35 ELECTRIC CIRCUITS

Objectives

- Describe the configuration of a working circuit. (35.1)
- Explain how current can be turned on or off in a circuit, and how electrical devices can be connected in a circuit. (35.2)
- Describe the characteristics of a series circuit. (35.3)
- Describe the characteristics of a parallel circuit. (35.4)
- Interpret circuit diagrams. (35.5)
- Determine the equivalent resistance of circuits having two or more resistors. (35.6)
- Explain the cause and prevention of overloading household circuits. (35.7)

discover!

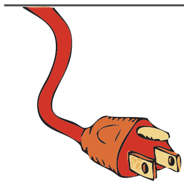
MATERIALS lightbulb, wire, battery

EXPECTED OUTCOME Students will discover different ways to construct a circuit from the battery, the bulb, and the wire.

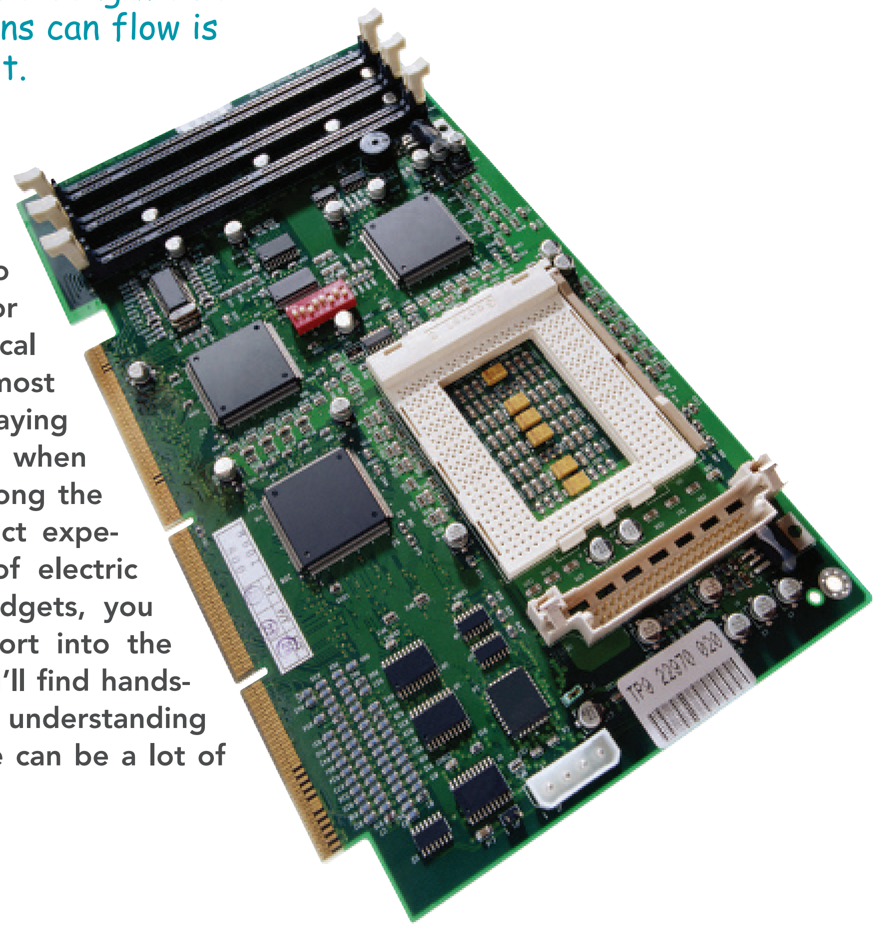
ANALYZE AND CONCLUDE

1. The bulb will light whenever a closed conducting path is formed.
2. Six different arrangements (when you take into account the orientation of the wire) will result in a lighted bulb. See Figure 35.2b.
3. Conditions include a working voltage source, a working lightbulb, and a closed conducting path, or circuit.

35 ELECTRIC CIRCUITS



THE BIG IDEA Any path along which electrons can flow is a circuit.



Mechanical things seem to be easier to figure out for most people than electrical things. Maybe this is because most people have had experience playing with blocks and mechanical toys when they were children. If you are among the many who have had far less direct experience with the inner workings of electric devices than with mechanical gadgets, you are encouraged to put extra effort into the laboratory part of this course. You'll find hands-on laboratory experience aids your understanding of electric circuits. The experience can be a lot of fun, too!

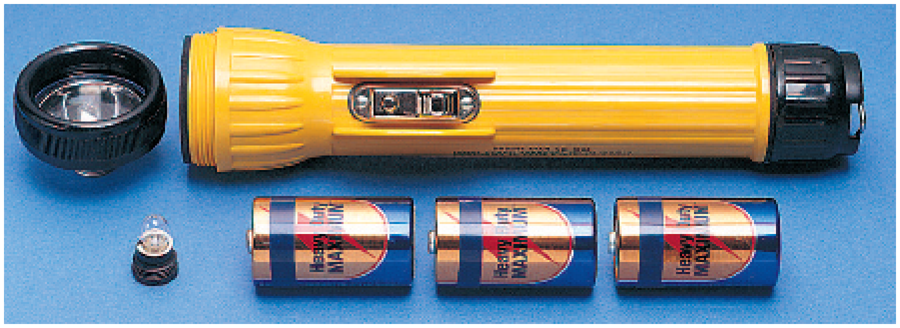
discover!

What Does It Take to Light a Lightbulb?

1. Try to light a lightbulb with just a battery and a single piece of wire.
2. Now try to get the same result with different arrangements of the wire, the battery, and the lightbulb.

Analyze and Conclude

1. **Observing** Describe both successful and unsuccessful attempts to light the lightbulb.
2. **Predicting** How many possible arrangements of the wire, the battery, and the lightbulb will result in the bulb being lit?
3. **Making Generalizations** What conditions are necessary in order for the bulb to light?



◀ **FIGURE 35.1**
A flashlight consists of a reflector cap, a lightbulb, batteries, and a barrel-shaped housing with a switch.

35.1 A Battery and a Bulb

Take apart an ordinary flashlight like the one shown in Figure 35.1. If you don't have any spare pieces of wire around, cut some strips from some aluminum foil that you probably have in one of your kitchen drawers. Try to light up the bulb using a single battery[35.1] and a couple of pieces of wire or foil.

Some of the ways you *can* light the bulb and some of the ways you *can't* light it are shown in Figure 35.2. The important thing to note is that there must be a complete path, or **circuit,** that includes the bulb filament and that runs from the positive terminal at the top of the battery to the negative terminal, which is the bottom of the battery. Electrons flow from the negative part of the battery through the wire or foil to the side (or bottom) of the bulb, through the filament inside the bulb, and out the bottom (or side) and through the other piece of wire or foil to the positive part of the battery. The current then passes through the interior of the battery to complete the circuit.

The flow of charge in a circuit is very much like the flow of water in a closed system of pipes. In a flashlight, or for the setups shown in Figure 35.2b, the battery is analogous to a pump, the wires are analogous to the pipes, and the bulb is analogous to any device that operates when the water is flowing. When a valve in the line is opened and the pump is operating, water already in the pipes starts to flow.

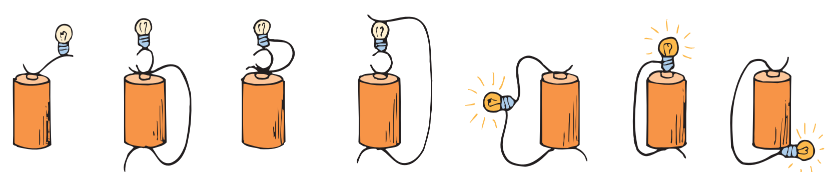
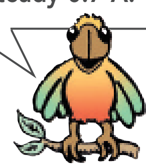


FIGURE 35.2 ▲
a. Unsuccessful ways to light a bulb. **b.** Successful ways to light a bulb.

Filament resistance in a 120-V, 60-W bulb increases about 15 times from room temperature to its nearly 3000-K operating temperature in a time of about 100 milliseconds. The initial 10-A current drawn quickly decreases to a steady 0.7 A.



This chapter extends the previous chapter to simple series and parallel DC circuits. Since circuits are not the background for any other chapters in the text, this chapter may be omitted from your course.

PAUL

35.1 A Battery and a Bulb

Key Term
circuit

Common Misconception
Electric current flows out of and into a battery.

FACT Electrons flow continuously around the circuit.

▶ **Teaching Tip** Explain what it means to say that a battery is dead. A battery, like anything else, has resistance. If the electrodes in a battery become corroded, the internal resistance prevents the flow of charge—we say the battery is dead. A dead battery may register full voltage on a voltmeter because the voltmeter draws only a tiny current that is easily supplied by the battery. Drawing a greater current is another story. This is similar to what happens in a rusty water pipe. As long as water does not flow in the pipe, a check at a faucet will show full water pressure but when the faucet is opened and water flows in the pipe, pressure is reduced by the rusty obstruction to the flow. In both cases, the resistance only reduces the pressure or voltage when current flows. Putting a load on the battery produces an appreciable voltage drop because too much energy is required to force the charge though its internal resistance.

CONCEPT CHECK In a flashlight, when the switch is turned on to complete an electric circuit, the mobile electrons already in the wires and the filament begin to drift through the circuit.

35.2 Electric Circuits

Key Terms
in parallel, in series

▶ **Teaching Tip** The "open" and "closed" terminology for circuits can be confusing. An open circuit (open switch) is one in which current does not flow (unlike an open door or an open highway). A closed circuit (closed switch) is one in which current does flow (unlike a closed door or closed highway).

CONCEPT CHECK For a continuous flow of electrons, there must be a complete circuit with no gaps.

Teaching Resources

- **Reading and Study Workbook**
- **Presentation*EXPRESS***
- **Interactive Textbook**

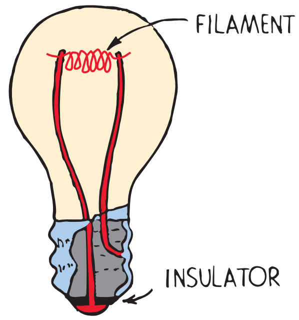


FIGURE 35.3 ▲
Electrons do not pile up inside a bulb, but instead flow through its filament.

✅ **In a flashlight, when the switch is turned on to complete an electric circuit, the mobile conduction electrons already in the wires and the filament begin to drift through the circuit.** The water flows *through* the pump and electrons in effect flow *through* the battery. Neither the water nor the electrons "squash up" and concentrate in certain places; they flow continuously around a loop, or circuit.

CONCEPT CHECK **What happens to the mobile conduction electrons when you turn on a flashlight?**

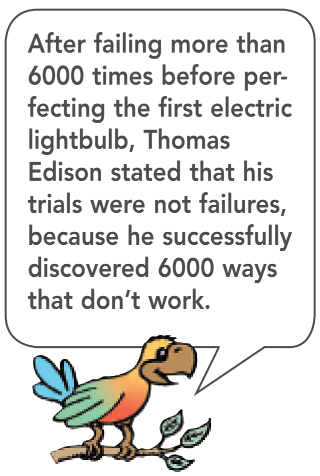
35.2 Electric Circuits

Any path along which electrons can flow is a circuit. ✅ **For a continuous flow of electrons, there must be a complete circuit with no gaps.** A gap is usually provided by an electric switch that can be opened or closed to either cut off or allow electron flow.

The water analogy is quite useful for gaining a conceptual understanding of electric circuits, but it does have some limitations. An important one is that a break in a water pipe results in water spilling from the circuit, whereas a break in an electric circuit results in a complete stop in the flow of electricity. Another difference has to do with turning current off and on. When you *close* an electrical switch that connects the circuit, you allow current to flow in much the same way as you allow water to flow by *opening* a faucet. Opening a switch stops the flow of electricity. An electric circuit must be closed for electricity to flow. Opening a water faucet, on the other hand, starts the flow of water. Despite these and some other differences, thinking of electric current in terms of water current is a helpful way to study electric circuits.

Most circuits have more than one device that receives electrical energy. These devices are commonly connected in a circuit in one of two ways, *series* or *parallel.* When connected **in series,** the devices in a circuit form a single pathway for electron flow between the terminals of the battery, generator, or wall socket (which is simply an extension of these terminals). When connected **in parallel,** the devices in a circuit form branches, each of which is a separate path for the flow of electrons. Both series and parallel connections have their own distinctive characteristics. This chapter briefly treats circuits with these two types of connections.

CONCEPT CHECK **How can a circuit achieve a continuous flow of electrons?**



Physics on the Job

Electrician An electrician is called upon whenever a building is being constructed or rewired. Electricians install wiring and connect the circuits to the local power company. The first step an electrician must take is to prepare a wiring diagram that shows how the series and parallel circuits will be arranged and where the switches will be located. The next step is to install the circuits and make sure current flows through the circuits properly and safely. The electrician must also make sure that the wiring meets local codes. Builders and contractors rely on electricians for any structure that uses electricity—from tall skyscrapers to backyard lighting systems.

35.3 Series Circuits

Figure 35.4 shows three lamps connected in series with a battery. This is an example of a simple **series circuit,** or a circuit in which devices are arranged so that charge flows through each in turn. When the switch is closed, a current exists almost immediately in all three lamps. The current does not "pile up" in any lamp but flows *through* each lamp. Electrons in all parts of the circuit begin to move at once. Some electrons move away from the negative terminal of the battery, some move toward the positive terminal, and some move through the filament of each lamp. Eventually the electrons move all the way around the circuit. A break anywhere in the path results in an open circuit, and the flow of electrons ceases. Burning out of one of the lamp filaments or simply opening the switch could cause such a break.

think!

What happens to the light intensity of each lamp in a series circuit when more lamps are added to the circuit?
Answer: 35.3.1

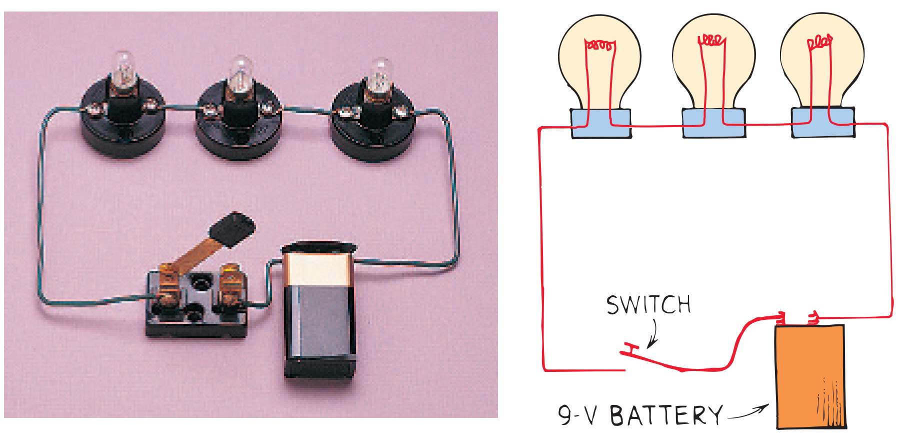


FIGURE 35.4 ▲
In this simple series circuit, a 9-volt battery provides 3 volts across each lamp.

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35.3 Series Circuits

Key Term
series circuit

▶ **Teaching Tip** Compare a series circuit to a single-lane road with no alternate routes or paths. If there is a roadblock or obstruction, traffic will stop.

Teaching Tip Make a simple series circuit, as shown in Figure 35.4, and apply the five characteristics to it. Show that the circuit is broken when any bulb is loosened.

Demonstration

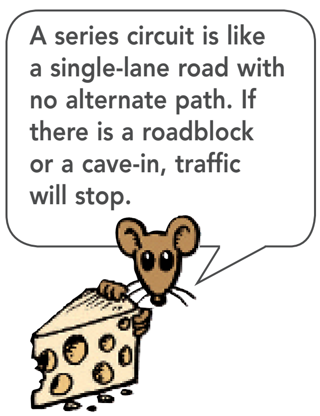
Show the features of a series circuit by stringing the lamps together and attaching the ends to the extended terminals.

The circuit shown in Figure 35.4 illustrates the following important characteristics of series connections:

1. Electric current has but a single pathway through the circuit. This means that the current passing through each electric device is the same.
2. This current is resisted by the resistance of the first device, the resistance of the second, and the third also, so that the total resistance to current in the circuit is the sum of the individual resistances along the circuit path.
3. The current in the circuit is numerically equal to the voltage supplied by the source divided by the total resistance of the circuit. This is Ohm's law.
4. Ohm's law also applies separately to each device. The *voltage drop*, or potential difference, across each device depends directly on its resistance. This follows from the fact that more energy is used to move a unit of charge through a large resistance than through a small resistance.
5. The total voltage impressed across a series circuit divides among the individual electric devices in the circuit so that the sum of the voltage drops across the individual devices is equal to the total voltage supplied by the source. This follows from the fact that the amount of energy used to move each unit of charge through the entire circuit equals the sum of the energies used to move that unit of charge through each of the electric devices in the circuit.

It is easy to see the main disadvantage of a series circuit. **If one device fails in a series circuit, current in the whole circuit ceases and none of the devices will work.** Some cheap party lights are connected in series. When one lamp burns out, it's "fun and games" (or frustration) trying to find which bulb to replace.

Most circuits are wired so that it is possible to operate electric devices independently of each other. In your home, for example, a lamp can be turned on or off without affecting the operation of other lamps or electric devices. This is because these devices are connected not in series but in parallel to one another.



CONCEPT CHECK If one device fails in a series circuit, current in the whole circuit ceases and none of the devices will work.

CONCEPT CHECK **What happens to current in other lamps if one lamp in a series circuit burns out?**

think!

Look at the circuit shown in Figure 35.4. If the current through one of the bulbs is 1 A, can you tell what the current is through each of the other two bulbs? If the voltage across bulb 1 is 2 V, and across bulb 2 is 4 V, what is the voltage across bulb 3?
Answer: 35.3.2

Teaching Resources

- **Reading and Study Workbook**
- **Transparency** *81*
- **Presentation*EXPRESS***
- **Interactive Textbook**
- **Next-Time Questions** *35-1, 35-2*

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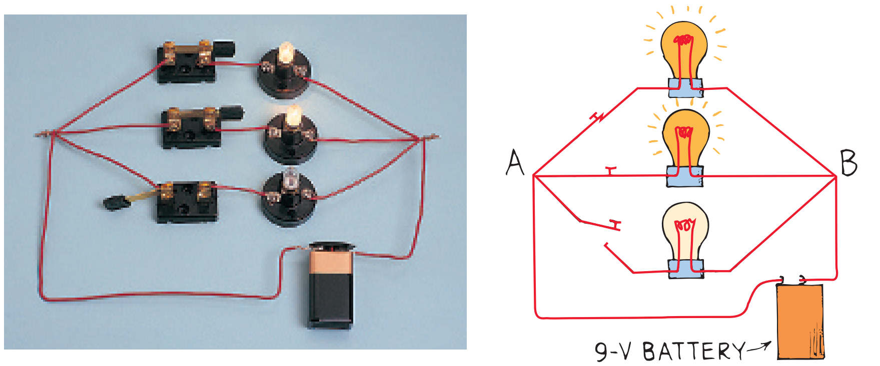

◀ **FIGURE 35.5**
In this simple parallel circuit, a 9-volt battery provides 9 volts across each lamp.

35.4 Parallel Circuits

Figure 35.5 shows three lamps connected to the same two points A and B. In a **parallel circuit,** each electric device is connected to the same two points of the circuit. Notice that each lamp has its own path from one terminal of the battery to the other. There are three separate pathways for current, one through each lamp. In contrast to a series circuit, the current in one lamp does not pass through the other lamps. Also, unlike lamps connected in series, the parallel circuit is completed whether all, two, or only one lamp is lit. **In a parallel circuit, each device operates independent of the other devices. A break in any one path does not interrupt the flow of charge in the other paths.**

The circuit shown in Figure 35.5 illustrates the following major characteristics of parallel connections:

1. Each device connects the same two points A and B of the circuit. The voltage is therefore the same across each device.
2. The total current in the circuit (that is, the total current through the battery) divides among the parallel branches. Current passes more readily into devices of low resistance, so the amount of current in each branch is inversely proportional to the resistance of the branch. Ohm's law applies separately to each branch.
3. The total current in the circuit equals the sum of the currents in its parallel branches.
4. As the number of parallel branches is increased, the total current through the battery increases. From the battery's perspective, the overall resistance of the circuit is *decreased.* This means the overall resistance of the circuit is less than the resistance of any one of the branches.

CONCEPT CHECK What happens if one device in a parallel circuit fails?

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think!
What happens to the light intensity of each lamp in a parallel circuit when more lamps are added in parallel to the circuit?
Answer: 35.4

35.4 Parallel Circuits

Key Term
parallel circuit

Common Misconception
In a parallel circuit, the equivalent resistance of the circuit increases with the addition of more resistors.

FACT The equivalent resistance actually decreases with the addition of more resistors.

▶ **Teaching Tip** Compare a parallel circuit to a road with alternate routes. If there is a roadblock or obstruction, the traffic can move along the alternate routes. The greater the number of routes, the less resistance to traffic going from one place to another along these routes.

▶ **Teaching Tip** Make a simple parallel circuit, as shown in Figure 35.5, and apply the four characteristics to it.

CONCEPT CHECK In a parallel circuit, each device operates independent of the other devices. A break in any one path does not interrupt the flow of charge in the other parts.

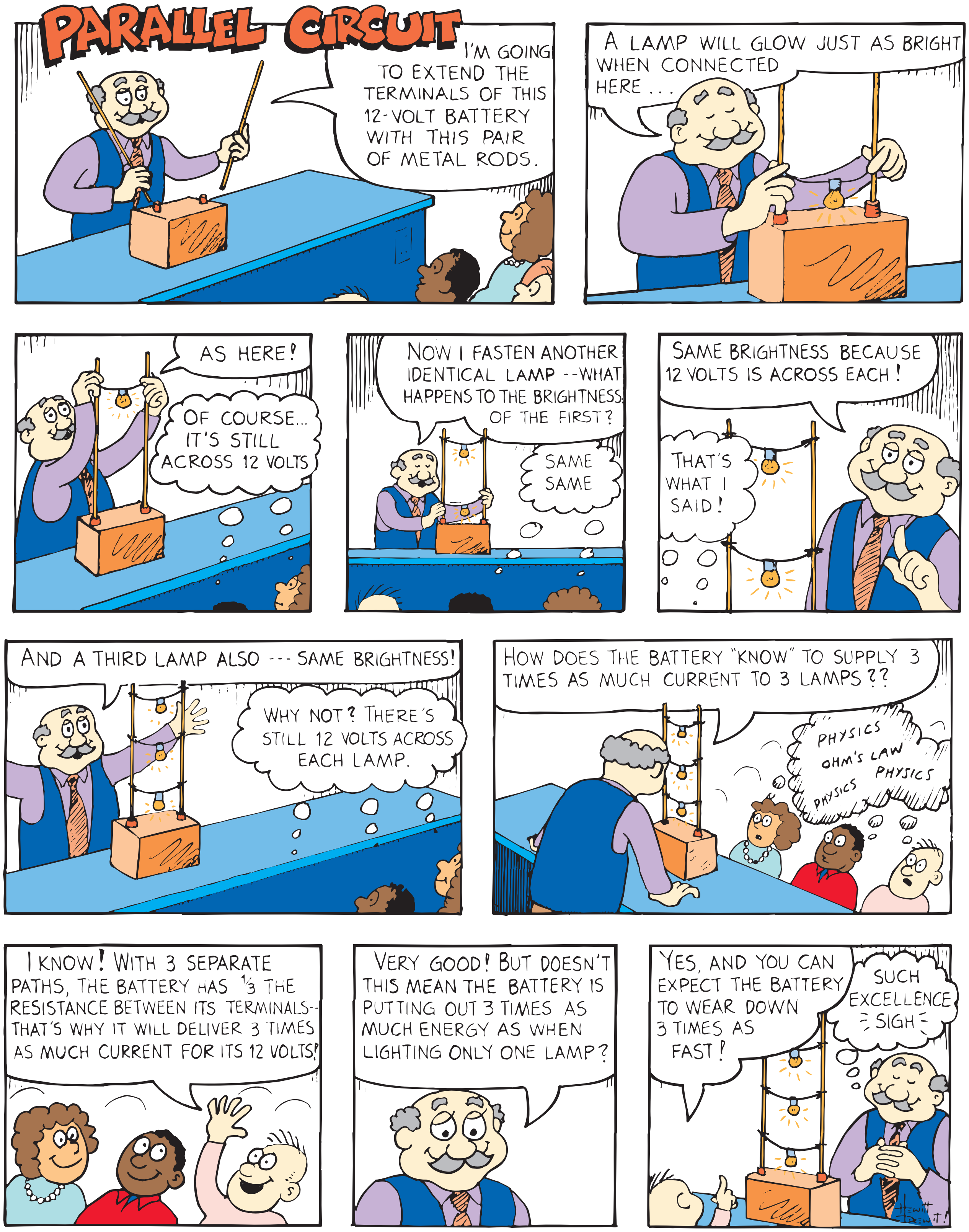
Teaching Resources
- **Reading and Study Workbook**
- **Concept-Development Practice Book** *35-1*
- **Problem-Solving Exercises in Physics** *17-4*
- **Laboratory Manual** *91, 94, 95*
- **Transparency** *82*
- **Presentation*EXPRESS***
- **Interactive Textbook**

Demonstration

Show the parallel circuit connection between the extended battery terminals. Show that the circuit remains in operation when any bulb is loosened. If you attach an ammeter between the battery terminal and the extension rod, you can show how the circuit draws more current as more lamps are added.

This is the simplest and most visually comprehensible demonstration of parallel circuits I have to offer. Neat!

PAUL



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35.5 Schematic Diagrams

Electric circuits are frequently described by simple diagrams, called **schematic diagrams,** that are similar to those of the last two figures. Some of the symbols used to represent certain circuit elements are shown in Figure 35.6. **In a schematic diagram, resistance is shown by a zigzag line, and ideal resistance-free wires are shown with solid straight lines. A battery is represented with a set of short and long parallel lines.** The convention is to represent the positive terminal of the battery with a long line and the negative terminal with a short line. Sometimes a two-cell battery is represented with a pair of such lines, a three-cell with three, and so on. Figures 35.7a and 35.7b show schematic diagrams for the circuits of Figures 35.4 and 35.5.

CONCEPT CHECK What symbols are used to represent resistance, wires, and batteries in schematic diagrams?

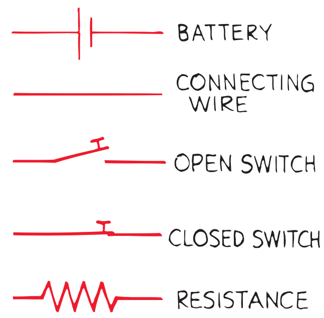
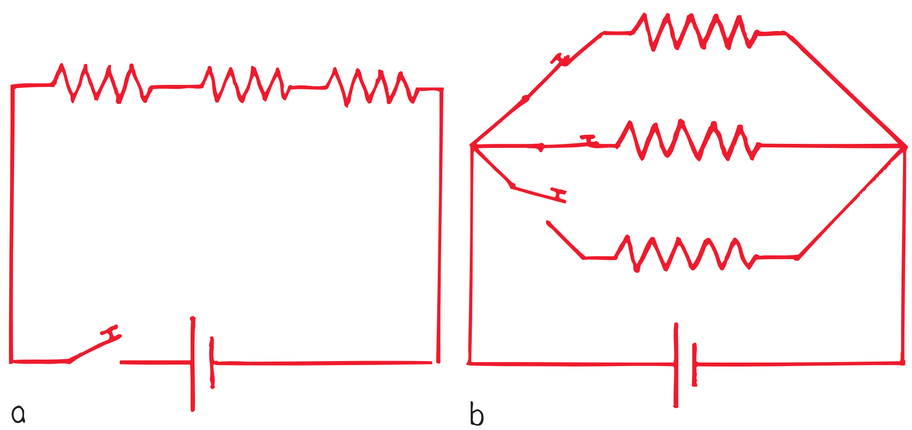


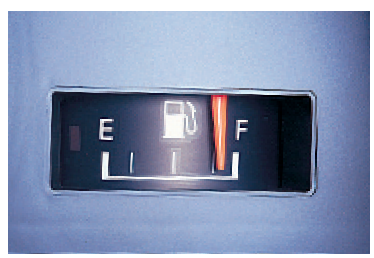
FIGURE 35.6 ▲
Symbols of some common circuit devices.



◀ FIGURE 35.7
These schematic diagrams represent **a.** the circuit of Figure 35.4, with three lamps in series; and **b.** the circuit of Figure 35.5, with three lamps in parallel.

Link to TECHNOLOGY

Measuring with Current A fuel gauge in an automobile uses variable resistance to measure the level in the gasoline tank. A float in the tank adjusts the resistance of a variable electric resistor. Maximum resistance occurs when the float bottoms out in the tank. Maximum resistance produces the minimum current, which barely deflects the pointer on the fuel gauge. When the tank is full, the variable resistor has its lowest resistance and the maximum current flows through the fuel gauge. For this current, the gauge is calibrated to read a full tank. Between empty and full, corresponding values of current produce appropriate deflections of the fuel gauge pointer.



35.5 Schematic Diagrams

Key Term
schematic diagram

▶ **Teaching Tip** For simplicity, the battery symbol in Figure 35.6 suggests a single cell. Many batteries have two or more cells.

▶ **Teaching Tip** Have your students make up simple circuits with lamps, wires, and a battery, and then represent their own circuits with circuit diagrams.

CONCEPT CHECK In a schematic diagram, resistance is shown by a zigzag line, and ideal resistance-free wires are shown with solid straight lines. A battery is represented with a set of short and long parallel lines.

Teaching Resources

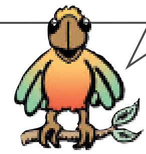
- Reading and Study Workbook
- Transparency *83*
- Presentation*EXPRESS*
- Interactive Textbook

35.6 Combining Resistors in a Compound Circuit

Note that the numerical values of resistors in the text lend themselves to simple computations. This is because the important goal is teaching concepts, not handling calculations. Give some forethought to the resistance values you select for sample circuits, and also avoid arithmetic complications that will detract from the concepts. More challenging circuits can be presented after students have a basic understanding. A calculator helps.

PAUL

The resistance in the filament of a lightbulb varies with temperature. When cold (at room temperature) it may be only 16 Ω in a 120-V, 60-W bulb, while 100 ms later when it reaches its operating temperature, filament resistance increases to a steady 240 Ω.



35.6 Combining Resistors in a Compound Circuit

Sometimes it is useful to know the *equivalent resistance* of a circuit that has several resistors in its network. The equivalent resistance is the value of the single resistor that would comprise the same load to the battery or power source. ✓ **The equivalent resistance of resistors connected in series is the sum of their values.** For example, the equivalent resistance for a pair of 1-ohm resistors in series is simply 2 ohms.

The equivalent resistance for a pair of 1-ohm resistors in parallel is 0.5 ohm. (The equivalent resistance is *less* because the current has "twice the path width" when it takes the parallel path. In a similar way, the more doors that are open in an auditorium full of people trying to exit, the *less* will be the resistance to their departure.) ✓ **The equivalent resistance for a pair of equal resistors in parallel is half the value of either resistor.** Figure 35.8 shows how you can simplify schematic diagrams by using equivalent resistances.

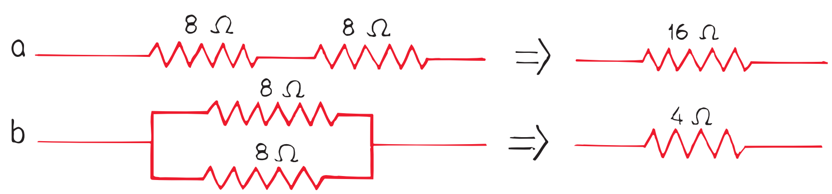


FIGURE 35.8 ▲
a. The equivalent resistance of two 8-ohm resistors in series is 16 ohms. **b.** The equivalent resistance of two 8-ohm resistors in parallel is 4 ohms.

Figure 35.9 shows a combination of three 8-ohm resistors. The two resistors in parallel are equivalent to a single 4-ohm resistor, which is in series with an 8-ohm resistor and adds to produce an equivalent resistance of 12 ohms. If a 12-volt battery were connected to these resistors, can you see from Ohm's law that the current through the battery would be 1 ampere? (In practice it would be less, for there is resistance inside the battery as well, called the battery's *internal resistance.*)

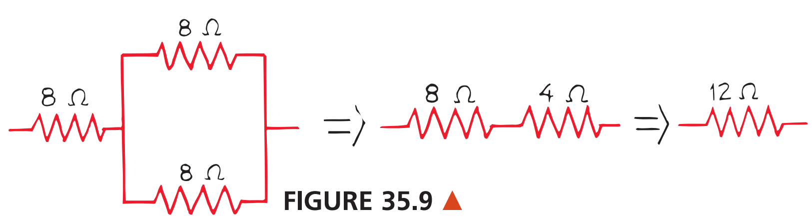
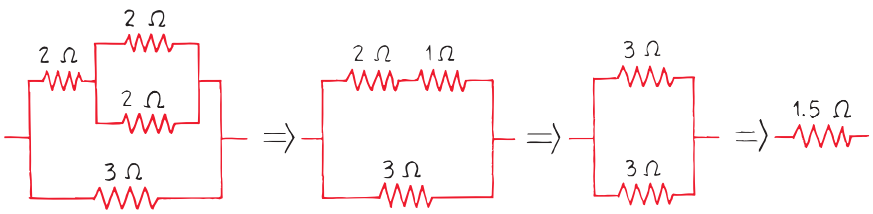
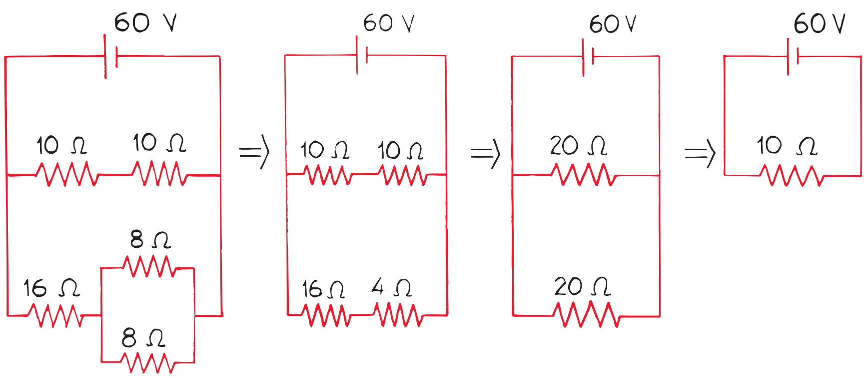


FIGURE 35.9 ▲
The equivalent resistance of the circuit is found by combining resistors in successive steps.



◀ **FIGURE 35.10**
The equivalent resistance of the top branch is 3 ohms, which is in parallel with the 3-ohm resistance of the lower branch. The overall equivalent resistance is 1.5 ohms.



◀ **FIGURE 35.11**
Schematic diagrams for an arrangement of various electric devices. The equivalent resistance of the circuit is 10 ohms. (The 60-V battery is for numerical convenience—most batteries are less than 60 V.)

Two more complex combinations are broken down in successive equivalent combinations in Figures 35.10 and 35.11. It's like a game: Combine resistors in series by adding; combine a pair of equal resistors in parallel by halving.[35.6] The value of the single resistor left is the equivalent resistance of the combination.

CONCEPT CHECK **What is the equivalent resistance of resistors in series? Of equal resistors in parallel?**

35.7 Parallel Circuits and Overloading

Electric current is usually fed into a home by way of two lead wires called *lines.* These lines are very low in resistance and are connected to wall outlets in each room. About 110 to 120 volts are impressed on these lines by the power company. This voltage is applied to appliances and other devices that are connected in parallel by plugs to these lines.

As more devices are connected to the lines, more pathways are provided for current. What effect do the additional pathways produce? The answer is, a lowering of the combined resistance of the circuit. Therefore, a greater amount of current occurs in the lines. Lines that carry more than a safe amount of current are said to be *overloaded.* The resulting heat may be sufficient to melt the insulation and start a fire.

See Note 35.6 on page 908 for more on equivalent resistances.

think!

Use Figure 35.11 to answer the following questions.

What is the current in amperes through the battery? (Neglect the internal resistance of the battery.)
Answer: 35.6.1

What is the current in amperes through the pair of 10-ohm resistors? Through *each* of the 8-ohm resistors?
Answers: 35.6.2

How much power is provided by the battery?
Answer: 35.6.3

CONCEPT CHECK The equivalent resistance of resistors connected in series is the sum of their values. The equivalent resistance for a pair of equal resistors in parallel is half the value of either resistor.

Teaching Resources

- **Reading and Study Workbook**
- **Concept-Development Practice Book** *35-2, 35-3*
- **Transparency** *84*
- **Presentation*EXPRESS***
- **Interactive Textbook**
- **Next-Time Question** *35-3*

35.7 Parallel Circuits and Overloading

▶ **Teaching Tip** Discuss the consequences of too many appliances operating on the same line, and why different sets of lines are directed to various parts of the home. Most home wiring is rated at 30 A maximum. A common air conditioner uses about 2400 W, so if operating on 120 V the current would be 20 A. To start, the current is more. If other devices are drawing current on the same line, the fuse will blow when the air conditioner is turned on, so a 220-V line is usually used for such heavy appliances. Point out that the household voltage in most of the world is 220–240 V.

▶ **Teaching Tip** Draw a simple parallel circuit of lamps and appliances, such as the one in Figure 35.12, on the board. Estimate the current flowing through each device, and point out that the current in any branch is not affected when other devices are turned on. Show on your diagram the currents in the branches and in the lead wires. Show where the fuse goes and describe its function. Then short your circuit and blow the fuse.

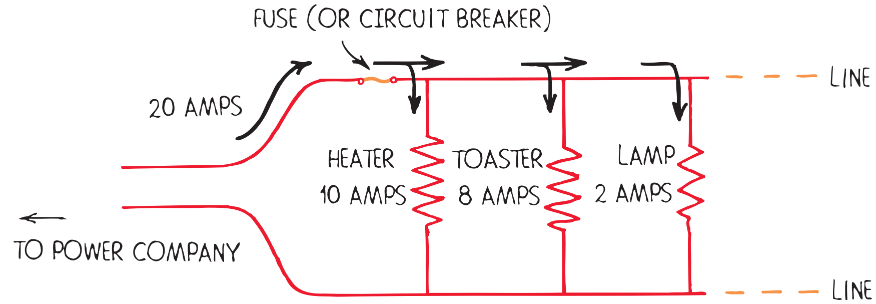
▶ **Teaching Tip** The "UL" label on a product indicates that it has been tested for electrical, fire, and other hazards by engineers of Underwriters Laboratories.

CONCEPT CHECK To prevent overloading in circuits, fuses or circuit breakers are connected in series along the supply line.

Teaching Resources

- **Reading and Study Workbook**
- **Laboratory Manual *96***
- **Presentation*EXPRESS***
- **Interactive Textbook**

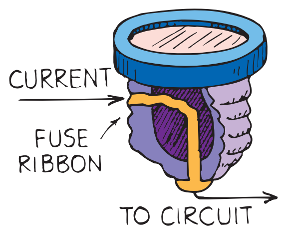
FIGURE 35.12 ▶
The more devices you connect to your household supply line, the more you increase the total line current.



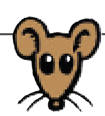
You can see how overloading occurs by considering the circuit in Figure 35.12. The supply line is connected to an electric toaster that draws 8 amperes, to an electric heater that draws 10 amperes, and to an electric lamp that draws 2 amperes. When only the toaster is operating and drawing 8 amperes, the total line current is 8 amperes. When the heater is also operating, the total line current increases to 18 amperes (8 amperes to the toaster and 10 amperes to the heater). If you turn on the lamp, the line current increases to 20 amperes. Connecting any more devices increases the current still more.

✅ **To prevent overloading in circuits, fuses or circuit breakers are connected in series along the supply line.** In this way the entire line current must pass through the fuse. The safety fuse shown in Figure 35.13 is constructed with a wire ribbon that will heat up and melt at a given current. If the fuse is rated at 20 amperes, it will pass 20 amperes, but no more. A current above 20 amperes will melt the fuse, which "blows out" and breaks the circuit. Before a blown fuse is replaced, the cause of overloading should be determined and remedied. Often, insulation that separates the wires in a circuit wears away and allows the wires to touch. This effectively shortens the path of the circuit, and is called a *short circuit.* A short circuit draws a dangerously large current because it bypasses the normal circuit resistance.

FIGURE 35.13 ▼
Above a specified current, the metal ribbon in a safety fuse melts and breaks the circuit.



In practice, the lines in your home are not perfect conductors. With the large current used to operate a vacuum cleaner, the connecting wires do warm up. But for most cases, the resistance of the lines can be neglected.



Circuits may also be protected by *circuit breakers,* which use magnets or bimetallic strips to open the switch. Utility companies use circuit breakers to protect their lines all the way back to the generators. Circuit breakers are used instead of fuses in modern buildings because they do not have to be replaced each time the circuit is opened. Instead, the switch can simply be moved back to the "on" position after the problem has been corrected.

CONCEPT CHECK **How can you prevent overloading in circuits?**

35 REVIEW

Go Online PHSchool.com
For: Self-Assessment
Visit: PHSchool.com
Web Code: csa – 3500

Concept Summary

- In a flashlight, when the switch is turned on to complete an electric circuit, the mobile conduction electrons already in the wires and the filament begin to drift through the circuit.
- For a continuous flow of electrons, there must be a complete circuit with no gaps.
- If one device fails in a series circuit, current in the whole circuit ceases and none of the devices will work.
- In a parallel circuit, each device operates independent of the other devices. A break in any one path does not interrupt the flow of charge in the other paths.
- In a schematic diagram, resistance is shown by a zigzag line, and ideal resistance-free wires are shown with solid straight lines.
- The equivalent resistance of resistors connected in series is the sum of their values. The equivalent resistance for a pair of equal resistors in parallel is half the value of either resistor.
- To prevent overloading, fuses or circuit breakers are connected in series along the supply line.

Key Terms

circuit *(p. 703)*
in series *(p. 704)*
in parallel *(p. 704)*
series circuit *(p. 705)*
parallel circuit *(p. 707)*
schematic diagram *(p. 709)*

think! Answers

35.3.1 The addition of more lamps results in a greater circuit resistance. This decreases the current in the circuit (and in each lamp), which causes dimming of the lamps.

35.3.2 Yes—it is also 1 A. (The same current passes through every part of a series circuit.) The voltage across bulb 3 is 3 V. Each coulomb of charge flowing in the wire from the battery has 9 J of electrical potential energy (9 V = 9 J/C). That energized coulomb of charge must distribute its energy among three bulbs in proportion to their resistances and return to the battery with 0 J. If it spends 2 J in one bulb and 4 in another, it must spend 3 J in the last bulb. 3 J/C = 3 V

35.4 The light intensity for each lamp is unchanged as other lamps are introduced (or removed). Although changes of resistance and current occur for the circuit as a whole, no changes occur in any individual branch in the circuit.

35.6.1 6 A. From Ohm's law: current = (voltage)/(resistance) = (60 V)/(10 Ω) = 6 A

35.6.2 The total resistance of the middle branch is 20 Ω. Since the voltage is 60 V, the current = (voltage)/(resistance) = (60 V)/(2 Ω) = 3 A. The current through the pair of 8-Ω resistors is 3 A, and the current through each is therefore 1.5 A. (The 3-A current divides equally between these equal resistances.)

35.6.3 Power = current × voltage = (6 A) × (60 V) = 360 watts

35 REVIEW

Teaching Resources

- Teacher*EXPRESS*
- Virtual Physics Lab *32*

35 ASSESS

Check Concepts

1. No, both the battery and the circuit itself provide electrons.
2. Gaps prevent the flow of electrons.
3. Series—single path for current; parallel—alternate paths
4. 2 V
5. It stops.
6. 6 V
7. Current continues to flow.
8. **a.** Parallel **b.** Parallel, 6 V across each
9. Increases; decreases (more paths)
10. 16 Ω; 4 Ω (twice the paths)
11. There are more paths for electron flow.
12. Wires carry more than the safe current, and they get hot.
13. To stop dangerously high current
14. Excess current is drawn.
15. Circuit offering path of much less resistance

35 ASSESS

Check Concepts

Section 35.1

1. Are all the electrons flowing in a circuit provided by the battery?

Section 35.2

2. Why must there be no gaps in an electric circuit for it to carry current?
3. Distinguish between a series circuit and a parallel circuit.

Section 35.3

4. If three lamps are connected in series to a 6-volt battery, how many volts are impressed across each lamp?
5. If one of three lamps blows out when connected in series, what happens to the current in the other two?

Section 35.4

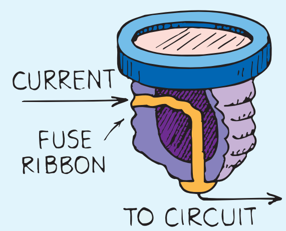
6. If three lamps are connected in parallel to a 6-volt battery, how many volts are impressed across each lamp?
7. If one of three lamps blows out when connected in parallel, what happens to the current in the other two?
8. **a.** In which case will there be more current in each of three lamps—if they are connected to the same battery in series or in parallel?
   b. In which case will there be more voltage across each lamp?

Section 35.6

9. What happens to the total circuit resistance when more devices are added to a series circuit? To a parallel circuit?
10. What is the equivalent resistance of a pair of 8-ohm resistors in series? In parallel?

Section 35.7

11. Why does the total circuit resistance decrease when more devices are added to a parallel circuit?
12. What does it mean when you say that lines in a home are overloaded?
13. What is the function of a fuse or circuit breaker in a circuit?



14. Why will too many electric devices operating at one time often blow a fuse or trip a circuit breaker?
15. What is meant by a short circuit?

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Think and Rank

16. B, A, C

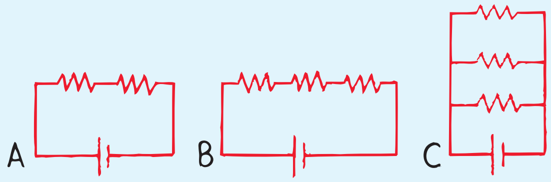
17. B, A, C

18. a. A, B, C
b. A, C, B

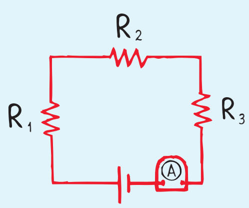
Think and Rank

Rank each of the following sets of scenarios in order of the quantity or property involved. List them from left to right. If scenarios have equal rankings, separate them with an equal sign. (e.g., A = B)

16. The resistors in the circuits below are all identical. Rank the circuits according to the size of the equivalent resistance for each, from most resistance to least resistance.



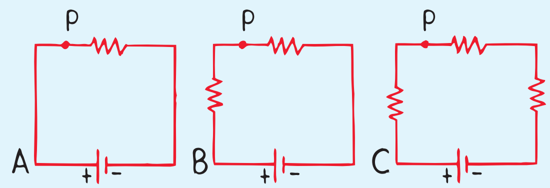
17. The circuit below contains resistors R_1, R_2, and R_3.



Rank the following combinations of resistances in terms of the current measured by the ammeter, from highest to lowest.

(A) $R_1 = 1\ \Omega, R_2 = 2\ \Omega, R_3 = 3\ \Omega$
(B) $R_1 = 2\ \Omega, R_2 = 1\ \Omega, R_3 = 2\ \Omega$
(C) $R_1 = 3\ \Omega, R_2 = 3\ \Omega, R_3 = 1\ \Omega$

18. The resistors in the circuits below are 10 Ω each. Each circuit is powered with a 12-V battery. Assume that the battery and connecting wires have negligible resistance.



a. Rank the circuits in terms of the amount of current passing point P in each circuit, from greatest current to least current.
b. Suppose a voltmeter is connected between point P and the negative terminal of the battery. Rank the circuits in terms of voltmeter readings, from highest voltage to lowest voltage.

Plug and Chug

To answer Questions 19–24, you will need to know the following information.

The equivalent resistance of resistors in series is their sum. The equivalent resistance for resistors in parallel can be calculated as follows:

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

In the special case of only two parallel branches with resistances R_1 and R_2, this becomes

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

The equation above is often called the "product-over-sum" rule.

Plug and Chug

19. $R_{eq} = R_1 + R_2 = 6\ \Omega + 6\ \Omega = 12\ \Omega$

20. $R_{eq} = (R_1R_2)/(R_1 + R_2) = (6\ \Omega \times 6\ \Omega)/(6\ \Omega + 6\ \Omega) = 3\ \Omega$

21. $I = V/R = (12\ V)/(30\ \Omega) = 0.4\ A$

22. $R_{eq} = 90\ \Omega$, so $I = V/R = (12\ V)/(90\ \Omega) = 0.13\ A$

23. $R_{eq} = 60\ \Omega$, so $I = V/R = (48\ V)/(60\ \Omega) = 0.8\ A$

24. $R_{eq} = 15\ \Omega$, so $I = V/R = (48\ V)/(15\ \Omega) = 3.2\ A$

Think and Explain

25. The automobile's cooling system is a better analogy to an electric circuit because it is a closed system that contains a pump. A garden hose doesn't recirculate water as a car's cooling system does.

26. The only thing the appliance "uses up" is the fuel that powered the electric generating station (and some of your dollars).

27. If a bird's extended wings make electrical contact with parallel wires between which there is a potential difference, zap! A short circuit results. Parallel wires are spaced so this doesn't happen.

28. Agree. Current through the battery depends on resistance of external circuit.

29. Current will be greater in the bulb connected to the 220-V source.

30. Series—the resistances add.

31. Parallel—the equivalent resistance is less than the smaller resistance of the two.

32. Agree with both.

33. Bulbs glow brighter in parallel, as the voltage of the battery is impressed across each bulb.

35 ASSESS

19. Calculate the equivalent resistance of two 6-Ω resistors in series.

20. Calculate the equivalent resistance (using the "product-over-sum" rule) of a pair of 6-Ω resistors in parallel.

21. Calculate the current in a 12-V battery that powers a single 30-Ω resistor.

22. Calculate the current in a 12-V battery that powers three 30-Ω resistors connected in series.

23. Calculate the current in a 48-V battery that powers a pair of 30-Ω resistors connected in series.

24. Calculate the current in a 48-V battery that powers a pair of 30-Ω resistors connected in parallel.

Think and Explain

25. One example of a water system is a garden hose that waters a garden. Another is the cooling system of an automobile. Which of these exhibits behavior more analogous to that of an electric circuit? Why?

26. Sometimes you hear someone say that a particular appliance "uses up" electricity. What is it that the appliance actually "uses up," and what becomes of it?

27. Why are the wingspans of birds a consideration in determining the spacing between parallel wires in a power line?

28. Your lab partner says that a battery provides not a source of constant current, but a source of constant voltage. Do you agree or disagree, and why?

29. Will the current in a lightbulb connected to a 220-V source be greater or less than that in the same bulb when it is connected to a 110-V source?

30. To connect a pair of resistors so that their equivalent resistance will be greater than the resistance of either one, should you connect them in series or in parallel?

31. To connect a pair of resistors so that their equivalent resistance will be less than the resistance of either one, should you connect them in series or in parallel?

32. Hector says that adding bulbs in series to a circuit provides more obstacles to the flow of charge, reducing current in the circuit. Jeremy says that adding bulbs in parallel provides more paths so more current can flow. With whom do you agree or disagree?

33. Consider a pair of flashlight bulbs connected to a battery. Emily asks if they glow brighter when connected in series, or in parallel. She looks to you for an answer. What is your answer?

34. Harry asks whether a battery will run down slower or faster when it connects to a pair of bulbs in series or to the same pair in parallel. He looks to you for an answer. What is your answer?

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35. As more and more lamps are connected in series to a flashlight battery, what happens to the brightness of each lamp?

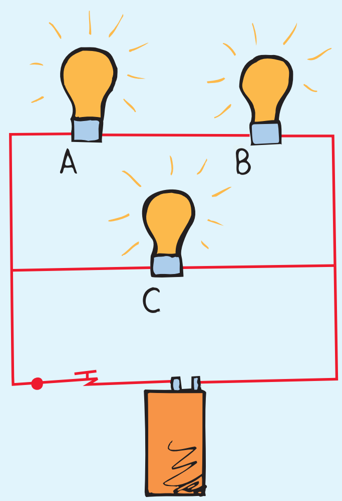
36. As more and more lamps are connected in parallel to a battery, and if the current does not produce heating inside the battery, what happens to the brightness of each lamp?

37. If several bulbs are connected in series to a battery, they may feel warm to the touch even though they are not visibly glowing. What is your explanation?

38. Are automobile headlights wired in parallel or in series? What is your evidence?

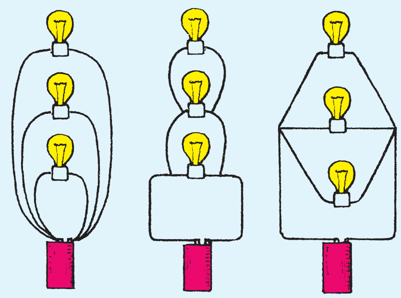
39. Why are household appliances almost never connected in series?

40. In the circuit shown, how do the brightnesses of the identical bulbs compare? Which lightbulb draws the most current? What happens if bulb A is unscrewed? If bulb C is unscrewed?



41. A number of lightbulbs are to be connected to a battery. Which will provide more overall brightness, connecting them in series or in parallel? Which will run the battery down faster, the bulbs connected in series or the bulbs connected in parallel?

42. Are these circuits equivalent to one another? Why or why not?



43. A battery has internal resistance, so if the current it supplies goes up, the voltage it supplies goes down. If too many bulbs are connected in parallel across a battery, will their brightness diminish? Explain.

44. A three-way bulb uses two filaments to produce three levels of illumination (50 W, 100 W, and 150 W) using a 120-V socket. When one of the filaments burns out, only one level of illumination (50 W or 100 W) is available. Are the filaments connected in series or in parallel?

45. How does the line current compare with the total currents of all devices connected in parallel?

34. Battery runs down faster with bulbs in parallel because more current flows through the battery due to the smaller resistance of the circuit.

35. The total resistance increases and the current decreases. The lamps therefore become dimmer.

36. Voltage across each lamp is the same and the brightness of the lamps is not affected.

37. Heat but no visible light due to low current

38. Parallel; when one goes out the other stays lit.

39. In a series circuit, the current in an appliance would vary as other appliances were introduced to the circuit. Also, if one device failed, current would cease all along the circuit.

40. Bulb C is brightest, for it draws the most current; bulb B goes out and C remains lit without change in brightness; both A and B remain lit without change in brightness.

41. Parallel; parallel

42. Yes, they are equivalent. Each branch is individually connected to battery.

43. Yes, because of increased internal resistance in the battery, reducing available voltage in circuit.

44. They must be connected in parallel. When one filament glows, 100 W are dissipated. When the other filament glows, 50 W are dissipated. So if either burns out, only the other is available. The 150-W setting occurs when both glow simultaneously.

45. The line current in a circuit is the sum of all the currents in the branches it feeds.

46. Current divides in a branch, but never reduces to zero unless the branch resistance is infinite. Across a non-infinite resistor, voltage produces current in accord with Ohm's law.

47. a. Both bulbs will have the same current when connected in series—a characteristic of series circuits.

b. When connected in parallel, more current will flow in the brighter 100-W bulb.

Think and Solve

48. $I = V/R = (240\ \text{V})/(30\ \Omega) = 8\ \text{A}$

49. From $I = V/R$, $R = V/I = (3.0\ \text{V})/(1.2\ \text{A}) = 2.5\ \Omega$

50. From $I = V/R$, $V = IR = (1.5\ \text{A})(4\ \Omega) = 6\ \text{V}$

51. The product-over-sum rule for the equivalent resistance for a pair of resistors in parallel gives

$R_{eq} = (16 \times 8)/(16 + 8) = 5.3\ \Omega$.

52. a. The pair of 10-Ω resistors makes up the parallel part; the equivalent resistance is 5 Ω.

b. The equivalent resistance of the entire circuit is 40 Ω: $20\ \Omega + 5\ \Omega + 15\ \Omega = 40\ \Omega$

53. By the product-over-sum rule, two would give 2 Ω, and a pair of twos would give 1 Ω, and a pair of these would give 0.5 Ω. That's eight 4-Ω resistors in parallel, or $1/0.5 = 2 = 8 \times 1/4$.

54. $R_{eq} = 5\ \Omega + 15\ \Omega = 20\ \Omega$; $I = V/R = (10\ \text{V})/(20\ \Omega) = 0.5\ \text{A}$

35 ASSESS *(continued)*

46. Your friend says that electric current takes the path of least resistance. Why is it more accurate in the case of a parallel circuit to say that greatest current travels in the path of least resistance?

47. A 60-W bulb and a 100-W bulb are connected in series in a circuit.

a. Which bulb has the greater current flowing in it?

b. Which has the greater current when they are connected in parallel?

Think and Solve

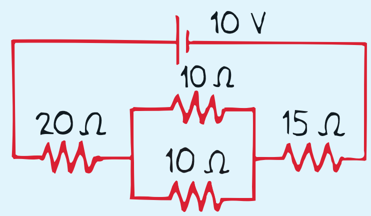
48. A 30-Ω resistor is connected to a 240-V source. How much current flows in the resistor?

49. A lightbulb connected to a 3.0-V battery draws 1.2 A of current. Calculate the resistance of the bulb.

50. A lantern battery is connected to a 4-Ω device that draws 1.5 A. Calculate the battery voltage.

51. A 16-Ω loudspeaker and an 8-Ω loudspeaker are connected in parallel across the terminals of an amplifier. Assuming the speakers behave as resistors, calculate the equivalent resistance of the two speakers.

52. Consider the combination series and parallel circuit shown here.

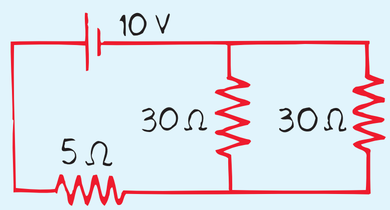


a. Identify the parallel part of the circuit. What is the equivalent resistance of this part? In other words, what single resistance could replace this part of the circuit and not change the total current from the battery?

b. What is the equivalent resistance of all the resistors? In other words, what single resistance could replace the whole circuit without changing the current produced by the battery?

53. How many 4-Ω resistors must be connected in parallel to create an equivalent resistance of 0.5 Ω?

54. What is the current in the battery of the circuit shown below? (What must you find before you can calculate the current?)



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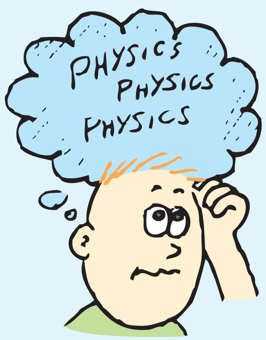
55. The rear window defrosters on automobiles are made up of several strips of heater wire connected in parallel. Consider the case of four wires, each of 6 Ω resistance, connected to 12 V.

a. What is the equivalent resistance of the four wires? (Consider the wires to be two groups of two.)

b. What is the total current drawn?



56. A 4-watt night light is plugged into a 120-volt circuit and operates continuously for a 30-day month.

a. How much current does it draw?

b. What is the resistance of its filament?

c. How much energy does it use in the month?

d. What is the cost of its operation for the month at the utility rate of 10 cents per kilowatt-hour?

57. The same voltage V is impressed on each of the branches of a parallel circuit. The voltage source provides a total current I_{total} to the circuit, and "sees" a total equivalent resistance of R_{eq} in the circuit. That is, $V = I_{total}R_{eq}$. The total current is equal to the sum of the currents through each branch of the parallel circuit. In a circuit with n branches, $I_{total} = I_1 + I_2 + I_3 \ldots I_n$. Use Ohm's law $(I = V/R)$ and show how the equivalent resistance of a parallel circuit with n branches is given by the following equation.

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

58. Show how the expression given in Question 57, when applied to two branches with resistances R_1 and R_2, can be written as follows.

$$R_{eq} = \frac{R_1R_2}{R_1 + R_2}$$

Activity

59. Obtain several drinking straws. Take a deep breath and then fully exhale through one of the straws. Note the time it takes to do this. Repeat, fully exhaling through a pair of straws side by side. Can you exhale in less time? Try with three side-by-side straws. How does this relate to resistors in parallel in electric circuits?

More Problem-Solving Practice
Appendix F

55. a. Each pair of parallel 6-Ω wires has an equivalent resistance of 3 Ω. The equivalent resistance of the four wires (two groups of two) is therefore 1.5 Ω.

b. $I = V/R = (12\text{ V})/(1.5\ \Omega) = 8\text{ A}$

56. a. From $P = IV$, $I = P/V = (4\text{ W})/(120\text{ V}) = 1/30\text{ A}$

b. From $I = V/R$, $R = V/I = (120\text{ V})/(1/30\text{ A}) = 3600\text{ V}$

c. 4 W = 0.004 kW. 1 month = 720 h, so 720 h × 0.004 kW = 2.88 kWh

d. 2.88 kWh × 10¢/kWh = 29¢

57. From $I_{total} = I_1 + I_2 + I_3 + \ldots + I_n$, a substitution of $I = V/R$ for each current gives $V/R_{eq} = V/R_1 + V/R_2 + V/R_3 + \ldots + V/R_n$. Dividing each term by V gives $1/R_{eq} = 1/R_1 + 1/R_2 + 1/R_3 + \ldots + 1/R_n$.

58. From $1/R_{eq} = 1/R_1 + 1/R_2 = (R_1 + R_2)/R_1R_2$, invert to get $R_{eq} = R_1R_2/(R_1 + R_2)$.

Activity

59. Exhaling through one straw takes about 5 s. But exhaling through a pair of straws takes much less than 5 s. More pathways for your breath is akin to more pathways for the flow of charge in a parallel circuit.

Teaching Resources

- Computer Test Bank
- Chapter and Unit Tests