

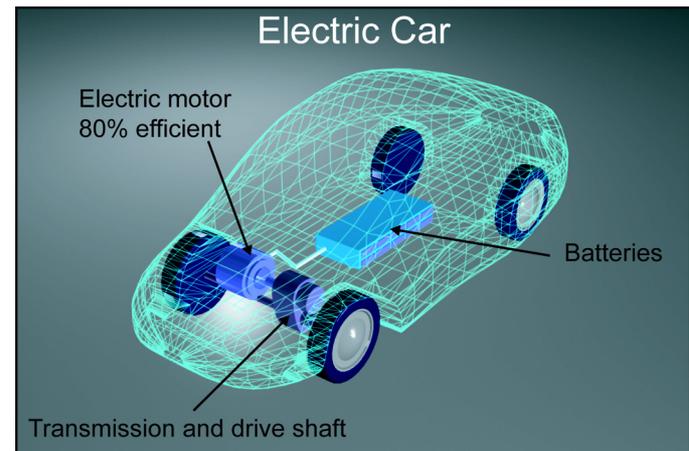
Chapter 14

Electrical Systems

You may recognize the abbreviations AC and DC. There is a classic rock music group called AC/DC that has helped to make the acronym famous. Did you know that in the late 1800's, a major disagreement over the use of AC and DC methods for transmitting electricity erupted between two famous inventors?

Thomas Edison favored the direct current (DC) method of moving electrical energy from electrical generation stations to homes and buildings. George Westinghouse argued that the alternating current (AC) method worked better. The feud became quite public, as each inventor tried to win support. The DC method works well over short distances, as between buildings in a densely populated city. AC works well over long distances but uses higher voltages than DC technology. Edison used some morbid methods for demonstrating his views of the danger involved with high voltage electrical transmission through his opponent's AC method.

Which inventor won the AC/DC debate? Does the United States rely on AC or DC technology for transmitting electrical energy? In this chapter, you will find out how our country distributes electricity, what the difference is between AC and DC current. You will also learn how electricity is "purchased" and paid for, as well as how simple electrical circuits are constructed and how they work.



Key Questions

- ✓ Why does a string of inexpensive holiday lights stop working when one bulb burns out?
- ✓ What is a "short circuit", and why can it be dangerous?
- ✓ How is electricity generated, and how does it get to your house?

14.1 Series Circuits

We use electric circuits for thousands of things from flashlights to computers to cars to satellites. There are two basic ways circuits can be built to connect different devices. These two types of circuits are called *series* and *parallel*. Series circuits have only one path for the current. Parallel circuits have branching points and multiple paths for the current. This section discusses series circuits. You will learn about parallel circuits in the next section.

What is a series circuit?

A series circuit has one path A **series circuit** contains only one path for electric current to flow. That means the current is the same at all points in the circuit. All the circuits you have studied so far have been series circuits. For example, a battery, three bulbs, and a switch connected in a loop form a series circuit because there is only one path through the circuit (Figure 14.1). The current is the same in each bulb, so they are equally bright.

A series circuit has only one path for the current so the current is the same at any point in the circuit.

Stopping the current

If there is a break at any point in a series circuit, the current will stop everywhere in the circuit. Inexpensive strings of holiday lights are wired with the bulbs in series. When one bulb burns out, the current stops and none of the bulbs will light until the bad bulb is replaced. The lights are connected this way because it requires the least amount of wire and therefore costs the least to manufacture.

Using series circuits

There are times when devices are connected in series for specific purposes. On-off switches are placed in series with the other components in most electrical devices. When a switch is turned to the off position, it breaks the circuit and stops current from reaching all of the components in series with the switch. Dimmer switches placed in series with light bulbs adjust the brightness by changing the amount of current in the circuit.

Vocabulary

series circuit, voltage drop, Kirchhoff's voltage law

Objectives

- ✓ Describe a series circuit.
- ✓ Calculate the resistance and current in a series circuit.
- ✓ Explain how the voltage changes across each resistor in a series circuit.

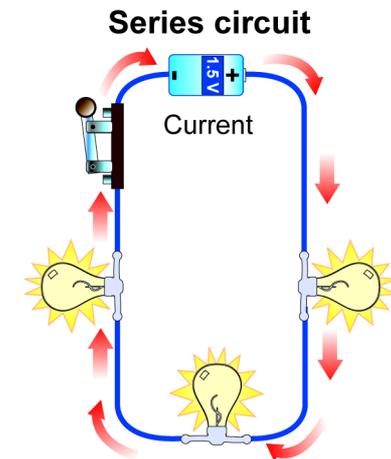


Figure 14.1: Three bulbs, a battery, and a switch are connected in series.



Current and resistance in a series circuit

Use Ohm's law You can use Ohm's law to calculate the current in a circuit if you know the voltage and resistance. If you are using a battery you know the voltage from the battery. If you know the resistance of each device, you can find the total resistance of the circuit by adding up the resistance of each device.

Adding resistances You can think of adding resistances like adding pinches to a hose (Figure 14.2). Each pinch adds some resistance. The total resistance is the sum of the resistances from each pinch. To find the total resistance in a series circuit, you add the individual resistances.

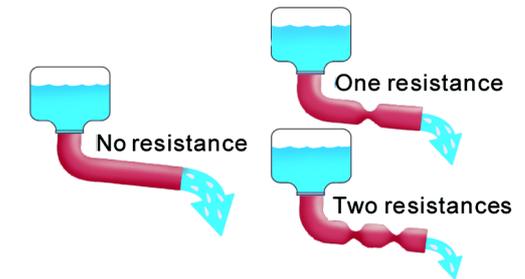


Figure 14.2: Adding resistors in a circuit is like adding pinches in a hose. The greater the number of pinches or resistors, the greater the resistance to current.

ADDING RESISTANCES IN SERIES

$$\underbrace{R_{total}} = \underbrace{R_1 + R_2 + R_3 + \dots}_{\text{Individual resistances } (\Omega)}$$

Total resistance (Ω)

Ignoring resistances Everything has some resistance, even wires. However, the resistance of a wire is usually so small compared with the resistance of light bulbs and other devices that we can ignore the resistance of the wire.



Calculating current

A series circuit contains a 12-V battery and three bulbs with resistances of 1 Ω , 2 Ω , and 3 Ω . What is the current in the circuit?

- 1. Looking for:** You are asked for the current in amps.
- 2. Given:** You are given the voltage in volts and resistances in ohms.
- 3. Relationships:** $R_{tot} = R_1 + R_2 + R_3$ Ohm's law: $I = V/R$
- 4. Solution:** $R_{tot} = 1 \Omega + 2 \Omega + 3 \Omega = 6 \Omega$ $I = (12 \text{ V})/(6 \Omega) = 2 \text{ A}$

Your turn...

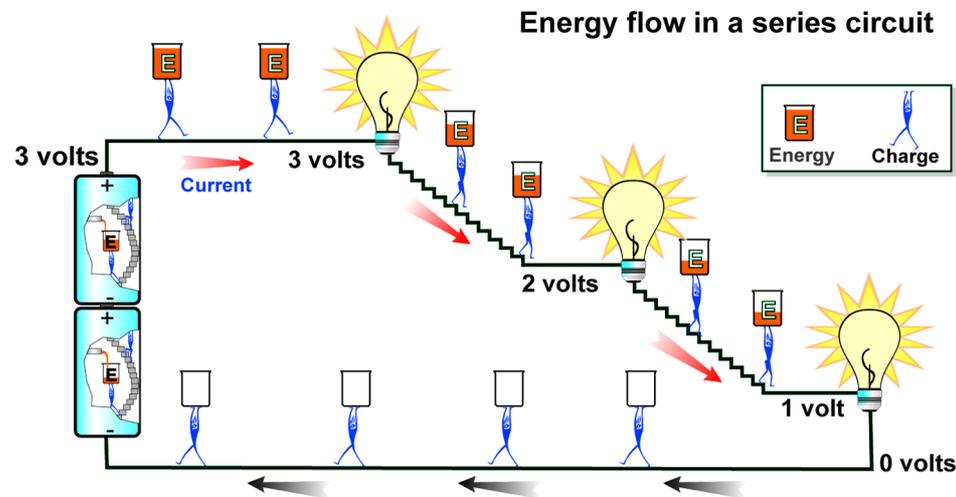
- a. A string of 5 lights runs on a 9-V battery. If each bulb has a resistance of 2 Ω , what is the current? **Answer:** 0.9 A
- b. A series circuit operates on a 6-V battery and has two 1 Ω resistors. What is the current? **Answer:** 3 A

Energy and voltage in a series circuit

Energy changes forms Energy cannot be created or destroyed. The devices in a circuit convert electrical energy carried by the current into other forms of energy. As each device uses power, the power carried by the current is reduced. As a result, the *voltage gets lower after each device that uses power*. This is known as the **voltage drop**. The voltage drop is the difference in voltage across an electrical device that has current flowing through it.

Charges lose their energy Consider a circuit with three bulbs and two batteries. The voltage is 3 V so each amp of current leaves the battery carrying 3 watts. As the current flows through the circuit, each bulb changes 1/3 of the power into light and heat. Because the first bulb uses 1 watt, the voltage drops from 3 V to 2 V as the current flows through the first bulb. Remember, the current in a series circuit is the same everywhere! As power gets used, the voltage gets lower.

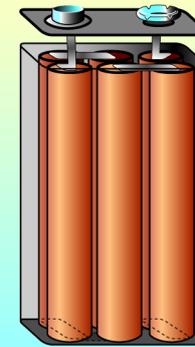
Voltage If the three bulbs are identical, each gives off the same amount of light and heat. Each uses the same amount of power. A meter will show the voltage drop from 3 volts to 2 volts to 1 volt, and finally down to zero volts after the last bulb. After passing through the last bulb, the current returns to the battery where it is given more power and the cycle starts over.



Batteries and cells

You may have heard a D battery called a “D cell.” The terms “battery” and “cell” are often used interchangeably. However, technically there is a difference between the two. Cells are the building blocks of batteries; AAA, AA, C, and D batteries each contain a single 1.5- volt cell. A chemical reaction inside a cell supplies electric current to devices connected to it.

Standard 9-volt battery



A 9-volt battery like the kind used in smoke detectors contains six tiny 1.5-volt cells connected in series. Each cell adds 1.5 volts to the total. You can make 9V yourself by connecting six 1.5V batteries. Can you figure out how to connect them?



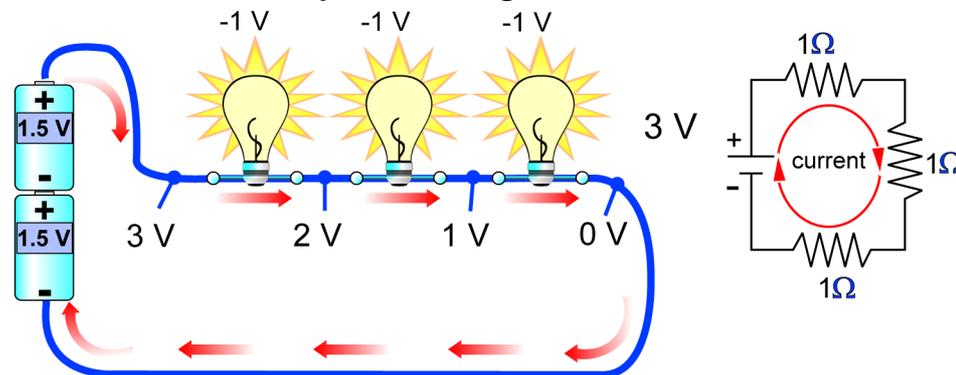
Voltage drops and Ohm's law

Voltage drops Each separate bulb or resistor creates a voltage drop. The voltage drop across a bulb is measured by connecting an electrical meter's leads at each side of the bulb (Figure 14.3). The greater the voltage drop, the greater the amount of power being used per amp of current flowing through the bulb.

Ohm's law The voltage drop across a resistance is determined by Ohm's law in the form $V = IR$. The voltage drop (V) equals the current (I) multiplied by the resistance (R) of the device. In a series circuit, the current is the same at all points, but devices may have different resistances. In the circuit below each bulb has a resistance of 1 ohm, so each has a voltage drop of 1 volt when 1 amp flows through the circuit.

Applying Kirchhoff's law In the circuit below, three identical bulbs are connected in series to two 1.5-volt batteries. The total resistance of the circuit is 3Ω . The current flowing in the circuit is 1 amp ($I = 3V \div 3\Omega$). Each bulb creates a voltage drop of 1 volt ($V = IR = 1\text{ A} \times 1\Omega$). The total of all the voltage drops is 3 V, which is the same as the voltage of the battery.

Each resistance drops the voltage



Energy conservation The law of conservation of energy also applies to a circuit. Over the entire circuit, the power used by all the bulbs must equal the power supplied by the battery. This means the total of all the voltage drops must add up to the battery's voltage. This rule is known as **Kirchhoff's voltage law**, after German physicist Gustav Robert Kirchhoff (1824-87).

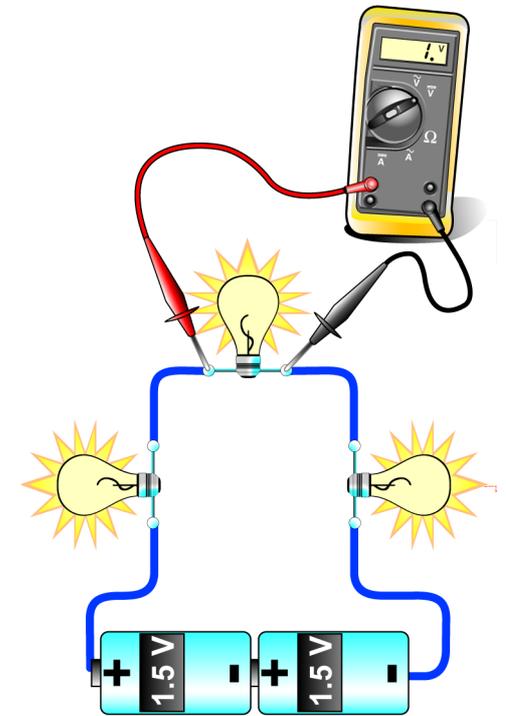


Figure 14.3: Using a multimeter to measure the voltage drop across a bulb in a circuit.

Solving series circuit problems

Unequal resistances Ohm's law is especially useful in series circuits where the devices do *not* have the same resistance. A device with a larger resistance has a greater voltage drop. However, the sum of all the voltage drops must still add up to the battery's voltage. The example below shows how to find the voltage drops in a circuit with two different light bulbs.



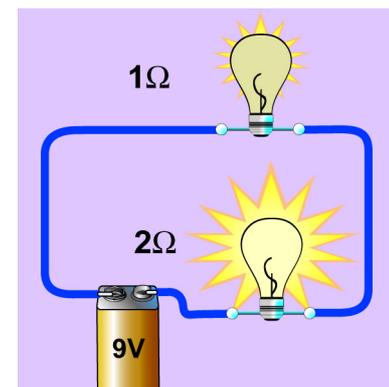
Calculating voltage drops

The circuit shown at right contains a 9-volt battery, 1-ohm bulb, and a 2-ohm bulb. Calculate the circuit's total resistance and current. Then find each bulb's voltage drop.

- Looking for:** You are asked for the total resistance, current, and voltage drops.
- Given:** You are given the battery's voltage and the resistance of each bulb.
- Relationships:** Total resistance in a series circuit: $R_{\text{tot}} = R_1 + R_2$
Ohm's law: $I = V/R$ or $V = IR$
- Solution:** Calculate the total resistance: $R_{\text{tot}} = 1 \Omega + 2 \Omega = 3 \Omega$
Use Ohm's law to calculate the current:
 $I = (9 \text{ V}) / (3 \Omega) = 3 \text{ A}$
Use Ohm's law to find the voltage across the 1 Ω bulb:
 $V = (3 \text{ A})(1 \Omega) = 3 \text{ V}$
Use Ohm's law to find the voltage across the 2 Ω bulb:
 $V = (3 \text{ A})(2 \Omega) = 6 \text{ V}$

Your turn...

- The battery in the circuit above is replaced with a 12-volt battery. Calculate the new current and bulb voltages.
Answer: 4 A, 4 V across 1 Ω bulb, 8 V across 2 Ω bulb
- A 12-volt battery is connected in series to 1 Ω and 5 Ω bulbs. What is the voltage across each bulb? **Answer:** 2 V, 10 V



14.1 Section Review

- What do you know about the current at different points in a series circuit?
- Three bulbs are connected in series with a battery and a switch. Do all of the bulbs go out when the switch is opened? Explain.
- What happens to a circuit's resistance as more resistors are added in series?
- A series circuit contains a 9-volt battery and three identical bulbs. What is the voltage drop across each bulb?



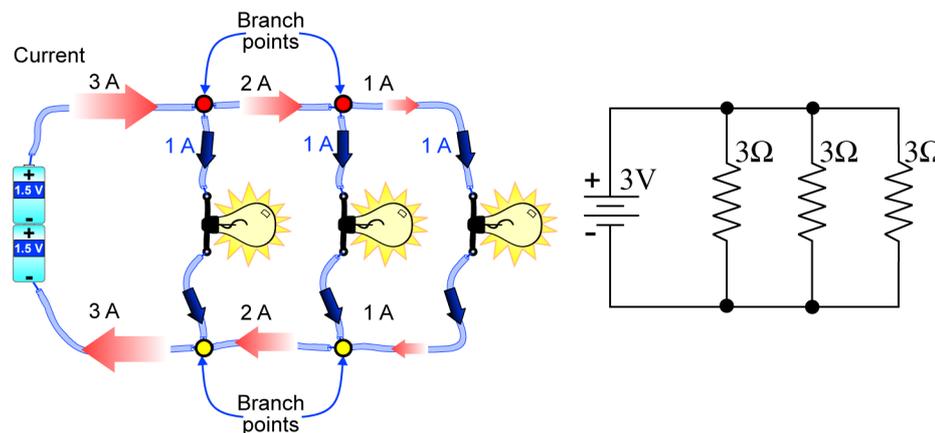
14.2 Parallel Circuits

It would be a real problem if your refrigerator went off when you turned out the light! That is why houses are wired with parallel circuits instead of series circuits. Parallel circuits provide each device with a separate path back to the power source. This means each device can be turned on and off independently from the others. It also means that each device sees the full voltage of the power source without voltage drops from other devices.

What is a parallel circuit?

Parallel branches A **parallel circuit** is a circuit with more than one path for the current. Each path in the circuit is sometimes called a *branch*. The current through a branch is also called the *branch current*. The current supplied by the battery in a parallel circuit splits at one or more branch points.

Example: three bulbs in parallel All of the current entering a branch point must exit again. This rule is known as **Kirchhoff's current law** (Figure 14.4). For example, suppose you have three identical light bulbs connected in parallel as shown below. The circuit has two branch points where the current splits (red dots). There are also two branch points where the current comes back together (yellow dots). You measure the branch currents and find each to be 1 amp. The current supplied by the battery is the sum of the three branch currents, or 3 amps. At each branch point, the current entering is the same as the current leaving.



Vocabulary

parallel circuit, Kirchhoff's current law, short circuit

Objectives

- ✓ Describe how current divides in a parallel circuit.
- ✓ Determine the voltage across and current through each branch of a parallel circuit.
- ✓ Explain why circuit breakers and fuses are used in homes.

Kirchhoff's current law

All current flowing into a branch point must flow out again

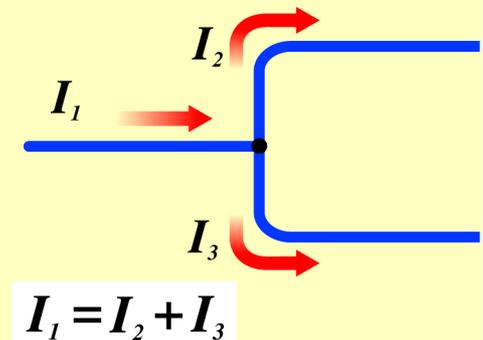


Figure 14.4: All the current entering a branch point in a circuit must also exit the point.

Voltage and current in a parallel circuit

Each branch has the same voltage

The voltage is the same anywhere along the same wire. This is true as long as the resistance of the wire itself is very small compared to the rest of the circuit. If the voltage is the same along a wire, then the *same voltage appears across each branch of a parallel circuit*. This is true even when the branches have different resistances (Figure 14.5). Both bulbs in this circuit see 3 V from the battery since each is connected back to the battery by wires without any other electrical devices in the way.

The voltage is the same across each branch of a parallel circuit.

Parallel circuits have two big advantages over series circuits.

1. Each device in the circuit has a voltage drop equal to the full battery voltage.
2. Each device in the circuit may be turned off independently without stopping the current in the other devices in the circuit.

Parallel circuits in homes

Parallel circuits need more wires to connect, but are used for most of the wiring in homes and other buildings. Parallel circuits allow you to turn off one lamp without all of the other lights in your home going out. They also allow you to use many appliances at once, each at full power.

Current in branches

Because each branch in a parallel circuit has the same voltage, the current in a branch is determined by the branch resistance and Ohm's law, $I = V/R$ (Figure 14.6). The greater the resistance of a branch, the smaller the current. Each branch works independently so the current in one branch does not depend on what happens in other branches

Total current

The total current in a parallel circuit is the sum of the currents in each branch. The only time branches have an effect on each other is when the total current is more than the battery or wall outlet can supply. A battery has a maximum amount of current it can supply at one time. If the branches in a circuit try to draw too much current the battery voltage will drop and less current will flow.

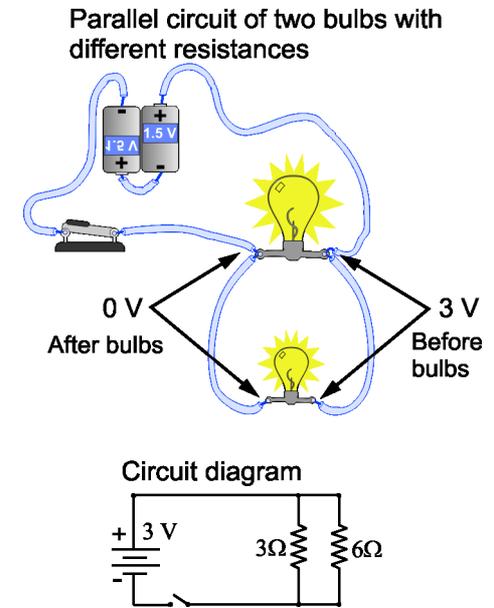


Figure 14.5: The voltage across each branch of a parallel circuit is the same.

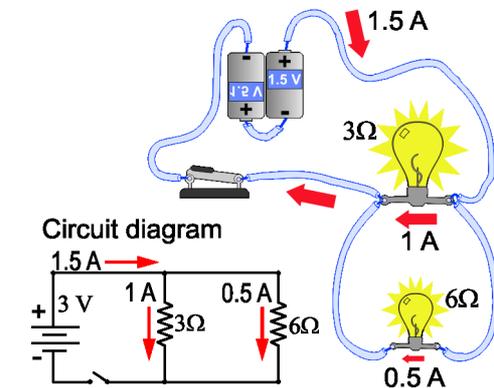


Figure 14.6: The current in each branch depends on the branch resistance. The current may be different for each branch.



Calculating current and resistance in a parallel circuit

More branches mean less resistance

In series circuits, adding an extra resistor increases the total resistance of the circuit. The opposite is true in parallel circuits. Adding a resistor in a parallel circuit provides another independent path for current. More current flows for the same voltage so the total resistance is *less*.

Example of a parallel circuit

Figure 14.7 compares a series circuit with a parallel circuit. In the series circuit, the current is 6 amps ($I = V/R = 12V \div 2\Omega$). In the parallel circuit, the current is 6 amps *in each branch*. The total current is 12 amps. So what is the total resistance of the parallel circuit? Ohm's law solved for resistance is $R = V \div I$. The total resistance of the parallel circuit is the voltage (12 V) divided by the total current (12 A) or 1 ohm. The resistance of the parallel circuit is *half* that of the series circuit.



Current in parallel circuits

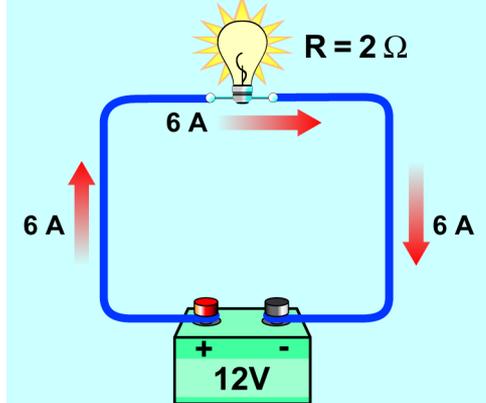
All of the electrical outlets in Jonah's living room are on one parallel circuit. The circuit breaker cuts off the current if it exceeds 15 amps. Will the breaker trip if he uses a light (240 Ω), stereo (150 Ω), and an air conditioner (10 Ω)?

1. **Looking for:** You are asked whether the current will exceed 15 amps.
2. **Given:** You are given the resistance of each branch and the circuit breaker's maximum current.
3. **Relationships:** Ohm's law: $I = V/R$
4. **Solution:** Because the devices are plugged into electrical outlets, the voltage is 120 volts for each.
 $I_{\text{light}} = (120 \text{ V}) / (240 \Omega) = 0.5 \text{ A}$
 $I_{\text{stereo}} = (120 \text{ V}) / (150 \Omega) = 0.8 \text{ A}$
 $I_{\text{AC}} = (120 \text{ V}) / (10 \Omega) = 12 \text{ A}$
 The total is 13.3 A, so the circuit breaker will not trip.

Your turn...

- a. Will the circuit breaker trip if Jonah also turns on a computer ($R = 60 \Omega$)?
Answer: Yes. The additional current is 2 A, so the total is 15.3 A.
- b. What is the total current in a parallel circuit containing a 12-V battery, a 2 Ω resistor, and a 4 Ω resistor? **Answer:** 9 A

Series circuit



Parallel circuit

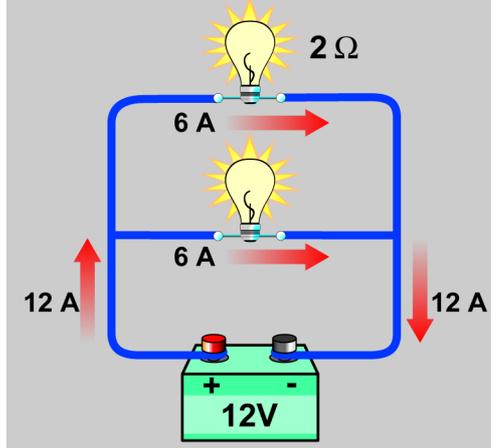


Figure 14.7: The parallel circuit has twice the current and half the total resistance of the series circuit.

Short circuits, circuit breakers, and fuses

Heat and wires When electric current flows through a resistance, some of the power carried by the current becomes heat. Toasters and electric stoves are designed to use electric current to make heat. Although the resistance of wires is low, it is not zero and so wires heat up when current flows through them. If too much current flows through too small a wire, the wire overheats and may melt or start a fire.

Short circuits A **short circuit** is a parallel path in a circuit with very low resistance. A short circuit can be created accidentally by making a parallel branch with a wire (Figure 14.8). A plain wire may have a resistance as low as 0.001Ω . Ohm's law tells us that with a resistance this low, 1.5 V from a battery results in a (theoretical) current of 1,500 A! A short circuit is dangerous because currents this large melt wires and burn anyone working with the circuit.

Parallel circuits in homes Appliances and electrical outlets in homes are connected in many parallel circuits. Each circuit has its own fuse or circuit breaker that stops the current if it exceeds the safe amount, usually 15 or 20 amps (Figure 14.9). If you turn on too many appliances in one circuit at the same time, the circuit breaker or fuse cuts off the current. To restore the current, you must first disconnect some or all of the appliances. Then, either flip the tripped circuit breaker (in newer homes) or replace the blown fuse (in older homes). Fuses are also used in car electrical systems and in electrical devices such as televisions.

14.2 Section Review

1. Is the voltage across each branch of a parallel circuit the same? Is the current in each branch the same?
2. Why do home electrical systems use parallel wiring?
3. What happens to the total current in a parallel circuit as more branches are added? Why?
4. What is the total resistance of two 12-ohm resistors in parallel? What is the total for three 12-ohm resistors in parallel?

Short circuit, a large amount of current passes through the short circuit branch. Almost no current is through the bulb.

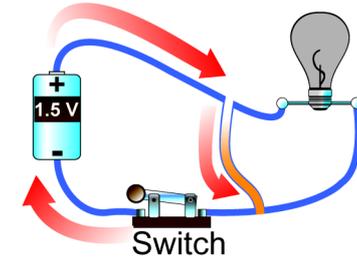


Figure 14.8: A short circuit is created when there is a parallel branch of very low resistance. The current in this branch can be dangerously large.

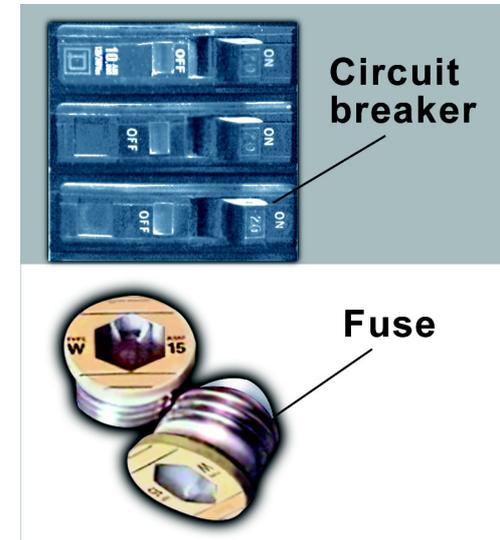


Figure 14.9: Houses and other buildings use either circuit breakers or fuses to cut off the current if it gets too high.



14.3 Electrical Power, AC, and DC Electricity

If you look at a stereo, hair dryer, or other household appliance, you may find a label giving its power in watts. In this section you will learn what the power ratings on appliances mean, and how to figure out the electricity costs of using various appliances.

Electric power

A watt is a unit of power Electrical power is measured in watts, just like mechanical power you learned about in Chapter 4. Electrical power is the rate at which electrical energy is changed into other forms of energy such as heat, sound, or light. Anything that “uses” electricity is actually converting electrical energy into some other type of energy. The watt is an abbreviation for one joule per second. A 100-watt light bulb uses 100 joules of energy *every second* (Figure 14.10).

The three electrical quantities

We have now learned three important electrical quantities:

Current (I)	Current is what carries power in a circuit. Current is measured in amperes (A).
Voltage (V)	Voltage measures the difference in energy carried by charges at two points in a circuit. A difference in voltage causes current to flow. Voltage is measured in volts (V). One volt is one watt per amp of current.
Resistance (R)	Resistance measures the ability to resist current. Resistance is measured in ohms (Ω). One amp of current flows if a voltage of 1 V is applied across a resistance of 1 Ω .

Paying for electricity

Electric bills sent out by utility companies don’t charge by the volt, the amp, or the ohm. Electrical appliances in your home usually include another unit – the *watt*. Most appliances have a label that lists the number of watts or kilowatts. You may have purchased 60-watt light bulbs, a 1000-watt hair dryer, or a 1200-watt toaster oven. Electric companies charge for the energy you use, which depends on how many watts each appliance consumes and the amount of time each is used during the month.

Vocabulary

kilowatt, kilowatt-hour, direct current, alternating current, transformer

Objectives

- ✓ Calculate power in a circuit.
- ✓ Calculate the cost of running an appliance.
- ✓ Distinguish between alternating and direct current.

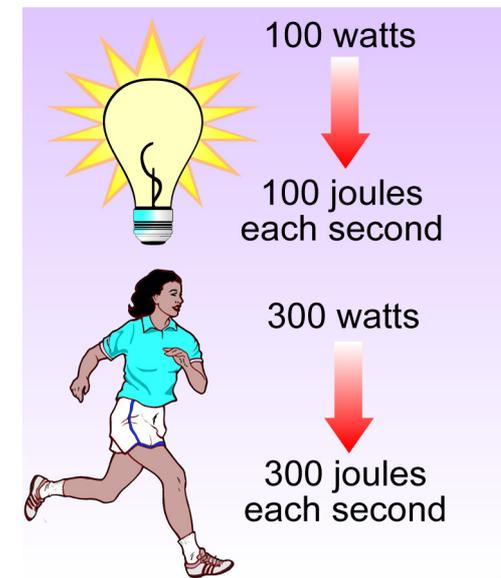


Figure 14.10: One watt equals one joule per second.

Calculating power in a circuit

Calculating power Since one volt is a watt per amp, to calculate power in an electric circuit you multiply the voltage by the current. To calculate the power of a device in a circuit, multiply the voltage drop across the device by the current.

ELECTRICAL POWER

$$\text{Power (watts)} \rightarrow P = IV \leftarrow \text{Voltage (volts)}$$

Current (amps)

Watts and kilowatts Most electrical appliances have a label that lists the power in watts (Figure 14.11) or kilowatts (kW). The **kilowatt** is used for large amounts of power. One kilowatt (kW) equals 1,000 watts. Another common unit of power, especially on electric motors, is the horsepower. One horsepower is 746 watts. The range in power for common electric motors is from 1/25th of a horsepower (30 watts) for a small electric fan to 1 horsepower (746 watts) for a garbage disposal.

ELECTROSTATIC COPYING
RATING 120V 60 Hz
12A 1400 W

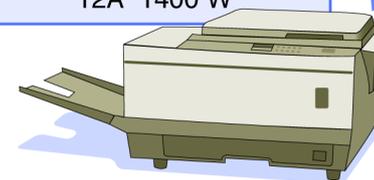


Figure 14.11: Most appliances have a label that lists the power in watts.

Equation	... gives you if you know ...
$P = I \times V$	power (P)	current and voltage
$I = P \div V$	current (I)	power and voltage
$V = P \div I$	voltage (V)	power and current



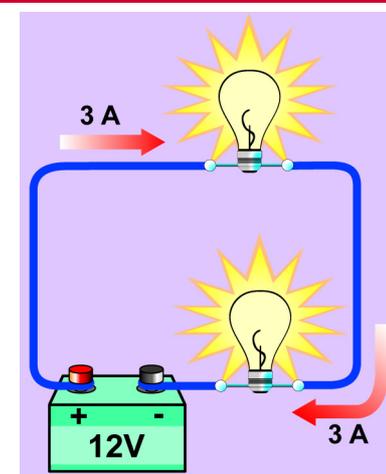
Calculating power

A 12-volt battery is connected in series to two identical light bulbs. The current in the circuit is 3 amps. Calculate the power output of the battery.

- Looking for:** You are asked for the power in watts supplied by the battery.
- Given:** You are given the battery voltage in volts and current in amps.
- Relationships:** Power: $P = IV$
- Solution:** Battery: $P = (3 \text{ A})(12 \text{ V}) = 36 \text{ W}$

Your turn...

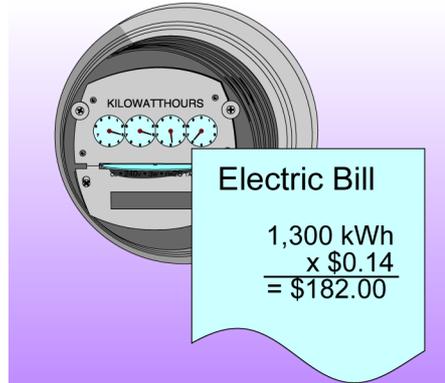
- A 12-volt battery is connected in parallel to the same identical light bulbs as used in the example. The current through each bulb is now 6 amps. Calculate the power output of the battery. **Answer:** 144 W for battery
- The label on the back of a television states that it uses 300 watts of power. How much current does it draw when plugged into a 120-volt outlet? **Answer:** 2.5 amps





Buying electricity

Kilowatt-hours Utility companies charge customers for the number of **kilowatt-hours** (abbreviated kWh) used each month. One kilowatt-hour means that a kilowatt of power has been used for one hour. A kilowatt-hour is not a unit of power but a unit of *energy*. A kilowatt-hour is a relatively large amount of energy, equal to 3.6 million joules. If you leave a 1,000-watt hair dryer on for one hour, you have used one kilowatt-hour of energy. You could also use 1 kilowatt-hour by using a 100-watt light bulb for 10 hours. The number of kilowatt-hours used equals the number of kilowatts multiplied by the number of hours the appliance was turned on.



Appliance	Power (watts)
Electric stove	3,000
Electric heater	1,500
Toaster	1,200
Hair dryer	1,000
Iron	800
Washing machine	750
Television	300
Light	100
Small fan	50
Clock radio	10

Figure 14.12: Typical power usage of some common appliances.

You pay for kilowatt-hours Electric companies charge for kilowatt-hours used during a period of time, often a month. Your home is connected to a meter that counts up total number of kilowatt-hours used and a person comes to read the meter once a month. If you know the cost per kilowatt-hour the utility company charges, you can estimate the cost of operating any electrical appliance.



Electricity costs

How much does it cost to run an electric stove for 2 hours? Use the power in Figure 14.12 and a cost of \$0.15 per kilowatt-hour.

- Looking for:** You are asked for the cost to run a stove for 2 hours.
- Given:** You are given the time, the power, and the price per kilowatt-hour.
- Relationships:** 1 kilowatt = 1000 watts number of kilowatt-hours = (# of kilowatts) x (hours appliance is used)
- Solution:**

$$3000 \text{ W} = 3 \text{ kW} \quad 3 \text{ kW} \times 2 \text{ hr} = 6 \text{ kWh} \quad 6 \text{ kWh} \times \frac{\$0.15}{\text{kWh}} = \$0.90$$

Your turn...

- At \$0.15 per kilowatt-hour, what is the cost of running an electric heater for 4 hours? **Answer:** \$0.90
- At \$0.15 per kilowatt-hour, what is the cost of running a clock radio for 24 hours? **Answer:** \$0.04 (rounded to nearest cent)

Alternating (AC) and direct (DC) current

Direct current The current from a battery is always in the same direction, from the positive to the negative end of the battery. This type of current is called **direct current** or DC. Although the letters “DC” stand for “direct current” the abbreviation “DC” is used to describe both voltage and current. A DC voltage is one that stays the same sign over time. The terminal that is positive stays positive and the terminal that is negative stays negative. Your experiments in the lab use DC since they use batteries.

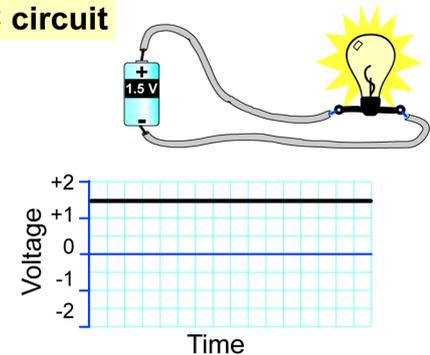
Alternating current The electrical system in your house uses **alternating current** or AC. Alternating current constantly switches direction. You can theoretically create alternating current with a battery if you keep reversing the way it is connected in a circuit (Figure 14.13). In the electrical system used in the United States, the current reverses direction 60 times per second. It would be hard to flip a battery this fast!

*A DC current or voltage keeps the same sign over time.
An AC current or voltage reverses sign, usually 60 times per second in the US.*

Electricity in other countries For large amounts of electricity, we use alternating current because it is easier to generate and to transmit over long distances. All the power lines you see overhead carry alternating current. Other countries also use alternating current. However, in many other countries, the current reverses itself 50 times per second rather than 60, and wall sockets are at a different voltage. When visiting Asia, Africa, or Europe, you need special adapters to use electrical appliances you bring with you from the United States.

Peak and average voltages The 120 volt AC (VAC) electricity used in homes and businesses alternates between peak values of +170 V and -170 V (Figure 14.14). This kind of electricity is called 120 VAC because +120V is the *average* positive voltage and -120V is the *average* negative voltage. AC electricity is usually described by the average voltage, not the peak voltage.

DC circuit



AC circuit

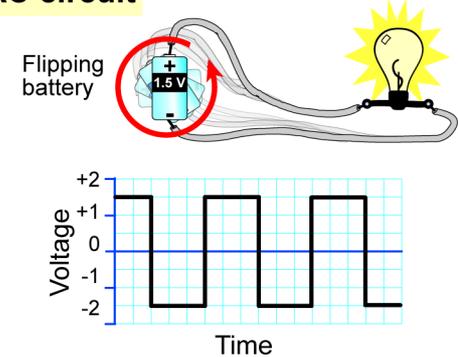


Figure 14.13: Direct current is in one direction, but alternating current reverses.

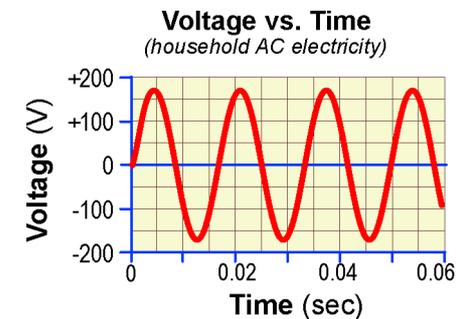


Figure 14.14: The voltage in your wall outlets goes from +170 V to -170 V.



Electricity, power, and heat

How do you get more power? How do you get more power when you need it? From the power formula, we can see that increasing voltage or current will increase power. The problem with raising voltage is that the electricity in a standard wall outlet is 120 volts and it is hard to change. While certain appliances use 240 volts, the higher voltage is more dangerous so 120 volts is used for most electrical appliances.

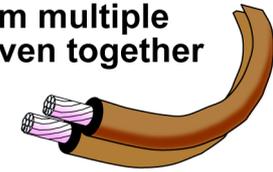
Higher power usually means more current The most common way to get higher power is to use more current. However, heat becomes a problem when wires carry large currents. A wire's voltage drop (from Ohm's law) equals the current multiplied by the wire's resistance. Because a wire's resistance is small, the voltage drop is usually small enough to be ignored. But if there is a large current, there can be a significant voltage drop. Remember, power is voltage drop multiplied by current. In a wire, this power is converted into heat. A small amount of heat can safely be transferred away from the wire by conduction or convection. Too much heat could melt the wire or start a fire.

Reducing heat in electrical wires Wires are made in different sizes to carry different amounts of current. A large diameter wire has less resistance and can safely carry more current than a smaller, thinner wire. A 12-gauge wire is thicker than a 14-gauge wire and can carry more current (Figure 14.15). You should always use the right wire for the current that is flowing. This includes extension cords, which you may use without thinking about whether they are safe or not. Extension cords are made with 18-gauge wire, 16-gauge, 14-gauge, and 12-gauge wire.

Length and resistance The length of a wire also affects its resistance. The longer a wire is, the more resistance it has. Think about moving around your school and how you can get through a short, crowded hallway quickly. But it takes a long time to get down a long, crowded hallway.

Check your extension cords for safety All extension cords are rated for how many amps of current they can carry safely. *Always* check to see if the extension cord can carry *at least* as much current as the device you are using requires. For powerful tools, such as a saw, you should use a 14-gauge or 12-gauge heavy-duty extension cord that is rated to carry 15-20 amps. Many fires have been caused by using the wrong extension cord.

Extension cords are made from multiple wires woven together



12-gauge wire 

14-gauge wire 

16-gauge wire 

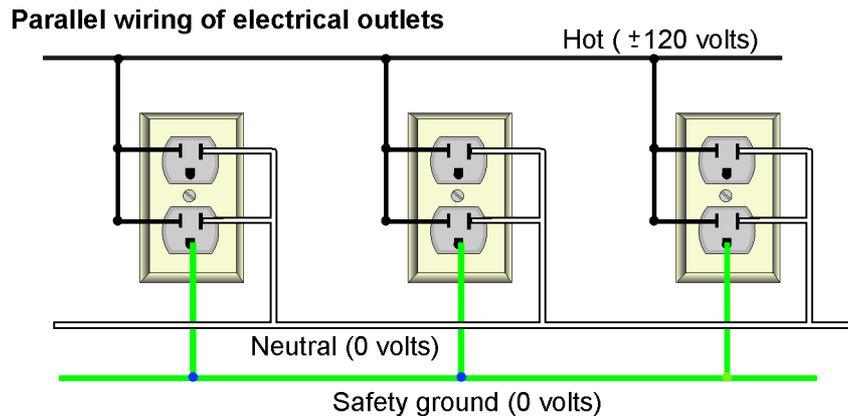
18-gauge wire 

Wire gauge	Maximum current (amps)
12	20
14	15
16	10

Figure 14.15: *The larger the gauge of a wire, the smaller its diameter, and the smaller the amount of current the wire can safely carry.*

Electricity in homes and buildings

Circuit breaker panel The 120 VAC electricity comes into a normal home or building through a circuit breaker panel. The circuit breakers protect against wires overheating and causing fires. Each circuit breaker protects one parallel circuit which may connect many wall outlets, lights, switches, or other appliances.



Hot, neutral, and ground wires Each wall socket has three wires feeding it. The hot wire carries 120 volts AC. The neutral wire stays at zero volts. When you plug something in, current flows in and out of the hot wire, through your appliance (doing work) and back through the neutral wire. The ground wire is for safety and is connected to the ground (0 V) near your house. If there is a short circuit in your appliance, the current flows through the ground wire rather than through you.

Ground fault interrupt (GFI) outlets Electrical outlets in bathrooms, kitchens, or outdoors are now required to have ground fault interrupt (GFI) outlets installed (Figure 14.16). A GFI outlet contains a circuit that compares the current flowing out on the hot wire and back on the neutral wire. If everything is working properly, the two currents should be exactly the same. If they are different, some current must be flowing to ground through another path, such as through your hand. The ground fault interrupter detects any difference in current and immediately breaks the circuit. GFI outlets are excellent protection against electric shocks, especially in wet locations.

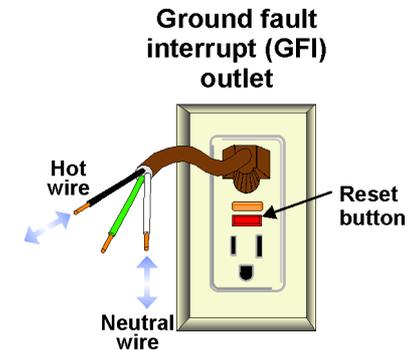
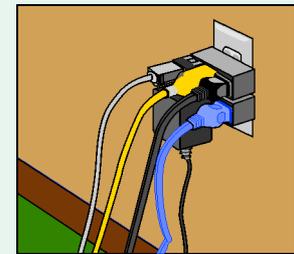


Figure 14.16: A ground fault interrupt outlet might be found in bathrooms and kitchens where water may be near electricity.

Too many plugs!



If you plug too many appliances into the same circuit or outlet, you will eventually use more current than the wires can carry without overheating. Your circuit breaker will click open and stop the current. You should unplug things to reduce the current in the circuit before resetting the circuit breaker.



Distributing electricity

Why electricity is valuable Electricity is a valuable form of energy because electrical power can be moved easily over large distances. You would not want a large power plant in your backyard! One large power plant converts millions of watts of chemical or nuclear energy into electricity. The transmission lines carry the electricity to homes and businesses, often hundreds of miles away.

Power transmission lines Overhead power lines use a much higher voltage than 120V. That is because the losses due to the resistance of wires depend on the current. At 100,000 volts each amp of current carries 100,000 watts of power, compared to the 120 watts per amp of household electricity. Big electrical transmission lines operate at very high voltages for this reason (Figure 14.17). The wires are supported high on towers because voltages this high are *very dangerous*. Air can become a conductor over distances of a meter at high voltages. *Never* go near a power line that has fallen on the ground in a storm or other accident.

Transformers A device called a **transformer** converts high-voltage electricity to lower voltage electricity. Within a few kilometers of your home or school the voltage is lowered to 13,800 V or less. Right near your home or school the voltage is lowered again to the 120 V or 240 V that actually come into the circuits connecting your wall outlets and appliances.

Changing AC to DC Many electronic devices, like cell phones or laptop computers, use DC electricity inside, but also can be plugged into the AC electricity from a wall outlet with an *AC adapter* (Figure 14.18). An “AC adapter” is a device that changes the AC voltage from the wall outlet into DC voltage for the device. The adapter also steps the voltage down from 120 volts to the battery voltage, which is usually between 6 and 20 volts.

14.3 Section Review

1. How is an appliance's power related to the amount of energy it uses?
2. How many watts or joules are a horsepower, kilowatt, and kilowatt-hour.
3. What does the electric utility company charge you for each month?
4. What is the difference between direct current and alternating current?

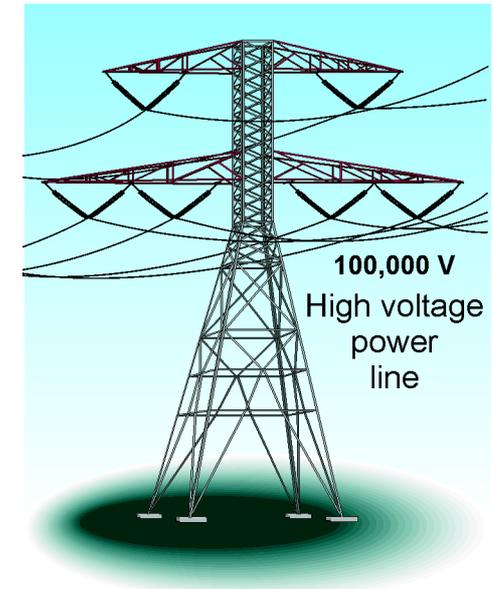


Figure 14.17: Electrical power lines may operate at voltages of 100,000 volts or greater.

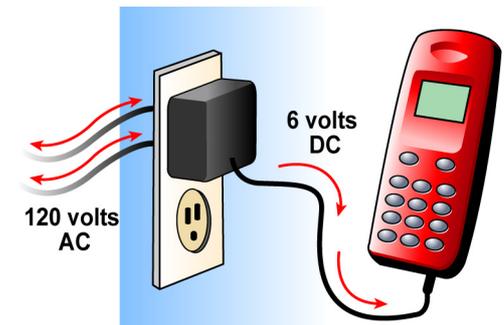


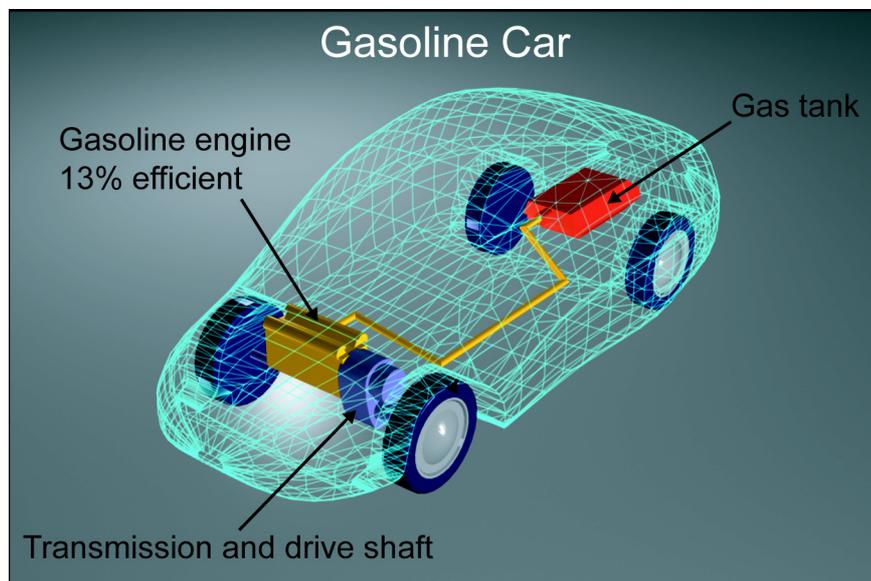
Figure 14.18: Special adapters can change AC into DC and lower the voltage.

How do Hybrid Cars Work?

Gas-electric hybrid cars look and drive about like any other car, but use 20-30% less gas than their non-hybrid counterparts. For example, a hybrid car's gas mileage is about 50 miles per gallon. The gas mileage for standard cars ranges from 10 to 30 miles per gallon. To understand how hybrid cars get better gas mileage, we have to look at the engines.

Cars powered by gasoline

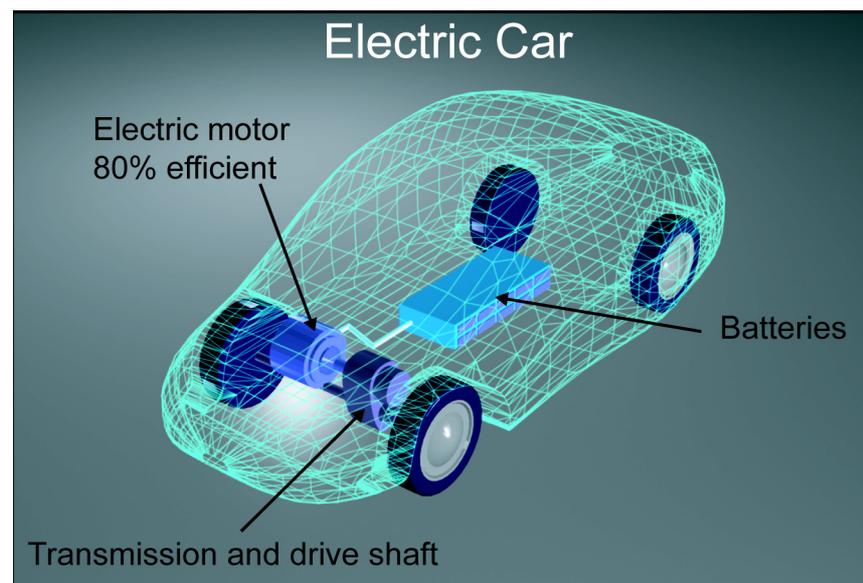
The efficiency of a gasoline engine is about 13%. This means that when the car is in motion, it only uses about 13% of the available energy from a tank of gas. The rest of the available energy from a tank of gas is lost as heat. The more energy that is lost as heat, the less efficient an engine or any system is.



Although the combustion of a gasoline engine produces many pollutants, gasoline is very energy-rich and easy for a car to carry. These two features have made the gasoline engine so easily adopted when oil was inexpensive and there was less concern for the impact of cars on the global environment.

Cars powered by electricity

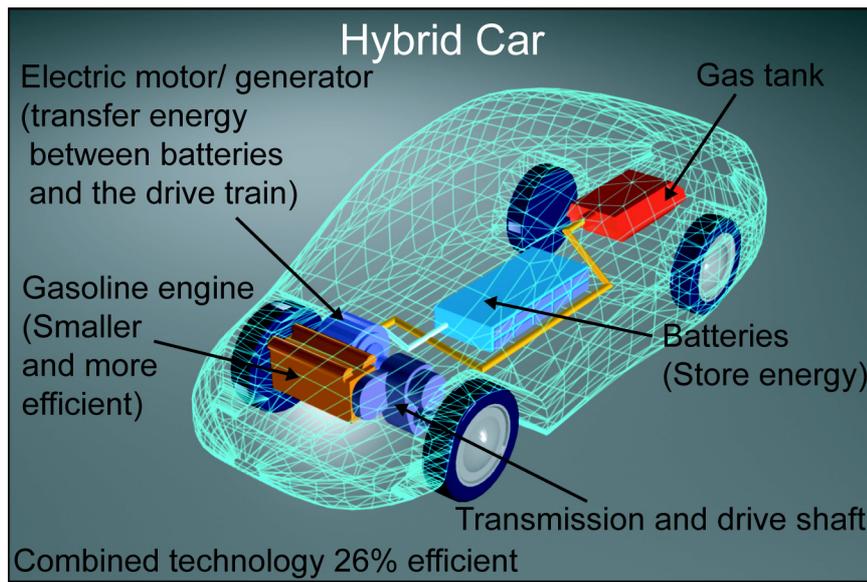
Compared to gasoline-powered cars, electric motors are very efficient — 80% from batteries — and they produce no pollutants.



To run an electric car, the batteries need to be charged, often this is done by plugging in the car during the night. Unfortunately, batteries are heavy and don't have as much energy as gasoline. For instance, the available energy in a typical car battery is equivalent to about a small cupful of gasoline. Until there is a better electrical storage system, cars powered by electricity from a battery must be small and only used to travel short distances.

The best of both technologies

A hybrid car uses the best of both worlds—a gasoline-powered engine and an electric motor. By combining technologies, the efficiency is improved to about 26%. The electric motor helps the gas-powered system be more efficient by using electricity to transfer energy within the system.



How do hybrids compare?

In a hybrid car, the gasoline engine and electric motor work together to accelerate the car. This allows the gasoline engine to be smaller and more efficient. Every time a standard car slows down, kinetic energy is lost as the brakes heat up. In contrast, the hybrid's electric motor operates as a generator during braking. When the car slows down, kinetic energy is converted to electrical energy that charges the batteries. Then, to speed up the car, the stored energy in the batteries is converted into useful kinetic energy by the motor.

In addition to getting great gas mileage, hybrid cars are rated as ultra-low emissions vehicles (ULEVs). This means that they do not produce as many pollutants as standard cars. Hybrid cars produce less pollution because the engine is smaller and simply uses less gasoline. Also, when a hybrid car comes to a stop, the engine automatically shuts off to save gas. When it is time to go again, the car turns on instantly. At very low speeds, as when you are driving in a city, the electric motor runs the car instead of the gasoline engine. When the electric motor is used, there is less pollution.

Hybrid technology is just a beginning

The gas-electric hybrid is only one of the many types of more efficient motor-powered vehicles that are being developed today. Driving this development is an interest in decreasing our use of fossil fuels for transportation. Interest in developing alternative transportation technologies will continue because they are potentially more efficient and less polluting.

In the meantime, since we all need to travel and often use gasoline-powered vehicles, how can you reduce your use of fossil fuels so that you save money and reduce pollution? Here are some options: share rides, take public transportation, and drive a medium-sized or small car that has high gas mileage.

Questions:

1. If you only need to drive two miles per day, which kind of car would be the best to use? Justify your answer.
2. Why is the efficiency of gasoline-powered cars so low?
3. Hybrid cars are better for driving in cities but not as efficient for highway driving? Why?
4. Some hybrid cars have efficiency meters—a gauge that shows your miles per gallon—so you can monitor and improve your driving habits. Make a list of driving habits that help you save gas.

Chapter 14 Review

Understanding Vocabulary

Select the correct term to complete the sentences.

parallel circuit	kilowatt-hour	electrical power
horsepower	series circuit	short circuit
transformer	direct	Kirchhoff's voltage law
Kirchhoff's current law	kilowatt	voltage drop
alternating		

Section 14.1

1. A _____ contains only one path for the current.
2. According to _____, if a circuit contains a 3-volt battery, the voltage drops around the complete circuit must add to 3 volts.
3. There is a _____ across each resistor in a circuit when current is flowing.

Section 14.2

4. _____ states that all the current entering a point in a circuit must also leave that point.
5. A _____ is created when a circuit contains one branch with very little or no resistance.
6. A _____ contains multiple paths or branches for the current.

Section 14.3

7. One _____ equals 1000 watts.
8. The rate of converting electrical energy into another form of energy is called _____.
9. The _____ is a unit used by electric utility companies to measure the electrical energy your home uses each month.
10. One _____ is equal to 746 watts.
11. A battery creates _____ current.
12. Electrical appliances in your home use _____ current.
13. A _____ converts high-voltage electricity to lower voltage electricity.

Reviewing Concepts

Section 14.1

1. Draw a circuit diagram for a circuit containing a battery and two bulbs in series.
2. Is the current at every point in a series circuit the same?
3. One of the bulbs burns out in a string of lights. What happens to the current in the circuit? What happens to the other bulbs?
4. Explain how to calculate the total resistance of a series circuit.
5. As more bulbs are added to a series circuit, what happens to the resistance of the circuit? What happens to the brightness of the bulbs?
6. Explain Kirchhoff's voltage law.

Section 14.2

7. What is a parallel circuit?
8. Draw the circuit diagram for a circuit containing two bulbs in parallel.
9. What does Kirchhoff's current law say about the current entering any point in a circuit?
10. Each branch in a parallel circuit has the same _____.
11. List two advantages of parallel circuits over series circuits.
12. Does the wiring in your home connect the appliances in series or parallel? How could you prove this?
13. What happens to the total resistance of a parallel circuit as more branches are added? Why?
14. How do you calculate the total resistance of two parallel resistors?
15. What is a short circuit?
16. Why can short circuits be dangerous?

Section 14.3

17. A light bulb has a power of 60 watts. Explain what this means in terms of energy and time.
18. Explain how to calculate the power of an electrical appliance.
19. What is the meaning of the kilowatt-hour?

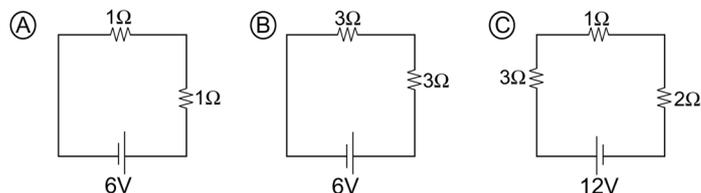


20. What is the difference between direct current and alternating current?
21. How frequently does the alternating current used in the United States reverse direction?
22. Do thinner or thicker wires have more resistance?
23. Do longer or shorter wires have more resistance?
24. Why is it dangerous to connect several extension cords to make one long cord?
25. What is the purpose of the AC adapter on the end of the cord used for cell phones?

Solving Problems

Section 14.1

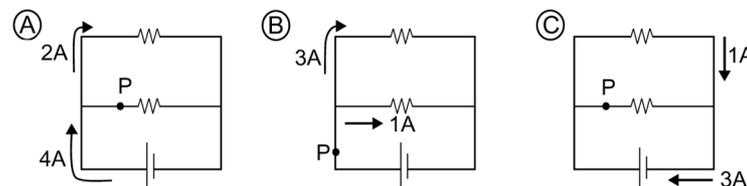
1. A circuit contains 5-ohm, 3-ohm, and 8-ohm resistors in series. What is the total resistance of the circuit?
2. A circuit contains a 9 volt battery and two identical bulbs. What is the voltage drop across each?
3. A circuit contains a 12 volt battery and two 3-ohm bulbs in series. Draw a circuit diagram and use it to find the current in the circuit and the voltage drop across each bulb.
4. A circuit contains a 12 volt battery and three 1-ohm bulbs in series. Draw the circuit diagram and find the current in the circuit.
5. Calculate the total resistance of each circuit shown below. Then calculate the current in each.



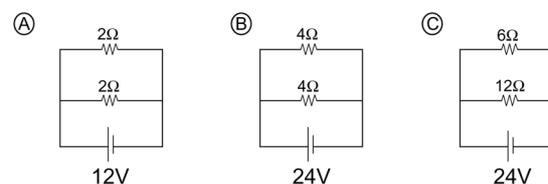
6. A circuit contains two 1-ohm bulbs in series. The current in the circuit is 1.5 amperes. What is the voltage provided by the batteries?
7. A circuit contains two identical resistors in series. The current is 3 amperes, and the batteries have a total voltage of 24 volts. What is the total resistance of the circuit? What is the resistance of each resistor?

Section 14.2

8. Find the amount and direction of the current through point P in each of the circuits shown below.

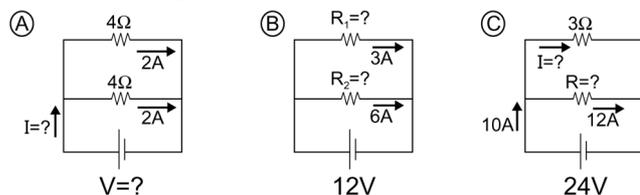


9. Do the following for each of the three circuits shown below.
 - a. Find the voltage across each resistor.
 - b. Use Ohm's law to find the current through each resistor.
 - c. Find the total current in the circuit.
 - d. Find the total resistance of the circuit.



10. A parallel circuit contains a 6-volt battery and two 6-ohm bulbs.
 - a. Draw the circuit diagram for this circuit.
 - b. Calculate the current through each branch.
 - c. Calculate the total current.
 - d. Use Ohm's law to calculate the total resistance of the circuit.
 - e. Use the formula for combining parallel resistors to calculate the total resistance of the circuit.
11. A parallel circuit contains a 24 V battery, 4 Ω bulb and a 12 Ω bulb.
 - a. Draw the circuit diagram for this circuit.
 - b. Calculate the current through each branch.
 - c. Calculate the total current in the circuit.
 - d. Use Ohm's law to calculate the total resistance of the circuit.
 - e. Use the formula for combining parallel resistors to calculate the total resistance of the circuit.

12. Find the unknown quantity in each of the circuits below.



Section 14.3

- Calculate the power of each of the following appliances when plugged into a 120-volt outlet.
 - an iron that draws 10 A of current
 - a stereo that draws 2 A of current
 - a light bulb that draws 0.5 A of current
- Calculate the current each of the following appliances draws when plugged into a 120-volt outlet.
 - a 100 watt computer
 - a 1200 watt microwave
 - a 30 watt radio
- A portable MP3 player requires 1.5 A of current and has a power of 15 watts. What is the voltage of the rechargeable battery it uses?
- A flashlight contains a 6-watt bulb that draws 2 A of current. How many 1.5-volt batteries does it use?
- Alex uses a 1000 watt heater to heat his room.
 - What is the heater's power in kilowatts?
 - How many kilowatt-hours of electricity does Alex use if he runs the heater for 8 hours?
 - If the utility company charges \$0.15 per kilowatt-hour, how much does it cost to run the heater for 8 hours?
- You watch a 300-watt television for two hours while you watch a movie.
 - What is the television's power in kilowatts?
 - How many kilowatt-hours of electricity did you use?
 - If the utility company charges \$0.15 per kilowatt-hour, how much did it cost you to watch the movie?

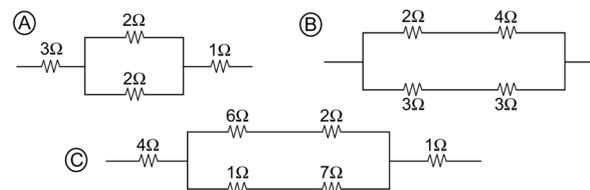
Applying Your Knowledge

Section 14.1

- Some appliances contain components that are connected in series. For example, many microwave ovens have a light that turns on while the microwave is running. Look around your house and see how many appliances you can find that use series circuits.

Section 14.2

- A car contains a warning bell that turns on if you open the door while the key is in the ignition. The bell also turns on if you open the door while the headlights are on. A single circuit with three switches and a bell can be built to ring in both cases. Figure out how the circuit is designed. Draw a circuit diagram that shows your solution.
- Many circuits contain resistors in series and in parallel. Apply what you have learned about circuits to find the total resistance of each of the sets of resistors below.



Section 14.3

- Look at the back or underside of appliances in your home. Find the power of three appliances. Calculate the amount of current each draws when plugged into a 120-volt outlet.
- Choose an appliance with a known power that you use frequently, such as a clock radio, stereo, or light.
 - Calculate the power in kilowatts.
 - Determine the amount of time you use the appliance in one day.
 - Calculate the number of kilowatt-hours of energy the appliance uses in one day.
 - Calculate the number of kilowatt-hours of energy it uses in one year.
 - Find out the cost of electricity in your home.
 - Calculate the cost of running the appliance for one year.