Apply Your Knowledge *(Continued)*

6. Battery disposal has become an issue in recent years. Secondary cells, in particular, must be disposed of properly to avoid environmental and health hazards. Find out what the hazards are and how communities are currently dealing with these issues. How can these methods be improved? Develop and propose a new disposal plan that would be safe for humans and the environment.
7. Research one career related to the information you have studied in this chapter. Create a report that states the following:
   - The occupation you selected
   - The education requirements to enter this occupation
   - The possibilities for promotion to a higher level
   - What someone with this career does on a daily basis
   - The earning potential for someone with this career

   You might find this information on the Internet or in your library. If possible, interview a person who already works in this field to answer the five points. Finally, state why you might or might not be interested in pursuing this occupation when you finish school.

STEM Applications

1. **MATH** Ohm's law states that voltage is equal to current times the resistance in an electrical circuit ($V = I \times R$, where V = voltage, I = current, and R = resistance). You will learn more about Ohm's law in the next chapter. However, just by looking at the formula, you may be able to see how Ohm's law applies to transformers. Write a statement explaining how Ohm's law relates to the transmission and distribution of electrical power.
2. **ENGINEERING** Design and make an electrical system to power a head-mounted LED flashlight that could be worn at night on a camping trip. Consider whether to use a generator or battery-operated design. Find out how much voltage is needed and design the flashlight accordingly.
3. **SCIENCE** Although most metals conduct electricity, most electrical wires are made of copper. However, copper is not the metal that best conducts electricity. Find out more about how well common metals conduct electricity. Include copper, tungsten, zinc, aluminum, gold, silver, nickel, and platinum in your research. Make a chart to show your findings. Which metal is the best conductor of electricity? Why is copper used instead for most wiring applications? Which other metals, if any, could be used in electrical wires to conduct electricity efficiently?

CHAPTER 12 Using Electricity and Electronics

Better by Design

Leah Buechley designs wearable electronics

Leah Buechley is an American textile researcher who weaves, solders, and sews LEDs and electronics into cloth to build soft, flexible, wearable computers. For example, she constructed the LED bracelet shown here by weaving LEDs and beads together on a traditional beading loom. Computer chips and other electronic components are attached to the bracelet via custom-made fabric circuit boards that Leah developed. Leah also designed a construction kit called the LilyPad Arduino that allows others to build their own computational (electronic) textiles.

An LED bracelet shows up well in dark environments. What e-fashion products would you design and make?

"I believe in learning, inventing, and designing through building and hands-on experimenting."

Reading Target

Connecting to Prior Knowledge

One good way to prepare yourself to read new material is to think about what you already know about the subject. You use electric circuits and electronic devices every day. What do you know about these circuits and devices? Use the Reading Target at the end of this chapter to record your ideas, even if you are not sure of some of the facts.

Key Terms

amperes
AND gate
capacitors
circuit breaker
conductivity
conductors
diodes
electronics
farads
fuse
insulators
integrated circuit
laser
load
logic gates
NAND gate
NOR gate
NOT gate (inverter)
ohms
Ohm's law
OR gate
overload
parallel circuit
potentiometers
rectifiers
resistance
rheostats
schematics
semiconductors
series circuit
series-parallel circuit
short circuit
superconductor
switch
transistor
voltage
volts
watt
Watt's law

Objectives

After reading this chapter, you will be able to:

- Design, draw, and build different types of electric circuits.
- Identify the characteristics of conductors, insulators, and semiconductors.
- Use Ohm's law and Watt's law to calculate current, voltage, resistance, and power.
- Name and state the function of common electronic components.
- Discuss the impact of electronics technology on personal privacy and security.

Useful Web sites:
www.media.mit.edu/~leah/
www.lumalive.com/
www.numetrex.com
www.instructables.com/id/turn-signal-biking-jacket/

Think about the things that electricity does. It operates motors found in many large and small appliances. The motors run electric mixers, blowers, pumps, dishwashers, washing machines, and many other appliances. They power subway trains and golf carts. Electricity also operates the lights in movie theaters, sports stadiums, and your home. It operates alarm systems, your MP3 player, and kidney dialysis machines.

Prior to the late 1800s, electricity was a curiosity. Electrical appliances were almost unknown. This situation changed in 1879 when Thomas Edison invented a reliable light bulb that lasted a long time. People started switching from gas lights to electric lighting.

Today, factories use electricity and electrical circuits to start and stop machines automatically. Electricity controls assembly lines and robots. Whole factories can be run electrically. A few people working at computers can control machines, lights, assembly lines, packaging, and loading of products. Indeed, it is hard to imagine what we would do without electricity.

SAFETY: Remember that every time you work with electricity, you must think about the hazards and risks involved.

- Water and electricity are a dangerous combination. Keep all electrical devices away from sinks, swimming pools, and bodies of water.
- Do not fly kites near power lines.
- If a ball or other object gets stuck in a tree near a power line, do not try to get it down.
- Use only 1.5 V cells or 9 V batteries to power your experiments in this course.

Electric Circuits

An electric circuit is a closed path for electric current. The path starts from a source, such as a cell or battery. It continues through a resistance (load), such as a lamp, before it returns to its source. All power systems, including electrical circuits, must have a source, a process, and at least one load. To make a simple circuit, connect a lamp, two pieces of wire, and a 1.5 V cell. In the circuit shown in Figure 12-1, a wire is connected to the negative terminal of the cell. Electrons flow from the negative terminal and continue through the wire and the lamp to the positive terminal.

Figure 12-1 is a pictorial view of this circuit. However, it takes too long to make a picture of each component. This is especially true when the circuit is complicated. Therefore, designers use symbols rather than pictures. See Figure 12-2. Symbols can be drawn quickly and are understood everywhere. Diagrams of circuits using symbols are called *schematics*.

The circuit in Figure 12-2 has voltage, resistance, and current. Voltage is supplied by the cell. The resistance is the glowing element in the lamp. The current is the flow of electrons in the circuit.

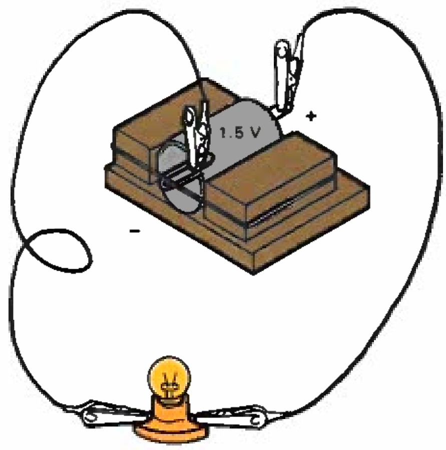


Figure 12-1. A simple circuit showing a lamp lit by a 1.5 V cell.

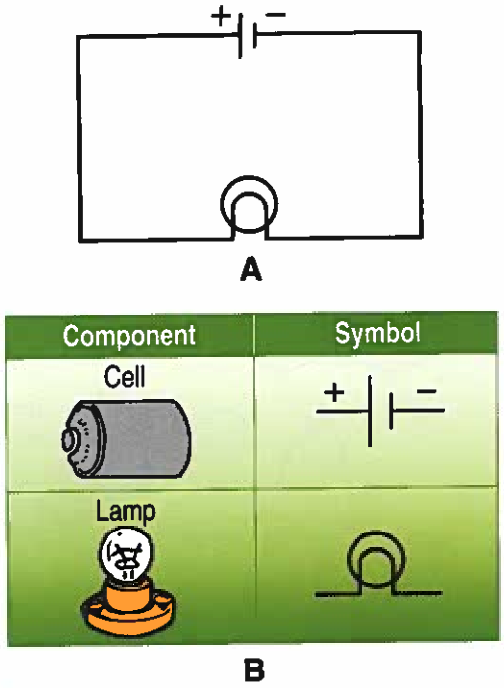


Figure 12-2. A—The circuit pictured in Figure 12-1 shown as a schematic. B—Circuit components and their symbols.

To turn the lamp on and off, you could connect and disconnect a wire at any one of the four places shown in **Figure 12-3**. However, an easier method would be to add a switch to the circuit.

A ***switch*** is a device that allows the circuit to be turned on and off. With the switch closed, current flows and the lamp lights up. When the switch is open, the flow stops, and the lamp turns off. Mechanical switches are also used to direct current to various points. **Figure 12-4** shows the simplest type of switch: a single-pole, single-throw (SPST) switch. **Figure 12-5** shows six of the many types of switches.

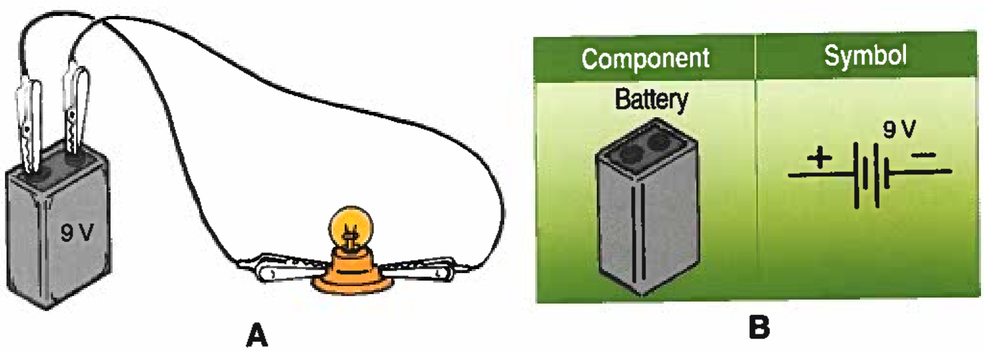


Figure 12-3. A—To turn off the lamp, release any of the four clips. B—A 9 V battery and its symbol.

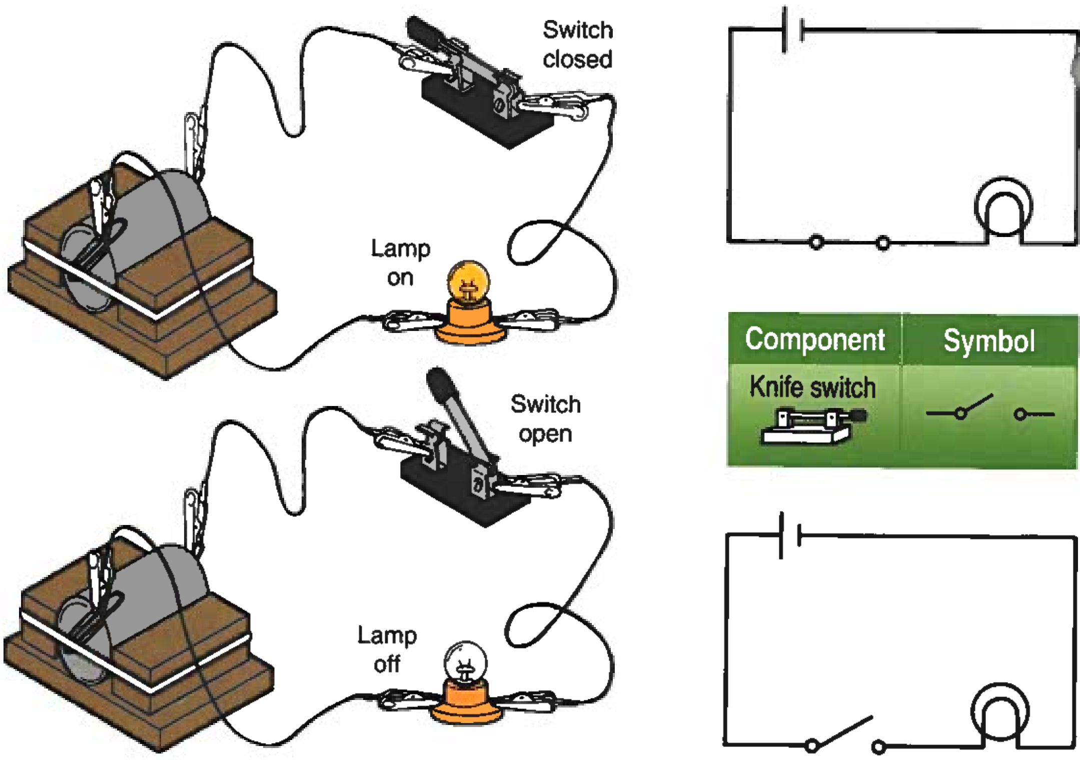


Figure 12-4. Study the open and closed switches and their diagrams. What is the difference between the two circuit diagrams?

Not all switches are purely mechanical. Fiber optics can also be used to create a switch. For example, in automatic faucets found in public washrooms, a dual fiber optics line is used. When hands are placed under the faucet, a beam of light from one line is reflected off the hands to the other line. The second line is connected to a sensor. The sensor sends a signal to a solenoid valve to release the water.

Protecting Circuits

Too much current can overheat and damage circuits. To prevent this, a fuse or a circuit breaker is added. See **Figure 12-6**. These are devices that open the circuit when current is too high. The fuse "blows" or burns out. The circuit breaker trips a contact. In either case, it opens the circuit. The circuit is no longer complete, so current stops.

When applied to using electricity, the term ***load*** means a source of resistance in the circuit. The bigger the load, the more current it needs.

High current can be caused by an overload or a short circuit. An ***overload*** occurs when lights or appliances in the circuit demand more current than the circuit can safely carry. A good example of this is when too many appliances are plugged into one outlet. A ***short circuit*** is a path of low resistance. It results in high current because the current avoids a section of a circuit, such as a lamp or a motor (load). See **Figure 12-7**.

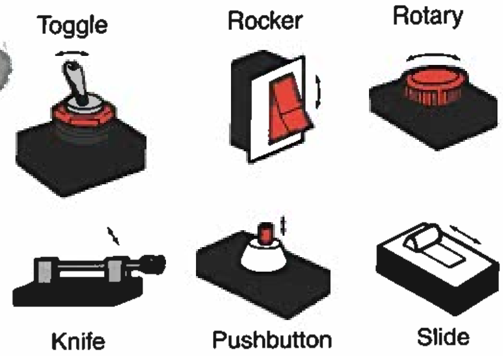


Figure 12-5. Six types of switches. Where have you seen these switches used?

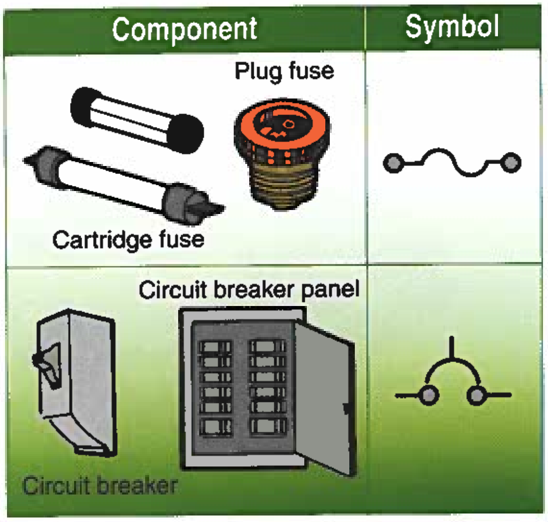


Figure 12-6. Overload protection devices such as fuses and circuit breakers protect the wiring and devices in a circuit.

How Fuses and Circuit Breakers Work

A *fuse* is a current-limiting device. When too much current reaches a fuse, a thin wire called a *filament* melts inside the fuse. See **Figure 12-8.** This stops the current flow before the circuit wires can be damaged. Once a fuse blows, it must be replaced.

When high current enters a *circuit breaker*, it heats a bimetal (two metals) strip. The strip bends because one metal expands more than the other. This opens contacts so no current can pass. Unlike a fuse, a circuit breaker can be reset and reused.

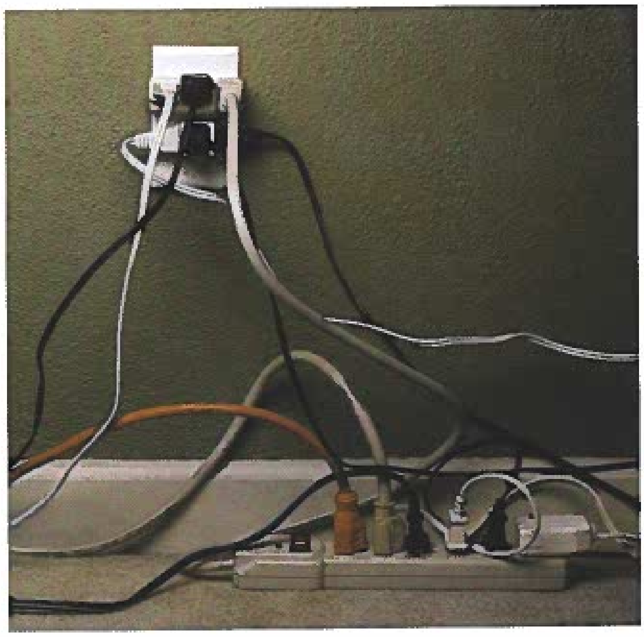


Figure 12-7. Overloading a circuit causes the wires to heat up, creating a fire hazard.

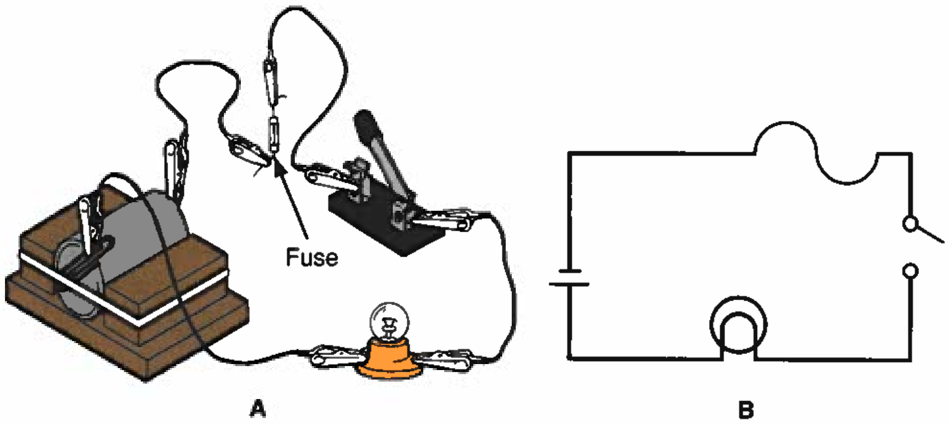


Figure 12-8. A fuse interrupts the flow of electricity when an overload occurs. A—Circuit with a fuse. B—Schematic of the same circuit.

Direction of Current

The direction of electricity in a circuit can be shown either as "electron flow" or "conventional current." See **Figure 12-9**.

Electron flow is based on the electron theory. This theory states that current moves from negative to positive. Conventional current is based on an older theory of electricity. Early scientists assumed a current moved from positive to negative. Both theories are acceptable. In this book, however, all explanations will be based on electron flow.

Types of Circuits

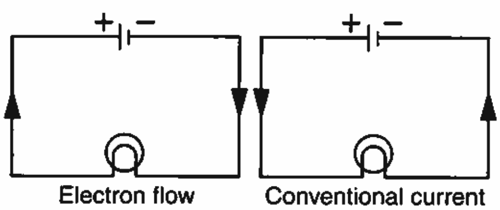
A circuit is a pathway along which electricity travels. The circuit shown in **Figure 12-9** contains only one lamp. If two or more lamps are put into this circuit, they can be connected in one of two ways, depending on the desired result.

Series Circuits

A ***series circuit*** is a circuit in which all loads are connected one after another so the same current enters each of them in turn. There is only one path for electron flow, as shown in **Figure 12-10**.

When lamps are connected in series, each gets an equal part of the voltage. For example, three lamps connected to a 1.5 V cell each receive 0.5 V. Therefore, each bulb is dimmer than if only one lamp is in the circuit. However, current remains the same across each lamp.

Figure 12-9. These circuit diagrams show the two theories of electric current. Electron flow moves from negative to positive. Conventional current moves from positive to negative.



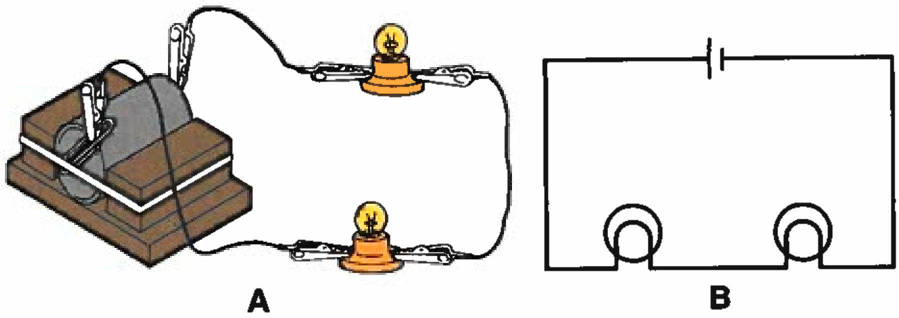


Figure 12-10. A—These lamps are connected in series. Electricity flows through each lamp in turn. B—The schematic for the series circuit shown in A.

In a series circuit, if one lamp burns out, all of the lamps go off. This is because the burned-out lamp opens the circuit, so current stops flowing. For this reason, very few series circuits are used in homes.

Parallel Circuits

A *parallel circuit* is a circuit that has more than one path for electron flow. See **Figure 12-11**. You can see that when lamps are in parallel, the current splits. It goes through each of the lamps without passing through any others first. In parallel circuits, the current varies in each path. However, voltage is always the same. If one bulb burns out, the circuit is not broken, and the other bulbs continue to burn. That is why most circuits in the home are parallel circuits.

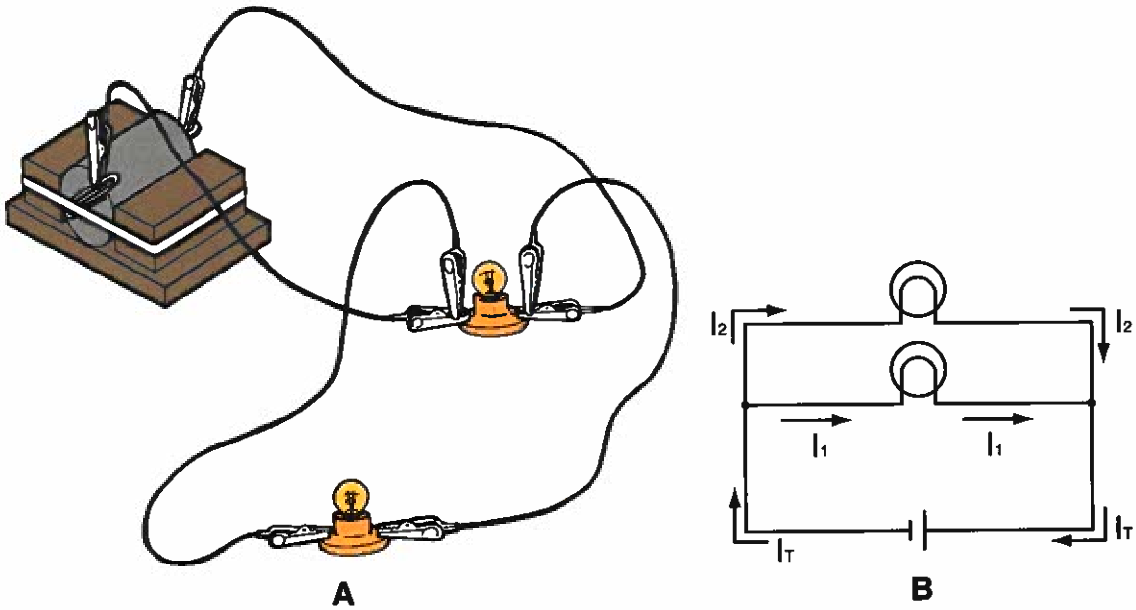


Figure 12-11. A—These lamps are connected in parallel, so there are two paths for current to follow. At the left intersection, the current splits into the two branches. At the right intersection, the separate currents add back together and equal the original current. B—The schematic for the parallel circuit shown in A.

Series-Parallel Circuits

The third kind of circuit is the *series-parallel circuit*. In these circuits some loads are wired in series, and others are wired in parallel. See **Figure 12-12**. They therefore exhibit characteristics of both series and parallel circuits. The different branches react to current and voltage in different ways. If a branch is a series branch, it behaves like a series circuit. Current is the same throughout that branch of the circuit, with the voltage dividing between the components. In a parallel branch, voltage remains the same throughout the branch. Current is divided between the parallel components.

In the circuits just described, lamps were connected in series, parallel, or series-parallel. Switches may also be connected in these ways. Look at **Figure 12-13**. For the bulb to light, both switch A and switch B have to be closed. In **Figure 12-14**, how many switches must be closed to close the circuit?

Figure 12-12. A series-parallel circuit has separate branches that are either series or parallel. Which of the loads in this circuit are wired in parallel? Which are wired in series?

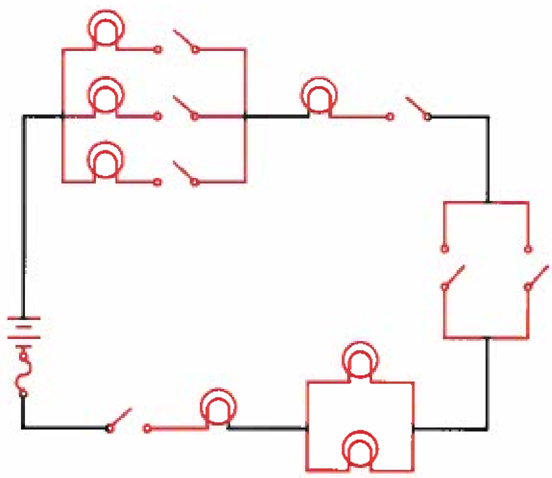
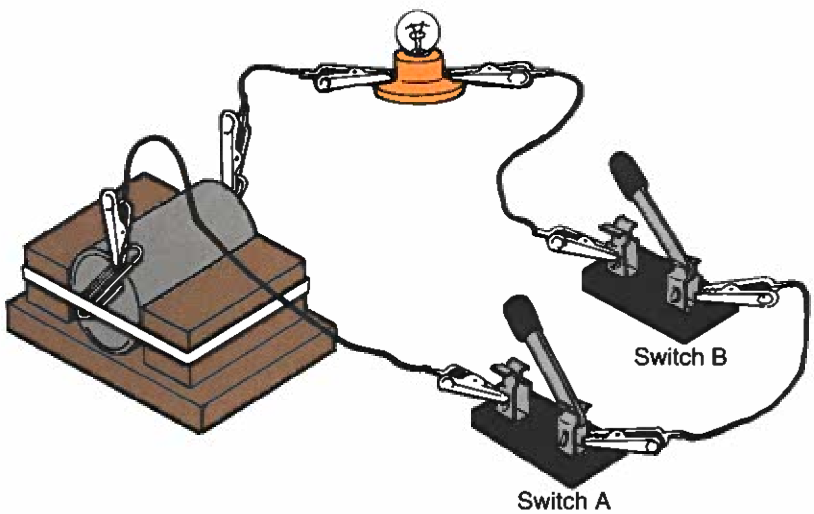


Figure 12-13. Because the switches are connected in series, this circuit conducts current only when both switches are closed.



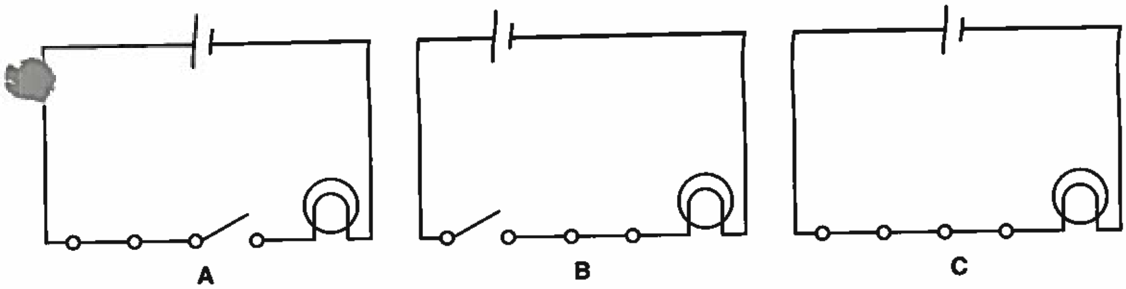


Figure 12-14. A, B, and C show the same circuit with the switches in different states. In which circuit or circuits is the bulb lit?

What happens when switches are connected in parallel, as shown in Figure 12-15? Switch A or switch B completes the circuit and turns on the light. Look at the diagrams in Figure 12-16.

Conductors, Insulators, and Semiconductors

As described in Chapter 10, materials that allow electric current to flow easily are called *conductors*. Copper, aluminum, silver, and most other metals are examples of good conductors. Copper is used most often for house wires. Strength, low cost, and low resistance to current make it a good choice. See Figure 12-17.

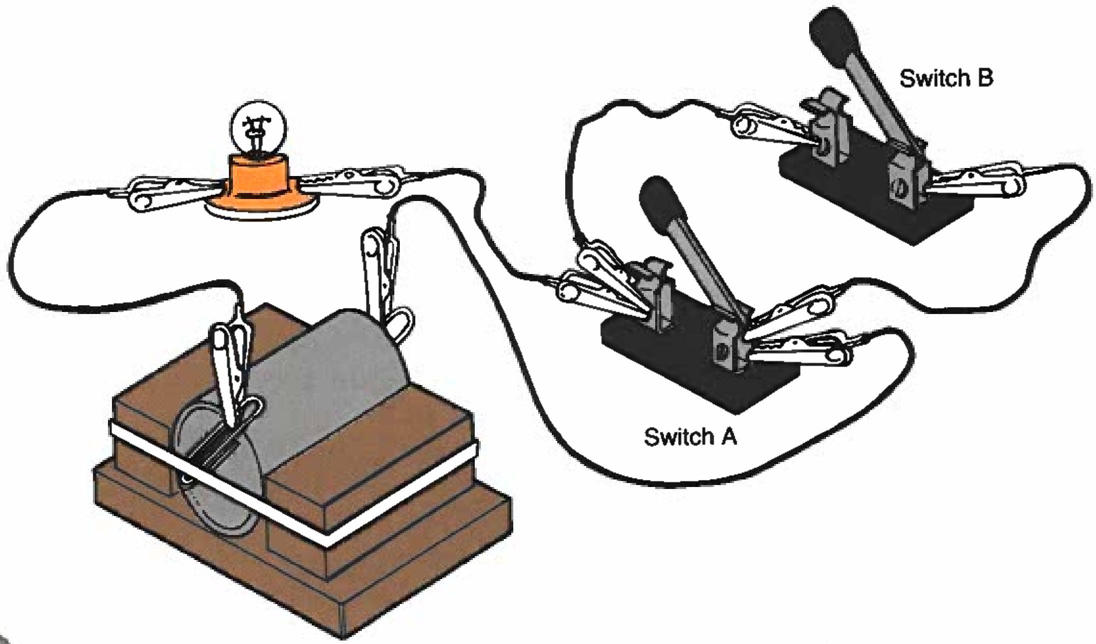


Figure 12-15. This parallel circuit conducts current when either switch A or switch B is closed.

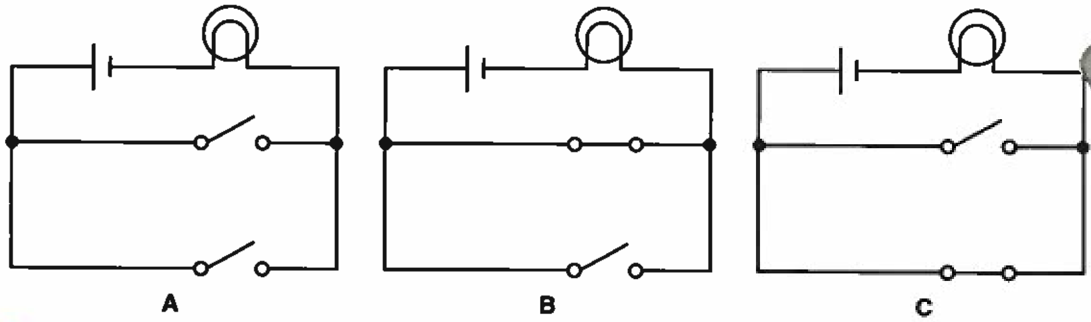


Figure 12-16. In which circuit or circuits is the bulb lit?

Figure 12-17. Copper is the most widely used conductor for electric wiring.

Materials that do not allow current to pass are called ***insulators***. Glass, rubber, plastic, porcelain, and paper are good insulators. Insulators play an important part in controlling electricity. They are wrapped around a conductor to prevent it from passing current to another conductor. This keeps the current in the correct path.

One of the most important uses of insulators is to protect us from electric current. See **Figure 12-18**. Our bodies conduct electricity, especially when wet. If you touch a live wire by accident, you get a dangerous shock. The shock may kill you.

Some materials are better conductors than others, and almost all materials have some resistance to the flow of electricity. Electricity produces heat as it forces its way through this resistance. The greater the resistance, the more heat produced. This can be used to our advantage. A resistance wire can be used to produce heat. The most common type of resistance wire is an alloy of nickel and chromium. It is called *nichrome wire*. Sometimes the resistance wire becomes red-hot. For example, resistance

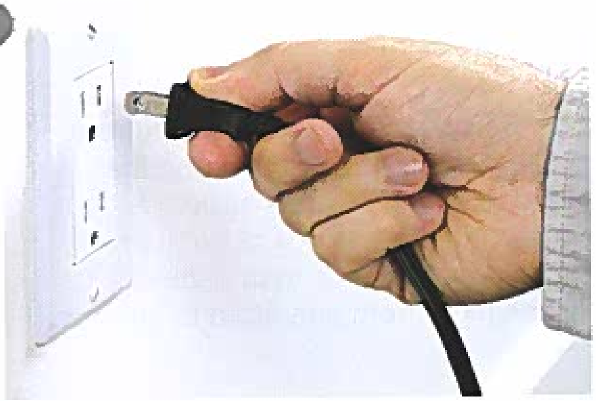


Figure 12-18. Insulators protect against shock. Where is insulation being used in this photo?

Figure 12-19. An electric heater works because an electric current makes a high-resistance wire red hot.

wires provide the heating in electric stoves, toasters, and other heating appliances. See **Figure 12-19**. Sometimes the conductor becomes white-hot. This is the case with an incandescent light bulb.

Semiconductors are materials that do not conduct as well as copper or silver. Nor do they insulate as well as rubber or glass. They have some characteristics of each. **Figure 12-20** provides examples of conductors, semiconductors, and insulators.

For many years, technologists have dreamed of producing a material that will conduct electricity without resistance. Such a material is called a *superconductor*. The advantage is that current flowing in a superconductor can flow forever.

Until recently, superconductivity was possible only at low temperatures close to absolute zero, –459° F (–273° C). When mercury is cooled to a few degrees above absolute zero, it conducts electricity with no resistance.

Recently, materials have been discovered that conduct at higher temperatures. When these superconductors become widely available, they will revolutionize the electronics industry. The absence of electrical resistance reduces the amount of heat produced. This allows components to be packed more closely together, reducing the size of components. Superconductors will also enable computers to operate at much greater speeds.

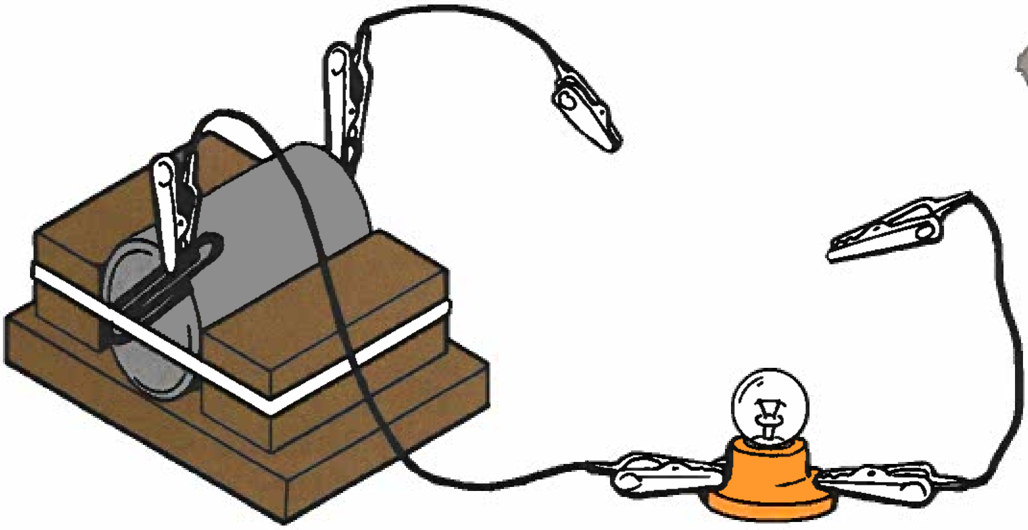
Science Application

Testing Conductivity

A material's ***conductivity*** is its ability to conduct electric current. The difference between a material that conducts well and one that conducts poorly or not at all is related to the material's structure. You already know that electrons move around the nucleus of an atom. In some materials, the electrons are held more tightly than in others. Electrons that are not held tightly can jump from one atom to another, producing electric current.

Science Activity

To test the conductivity of materials, you will need a battery, battery holder, two metal paper clips, and test leads, as shown in the illustration. Also collect small samples of a variety of materials. Include wood, glass, and various kinds of metal and plastics. Some of the materials should be examples of small products, such as coins and hardware items. Set up your test equipment as shown. Then connect each material to the circuit. Test each material and record your findings. Write a report to document your experiment, and include the report in your portfolio.



Class	Materials	
Conductors	• Copper • Silver	• Tungsten • Nichrome
Semiconductors	• Silicon • Germanium	
Insulators	• Rubber • Glass • Porcelain	• Nylon • PVC • Mica

Figure 12-20. *Classification of materials commonly used in electrical and electronics applications.*

Measuring Electrical Energy

When measuring electrical energy, three terms are important: volts, ohms, and amperes. One way to understand their meaning is to compare electricity to water. Water flows through a hose under pressure. If pressure is increased, more water flows than before. Electricity inside a wire is also under pressure. With electricity, the electrical pressure (E) is called ***voltage*** and is measured in ***volts*** (V). See **Figure 12-21**.

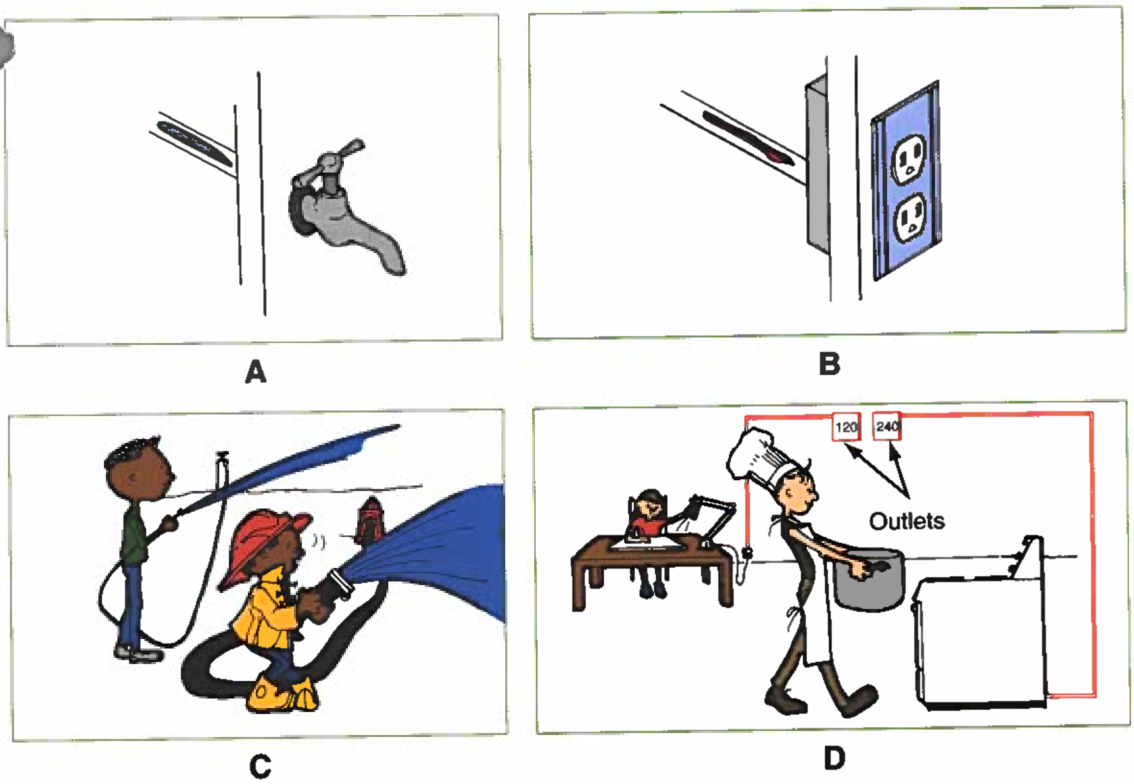


Figure 12-21. Comparison of electricity pressure and water pressure. A—Water behind a faucet is always under pressure. B—Electricity behind an outlet is also under pressure. C—To use water, you attach a hose and turn on a faucet. D—To use electricity, you connect a wire to an outlet and usually toggle a switch.

As the water flows through the pipe, it meets resistance. The smaller and longer the pipe, the greater the resistance. So it is with electricity. Flow is affected by diameter and length of the wire. Also, electricity flows more easily through some materials than through others. Electrical resistance (R) is measured in *ohms* (Ω).

The amount of water that flows out of the end of the pipe in a given period depends on both pressure and resistance. See Figure 12-22. The higher the pressure and the weaker the resistance is, the greater the amount of water leaving the hose.

Ohm's Law

The amount of electricity that passes a point in a conductor in a given period also depends on pressure and resistance. The movement of electrical current through circuits can be described in the same way that water flows through pipes. Current is similar to water flow speed. Voltage is similar to the water pressure. Resistance can be compared to the diameter of a water pipe, which can act as a restriction to flow. Electrical current (I) is measured in *amperes* (A): the higher the pressure and the weaker the resistance in ohms, the higher the current.

This relationship between voltage, resistance, and current is described by a formula known as *Ohm's law*. See Figure 12-23. Ohm's law is written as:

$$\text{Voltage} = \text{Current} \times \text{Resistance}$$

(or)

$$\text{Volts} = \text{Amps} \times \text{Ohms}$$

(or)

$$E = I \times R$$

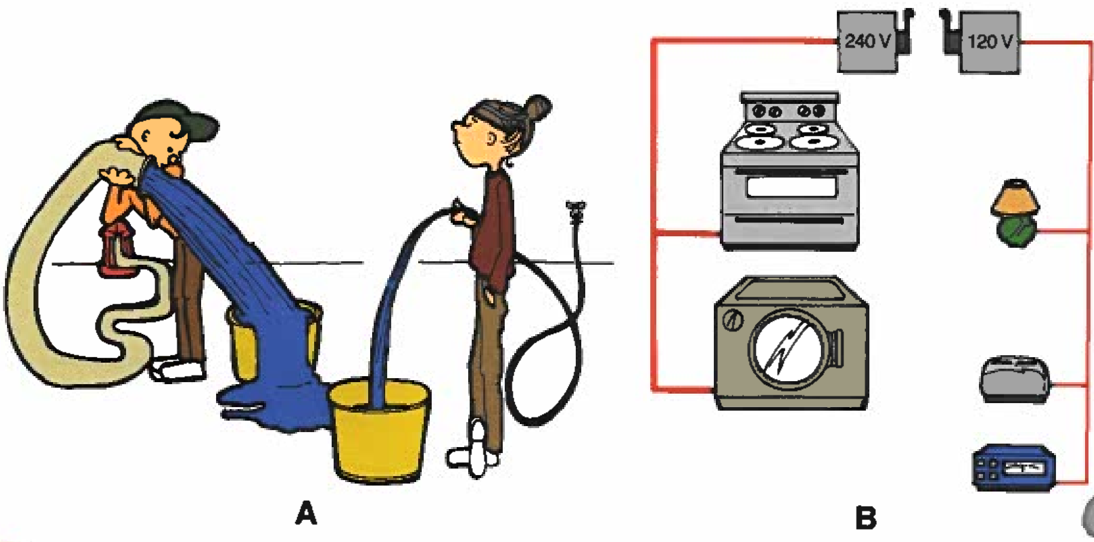


Figure 12-22. Comparison of electricity and water pressure and resistance. A—High pressure and a large hose equal heavy water flow. B—High voltage and a large conductor equal high electron flow.

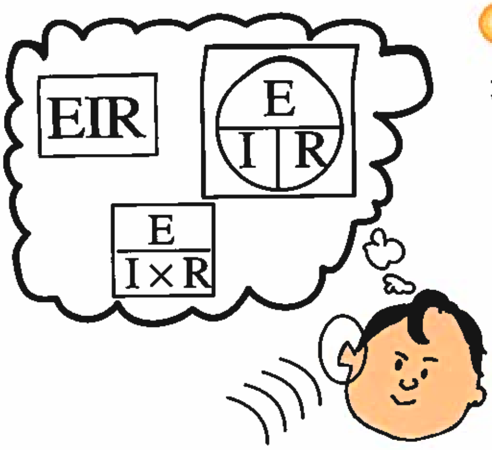


Figure 12-23. To remember Ohm's law, *just think of listening to your instructor with* your EIR (pronounced like "ear"). Voltage is often represented using the letter E for electromotive force.

Watt's Law

Another unit of electrical measurement is the watt. A *watt* is the unit used to measure the work performed by an electric current. To calculate the power (P) in watts, use *Watt's law* to multiply the voltage by the current. See Figure 12-24.

$$\text{Power} = \text{Current} \times \text{Voltage}$$

(or)

$$\text{Watts} = \text{Amperes} \times \text{Volts}$$

(or)

$$P = I \times E$$

A monthly electricity bill is based on the number of watts used. See Figure 12-25. The utility company provides a meter for each home. The meter measures how many watts are used. The watt is a small unit, so the basic unit used by power companies is a kilowatt. One kilowatt is equal to 1000 watts.

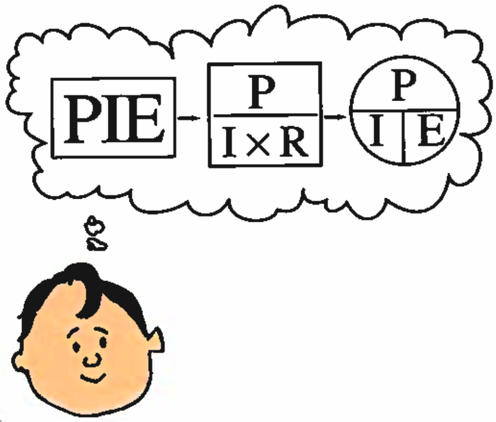


Figure 12-24. Remembering Watt's law is as easy as PIE.

Figure 12-25. A utility meter measures the amount of electricity used in kilowatt-hours (kWh).

Appliances are frequently switched on and off in most homes, so the electrical usage varies. The electricity used is measured over periods of one hour. The unit is therefore one kilowatt-hour. A kilowatt-hour means 1000 watts used for a period of one hour.

Figure 12-26 shows the dials of a typical electrical meter. Be careful when reading the dials. Some of them revolve clockwise, and some revolve counterclockwise. To read a dial, write down the number the pointer has passed. In Figure 12-26, the correct reading is 23,642.

Electronics

In this chapter, you have learned about the flow of electrons in a circuit. *Electronics* is the use of electrically controlled parts to control or change current in a circuit. It is the technology of controlling electron flow. Electrons can be used to control, detect, indicate, measure, and provide power. A variety of electronic materials and components carry out these functions.

Resistors

Resistors are to electronics what friction is to mechanics. The friction of brakes limits your speed on a bike. Resistors limit the amount of current flowing through a circuit. Resistors make it more difficult for current to flow. Many electric circuits have only one power source, for example a 9 V battery. But a different current may be needed by different components. Resistors change the current in parts of the circuit to match the needs of one or more components. In Figure 12-27, bulb A will be brighter than bulb B. The current in bulb B is smaller because there is a resistor in that loop of the circuit.

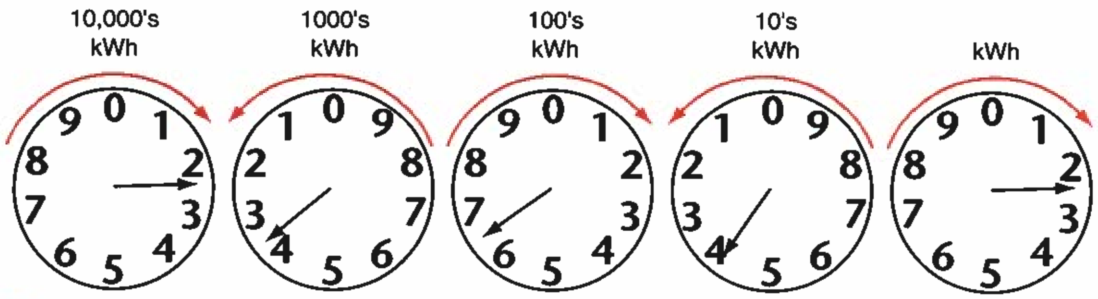


Figure 12-26. You can tell which way each pointer revolves by looking at the numbers. If the 1 is to the right of the 0, the pointer revolves clockwise. If the 1 is to the left of the 0, the pointer revolves counterclockwise. What is the reading of the meter in this figure?

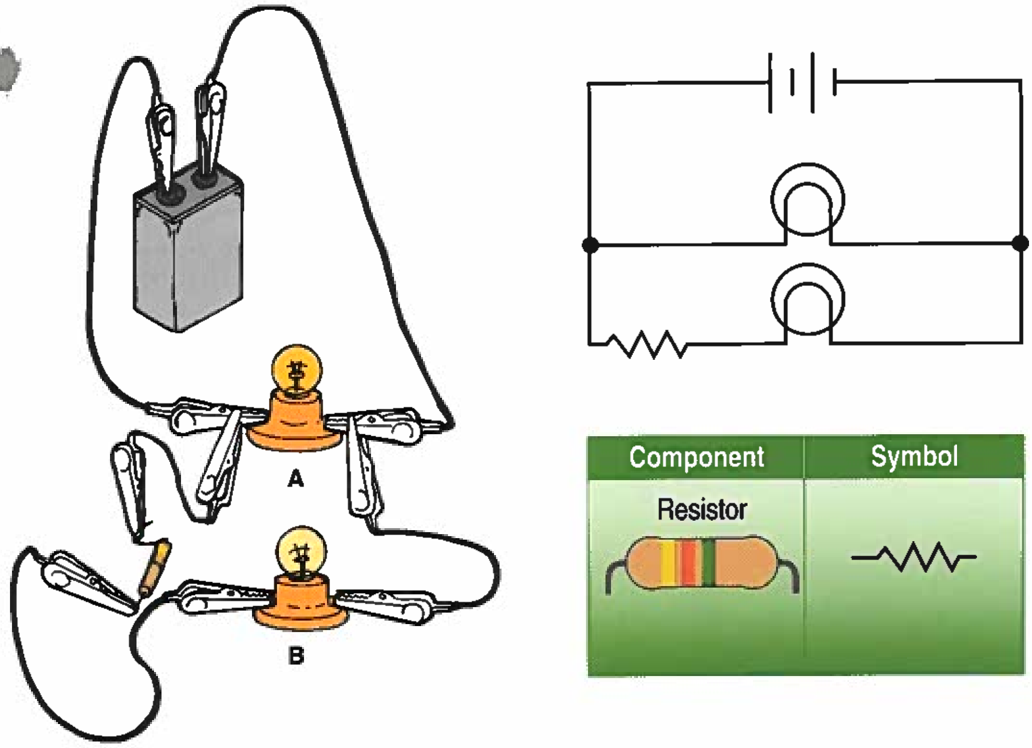


Figure 12-27. This parallel circuit has a resistor in one loop.

Resistors are made in many sizes and shapes. See **Figure 12-28**. All resistors do the same thing: they limit current. In a typical carbon composition resistor, powdered carbon is mixed with a glue-like binder. Changing the ratio of carbon particles to binder changes the resistance. The greater the amount of carbon used, the less resistance the resistor has. See **Figure 12-29**.

Resistors are made in a wide range of values. The value corresponds to the degree to which they limit the flow of electrons, their ***resistance***. Resistors are often quite small, which makes it difficult to show their values. To overcome this problem, resistors are usually marked with four colored bands. See **Figure 12-30**.

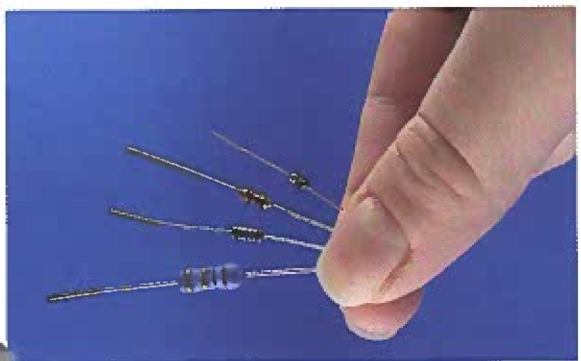


Figure 12-28. Resistors come in different shapes and sizes. They are often quite small.

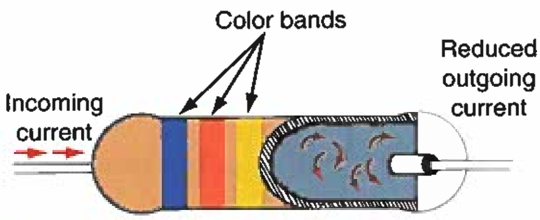


Figure 12-29. Resistors limit current flow.

Color	1st Band	2nd Band	3rd Band	4th Band
Black	0	0	Ω (no zeros)	
Brown	1	1	1 zero	
Red	2	2	2 zeros	
Orange	3	3	3 zeros	
Yellow	4	4	4 zeros	
Green	5	5	5 zeros	
Blue	6	6	6 zeros	
Violet	7	7	7 zeros	
Gray	8	8	8 zeros	
White	9	9	9 zeros	
Gold				5
Silver				10
None				20
	BAND 1	BAND 2	BAND 3	BAND 4

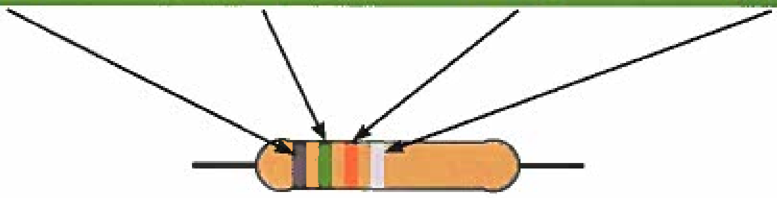


Figure 12-30. Calculating the value of a resistor.

You can calculate the value of a resistor from the first three bands. To read the value, hold the resistor with the colored bands to the left. Then use the table in Figure 12-30 to calculate the value of the resistor.

In Figure 12-31, the first band of the resistor is violet. The table shows us that a violet first band number stands for 7. The second band is green, which stands for 5. The third band is orange. An orange third band means that three zeros follow the first two numbers. The value of this resistor is 75,000 Ω, or 75 kΩ. (The k stands for "kilo" or thousand.) A resistor whose value is 75,000,000 Ω is written as 75 MΩ. (The M means "mega" or million.)

Resistors have a fourth band that is usually silver or gold. It indicates the accuracy or tolerance of the resistor. The fourth band of the resistor in Figure 12-31 is gold, indicating that the resistor has a tolerance of ±5%. Five percent of 75,000 is 3,750. Therefore, the actual resistor value is 75,000 ± 3,750, or between 71,250 Ω and 78,750 Ω.

Figure 12-31. Use the chart in Figure 12-30 to calculate the value of this resistor.

Two types of variable resistors are rheostats and potentiometers. *Rheostats* lower or raise the current in a circuit. See **Figure 12-32**. The dimmer used for car dashboard lights is one example. *Potentiometers* lower or raise the voltage. See **Figure 12-33**. They are used as volume controls in sound systems.

Diodes

Diodes are devices that allow current to flow in one direction only. Diodes have two ends: positive (anode) and negative (cathode). A dark band indicates the negative end, as shown in **Figure 12-34**.

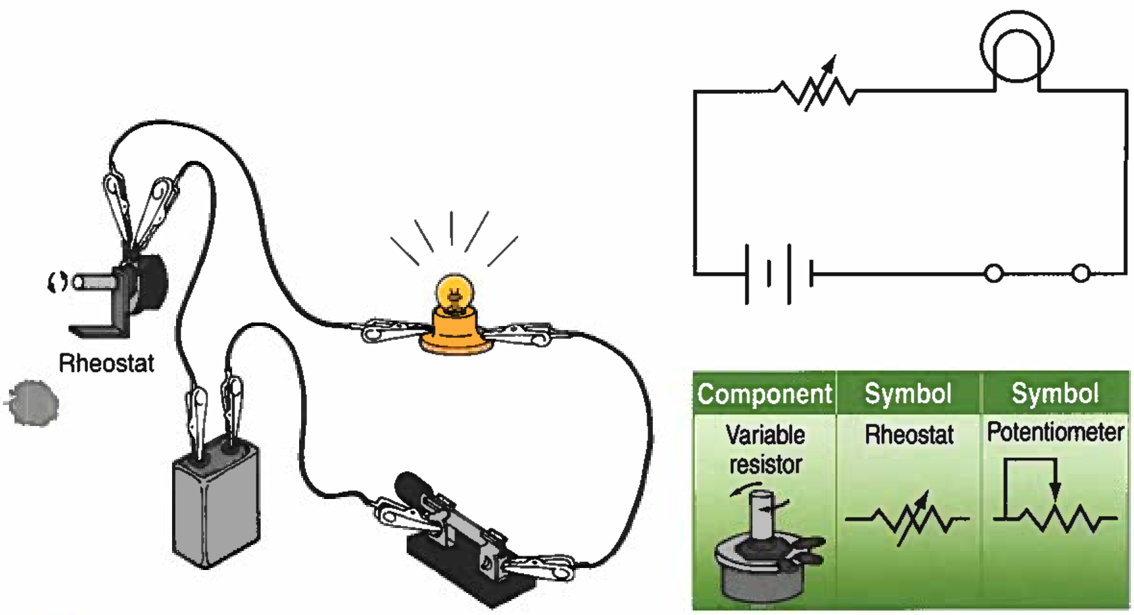


Figure 12-32. A rheostat is connected in series.

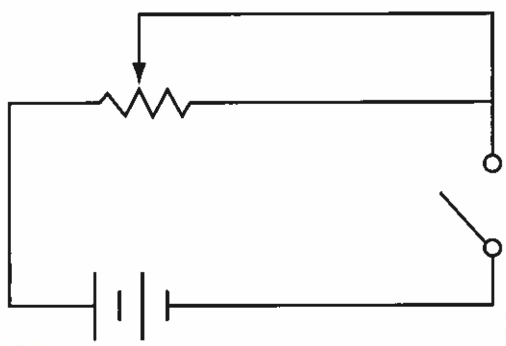


Figure 12-33. A potentiometer is connected in parallel.

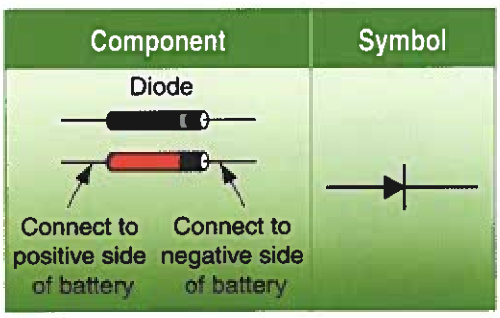


Figure 12-34. A dark band indicates the negative end of a diode.

Figure 12-35 shows two bulbs in parallel. Each branch of the circuit has a diode. Only bulb A will light, because the diode next to it is positioned correctly to allow electrons to flow. Diodes are most commonly used in *rectifiers*, which change alternating current to direct current. Some different types of diodes are shown in Figure 12-36.

Another type of diode is a light emitting diode (LED). LEDs also conduct in only one direction. They need less current to make them glow than most bulbs, but they are usually not as bright. Therefore, LEDs are used where brightness is not important. For example, they are used to show that electrical equipment is turned on and working, as shown in Figure 12-37. LEDs are also used in remote controls for TVs and other audio visual equipment. When a button is pressed on the remote, a pattern of low frequency infrared light is detected by the receiver. The receiver interprets the pattern to perform the desired task.

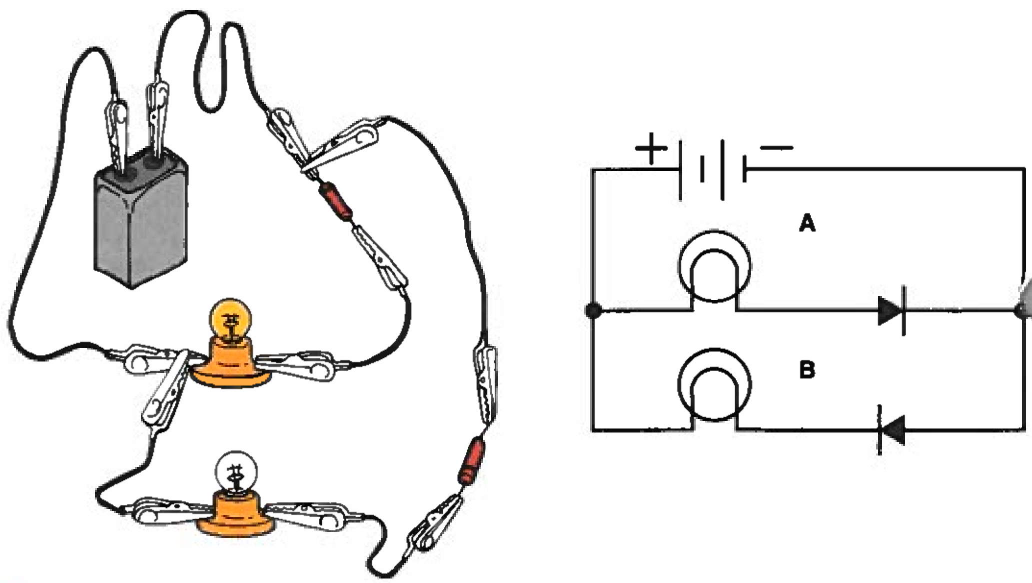


Figure 12-35. A circuit set up with two lamps in parallel. Each lamp has a diode connected in series, but only one lamp will light. Which lamp will light, and why?

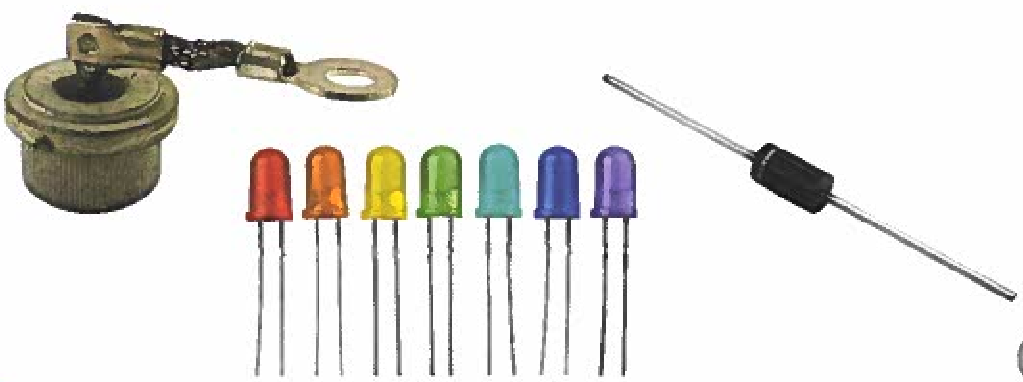


Figure 12-36. Different types of diodes.

Figure 12-37. LEDs are often used to show the status of electronic devices. How many LEDs do you see in this sound system?

Capacitors

Capacitors are designed to store an electrical charge and release it all in one quick burst. This extra storage of voltage is sometimes needed in circuits that need sudden increases in voltage. One example is a camera flash. A battery cannot supply a sudden high voltage surge for the flash mechanism. However, a capacitor can deliver energy fast enough. See **Figure 12-38**. A capacitor's storage potential is measured in units called *farads*.

SAFETY: A capacitor connected in a direct current circuit can store a charge for a considerable time after the voltage to the circuit has been switched off. **NEVER** touch the leads of a capacitor before it has been discharged.

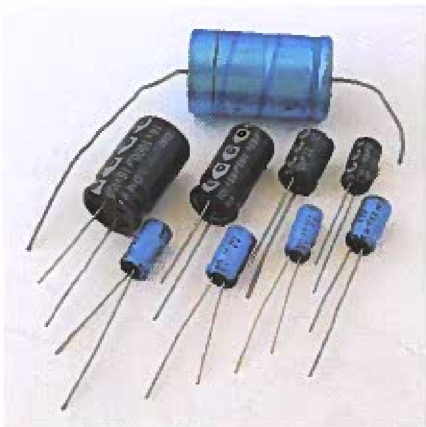
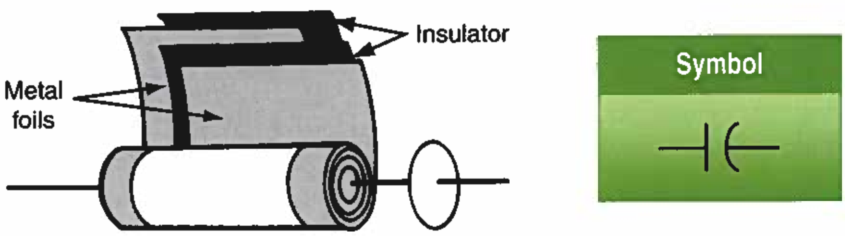


Figure 12-38. A capacitor is a "sandwich" made up of conductors and insulators.



Transistors

A *transistor*, Figure 12-39, contains a semiconductor material that acts like a switch. The most common semiconductor materials are silicon and germanium. The semiconductor allows electron flow only under certain conditions. By turning on and off, transistors signal the ones and zeros that combine to signify information stored in a computer.

All transistors have three terminals: a collector (c), a base (b), and an emitter (e). An electric current flows through the transistor only when an electrical voltage is applied to the base. For the base of an NPN transistor to have a voltage, it must be connected to the positive side of the battery. See Figure 12-40. If it is connected to the negative side of the battery, the base has a low voltage and the lamp will not light. See Figure 12-41. Therefore, the lamp can be switched on and off by changing the voltage on the base of the transistor.

Transistors are used as fast switches in timing, counting, and computer circuits. In these circuits, the signal is either on or off. Amplifying transistors are used in radios and stereos where a weak signal must be amplified in order to be heard over a speaker. Hearing aids also use transistors to amplify sound.

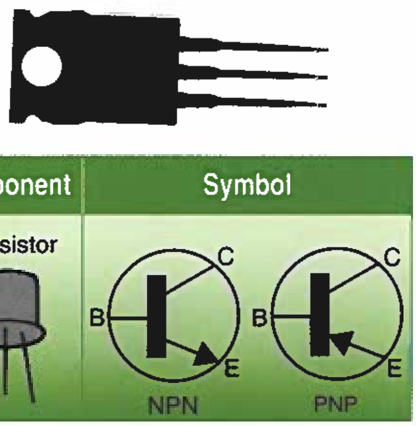


Figure 12-39. Negative voltage controls the output of a PNP transistor. Positive voltage controls the NPN transistor.

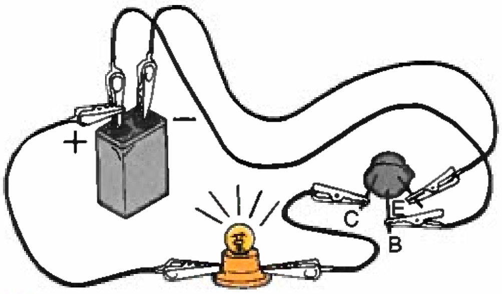


Figure 12-40. The base terminal of an NPN transistor is connected to the positive terminal of the battery. The lamp will light.

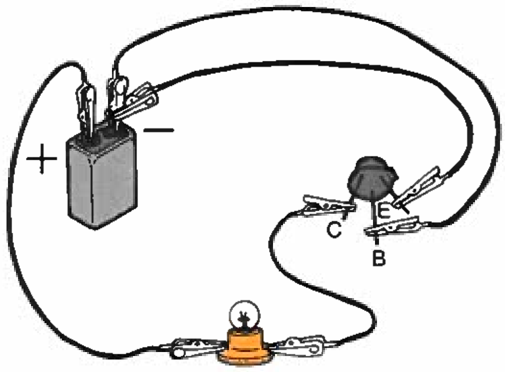


Figure 12-41. With the base terminal of the NPN transistor connected to the negative terminal of the battery, the lamp will not light.

Logic Gates

Logic gates are digital circuits formed by transistors, resistors, and diodes. They process one or more input signals in a logical way. Logic gates are based on the binary number system and have two states: off and on. These states correspond to the binary digits 0 and 1. **Figure 12-42** shows how the five basic logic gates work. The first column shows the symbol for each logic gate. The second column contains truth tables, which show the output states for every possible combination of input states. The third column explains how each logic gate functions.

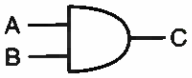
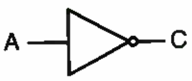
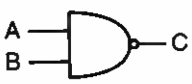
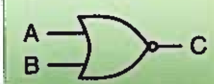
Symbol	Truth	Description
 AND Gate	Input: A, B; Output: C 0, 0 → 0 0, 1 → 0 1, 0 → 0 1, 1 → 1	Both the input value AND the output value must be 1 (on) in order for the output value to be 1. This is like having two switches in series.
 OR Gate	Input: A, B; Output: C 0, 0 → 0 0, 1 → 1 1, 0 → 1 1, 1 → 1	One OR more of the input values must be 1 (on) to create an output value of 1. This is like having two switches in parallel.
 NOT Gate (Inverter)	Input: A; Output: C 0 → 1 1 → 0	If the input value is 1 (on), the output value is NOT 1; it is 0 (off). If the input value is 0 (off), the output value is NOT 0; it is 1 (on). Because NOT gates reverse an input value, they are often called inverters.
 NAND Gate	Input: A, B; Output: C 0, 0 → 1 0, 1 → 1 1, 0 → 1 1, 1 → 0	Produces a 1 (on) only if all inputs are 0 (off). Produces a 0 if any or all of the inputs are 1. Notice the little circle at the end of the symbol, similar to the circle on the NOT gate. The NAND gate combines the function of the AND gate and the NOT gate.
 NOR Gate	Input: A, B; Output: C 0, 0 → 1 0, 1 → 0 1, 0 → 0 1, 1 → 0	Produces a 0 (off) only if all inputs are 1 (on). Produces a 1 (on) if any or all of the inputs are 0 (off). The NOR gate combines the OR gate and the NOT gate.

Figure 12-42. Characteristics and symbols for logic gates.

Integrated Circuits

The electronic circuits described so far in this chapter have been built using separate components. An *integrated circuit* is a more advanced circuit in which all the components, including transistors, resistors, capacitors and diodes, are placed together on silicon wafers. Many integrated circuits are about the size of your smallest fingernail, or smaller. They are also called *chips* or *ICs*. See **Figure 12-43**. The earliest ICs, built in the 1960s, only contained a few components. By the 1980s, hundreds of thousands of components were integrated onto a chip. Today a chip may contain several billion.

The world is full of integrated circuits. If you have ever received a greeting card that plays a song, you will know that the chips can be so small they are hard to find. Hidden between the layers of paper is a miniscule battery, a speaker, and a chip on which the sound is recorded. Communications, manufacturing, and transportation systems all rely on ICs.

The three types of integrated circuits are analog, digital, and mixed. Digital ICs work by computing binary mathematics electronically. Analog ICs work by processing continuous signals and perform functions such as sound amplification and mixing. A mixed integrated circuit combines both analog and digital circuits on a single chip. They are often used to convert analog signals to digital so that digital devices can process the signals.

The two main advantages of ICs compared to circuits with separate components are cost and performance. Cost is lower because the components are not added one at a time. Instead, they are printed onto a silicon wafer. Performance is higher because the components are small and close together. They consume little power.

A more recent development has been the introduction of programmable ICs. These devices contain circuits that can be programmed by the user rather than being fixed by the manufacturer. One type, PICAXE chips, are used for school microcontroller projects. They can be programmed using a computer language that is a variant of BASIC.

Figure 12-43. Integrated circuits, or ICs, are produced in various shapes and sizes and contain different circuitry for specific purposes.

Lasers

The term *laser* is an acronym for "Light Amplification by Stimulated Emission of Radiation." Laser light is a form of radiation that has been boosted to a high level of energy. It produces a strong, narrow beam of light. Lasers have made possible such conveniences as automatic supermarket checkouts, fiber optic communication, and a new generation of printing devices. Lasers are also key to the development of compact discs used in entertainment. Laser light is used to read or burn digital information onto the CD.

When a recording is made on a CD, the laser "burns" a pattern of pits on the center layer of the disc. During play, when the laser strikes a pit, it detects rapid flashes of high and low intensity signals that it reads as zeros and ones. This binary information is translated by a microprocessor (chip) back into music.

Blu-ray and HD DVD discs can contain more data than CDs or DVDs. The data pits can be smaller because they are read by a blue-violet laser. The blue-violet laser has a shorter wavelength than the red laser used to read CDs.

Lasers are also used for many other applications, including surgery, reading bar codes, and cutting metal and other materials. **Figure 12-44** shows an industrial laser cutter being used to make accurate cuts in metal.

Think **Green**

Recycling Electronic Devices

With electronics technology improving every day, our electronic devices become "old" quickly. New, improved products are constantly being introduced. When we replace our existing electronics with new versions, what happens to the old ones? How responsibly do we act?

The first question to ask yourself is whether you really need the latest and greatest products. Will they really work better than your existing electronics, or are they just a status symbol?

When you do decide to upgrade your electronic devices, the next question is what to do with the old ones. If the devices are in working condition, one good solution is to give them to charity. Many organizations collect electronics for use in schools and community programs. National organizations such as Goodwill and CollectiveGood have electronics recycling and reuse programs. Your community may also have donation and recycling opportunities. The next time you replace an electronic device, research opportunities for donating or recycling your old device. You may be able to help people in need, as well as doing your part to help the environment.

Figure 12-44. Lasers are used in industrial cutting machines because of their high level of precision.

Privacy and Security

All information transmitted electronically can potentially be accessed by spy agencies or hackers. Furthermore, data may be altered or deleted by those who spread a computer virus, whether that data belongs to you, a bank, or the government.

Electronic devices can be used to protect private homes. A video camera might be hidden behind the face of a clock or the eye of a teddy bear. However, outsiders may access other cameras installed in your home. For example, using the right software, hackers could turn on the small camera that is attached to a computer. If your computer has an "always-on" high-speed connection, someone else could use it as an Internet server.

It is likely that you are being watched when you use public electronic devices. At an ATM, the bank machine might record time-and-date-stamped video images of you as you withdraw cash. See Figure 12-45. When you use a cell phone, your location (in which wireless cell) can be calculated to within a few yards. At home on your computer, your Internet Service Provider (ISP) can record information related to your e-mails, the contents and source of every Web site you visit, and the length of time you spend there. Any member of your family can also check which Internet sites you access using special software downloaded from the Internet.

You can take some basic steps to help ensure your privacy. For example, for computer applications, create and use passwords that are difficult to break. Install security and firewall software to help keep unauthorized people from accessing your computer or Internet service. When you need to discuss confidential information on the telephone, use a wired (landline) telephone instead of a cell phone.

Figure 12-45. In many cities, traffic signals are enforced by security cameras. The cameras are programmed to take pictures of vehicles that fail to obey stoplights.

End Note

The era of electronics really started in 1947 when transistors were invented at the Bell Laboratories. Transistors provided a small, inexpensive, and efficient way to amplify electrical currents. Early transistors were used in transistor radios that were so much smaller that for the first time a person could carry a radio anywhere.

Today, one silicon chip can have millions of microscopic transistors, resistors, and conductors on it. Many products we use every day contain microprocessors that automate many tasks to make our lives easier.

Electronics can be used both to protect and to invade your privacy. How much access to personal data do we want government and business to have? This is an important question. The answer has to respect the right of an individual to privacy versus the legitimate needs of others to gather information for security purposes. Governments are concerned about national security issues, so the trend toward collecting even greater amounts of information will likely continue. Also, advertising and marketing companies are searching to find people's spending habits. As technology improves, so does the capability for electronic surveillance. How much is enough? How much is too much?

Summary

- An electric circuit is a continuous path from a source, through a load, and back to the source. The three basic types of circuits are series, parallel, and series-parallel.
- Materials that allow current to flow are called *conductors*. Those that do not allow current flow are called *insulators*. *Semiconductors* allow current under certain conditions.
- Electrical energy is measured in terms of volts, ohms, and amperes. Work performed by an electrical current is measured in watts.
- Electronics is the use of electrically controlled parts to control or change current in a circuit.
- Advances in electronics technology provide ways to collect information about people without their knowledge.

Reading Target

Connecting to Prior Knowledge

Copy the following graphic organizer onto a separate sheet of paper. Allow space in each row for one or more sentences. Before you read the chapter, write sentences in the first column to record your current knowledge about electric circuits and electronic components and devices. As you read through the chapter, record new concepts you learned by reading the chapter. When you are finished, review the chart to see how much you have learned. If you have questions about topics in the chapter, record your questions at the bottom of the chart. Ask your questions in class or do research on your own to find the answers.

What I Know (or Think I Know) about Electricity and Electronics	What I Learned in This Chapter
Electric Circuits	
Conductors, Insulators, and Semiconductors	
Measuring Electrical Energy	
Electronics	
Privacy and Security	
Further Questions:	

Test Your Knowledge

Write your answers to these review questions on a separate sheet of paper.

1. Define the term *electric circuit*.
2. What might happen if too many appliances are plugged into the same electrical outlet?
3. Explain how a fuse protects a circuit from overload.
4. Briefly explain the differences between a series circuit, a parallel circuit, and a series-parallel circuit.
5. Name four materials that are conductors of electric current and four insulators.
6. A portable electric heater with a resistance of 15 ohms is connected to a 120 V AC outlet. What is the current flow in the circuit?
7. What is an integrated circuit?
8. Name the five basic types of logic gates.
9. Calculate the value of each of the following resistors.

	1st Band	2nd Band	3rd Band	4th Band
A.	red	green	yellow	silver
B.	orange	blue	brown	gold
C.	white	brown	red	none
D.	violet	green	orange	silver

10. Name two things you can do to help prevent unauthorized access to your private information.

Critical Thinking

1. Suppose you are fixing a snack after school one day, and suddenly all the kitchen lights go out. You check the refrigerator, and it has no power. Then you check the rest of the house, and you find that the TV still works in the family room. Where would you begin looking for the source of the outage in the kitchen? Why?
2. Some of the needs and wants people express are created by the use of inventions and innovations. Explain how this is true of the development of integrated circuits and microprocessors. What needs and wants have they caused? How would our society be different without them?
3. Advances in electronics technology has led to widespread use of robots in manufacturing. Probe the pros and cons of using robots to manufacture products. What are the advantages? What are the disadvantages?
4. Technologists work constantly to design new products and improve existing products in many different fields. They do not work alone, however. Write a paragraph explaining how technologists in various fields (such as electronics and manufacturing) work together with technologists, scientists, and other workers in other fields.

Apply Your Knowledge

1. Draw a circuit diagram for a circuit that contains a lamp, dry cell, fuse, and switch connected in series.
2. Draw a circuit diagram for a circuit that contains two lamps and a dry cell connected in parallel.
3. Airport security systems use a variety of security measures to help increase passenger safety. These measures increase security at the expense of privacy. Research the various security measures being used at airports. Explain how these measures have been influenced by past events, and predict what measures may be added in the future.
4. Describe how you could build a circuit that would turn on a light whenever someone enters a room and turn the light off 5 minutes after the person leaves the room. What components would you need? Sketch the circuit.
5. Search the Internet for information about electronic privacy. Can organizations collect, use, or disclose personal information about you without first telling you their intentions and obtaining your consent? How clear must their explanations be as to what they intend to do with the information? Write a report explaining your findings.
6. Research one career related to the information you have studied in this chapter. Create a report that states the following:
   - The occupation you selected
   - The education requirements to enter this occupation
   - The possibilities for promotion to a higher level
   - What someone with this career does on a daily basis
   - The earning potential for someone with this career

   You might find this information on the Internet or in your library. If possible, interview a person who already works in this field to answer the five points. Finally, state why you might or might not be interested in pursuing this occupation when you finish school.

STEM Applications

1. **MATH** Ohm's law states that voltage equals current times resistance, or $E = I \times R$. Rewrite this equation to find the current in a circuit if you know the voltage and resistance. Then use your equation to find the current in a 12 V circuit if the total resistance is 8 Ω.

2. **ENGINEERING** Design a lighting circuit for a public restroom in which the exterior light above the door stays lit all the time, but the interior light comes on only when the door is closed. Sketch a diagram for your design.

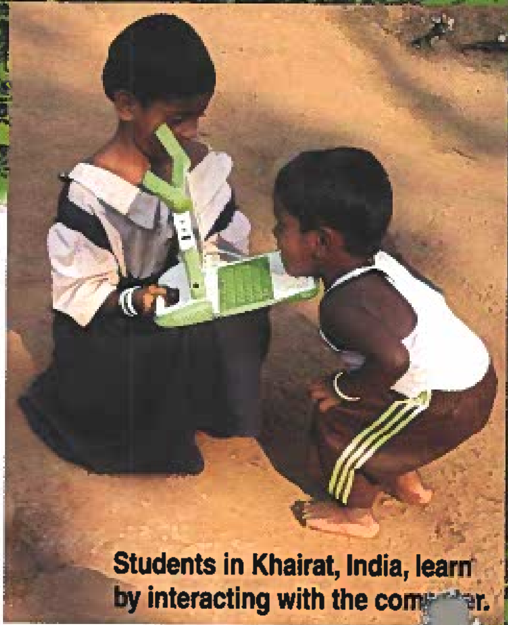
CHAPTER 13

Information and Communication Technology

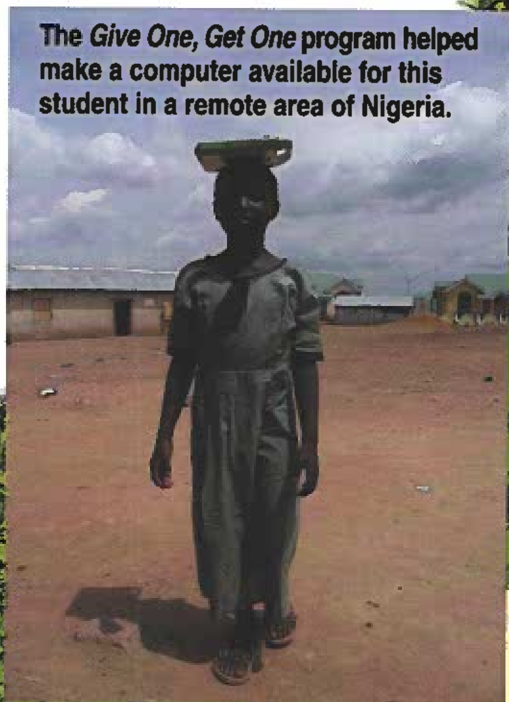
Better by Design

Nicholas Negroponte leads the One Laptop per Child design team

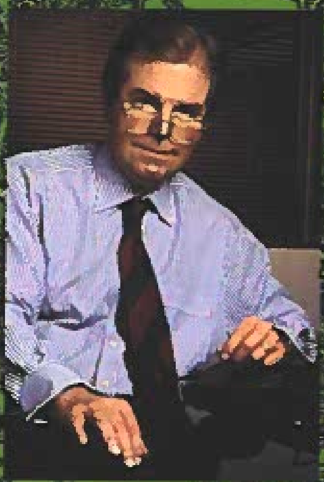
Nicholas Negroponte is a computer scientist who wants to provide every child worldwide with a laptop with software designed for joyful, self-empowered learning. To achieve this objective, the *One Laptop per Child* association has developed the XO laptop. The XO uses open-source software and has a video/still camera. Importantly, it contains no hazardous materials. The laptop can be recharged by human power using a crank, a pedal, or a pull-cord. The *Give One, Get One* program asks donors to pay $400 for two XOs: one XO laptop is sent to the purchaser and a second is sent to a student in a poor country.



Students in Khairat, India, learn by interacting with the computer.



The *Give One, Get One* program helped make a computer available for this student in a remote area of Nigeria.



"Computing is not about computers any more. It is about living."