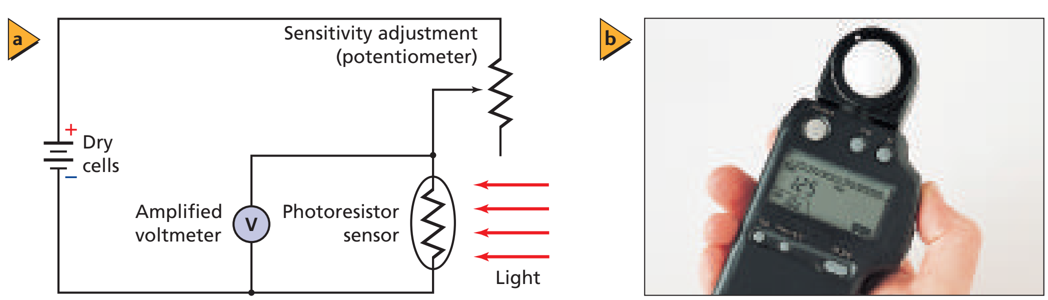
$$V_B = IR_B$$

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

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

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 Ω when light is striking it compared with a resistance of 400,000 Ω 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).**



PHYSICS PROJECT Activity

Photoresistors In addition to the use of photoresistors in photographic light meters, these devices are commonly used as light sensors in security lights that automatically turn on when it gets dark. At night, or even during daytime stormy weather, the resistance in the equipment is very high—in the megaohm range. During the day when the sensor is illuminated, the resistance drops, typically to a few hundred ohms. Have students research the development and use of photoresistors in security lights or other equipment and graphically depict how they are set up and operated. **L2 Kinesthetic, Visual-Spatial**

▶ EXAMPLE Problem 1

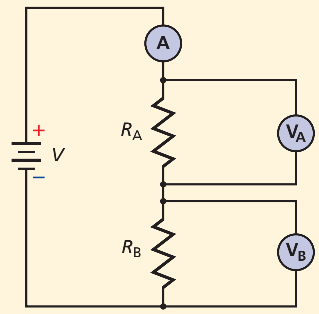
Voltage Drops in a Series Circuit Two resistors, 47.0 Ω and 82.0 Ω, are connected in series across a 45.0-V battery.

a. What is the current in the circuit?

b. What is the voltage drop across each resistor?

c. If the 47.0-Ω resistor is replaced by a 39.0-Ω resistor, will the current increase, decrease, or remain the same?

d. What is the new voltage drop across the 82.0-Ω resistor?



1 Analyze and Sketch the Problem

- Draw a schematic of the circuit.

Known:	Unknown:
$V_{source} = 45.0$ V	$I = ?$
$R_A = 47.0$ Ω	$V_A = ?$
$R_B = 82.0$ Ω	$V_B = ?$

2 Solve for the Unknown

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

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

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

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

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

b. Use $V = IR$ for each resistor.

$$V_A = IR_A$$

$$= (0.349\ \text{A})(47.0\ \Omega) \qquad \text{Substitute } I = 0.349\ \text{A}, R_A = 47.0\ \Omega$$

$$= 16.4\ \text{V}$$

$$V_B = IR_B$$

$$= (0.349\ \text{A})(82.0\ \Omega) \qquad \text{Substitute } I = 0.349\ \text{A}, R_B = 82.0\ \Omega$$

$$= 28.6\ \text{V}$$

Math Handbook
Operations with Significant Digits
pages 835–836

c. Calculate current, this time using 39.0 Ω as R_A.

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

$$= \frac{45.0\ \text{V}}{39.0\ \Omega + 82.0\ \Omega} \qquad \text{Substitute } V_{source} = 45.0\ \text{V}, R_A = 39.0\ \Omega, R_B = 82.0\ \Omega$$

$$= 0.372\ \text{A}$$

The current will increase.

d. Determine the new voltage drop in R_B.

$$V_B = IR_B$$

$$= (0.372\ \text{A})(82.0\ \Omega) \qquad \text{Substitute } I = 0.372\ \text{A}, R_B = 82.0\ \Omega$$

$$= 30.5\ \text{V}$$

3 Evaluate the Answer

- **Are the units correct?** Current is A = V/Ω; voltage is V = A·Ω.
- **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_{source}, which is 45 V.

▶ IN-CLASS Example

Question 15 V are applied across three resistors in series: 15.0 Ω, 22.0 Ω, and 47.0 Ω. Determine the current in the circuit and the voltage across the 47.0-Ω resistor. How will the current change by using a 60.0-Ω resistor instead of the 47.0-Ω resistor? Also demonstrate that the total power is equal to the sum of the individual dissipations using the 15.0-Ω, 22.0-Ω, and 47.0-Ω resistors. If there is time, derive the equation $V_A = (V)(R_A)/(R_A + R_B + R_C)$.

Answer

$I = V/R$
$= 15\ \text{V}/(15.0\ \Omega + 22.0\ \Omega + 47.0\ \Omega)$
$= 0.18$ A

$V = IR$
$= (0.18\ \text{A})(47.0\ \Omega)$
$= 8.5$ V

$I = V/R$
$= 15\ \text{V}/(15.0\ \Omega + 22.0\ \Omega + 60.0\ \Omega)$
$= 0.15$ A

The current will decrease when the resistance increases.

$P = IV$
$= (0.18\ \text{A})(15.0\ \text{V})$
$= 2.7$ W

$P_{(15)} = I^2R$
$= (0.18\ \text{A})^2(15.0\ \Omega)$
$= 0.49$ W

$P_{(22)} = I^2R$
$= (0.18\ \text{A})^2(22.0\ \Omega)$
$= 0.71$ W

$P_{(47)} = I^2R = (0.18\ \text{A})^2(47.0\ \Omega)$
$= 1.5$ W

$P = 0.49\ \text{W} + 0.71\ \text{W} + 1.5\ \text{W}$
$= 2.7$ W

Teacher F.Y.I. — CONTENT BACKGROUND

Voltage Drops in Wire Installation One of the main concerns when installing long lengths of wire is voltage drop. There can be a significant amount of voltage lost between the power supply and the equipment that needs the power if the proper wire is not used. When designing the electrical systems for buildings, electrical engineers must specify the proper wire for each installation to make sure there is enough voltage for the intended load. To do so, they must consider the length of the wire from the power supply to the load, as well as the return of the line from the load, the amount of voltage lost per foot for each type of wire, and the load current.
L2 Linguistic

Reinforcement

Series Circuit Setup Ask students to compare a series circuit to a chain. They should mention that the links are connected end to end, one after each other. Also, a chain fails if one link breaks (opens). **L1**

PRACTICE Problems

Additional Problems, Appendix B

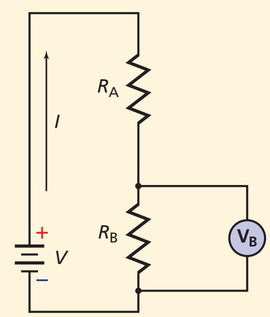
6. The circuit shown in Example Problem 1 is producing these symptoms: the ammeter reads 0 A, V_A reads 0 V, and V_B reads 45 V. What has happened?
7. Suppose the circuit shown in Example Problem 1 has these values: $R_A = 255\ \Omega$, $R_B = 292\ \Omega$, and $V_A = 17.0$ V. No other information is 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 Ω and 470 Ω, are connected as a voltage divider. What is the voltage across the 470-Ω resistor?

1 Analyze and Sketch the Problem

- Draw the battery and resistors in a series circuit.



Known:	Unknown:
$V_{source} = 9.0$ V	$V_B = ?$
$R_A = 390\ \Omega$	
$R_B = 470\ \Omega$	

2 Solve for the Unknown

$$R = R_A + R_B$$

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

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

$$V_B = IR_B$$

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

$$= \frac{(9.0\text{ V})(470\ \Omega)}{390\ \Omega + 470\ \Omega} \quad \text{Substitute } V_{source} = 9.0\text{ V}, R_A = 390\ \Omega, R_B = 470\ \Omega$$

$$= 4.9\text{ V}$$

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3 Evaluate the Answer

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

PRACTICE Problems

6. R_B has failed.
7. **a.** 66.7 mA **b.** 36.5 V
   c. $P = 2.43$ W, $P_A = 1.13$ W, $P_B = 1.30$ W
   d. Yes. The rate at which energy is converted, or power dissipated will equal the sum of all parts.
8. If not for the shorting mechanism, the entire set would go out when one lamp burns out. After several lamps fail and then short, the total resistance of the remaining working lamps results in an increased current sufficient to blow the fuse.
9. The resistor with the lower resistance will dissipate less power, and be cooler.
10. 7.46 V

IN-CLASS Example

INTERACTIVE CHALKBOARD with Image Bank
PowerPoint® Presentations

Question A voltage divider consisting of two 1.5-MW resistors is connected to a 12.0-V source. Determine the voltage across one resistor before and after a voltmeter is connected, assuming the voltmeter's resistance is $1.0\times10^7\ \Omega$.

Answer Before the voltmeter is connected, the voltage across each 1.5-MΩ resistor will be half the supply voltage, or 6.0 V. When the voltmeter is connected, it acts as a parallel resistance (see next page):

$R = 1/(1/1.5\text{ M}\Omega + 1/1.0\times10^7\ \Omega)$
$= 1/(1/1.5\times10^6\ \Omega + 1/1.0\times10^7\ \Omega)$
$= 1.3\text{ M}\Omega$

The voltage drop across the parallel combination is

$V = (12.0\text{ V})(1.3\text{ M}\Omega)/(1.3\text{ M}\Omega + 1.5\text{ M}\Omega) = 5.6$ V

QUICK DEMO

Loaded and Unloaded Voltage Dividers

Estimated Time 5 minutes

Materials variable DC power supply; multimeter; three 100-Ω, 1-W resistors; clip leads

Procedure Connect two of the resistors in series and connect the power supply across them. Turn on the supply to 6 V. Measure the voltage across one of the resistors. Adjust the power supply for 12 V and again measure the voltage. Begin to discuss parallel circuits by connecting the third resistor in parallel with the resistor where the voltage measurements have been taken. Again measure the voltage.

PRACTICE Problems — Additional Problems, Appendix B

11. A 22-Ω resistor and a 33-Ω resistor are connected in series and placed across a 120-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 kΩ, 4.7 kΩ, and 3.9 kΩ are connected in series across a 12-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.

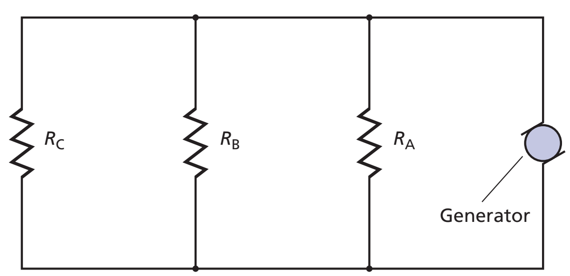
13. A student makes a voltage divider from a 45-V battery, a 475-kΩ resistor, and a 235-kΩ resistor. The output is measured across the smaller resistor. What is the voltage?

14. Select a resistor to be used as part of a voltage divider along with a 1.2-kΩ resistor. The drop across the 1.2-kΩ resistor is to be 2.2 V when the supply is 12 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.)*

PRACTICE Problems

11. a. 55 Ω **b.** 2.2 A
c. 48 V, 72 V
d. 1.20×10^2 V

12. a. 1.2×10^1 kΩ
b. 1.0×10^{-3} A
c. 3.3 V; 4.7 V; 3.9 V
d. 11.9 V

13. 15 V

14. 5.3 kΩ

Discussion

Question Draw a circuit diagram of a two-resistor voltage divider. Is it possible to make the divided voltage stable when varying loads are to be connected?

Answer Yes, but not just by using resistors. When a voltage divider is loaded, the voltage drops. It is possible to replace one of the voltage divider resistors with an integrated circuit voltage regulator, which can make the divided voltage more stable. A transistor can change its resistance and act as a regulator to hold the output more constant.
L2 Visual-Spatial

MINI LAB

Parallel Resistance

See page 71 of **FAST FILE Chapters 21–25 Resources** *for the accompanying Mini Lab Worksheet.*

Purpose to construct a simple parallel circuit and monitor the effect of adding resistors

Materials power supply; ammeter; wires; four 330-Ω, 0.5-W resistors or four 470-Ω, 0.5-W resistors Resistors of lower resistance may be used.

Expected Results The current in the circuit will increase as more parallel branches are added. With three branches, the current will be three times the original value.

Analyze and Conclude

5. Student tables will vary.

6. The resistance decreases with the addition of more branches.

CHALLENGE Activity

Parallel Circuits in Automobiles Interested students can investigate why the various devices in an automobile are wired in parallel and rated at 12 V. Have them evaluate the power source (a 12-V battery) and all the devices that require electrical power simultaneously, such as the ignition, headlights, taillights, and CD player. They can also estimate what will happen to the current and combined resistance of the parallel circuit if another load is added. Researching car circuit diagnostics, overloads, and fuses would also be useful. Have them graphically depict a hypothetical car's circuitry. **L3 Visual-Spatial**

Using an Analogy

Total Parallel Circuit Flow Use parallel roads to show how the total number of cars leaving a city can be determined by adding the flow for each and every road leaving the city.

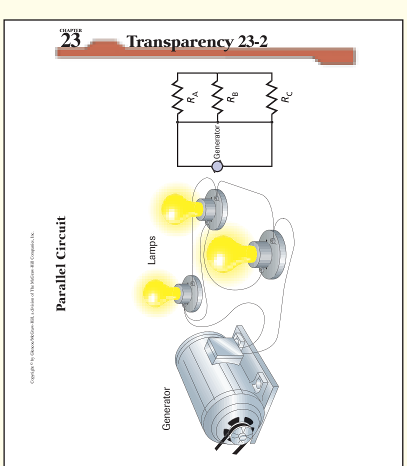
Reinforcement

Recognizing Series- and Parallel-Circuit Wiring Ask students to explain how they would be able to identify holiday light sets as series-wired or parallel-wired by inspecting and experimenting with them. **L2 Kinesthetic**

APPLYING PHYSICS

▶ The resistance that an ohmmeter measures is resistance of a wire. It puts current through a wire and then measures the voltage drop across the wire. Some practical applications for ohmmeters are to test the electrical resistance of motors, transformers, metal-to-wire connections, environmental sensors, high-voltage circuit breakers, and other disconnecting switches. Discuss other practical applications for this electrical testing equipment. ◀

Page 89, FAST FILE Chapters 21–25 Resources



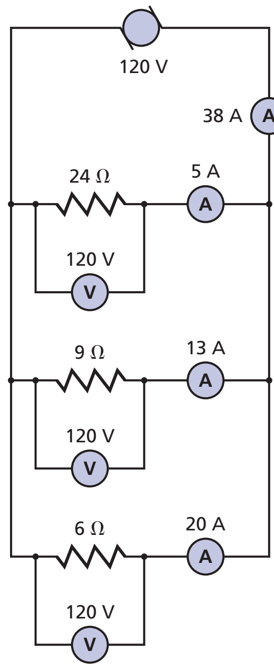


Figure 23-7 In a parallel circuit, the total current is equal to the sum of the currents in the individual paths.

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 $I = (120\ \text{V})/(24\ \Omega) = 5.0$ 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:

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

$$= \frac{120\ \text{V}}{38\ \text{A}}$$

$$= 3.2\ \Omega$$

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

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

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. ◀

DIFFERENTIATED INSTRUCTION Activity

Visually Impaired Prepare several lengths of light rope by tying several knots spaced about 5 cm apart. Tie several other ropes into parallel-circuit configurations, adding knots where necessary. Ask the students to identify which ropes are in series and which are examples of parallel circuits. Using a peg board, pegs, and light rope or string, have the students configure series and parallel circuits. Have the students explain each of the configurations, including where the resistors and voltage source would be and where the current would flow. **L2 Kinesthetic**

EXAMPLE Problem 3

Equivalent Resistance and Current in a Parallel Circuit Three resistors, 60.0 Ω, 30.0 Ω, and 20.0 Ω, are connected in parallel across a 90.0-V battery.

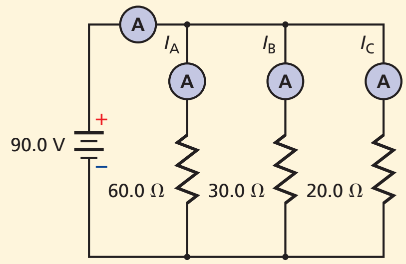
a. Find the current through each branch of the circuit.

b. Find the equivalent resistance of the circuit.

c. 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:	Unknown:	
$R_A = 60.0\ \Omega$	$I_A = ?$	$I = ?$
$R_B = 30.0\ \Omega$	$I_B = ?$	$R = ?$
$R_C = 20.0\ \Omega$	$I_C = ?$	
$V = 90.0$ V		

2 Solve for the Unknown

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

$$I_A = \frac{V}{R_A} = \frac{90.0\text{ V}}{60.0\ \Omega} = 1.50\text{ A}$$

Substitute V = 90.0 V, R_A = 60.0 Ω

$$I_B = \frac{V}{R_B} = \frac{90.0\text{ V}}{30.0\ \Omega} = 3.00\text{ A}$$

Substitute V = 90.0 V, R_B = 30.0 Ω

$$I_C = \frac{V}{R_C} = \frac{90.0\text{ V}}{20.0\ \Omega} = 4.50\text{ A}$$

Substitute V = 90.0 V, R_C = 20.0 Ω

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b. Use the equivalent resistance equation for parallel circuits.

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

Substitute R_A = 60.0 Ω, R_B = 30.0 Ω, R_C = 20.0 Ω

$$R = 10.0\ \Omega$$

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

$$I = \frac{V}{R} = \frac{90.0\text{ V}}{10.0\ \Omega} = 9.00\text{ A}$$

Substitute V = 90.0 V, R = 10.0 Ω

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, $I_A + I_B + I_C$.

IN-CLASS Example

Question Four resistors, 50.0 Ω, 40.0 Ω , 30.0 Ω, and 20.0 Ω, are connected with a parallel circuit across a 120-V battery. Find the current through each branch of the circuit, the equivalent resistance of the circuit, and the current through the battery.

Answer

$I_A = V/R_A$
$= 120\text{ V}/50.0\ \Omega = 2.4\text{ A}$

$I_B = V/R_B$
$= 120\text{ V}/40.0\ \Omega = 3.0\text{ A}$

$I_C = V/R_C$
$= 120\text{ V}/30.0\ \Omega = 4.0\text{ A}$

$I_D = V/R_D$
$= 120\text{ V}/20.0\ \Omega = 6.0\text{ A}$

$R = 1/(1/R_A + 1/R_B + 1/R_C + 1/R_D)$
$= 1/(1/50.0\ \Omega + 1/40.0\ \Omega + 1/30.0\ \Omega + 1/20.0\ \Omega)$
$= 7.8\ \Omega$

$I = V/R$
$= 120\text{ V}/7.8\ \Omega = 15\text{ A}$

Additional MINI LAB

Measuring Current and Voltage in a Parallel Circuit

Purpose to show that voltage is constant across parallel components

Materials 12-V DC power source, three 12-V lamps, a multimeter or a voltmeter and an ammeter

Procedure Connect a 12-V DC power supply to three 12-V lamps in parallel. Use a voltmeter to measure the voltage across each lamp. Use an ammeter to measure the current in each lamp and the current coming from the power supply.

Assessment What is the correct method of connecting an ammeter to measure one of the load currents? in series with that load What is the correct method of connecting an ammeter to measure the total current? in series with the energy source What is the correct method of connecting a voltmeter in this circuit? across the energy source or across any of the loads

Teacher F.Y.I. CONTENT BACKGROUND

Parallel-Circuit Fault-Current Protection A fault inside of an electrical product can energize the conductive metal housing and present a shock hazard to a user. Insulation can fail and allow a wire to contact the housing. Three-prong power cords provide user protection because the third prong connects the housing to ground. When insulation fails, the third prong conducts the fault current directly to ground over a low-resistance path, which prevents any significant current from reaching the user's body. The characteristics of parallel circuits explain why this is so—the parallel branch with the lowest resistance (in the case the third prong) will support most of the current.

PRACTICE Problems

Additional Problems, Appendix B

15. Three 15.0-Ω resistors are connected in parallel and placed across a 30.0-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-Ω resistor, a 60.0-Ω resistor, and a 40.0-Ω resistor are connected in parallel and placed across a 12.0-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-Ω resistors in problem 15 is replaced by a 10.0-Ω 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-Ω resistors change? If so, how?

18. A 150-Ω branch in a circuit must be reduced to 93 Ω. 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-Ω, 2-W resistor is connected in parallel with a 6.0-Ω, 4-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-W and a 100-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 V and the 100-W bulb glows more brightly. When connected in series, the current through each bulb is the same. Because the resistance of the 60-W bulb is greater than that of the 100-W bulb, the higher-resistance 60-W bulb dissipates more power and glows more brightly.

23.1 Section Review

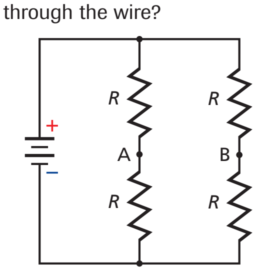
20. Circuit Types Compare and contrast the voltages and the currents in series and parallel circuits.

21. Total Current A parallel circuit has four branch currents: 120 mA, 250 mA, 380 mA, and 2.1 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 mA. How much current is supplied by the source?

23. Circuits A switch is connected in series with a 75-W bulb to a source of 120 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-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

PRACTICE Problems

15. a. 5.00 Ω
b. 6.00 A
c. 2.00 A

16. a. 20.0 Ω
b. 0.600 A
c. 0.100 A
0.200 A
0.300 A

17. a. Yes, it gets smaller.
b. Yes, it gets larger.
c. No, it remains the same. Currents are independent.

18. 2.4×10^2 Ω in parallel with the 150-Ω resistance

19. Neither. They both reach maximum dissipation at the same voltage.

3 ASSESS

Check for Understanding

Comparing Series and Parallel Circuits Activity Draw both series and parallel circuits on the chalkboard. Ask students to identify and compare the two. Ask what electric quantity is constant in each case. Ask how equivalent resistance is determined in each case. Finally, ask how current, voltage, resistance, and total and individual power dissipations are related. **L2 Visual-Spatial**

Reteach

Elements of Series and Parallel Circuits Demo Review elements by displaying wires, switches, lamps, resistors, power supplies, meters and fuses. Connect two resistors in series and measure the total resistance. Connect the same resistors in parallel and again measure the resistance.

23.1 Section Review

20. Students' answers should include the following ideas: (1) In a series circuit, the current in each device is the same, and the sum of the voltage drops is equal to the source voltage. (2) In a parallel circuit, the voltage drop across each device is the same, and the sum of the currents through each loop equals the source current.

21. 2.9 A

22. 810 mA

23. a. 0 V
b. 0 V, Because the sum of the voltages across the switch and the bulb is 120 V, there must be 120 V across the switch.

24. a. 0 A; the potentials of points A and B are the same.
b. nothing
c. nothing
d. nothing

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.

▶ **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

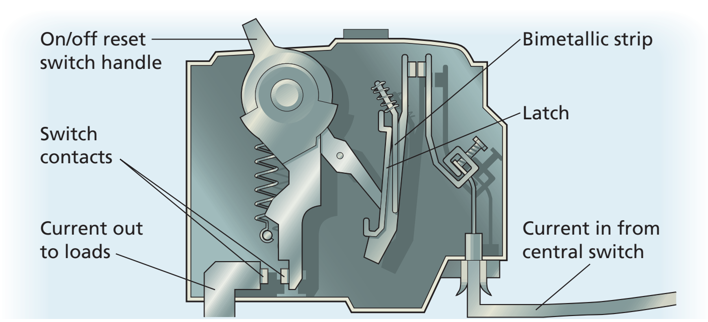
Safety Devices

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.

Circuit Breaker



■ **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.

Section 23.2

1 FOCUS

Bellringer Activity

Comparing Combined Series-Parallel Circuit Configurations Construct two series-parallel circuits. Each will use a 12-V power supply and three 12-V lamps. One circuit will have two lamps in series that are in parallel with the third. The other circuit will have two lamps in parallel that are in series with the third. Energize both circuits at the same time to make the comparisons easy.
L2 Visual-Spatial

Tie to Prior Knowledge

Energy Conservation Review energy conservation and relate it to series-parallel circuits. Solve a series-parallel circuit for the total and individual power dissipations. Show that the total dissipation is equal to the sum of the individual dissipations.

2 TEACH

Identifying Misconceptions

Circuit Breaker Operation There are several types of circuit breakers, some of which automatically reset when the breaker cools sufficiently. Discuss how a lack of understanding of this concept can lead people to draw false conclusions about the integrity of this type of circuit breaker.

23.2 Resource MANAGER

FAST FILE Chapters 21–25 Resources
- Transparency 23–3 Master, p. 93
- Transparency 23–4 Master, p. 95
- Study Guide, pp. 81–82
- Enrichment, pp. 87–88
- Section 23–2 Quiz, p. 84
- Physics Lab Worksheet, pp. 73–76

Teaching Transparency 23-3
Teaching Transparency 23-4

Connecting Math to Physics

Technology
TeacherWorks™ CD-ROM
Interactive Chalkboard CD-ROM
Exam*View*® Pro Testmaker CD-ROM
physicspp.com
physicspp.com/vocabulary_puzzlemaker

THE MECHANICAL UNIVERSE
HIGH SCHOOL ADAPTATION
Videotape
Simple DC Circuits

Concept Development

Arc Fault Circuit Interrupters Arc fault circuit interrupters use electronic detectors to respond to the electrical signals associated with arcing. They can shut down a circuit in many cases where an ordinary circuit breaker will not react. If a 120-V circuit is protected by a 15.0-A breaker, the maximum power is $P = IV = (15.0\ \text{A})(120\ \text{V}) = 1.80\ \text{kW}$. An arc at that power level is easily hot enough to ignite drapes, bedcovers, carpeting, and so on; a frayed and arcing power cord can start a fire.

Using Figure 23-10

Residential appliance circuits are often fused or breaker- protected with 15-A fuses. Ask students to determine the maximum number of 400.0-W, 120-V appliances that can operate simultaneously on such a circuit. $I = P/V = 400\ \text{W}/120\ \text{V} = 3.30\ \text{A}$ (each appliance)
Maximum number of appliances = 15.0 A/3.30 A = 4 appliances
L2 Logical-Mathematical

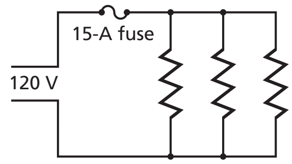
Reinforcement

Safety Devices Have students list the types of circuit protectors used in building wiring and how each one operates to protect household wiring. Also, ask which devices are more user-friendly. Go over which safety measures to follow to avoid tripping these devices and prevent accidents and injuries when using electrical equipment.
L2 Logical-Mathematical

Discussion

Question Residential wiring uses parallel circuits. Why is it necessary to understand series-parallel behavior to fully understand residential wiring?

Answer The resistance of the wires acts in series with the parallel loads. This action is what causes lights to dim when a heavy load is switched on. Also, the circuit breakers or fuses are in series and thus can deactivate the parallel loads.
L2 Logical-Mathematical



■ **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.

$$\frac{1}{R} = \frac{1}{60\ \Omega} + \frac{1}{20\ \Omega} + \frac{1}{10\ \Omega}$$
$$= \frac{1}{6\ \Omega}$$
$$R = 6\ \Omega$$

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 Ω. This resistance results in a huge current.

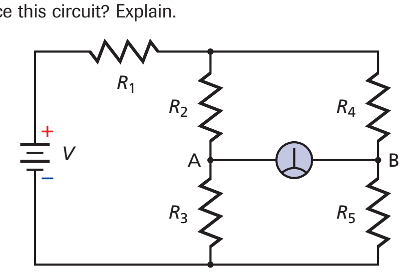
$$I = \frac{V}{R} = \frac{120\ \text{V}}{0.010\ \Omega} = 12{,}000\ \text{A}$$

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?



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CHALLENGE PROBLEM

1. Yes, making all the resistors equal will balance this circuit. You can also balance this circuit by adjusting the resistance values so that $R_2/R_3 = R_4/R_5$ remains equal, such as to make $R_2 = 20.0$ W, $R_3 = 22.5$ W , $R_4 = 40.0$ W , and $R_5 = 45.0$ W.
2. $\frac{R_3}{R_2} = \frac{R_5}{R_4}$
3. any resistor but R_1
4. R_1. A galvanometer can be damaged by too much current. If R_1 is adjustable, it is set for a high value before the circuit is energized. This limits the current flow through the galvanometer. As the balancing resistor is adjusted and as the meter reading approaches zero, the sensitivity is then increased by decreasing R_1.

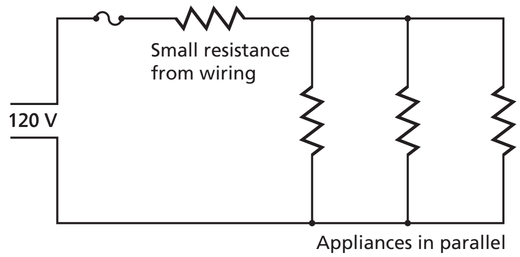


Figure 23-11 The small resistance inherent in wires is in series with the parallel resistances of household appliances.

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.

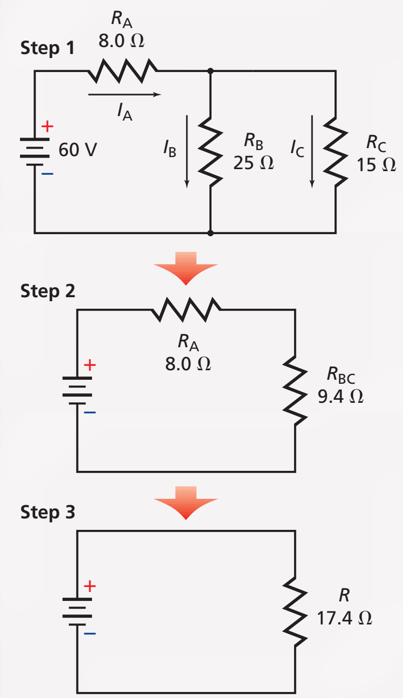
PROBLEM-SOLVING Strategies

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



Critical Thinking

Operation of SPDT Switches Single-pole, double-throw switches can be used to control a load from two locations. For example, a light in a stairwell can be controlled by a switch located at the top and the bottom of the stairwell. Draw a diagram for a SPDT switch on the chalkboard with a load and a source and explain its two-way operation. Ask students to think of other ways this type of circuit might be used, such as in a doorbell that has a push button at two different doors. **L2 Logical-Mathematical**

Using Models

Analyzing Current Values Suppose a dozen different current values in R_C had to be analyzed for the circuit included in the Problem-Solving Strategies. In such cases, the use of a model could save a lot of time. At the points where R_C is connected, find the voltage across the points if R_C were disconnected.

$V_{RB} = (60 V)(25\ \Omega)/(8.0\ \Omega + 25\ \Omega) = 45.5\ V$

Next, find the equivalent parallel resistance of R_A and R_B.

$1/R_P = 1/R_A + 1/R_B = 1/8.0\ \Omega + 1/25\ \Omega$

$R_P = 6.1\ \Omega$

In this case, the model is a 45.5-V battery in series with a 6.1-Ω resistor. If R_C is now connected to the model, its current is found by $V/R = 45.5\ V/(6.1\ \Omega + 25\ \Omega) =$ 1.5 A, which is the same value that can be obtained by calculating I_C in the figure.

$R = R_C + R_P = 15\ \Omega + 6.1\ \Omega = 21.1\ \Omega$

$I = V_{Source}/R = 45.5/21.1\ \Omega = 2.2\ A$

$V_C = IR_C = (2.2\ A)(25\ \Omega) = 55\ V$

$I_C = V_C/R_C = 55\ V/25\ \Omega = 2.2\ A$

CHALLENGE Activity

Balancing Circuits One model for the circuit shown in the Problem-Solving Strategies is appropriate when R_C can take on various values. A different model is needed when R_B can take on various values. Have students find that model that can be used to calculate the value of R_B. At the points where R_B is connected, determine the voltage if R_B were to become disconnected. $V_{RC} = (60\ V)(15\ \Omega)/(8.0\ \Omega + 15\ \Omega) = 39\ V$. Next, find the equivalent parallel resistance of R_A and R_C. $1/R_P = 1/R_A + 1/R_C = 1/8.0\ \Omega + 1/15\ \Omega = 5.2\ \Omega$. In this case, the model is a 39-V battery in series with a 5.2-Ω resistor. If R_B is connected to the model, its current is found by $V/R = 39\ V/(5.2\ \Omega + 25\ \Omega) =$ 1.4 A. **L3 Logical-Mathematical**

IN-CLASS Example

Question An air conditioner with a resistance of 50.0 Ω (R_A) and a computer with a resistance of 20.0 Ω (R_B) are connected in parallel to a 120.0-V source through a 2.00 Ω resistor (R_C) in series. Find the current through the computer when the air conditioner is and is not running.

Answer Current through computer when air conditioner is running:

$R_p = 1/(1/R_A + 1/R_B)$
$= 1/(1/50.0\ \Omega + 1/20.0\ \Omega)$
$= 14.3\ \Omega$

$R = R_C + R_p$
$= 2.00\ \Omega + 14.3\ \Omega$
$= 16.3\ \Omega$

$I = V_{source}/R$
$= 120.0\ \text{V}/16.3\ \Omega$
$= 7.36\ \text{A}$

$V_C = (2.00\ \Omega)(7.36\ \text{A}) = 14.7\ \text{V}$

$V_A = 120.0\ \text{V} - 14.7\ \text{V} = 105.3\ \text{V}$

$V_B = V_A = 105.3\ \text{V}$

$$I_B = \frac{V_B}{R_B} = \frac{105.3\ \text{V}}{20.0\ \Omega} = 5.26\ \text{A}$$

Current through computer when air conditioner is not running:

$R_B = 20.0\ \Omega$

$R = R_C + R_B$
$= 2.00\ \Omega + 20.0\ \Omega$
$= 22.0\ \Omega$

$I = V_{source}/R$
$= 120.0\ \text{V}/22.0\ \Omega$
$= 5.45\ \text{A}$

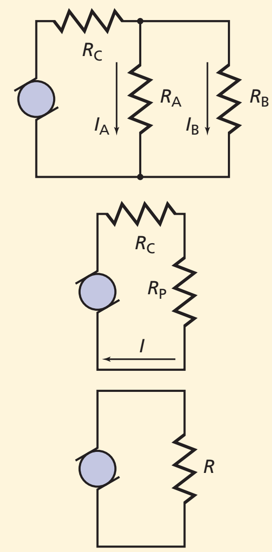
$V_C = (2.00\ \Omega)(5.45\ \text{A}) = 10.9\ \text{V}$

$V_B = 120.0\ \text{V} - 10.9\ \text{V} = 109.1\ \text{V}$

$$I_B = \frac{V_B}{R_B} = \frac{109.1\ \text{V}}{20.0\ \Omega} = 5.45\ \text{A}$$

EXAMPLE Problem 4

Series-Parallel Circuit A hair dryer with a resistance of 12.0 Ω and a lamp with a resistance of 125 Ω are connected in parallel to a 125-V source through a 1.50-Ω 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:		Unknown:	
$R_A = 125\ \Omega$	$R_C = 1.50\ \Omega$	$I = ?$	$I_A = ?$
$R_B = 12.0\ \Omega$	$V_{source} = 125\ \text{V}$	$R = ?$	$R_p = ?$

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.

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

$R_p = 10.9\ \Omega$

$R = R_C + R_p = 1.50\ \Omega + 11.0\ \Omega$ **Substitute $R_C = 1.50\ \Omega$, $R_p = 10.9\ \Omega$**

$= 12.4\ \Omega$

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

$= 10.1\ \text{A}$

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

$= 15.2\ \text{V}$

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

$= 1.10\times10^2\ \text{V}$

$$I_A = \frac{V_A}{R_A} = \frac{1.10\times10^2\ \text{V}}{125\ \Omega}$$ **Substitute $V_A = 1.10\times10^2\ \text{V}$, $R_A = 125\ \Omega$**

$= 0.880\ \text{A}$

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 A.

PRACTICE Problems

Additional Problems, Appendix B

25. A series-parallel circuit has three resistors: one dissipates 2.0 W, the second 3.0 W, and the third 1.5 W. How much current does the circuit require from a 12-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?

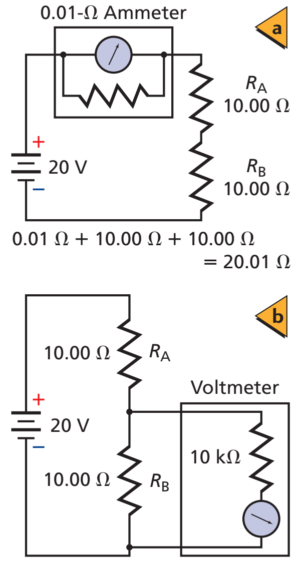
Teacher F.Y.I. — REAL-LIFE PHYSICS

Load Leveling Power companies must make investments in generating and transmission capacity to meet peak demands. Since the demand is often not at peak, their equipment is not always used near full capacity. This makes it more difficult for power companies to realize a profit and pay for equipment. As such, power companies charge many of their customers a premium rate during periods of peak use, a practice that encourages customers to level their use and lower their energy bills. Computerized load levelers can be used to control heating and cooling loads in large buildings and avoid high rates. For example, water can be heated after midnight when the rates are at their lowest point.

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-Ω resistor. Because the resistance of the ammeter is much less than that of the resistors, the current decrease is negligible.

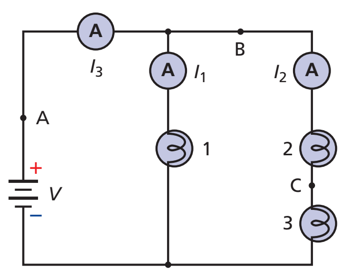
Another instrument, called a **voltmeter,** is used to measure the voltage drop across a portion of a circuit. To measure the potential drop across a resistor, a voltmeter is connected in parallel with the resistor. Voltmeters are designed to have a very high resistance so as to cause the smallest possible 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-kΩ 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 MΩ.



■ **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 A and I_1 measures 1.1 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 V, and a voltmeter connected across bulb 3 measures 4.2 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.

Physics Online physicspp.com/self_check_quiz

23.2 Section Review

29. Bulbs 2 and 3 are equal in brightness but dimmer than bulb 1.

30. 0.6 A

31. Both dim equally. The current in each is reduced by the same amount.

32. 8.0 V

33. No. Identical bulbs in series would have identical voltage drops since their currents are the same.

34. fuses, circuit breakers, and ground-fault interrupters

35. Yes. Because intensity is proportional to power, it would be necessary to use a bulb at location 1 that has four times the operating resistance of each of those at locations 2 and 3.
$V^2/4R = (V/2)^2/R$

PRACTICE Problems

25. 0.54 A

26. the 11 lights in series

27. Then, all of the working lights are in series. The 12 working lights will burn with equal intensity.

28. The shorted light will reduce the voltage across itself and its parallel companion to 0. The 11 series lights will burn with equal, but increased, intensity and the two parallel lights will go out.

QUICK DEMO

Series-Parallel Circuits

Estimated Time 10 minutes

Materials power supply, resistors or lamps, multimeter

Procedure Build a series-parallel circuit. Use the mulitmeter to measure all voltages and currents. Demonstrate that voltages in series add and that currents in parallel add.

3 ASSESS

Check for Understanding

Equivalent Resistance Ask students to calculate the equivalent resistance of the circuit in Figure 23-12b. (Ignore significant digits.) 19.99 Ω Ask how it would change if the voltmeter's resistance were 100 Ω. 19.09 Ω Ask them to explain the advantage of a large resistance for the voltmeter. It hardly changes the equivalent resistance of the circuit. L2

Extension

Circuit Design Ask groups of students to design a circuit using switches that can turn a light off or on from three or more locations. Give each group a three-way switch and a double-pole, double-throw switch, and an ohmmeter to get them started.
L2 **Visual-Spatial**

PHYSICSLAB

Time Allotment
one laboratory period

Process Skills use scientific explanations, observe and infer, compare and contrast, formulate models, think critically, measure, collect and organize data, draw conclusions

Safety Precautions Hazard from electric shock is minimal because of the low currents used in this experiment. Tell students to not try this lab with a home circuit. The much higher voltage from wall outlets in the home will result in higher currents that have the potential to kill.

Alternative Materials A 6-V battery can be used in place of the low-voltage power supply.

Teaching Strategies
- **You may want to check student circuits before they connect the power supply.**
- **Make sure students use the correct polarity when hooking up the meters. Improper polarity can damage the meters.**

PHYSICSLAB

Alternate CBL instructions can be found on the Web site.
physicspp.com

Series and Parallel Circuits

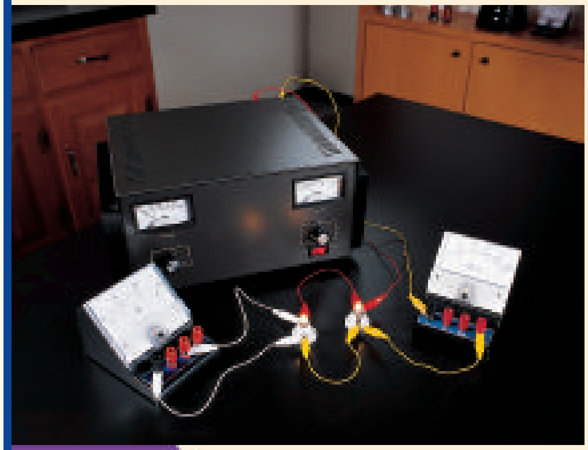
In every circuit there is a relationship among current, potential difference, and resistance in electric circuits. In this experiment, you will investigate how the relationship of current, potential difference, and resistance in series circuits compares to that in parallel circuits.

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.

632
Horizons Companies

Sample Data Data will vary depending on the type of lightbulbs used. The sample data are for two 6.3-V bulbs.

Step	Description
3	Both bulbs go out
4	5.20 V
5	2.60 V and 2.60 V
6	150 mA everywhere

Step	Description
8	300 mA
9	2.76 V everywhere
10	170 mA, 2.76 V, other bulb brighter
11	170 mA, 2.76 V, other bulb brighter

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

8. 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.
9. Check the potential difference across the entire circuit and across each lightbulb. Record the values in the data table.
10. 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.
11. 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

1. Calculate the resistance of the pair of lightbulbs in the series circuit.
2. Calculate the resistance of each lightbulb in the series circuit.
3. How does the resistance of the pair of lightbulbs compare to the individual resistance of each lightbulb?
4. How does the potential difference across the individual lightbulbs compare to the potential difference across the pair of lightbulbs in the series circuit?
5. 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

1. Summarize the relationship among current, potential difference, and resistance in a series circuit.
2. 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

1. 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)?
2. Why do lights in a home dim when a large appliance, such as an air conditioner, is turned on?

Physics Online

To find out more about series and parallel circuits, visit the Web site: **physicspp.com**

ALTERNATIVE INQUIRY LAB

To Make this Lab an Inquiry Lab: Without setting up any circuits beforehand, ask students what will happen to the current, potential difference, and resistance when more bulbs are added in combination series-parallel configurations. By altering the lab in this way, students will be encouraged to develop critical thinking about how circuits are set up and why. Have students brainstorm questions about those circuits. Allow them to explore these questions as time allows.

Analyze

1. (Note: All answers will depend on individual student data)
$R = V/I$
$= 5.20\ V/0.150\ A$
$= 34.7\ \Omega$
2. $R = V/I$
$= 2.60\ V/0.150\ A$
$= 17.3\ \Omega$
3. The sum of the individual resistances of each lightbulb adds up to the total resistance in the series circuit of the pair of lightbulbs.
4. The total potential difference of the pair of lightbulbs is the sum of potential differences of the individual lightbulbs.
5. $R = V/I$
$= 2.76\ V/0.170\ A$
$= 16.2\ \Omega$
This value is close to the calculated resistance of the bulb in the series circuit.

Conclude and Apply

1. In a series circuit, the current is the same, V_{source} equals the total of individual voltage drops, and total resistance equals the sum of individual resistances.
2. In a parallel circuit, the potential difference is the same everywhere, and the total current is equal to the sum of the currents going through each resistance.

Going Further

Data will still confirm statements made in Conclude and Apply.

Real-World Physics

1. Houses are wired in parallel. As demonstrated in step 9, the voltage in each parallel branch is the same as the circuit voltage.
2. The resistance in the house wiring acts like a series load connected in the parallel household circuits. As the device turns on, more current is necessary to start the motor. This causes the current going through other devices to momentarily decrease.

How it Works

Purpose
Students will apply the concepts of circuits, alternating current, and electromagnetic induction to how a ground-fault interrupter works.

Background
Prior to WWII, Charles Dalziel carefully studied the effect of electric shock on men and women. He established that a woman holding a live wire is unable to release it if as little as 11 mA of current flows through her body.

Later, sought as an expert to review electric shock fatalities, Dalziel realized that many of the deaths were the result of a person accidentally completing a path between a live conductor and ground, or a *ground fault.* He set out to build a device that would quickly open a circuit in the event of a ground fault of a few mA.

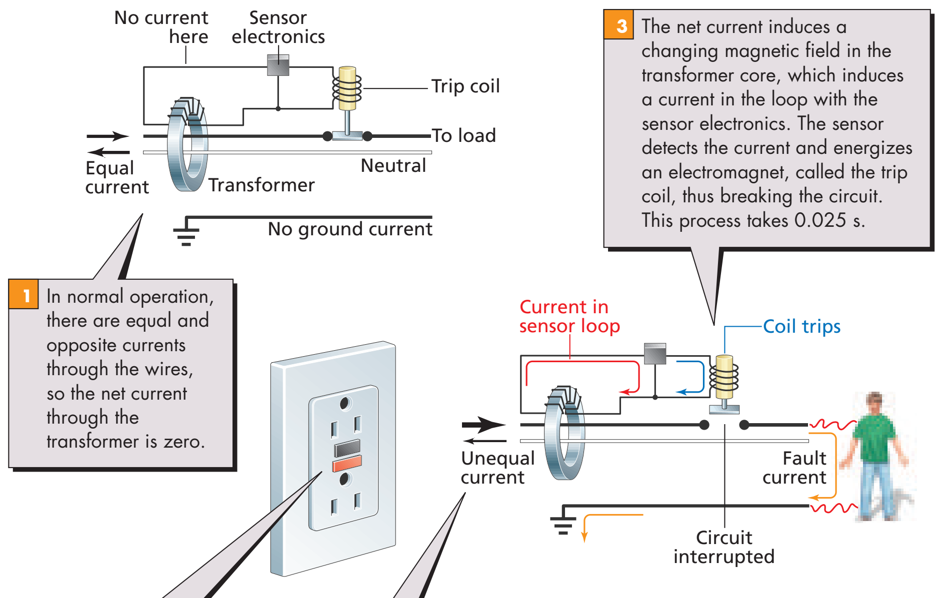
In 1961, he was successful, and he received a patent for the invention in 1965. The National Electric Code now requires GFCI outlets in new construction in kitchens, bathrooms, garages, unfinished basements, crawl spaces, and outdoor receptacles.

Visual Learning
Ask students to search their school or home for GFCI outlets. Have them record the outlet locations, press the test buttons, and report their findings. Mention to students that a single GFCI often protects several outlets.

Extensions
Have a student stand barefoot in a metal pan. Using a battery-operated ohmmeter, measure the resistance between the pan and one of the student's hands. Try the same thing with water in the pan. Calculate the current that would result from a 115 V potential difference.

How it Works — 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?



Thinking Critically

1. **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?
2. **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.
3. **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?

Thinking Critically

1. Water, when it contains dissolved solutes, is a good conductor, providing a low-resistance path to ground.
2. GFCIs will not protect the person. The currents through the hot and neutral wires remain equal.
3. $I = V/R = 115\ \text{V}/14{,}750\ \Omega = 7.80\ \text{mA}$ This is a small current.

Chapter 23 Study Guide

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.

$$R = R_A + R_B + \ldots$$

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

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

- 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.

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

- 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.

Chapter 23 Study Guide

Key Concepts

Summary statements can be used by students to review the major concepts of the chapter.

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VOCABULARY PuzzleMaker

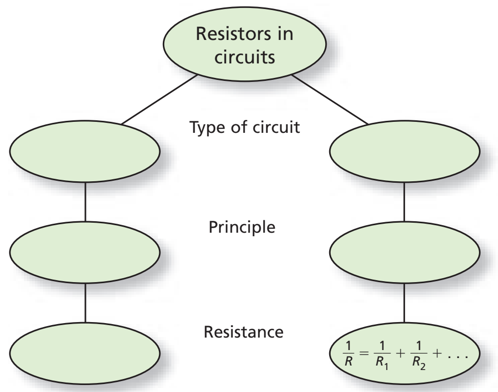
For additional help with vocabulary, have students access the Vocabulary PuzzleMaker online.

physicspp.com/vocabulary_puzzlemaker

Chapter 23 Assessment

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-Ω resistors connected in series and three 60-Ω 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)

Applying Concepts

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-Ω resistors in series. Circuit B contains three 60-Ω resistors in parallel. How does the current in the second 60-Ω resistor of each circuit change if a switch cuts off the current to the first 60-Ω 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-Ω resistor and a 15-Ω resistor, but there are only 30-Ω 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.
    a. If the lamps are connected in parallel, which is brighter (dissipates more power)?
    b. 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.
    a. The current is the same everywhere throughout the entire circuit.
    b. The total resistance is equal to the sum of the individual resistances.
    c. The voltage drop across each resistor in the circuit is the same.
    d. The voltage drop in the circuit is proportional to the resistance.
    e. Adding a resistor to the circuit decreases the total resistance.
    f. Adding a resistor to the circuit increases the total resistance.
    g. If the current through one resistor in the circuit goes to zero, there is no current in the entire circuit.
    h. If the current through one resistor in the circuit goes to zero, the current through all other resistors remains the same.
    i. 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?

 For more problems, go to Additional Problems, Appendix B.

Chapter 23 Assessment (Answers)

Concept Mapping

36. See Solutions Manual.

Mastering Concepts

37. When one bulb burns out, the circuit is open and all the bulbs go out.

38. Each new resistor provides an additional path for the current.

39. The equivalent resistance will be less than that of any of the resistors.

40. Appliances in parallel can be run independently of one another.

41. In a series circuit, the current is opposed by each resistance in turn. The total resistance is the sum of the resistors. In a parallel circuit, each resistance provides an additional path for current. The result is a decrease in total resistance.

42. The amount of current entering a junction is equal to the amount of current leaving.

43. The purpose of a fuse is to prevent conductors from being overloaded with current, causing fires due to overheating.

44. A short circuit is a circuit that has extremely low resistance. A short circuit is dangerous across any potential difference because it will produce a large current. The heating effect of the current can cause a fire.

45. An ammeter must have low resistance because it is placed in series in the circuit. If its resistance were high, it would significantly change the total resistance of the circuit.

46. A voltmeter must have very high resistance for the same reason that an ammeter has low resistance. If the voltmeter has low resistance, it would lower the resistance of the portion of the circuit it is across and increase the current in the circuit. This would produce a higher voltage drop across the part of the circuit where the voltmeter is located, changing the voltage it is measuring.

47. An ammeter is connected in series; a voltmeter is connected in parallel.

Applying Concepts

48. If one of the lamp filaments burns out, the current will cease and all the lamps will go out.

49. $V_B = VR_B/(R_A + R_B)$, so as R_A increases, V_B will decrease.

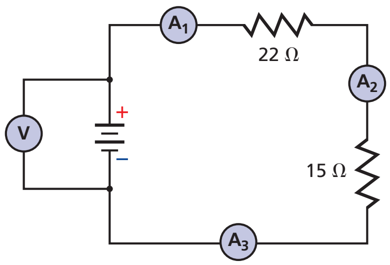
50. Circuit A: There will be no current in the resistor. Circuit B: The current in the resistor will remain the same.

51. If one of the filaments burns out, the resistance and the potential difference across the other lamps will not change; therefore their currents will remain the same.

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.

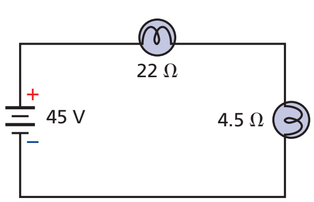
60. A series circuit has two voltage drops: 5.50 V and 6.90 V. What is the supply voltage?

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?

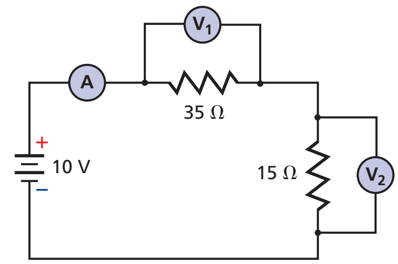
63. Ammeter 2 in Figure 23-14 reads 0.50 A.
a. Find the voltage across the 22-Ω resistor.
b. Find the voltage across the 15-Ω resistor.
c. What is the battery voltage?

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?



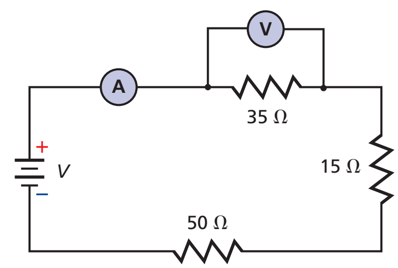
■ **Figure 23-15**

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?



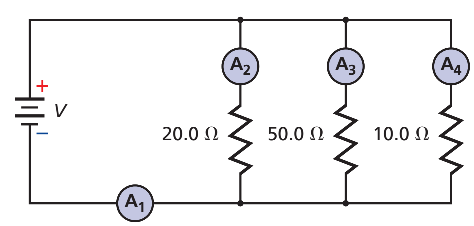
■ **Figure 23-16**

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

52. No, the 30-Ω resistors can be used in parallel. Three 30-Ω resistors in parallel will give a 10-Ω resistance. Two 30-Ω resistors in parallel will give a 15-Ω resistance.

53. Connect four of the bulbs in series.

54. a. The lamp with the lower resistance.
b. The lamp with the higher resistance.

55. a. series
b. series
c. parallel
d. series
e. parallel
f. series
g. series
h. parallel
i. parallel

56. The 30-A fuse allows more current to flow through the circuit, generating more heat in the wires, which can be dangerous.

Mastering Problems

23.1 Simple Circuits

Level 1

57. a. 0.20 A
b. 0.20 A

58. 12 kΩ

59. 0.40 kΩ

60. 12.4 V

61. 4.45 A

Level 2

62. a. 37 Ω
b. 7.4 V
c. 0.88 W
d. 1.5 W

63. a. 11 V
b. 7.5 V
c. 19 V

64. a. 26 Ω
b. 1.7 A
c. 37 V, 7.7 V
d. 63 W, 13 W

65. a. 0.20 A
b. 7.0 V
c. 3.0 V
d. 120 J

66. a. 50 Ω
b. 15 Ω
c. 2.0 A
d. 4×10^2 W

67. a. 10.0 Ω
b. 50.0 Ω
c. 19 A
d. 5.5 A
e. 2.2 A
f. 11 A

68. a. 2.0×10^{1} V
b. 3.4 A
c. 1.0 A
d. 2.0 A

69. down

70. a. 62 Ω
b. 6.0 V

71. a. 2.3×10^{2} Ω or 0.23 kΩ
b. 13 Ω
c. 3.6 W

72. a. 2.2×10^{2} Ω
b. 65 W
c. It increased.

73. a. 8.89 Ω
b. 4.50 A
c. 2.50 A

74. 66 Ω

75. 1.6×10^{2} Ω

Level 3

76. a. 52 Ω
b. 110 V
c. 9.8 Ω
d. 96 V

23.2 Applications of Circuits

Level 1

77. 45.0 Ω

78. 360 mW

79. 11 mA

80. 15 mA

Level 2

81. a. 50.0 Ω
b. 0.50 A
c. The 25.0 Ω resistor is the hottest; the 10.0 Ω resistor is the coolest.

82. a. 2.0 A
b. 3.0 A
c. 15 A

83. Yes. The 15-A current will melt the 12-A fuse.

68. For Figure 23-18, ammeter 3 reads 0.40 A.
a. What is the battery voltage?
b. What will ammeter 1 read?
c. What will ammeter 2 read?
d. What will ammeter 4 read?

69. What is the direction of the conventional current in the 50.0-Ω resistor in Figure 23-18?

70. The load across a battery consists of two resistors, with values of 15 Ω and 47 Ω, connected in series.
a. What is the total resistance of the load?
b. 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.
a. What is the equivalent resistance of the light string?
b. What is the resistance of a single light?
c. 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.
a. What is the resistance of the light string now?
b. Find the power dissipated by the string.
c. Did the power increase or decrease when the bulb burned out?

73. A 16.0-Ω and a 20.0-Ω resistor are connected in parallel. A difference in potential of 40.0 V is applied to the combination.
a. Compute the equivalent resistance of the parallel circuit.
b. What is the total current in the circuit?
c. What is the current in the 16.0-Ω resistor?

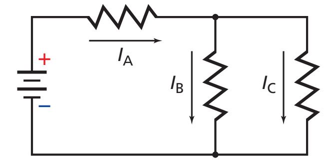
74. Amy needs 5.0 V for an integrated-circuit experiment. She uses a 6.0-V battery and two resistors to make a voltage divider. One resistor is 330 Ω. She decides to make the other resistor smaller. What value should it have?

75. Pete is designing a voltage divider using a 12-V battery and a 82-Ω 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.
a. Find the resistance of the television.
b. The television and 2.5-Ω wires connecting the outlet to the fuse form a series circuit that works like a voltage divider. Find the voltage drop across the television.
c. A 12-Ω hair dryer is plugged into the same outlet. Find the equivalent resistance of the two appliances.
d. 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 Ω. Find the equivalent resistance.



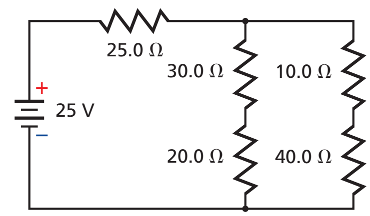
■ **Figure 23-19**

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.
a. Determine the total resistance.
b. Determine the current through the 25-Ω resistor.
c. Which resistor is the hottest? Coolest?



■ **Figure 23-20**

82. A circuit contains six 60-W lamps with a resistance of 240-Ω each and a 10.0-Ω heater connected in parallel. The voltage across the circuit is 120 V. Find the current in the circuit for the following situations.
a. Four lamps are turned on.
b. All of the lamps are turned on.
c. 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.

 For more problems, go to Additional Problems, Appendix B.

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 2.3×10^{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.

a. Compute the equivalent resistance of the circuit consisting of just the lamp and the lead lines to and from the lamp.

b. Find the current to the lamp.

c. Find the power dissipated in the lamp.

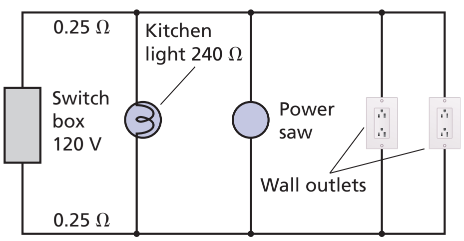


Figure 23-21

Mixed Review

87. A series circuit has two voltage drops: 3.50 V and 4.90 V. What is the supply voltage?

88. A parallel circuit has two branch currents: 1.45 A and 1.00 A. What is the current in the energy source?

89. A series-parallel circuit has three resistors, dissipating 5.50 W, 6.90 W, and 1.05 W, respectively. What is the supply power?

90. Determine the maximum safe power in each of three 150-Ω, 5-W resistors connected in series.

91. Determine the maximum safe power in each of three 92-Ω, 5-W resistors connected in parallel.

92. A voltage divider consists of two 47-kΩ resistors connected across a 12-V battery. Determine the measured output for the following.

a. an ideal voltmeter

b. a voltmeter with a resistance of 85 kΩ

c. a voltmeter with a resistance of 10×10^{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.

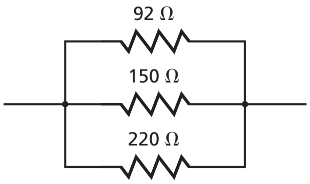


Figure 23-23

Thinking Critically

96. 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.

97. 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

Chapter 23 Assessment

84. See Solutions Manual.

85. 1.1×10^{3} s

86. a. 0.24 kΩ
b. 0.50 A
c. 6.0×10^{1} W

Mixed Review

Level 1

87. 8.40 V

88. 2.45 A

89. 13.45 W

Level 2

90. 15 W

91. 15 W

92. a. 6.0 V
b. 4.7 V
c. 6.0 V

Level 3

93. 7.0×10^{1} V

94. 11 W

95. 21 V

Thinking Critically

96. $R_{eq\,2} = \frac{R}{2}$, $R_{eq\,3} = \frac{R}{3}$, $R_{eq\,N} = \frac{R}{N}$

97. See Solutions Manual.

98. a. See Solutions Manual.
b. See Solutions Manual.
c. See Solutions Manual.
d. See Solutions Manual.

99. a. 0.134 A
b. 0.395 W
c. 0.014 W

100. a. 6.0 kΩ
b. 6.0 kΩ, 18 kΩ, 2.0 kΩ
c. No. Zero ohms is at full-scale, 6 kΩ is at midscale, and infinite Ω (or open-circuit) is at zero-scale.

Writing in Physics

101. Students' answers should include his voltage law, which is the conservation of energy applied to electric circuits, and his current law, which is conservation of charge applied to electric circuits. The voltage law states that the algebraic sum of the voltage drops around a closed loop is zero. The current law states that the algebraic sum of the current at a node is zero.

Cumulative Review

102. **a.** 1.00 m
b. 340 Hz
c. 170 m/s
d. 680 Hz
e. 230 Hz

103. −7.41 cm

104. 1.71

105. 4.2×10^{2} nm is the only wavelength of light for which destructive interference occurs.

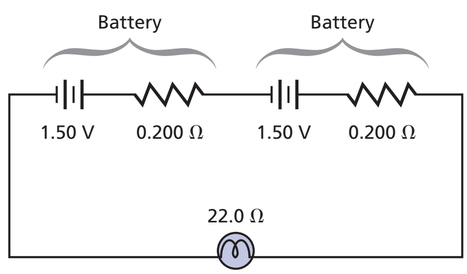
106. 0.40 m

107. **a.** *E*/9
b. 3*E*
c. *E*/3
d. *E*
e. *E*/3

108. 5.5 Ω

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.
a. Design A requires that should one bulb burn out, all other bulbs continue to produce light.
b. Design B requires that should one bulb burn out, those bulbs that continue working must produce the correct intensity.
c. Design C requires that should one bulb burn out, one other bulb also will go out.
d. 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 Ω. The bulb has a resistance of 22.0 Ω.
a. What is the current through the bulb?
b. How much power does the bulb dissipate?
c. 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.
a. What is the resistance of the adjustable resistor?
b. 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?
c. 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)
a. What would be the wavelength of the sound waves if the airplane were not moving?
b. What is the frequency of the sound waves produced by the airplane?
c. What is the speed of the airplane?
d. What is the frequency detected by an observer located directly in front of the airplane?
e. 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 cm. What is the location of the object's image? (Chapter 17)

104. The speed of light in a special piece of glass is 1.75×10^{8} 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 2.0×10^{-5} C and 8.0×10^{-6} 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)
a. *d* is tripled
b. *Q* is tripled
c. both *d* and *Q* are tripled
d. the test charge *q′* is tripled
e. all three, *d*, *Q*, and *q′*, are tripled

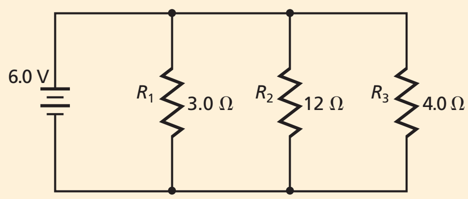
108. The current flow in a 12-V circuit drops from 0.55 A to 0.44 A. Calculate the change in resistance. (Chapter 22)

 For more problems, go to Additional Problems, Appendix B.

Standardized Test Practice

Multiple Choice

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



1. What is the equivalent resistance of the circuit?

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

2. What is the current in the circuit?

Ⓐ 0.32 A Ⓒ 1.2 A
Ⓑ 0.80 A Ⓓ 4.0 A

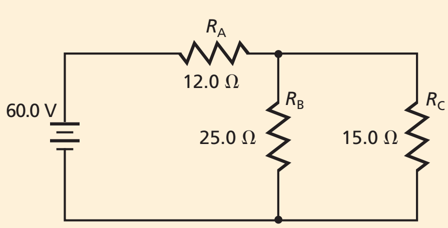
3. How much current is in R_3?

Ⓐ 0.32 A Ⓒ 2.0 A
Ⓑ 1.5 A Ⓓ 4.0 A

4. What would a voltmeter placed across R_2 read?

Ⓐ 0.32 V Ⓒ 3.8 V
Ⓑ 1.5 V Ⓓ 6.0 V

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



5. What is the equivalent resistance of the circuit?

Ⓐ 8.42 Ω Ⓒ 21.4 Ω
Ⓑ 10.7 Ω Ⓓ 52.0 Ω

6. What is the current in the circuit?

Ⓐ 1.15 A Ⓒ 2.80 A
Ⓑ 2.35 A Ⓓ 5.61 A

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

Ⓐ 0.67 Ω Ⓒ 12 Ω
Ⓑ 1.5 Ω Ⓓ 96 Ω

8. Which statement is true?

Ⓐ The resistance of a typical ammeter is very high.
Ⓑ The resistance of a typical voltmeter is very low.
Ⓒ Ammeters have zero resistance.
Ⓓ 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.

Standardized Test Practice

Rubric

The following rubric is a sample scoring device for extended response questions.

Extended Response

Points	Description
4	The student demonstrates a thorough understanding of the physics involved. The response may contain minor flaws that do not detract from the demonstration of a thorough understanding.
3	The student demonstrates an understanding of the physics involved. The response is essentially correct and demonstrates an essential but less than thorough understanding of the physics.
2	The student demonstrates only a partial understanding of the physics involved. Although the student may have used the correct approach to a solution or may have provided a correct solution, the work lacks an essential understanding of the underlying physical concepts.
1	The student demonstrates a very limited understanding of the physics involved. The response is incomplete and exhibits many flaws.
0	The student provides a completely incorrect solution or no response at all.

Multiple Choice

1. C **2.** D **3.** B
4. D **5.** C **6.** C
7. D **8.** D

Extended Answer

9. Chris must disconnect 5 lamps.
10. $I = 0.20$ A; $P = 1.6$ W