CHAPTER 15

Electricity and Electronics

OBJECTIVES

- describe the relationships among voltage, current, and resistance.
- explain the basic organization of the two main types of circuits.
- describe the operation and uses of diodes and transistors.
- explain the operation of an electronic or electrical device in terms of input, process, and output.

KEY TERMS

battery
circuit
current
electricity
electromagnetism
generator
Ohm's law
potential difference
resistance
transistor

Imagine that you lived 200 years ago. You would have been living in a world without electricity. Consider the ways in which your life would have been different.

Many people might argue that harnessing electrical energy has been the most significant technological event of all time. Our technologies use thousands of devices that rely on electricity and electronics.

This chapter will help you understand the nature of electricity as an energy source. It will also help you see how we use electricity and electronics to control technology.

WHAT IS ELECTRICITY?

The study of electricity can be difficult. One reason why is that we usually can't see electricity. We know it's there because we can see the results of its work. We feel the heat from a blow dryer and watch the paddles on the ceiling fan turn—but what *is* electricity?

Electricity is the flow of electrons through a pathway that conducts electricity—a wire, for example. *Electrons*, as will be explained, are tiny charged particles of an atom. Atoms are the building blocks of all things. The universe and everything in it is composed of atoms.

Composition of Matter

Matter is anything that occupies space and has mass. Matter is made up of atoms. Matter may take the form of a solid, a liquid, or a gas. It may be an element, a compound, or a mixture.

> **FASCINATING FACTS**
>
> The Greek word *elektron* is the source of the word *electricity*. In Greek, *electron* means amber. Amber is the hardened resin of pine trees that grew millions of years ago. When amber is rubbed, it can attract objects. One of the first known examples of static electricity was observed by the ancient Greeks. They noticed that rubbing amber caused it to attract objects.

An *element* is the purest form of matter. An element is made up of atoms. An *atom* is the smallest particle of an element that retains the properties of that element. For example, salt can be broken down into sodium and chlorine. Elements are so pure that they cannot be broken down any further. There are about 105 known elements. Every substance on Earth is made of one or more of these elements. Fig. 15-1.

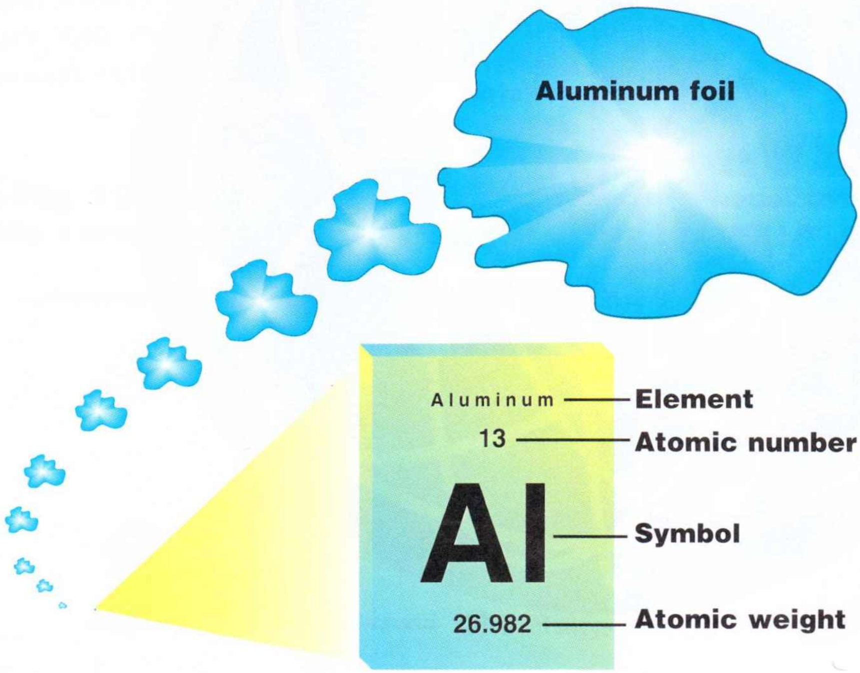


Fig. 15-1 The smallest part of an element that still behaves like that element is an atom. Assume that you were able to cut a piece of aluminum foil into smaller and smaller pieces. The smallest particle that still behaved like aluminum would be a single aluminum atom.

There are over 100 elements. Each one has a unique atomic structure. Every substance on Earth is made up of one or more of these elements.

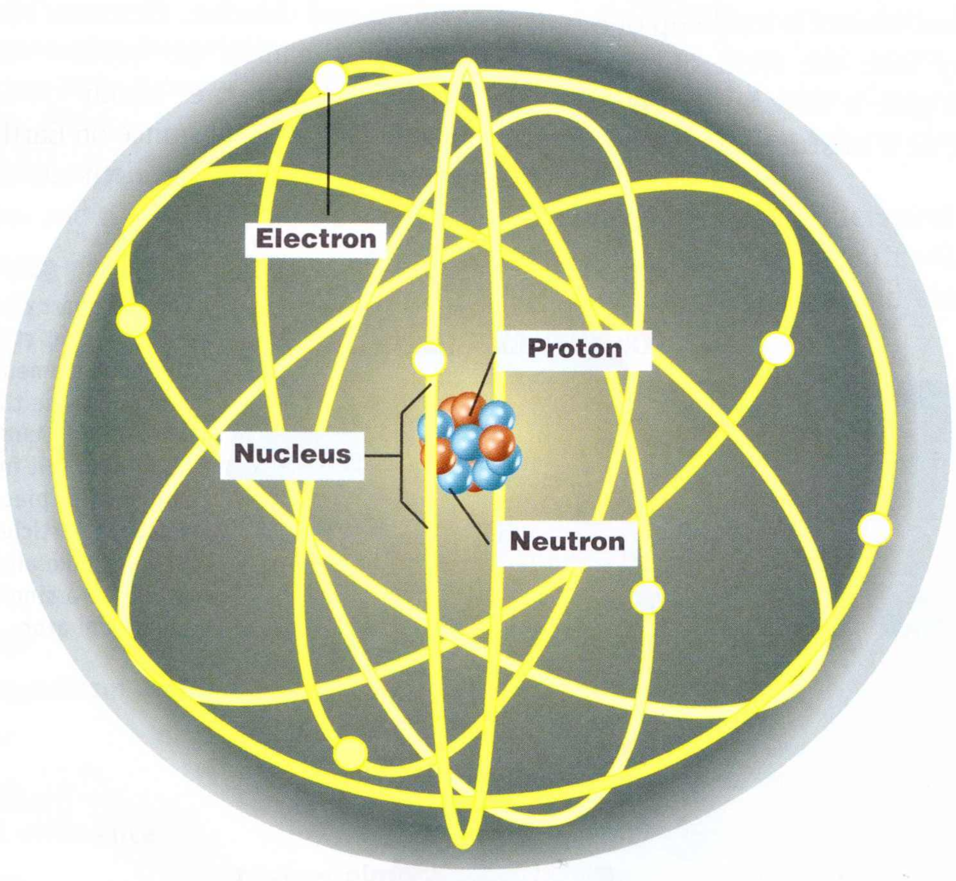
Many times, two or more different atoms combine to form molecules. *Molecules* combine to form compounds. *Compounds* are matter composed of chemically combined atoms of two or more elements. *Mixtures* are also a combination of two or more elements. However, these elements are not chemically combined. They retain their own properties. The *periodic table of elements* lists known elements.

Atomic Structure

An atom has two parts: a center portion, or *nucleus*, and a cloud of *electrons* that surrounds the nucleus. Tightly packed within the nucleus are particles called *protons* (PRO-tahns) and *neutrons* (NEW-trahns). Fig. 15-2.

The number of neutrons in an atom is always equal to or greater than the number of protons (except for hydrogen). Atoms of the same element may vary in the number of neutrons. Such atoms are called *isotopes* (I-so-topes).

Fig. 15-2 **A nucleus in the center of the atom consists of closely packed proton and neutron particles. A cloud of electrons surrounds the nucleus.**



A neutral atom has one electron for each proton in the nucleus. An atom can lose or gain electrons, however. This process, which upsets the balance of neutrality, is called *ionization* (I-on-uh-zay-shun). It is very important to the flow of electricity.

Energy Levels and Electrons

Electrons move about at various *energy levels* at different distances from the nucleus. The area in which the electrons move is known as the *electron cloud*. The energy levels of the atom are often referred to as *shells*. The innermost electrons are at the lowest energy level. Those of the outermost shell are at the highest energy level. The outermost shell is called the *valence* (VAY-lence) *shell*.

Electrons in the outermost subshell of the valence shell are called *valence electrons*. Valence electrons are more loosely bound to the atom than inner electrons. Since valence electrons have more energy and are more loosely bound, they can escape from the atom when enough external energy is absorbed. The escaped valence electron is called a *free electron*.

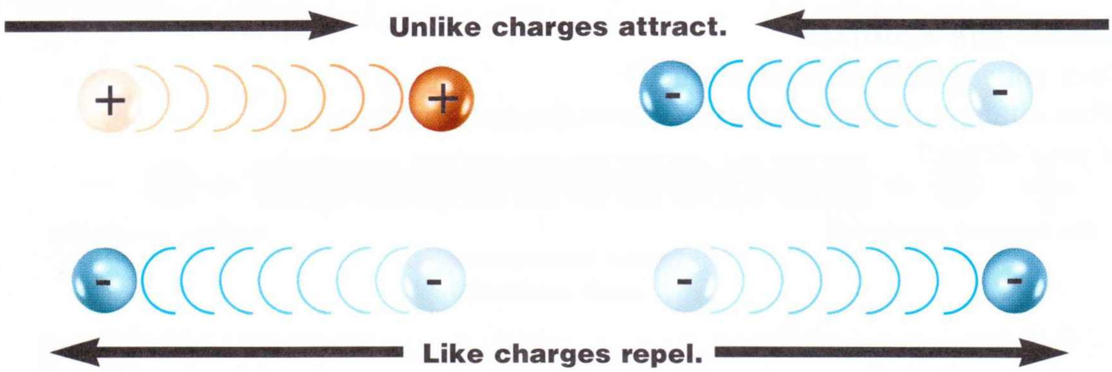
Atomic Charges

Protons and electrons in atoms contain tiny amounts of electrical energy, or *charges*. Protons have a positive charge, while electrons have a negative charge. Neutrons are neutral. They have no electrical charge.

When ionization occurs, the neutral atom loses or gains an electron and becomes an *ion* (I-on). When a neutral atom loses an electron, the atom becomes a *positive ion* because it has more protons than electrons. When a neutral atom gains an electron, the atom becomes negatively charged, or becomes a *negative ion*.

Similar to the poles on a magnet, like charged particles tend to repel each other. Unlike charged particles attract each other. This phenomenon is known as the *law of charges*. Fig. 15-3. Atoms seek the most stable level possible. It is the interaction between charged particles that causes the flow of electrons that we call electricity.

Fig. 15-3 When charged particles come close to each other, a force is produced. This force can be either a force of attraction or repulsion.



Voltage, Current, and Resistance

A charge has stored energy with the *potential* to do work. For example, the potential energy at the negative terminal of a battery differs from that at the positive terminal. In a complete electric path, this difference in potential causes a charge to move through the circuit. This **potential difference**, as it is called, is the *force* that causes electrons to flow.

A potential difference is also referred to as a *voltage*, or *electromotive force (emf)*. Voltage is an excess of electrons stored in one location and waiting to move.

Some materials are made of atoms that do not have a strong hold on valence electrons. These materials are called *conductors*. Metals are generally good conductors. Copper, aluminum, silver, and gold, for example, are excellent conductors. Fig. 15-4.

When voltage is applied to a conductor, the excess electrons of the negative end of the wire travel to the positive end, or the end with too few electrons.

The flow of electrons in a wire or other conductor is known as **current**. Current continues until the charges at both ends of the conductor are equal. Figure 15-5 shows how current flows through a conductor.

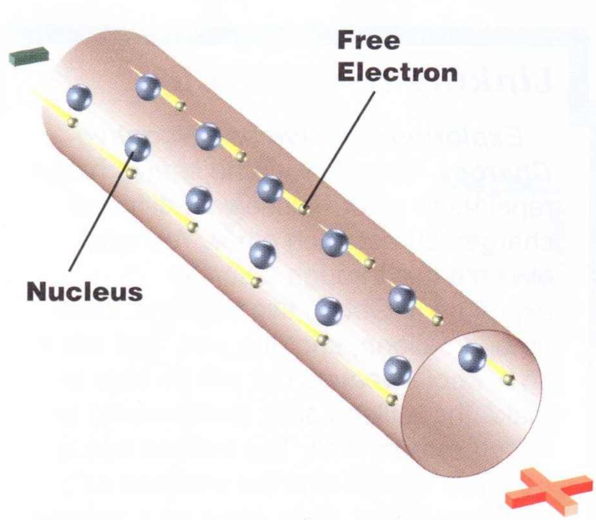


Fig. 15-4 Metals are good conductors of electricity. Materials that conduct electricity have electrons that are not held tightly in place. These electrons are free to move.

In contrast to conductors, some materials are made of atoms that have a tight hold on electrons and a few free electrons. Those materials that resist the flow of voltage are called *insulators*. Plastic and ceramic materials are good insulators. However, if enough voltage is applied, electrons can be forced from atom to atom through the insulator. Insulators have different strengths. The strength of an insulator represents its resistance.

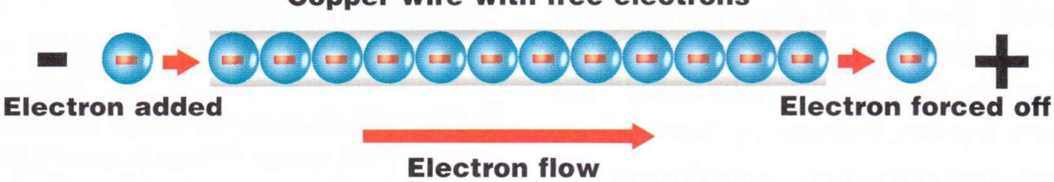


Fig. 15-5 The way in which current flows through a conductor.

Linking to SCIENCE

Exploring Positive and Negative Charges. Objects with the same charge repel each other. Those with different charges attract each other. You can observe this through a simple experiment. Obtain two balloons. Blow up one balloon, knot the end, and rub it on a wool sweater. You will be able to make the balloon stick (temporarily) to the classroom wall. The balloon has a negative charge and the wall has a positive charge. Now, blow up a second balloon and knot the end. Cut two 1-foot lengths of thread. Suspend each balloon from a thread by taping or tying. Rub the balloons on a wool sweater to give them a negative charge. Holding them by the thread ends, bring them close enough to touch. You'll see that they quickly move apart. Why?

Resistance is the opposition to the flow of electrons. Different substances have different resistances. Conductors have low resistance. Insulators have very high resistance.

SOURCES OF ELECTRICITY

As mentioned, for electrons to flow, there must be a potential difference, or voltage. The source that supplies this voltage is called a *voltage source*. It can be produced from a variety of different primary energy sources. These primary sources take energy in one form and convert it to electrical energy. Two voltage sources—batteries and generators—are discussed here.

Cells and Batteries

Have you ever wondered how a battery works? A **battery** is a device that converts chemical energy into electrical energy. A battery generates electrical energy (voltage) with a chemical reaction.

The batteries used in flashlights are also called "cells." A *cell* is a device made of two different conducting materials in a conducting solution. The conductors are called *electrodes* (e-LEC-trodes). The conducting solution is called an *electrolyte* (e-LEC-tro-light).

Dry cells have a paste electrolyte of powdered chemicals. A flashlight battery is a common dry cell. *Wet cells* contain a liquid electrolyte. A car battery is a wet cell. Fig. 15-6.

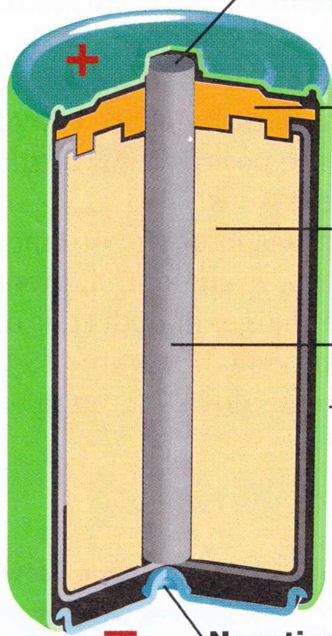


Fig. 15-6 Batteries change chemical energy into electrical energy. Voltage is created through chemical reaction. In a carbon zinc cell, electrons travel from the zinc to the carbon rod.

A chemical reaction occurs in the cell between the two electrodes. The electrolyte positively charges one electrode and negatively charges the other. In this way, the cell produces voltage.

When connected to a conductor, cells and batteries produce a current that flows in only one direction. This current is called *direct current* (dc).

Generators

Mechanical energy is the energy of motion. A **generator** is a device that changes mechanical energy into electrical energy. A generator uses *electromagnetic induction* to force electrons from their atoms. Early scientists found that they could produce an electric current by moving a wire through a magnetic field. When a wire cuts across the invisible lines of force of the magnetic field, voltage is induced in the wire. In addition, if the wire forms a complete circuit, a current is induced as well. Fig. 15-7.

Generators vary in type and in construction. A simple generator is made up of a coil of wire wrapped around a metal core and placed between the poles of a magnet. The wire coil and core assembly is called an *armature* (ARM-uh-chur). This can rotate. As the armature rotates, the coil cuts across the magnetic field. Consequently, voltage is induced in the coil.

Each half-turn, the two connections at the output of the generator change *polarity*. First one end is positive and the other end is negative, then vice versa. The current by such a voltage changes direction each time the polarity changes. This electricity is known as *alternating current* (ac).

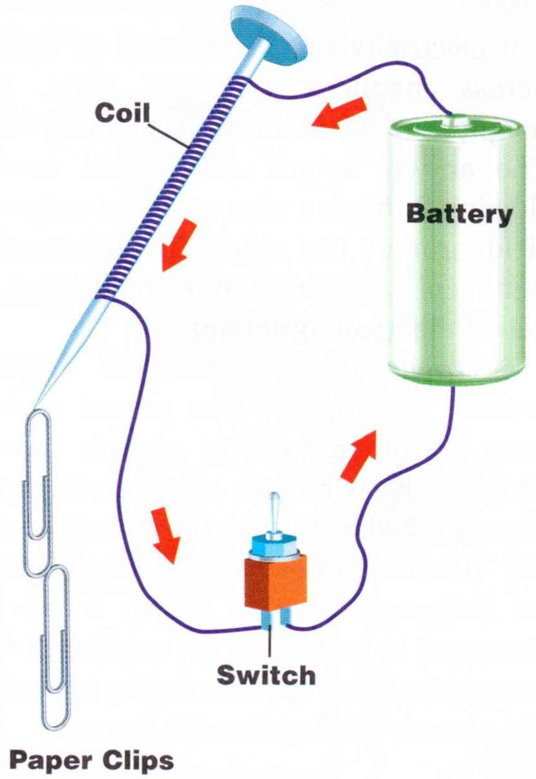


Fig. 15-7 An electromagnet can be made by winding fine insulated copper wire around an iron nail and connecting this device to a battery. An electromagnet can produce a stronger magnetic field than the field produced by a permanent magnet. An electromagnetic can also be turned on and off.

Most of the electricity we use is alternating current generated in power plants that use large generators. Mechanical energy is used to turn the rotating parts of these huge machines. This energy comes from *turbines*. These are bladed wheels that turn when struck by the force of steam or moving water. As the shaft turns, the armature rotates. This generates electrical energy, or voltage.

Electromagnets

If electricity can be induced by cutting across magnetic lines of force, can magnetism be induced from electricity? The answer is yes. An electric current flowing through a wire creates a magnetic field around the wire. The relationship between electricity and magnetism is called **electromagnetism**.

Electromagnets are powerful magnets created by wrapping wire around an iron core and then passing electric current through the wire. The magnetic field can be controlled by turning the current on and off. The strength of the magnetic field can be increased in two ways. It can be increased by increasing the number of coils wrapped around the core and by increasing the current flowing through the coil.

RELATIONSHIPS AMONG VOLTAGE, CURRENT, AND RESISTANCE

You have learned that the force used to move electrons is called voltage. Voltage is a measurable quantity. The unit of measure for voltage is the *volt*. The symbol for volts is *V*, though *E* is sometimes used.

You have also learned that current is the term used to describe the movement of electrons in a wire. Current is measured by counting how many electrons move past a certain point within a wire each second. The symbol for current is *I*. The unit of measure for current is the *ampere*, or *amp*. The symbol for amperes is A.

Finally, you have learned that resistance is the opposition to the flow of electrons. The symbol for resistance is *R*. The unit of measure for resistance is the *ohm*. The symbol for the ohm is the Greek letter Ω (omega).

Ohm's Law

When voltage is applied to a conductor, the current that moves through the conductor is directly proportional to the applied voltage. This relationship is known as **Ohm's law**. This law is basic to all studies of electricity. Table 15-A. Ohm's law is stated mathematically by the formula:

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

or

$$I = E/R$$

Table 15-A. Voltage, Current, and Resistance

Electrical energy depends on three factors: voltage, current, and resistance. The relationship of these three factors determines the amount of electrical energy produced.

Physical Quantity	Symbol	Measure of	Unit of Measure
Voltage	V or E	Force	Volts (V)
Current	I	Electron Flow	Amperes (A)
Resistance	R	Opposition to Flow	Ohms (Ω)

Linking to *MATHEMATICS*

Finding Resistance. Assume that a lightbulb uses 0.8A of current when operating in a 120-V circuit. Using Ohm's law, find the resistance of this lightbulb.

ELECTRICAL CIRCUITS

In electricity, a **circuit** (SIR-cut) is the pathway through which electrons travel. A *simple circuit* consists of a power source, a conductor, and a load. Fig. 15-8. A circuit that uses direct current as a power source might use a battery or a *photovoltaic* (foe-tow-vole-TAY-ik) cell. This is also known as a solar cell. The source of voltage for alternating current is usually a generator at the power plant.

Conductors provide a low-resistance path from the source to the load. Typically, copper or aluminum wires serve as conductors.

The *load* is the device that uses the electric energy. The load could be a motor, a buzzer, or a light. The load converts the electrical energy in the circuit into heat, light, mechanical, or other energy forms.

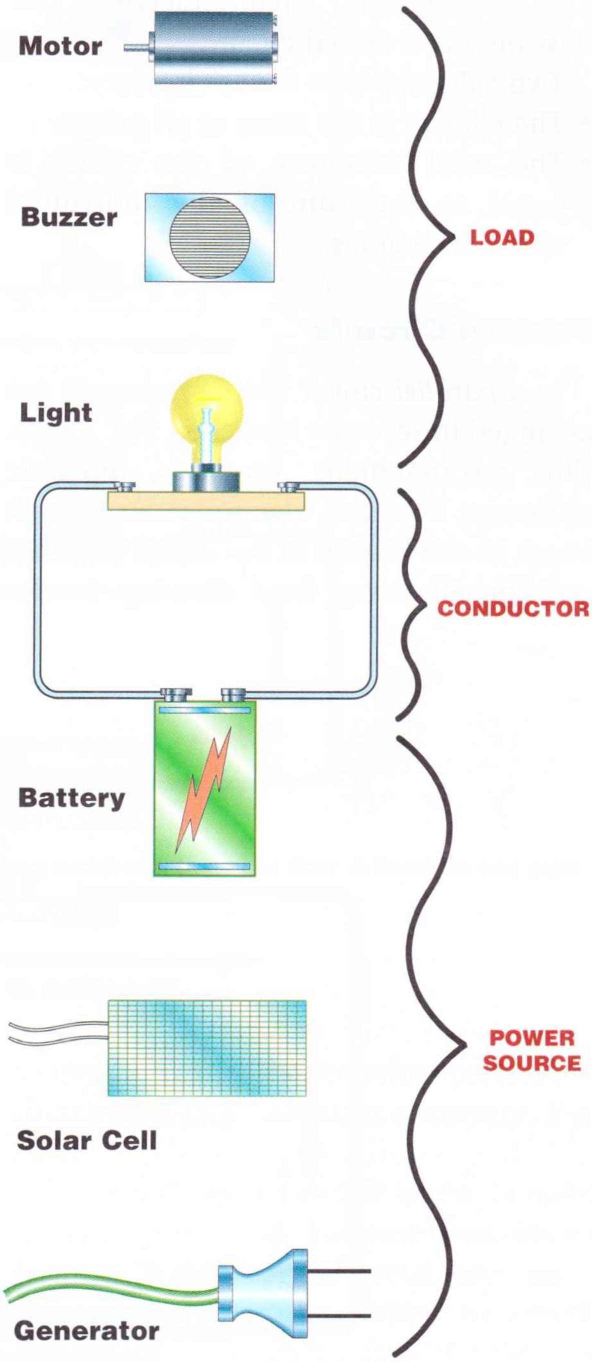
Main Types of Circuits

The main types of circuits are series circuits and parallel circuits.

Series Circuits

When the components are connected one after another, the circuit is called a *series circuit*. In a series circuit, there is

Fig. 15-8 An electrical circuit is the pathway that electricity follows. All circuits have a conductor, a load, and a power source.



only one pathway for electrons to follow. Fig. 15-9. A break in any part of the circuit stops all the electrons from flowing. This produces an open circuit. Electrons can flow only in a closed circuit.

Two rules apply to series circuits:

- The current is the same at all points.
- The total resistance of the circuit is equal to the sum of the individual resistance values.

Parallel Circuits

In a *parallel circuit* the components are arranged in separate branches. Fig. 15-10. This arrangement provides multiple pathways in which electrons can flow. A break in one branch of the circuit does not prevent electrons from flowing in the other branches. Two rules apply to parallel circuits:

- All branches are of equal voltage.
- Total current is equal to the sum of the branch currents.

Complex Circuits

A *complex circuit* uses switches or other electronic parts to control the flow of electrons from the source to the load. Switches, resistors, and circuit-protection devices are used in complex circuits.

Switches are used to open and close the circuit. Different types of switches open and close the circuit in different ways.

Resistors are devices that apply resistance to the flow of electrons in the circuit.

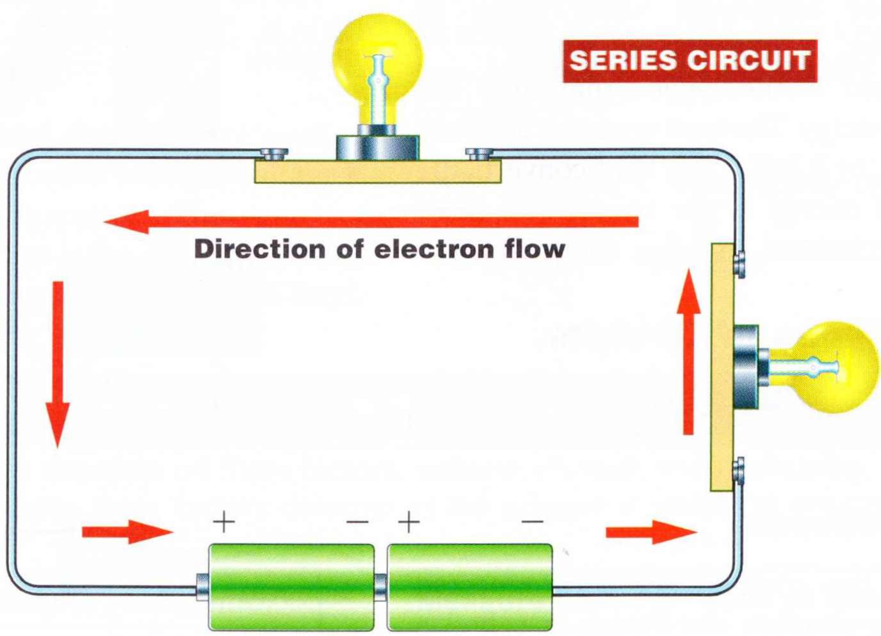


Fig. 15-9 A series circuit supplies only one path for the flow of electrons. If that path is broken at any point, the flow of electrons will stop.

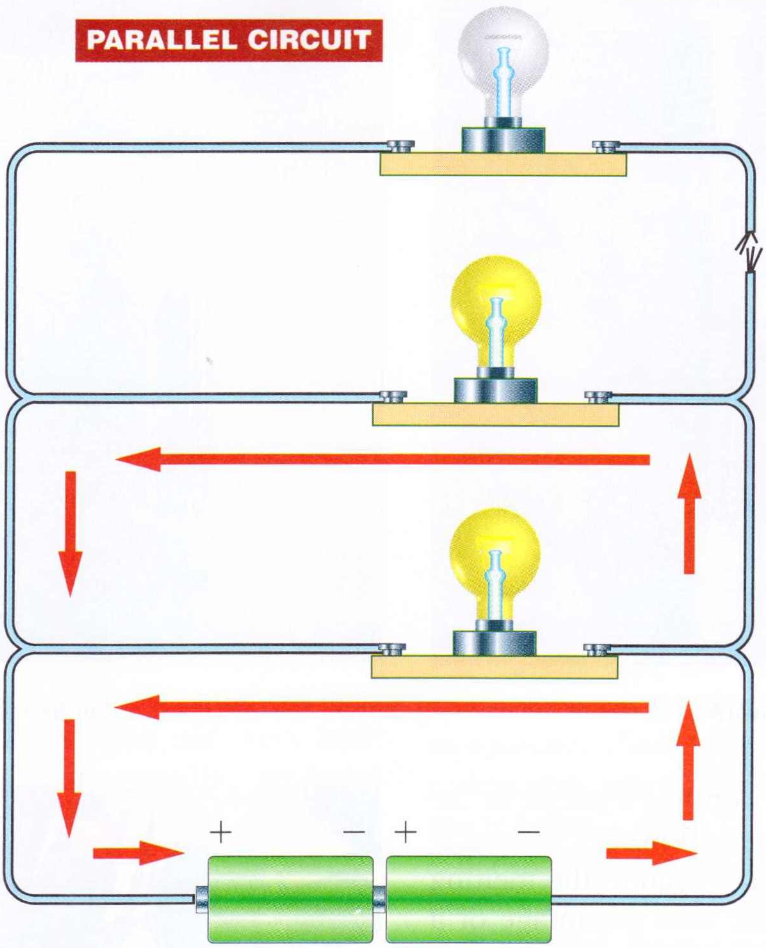


Fig. 15-10 A parallel circuit has many paths along which electrons can flow. A break in one path will not stop the flow of electrons in the other paths.

Potentiometers (puh-TEN-she-om-mutters) and *Rheostats* (REE-uh-stats) are adjustable resistors that can set a range of desired resistances. Potentiometers are used to vary voltage. Rheostats are used to vary current. A dimmer switch on a lamp is an adjustable resistor. The volume control on a radio is another example.

A complex circuit should also contain a circuit-protection device, such as a fuse or a circuit breaker. These devices protect the circuit from large amounts of current. Fig. 15-10.

A *fuse* will open a circuit when its rated current is exceeded. The fuse contains an element, a thin strip of metal, that melts at a specified current. When too much current runs through the fuse, the element will melt. The circuit will then open. Fig. 15-11A.

Fig. 15-11 Fuses(A) and circuit breakers (B) prevent the damage that can be caused by excessive current.

A *circuit breaker* controls a circuit in the same way as a fuse. However, it uses a process that does not require the melting of the fuse element. One advantage of a circuit breaker is that it can be reset and reused after the problem in the circuit has been fixed. Fig. 15-11B.

WHAT IS ELECTRONICS?

Electronics is the study of precisely controlling the flow of electrons. Fig. 15-12. Electronics is the outgrowth of our knowledge and development of electrical energy. Electricity and electronics are not the same.

There are key differences between electricity and electronics. Remember that electronics controls the flow of electrons. Electricity controls voltage levels and the flow of current.

Fig. 15-12 In electronics, the flow of electricity is controlled by various devices. For example, resistors are placed in a circuit to reduce the flow of electricity. Fuses guard against damage. Transistors control the flow of current.

Linking to COMMUNICATION

Researching Power Blackouts. Using the media center of your school, research the New York blackout of 1968. Determine the cause and length of the outage and the immediate and long-term effects. Write a one-page essay presenting the details of the power failure.

Semiconductors

The precise control of electrons began with the invention of the vacuum tube. In 1948, however, the Bell Telephone Company invented the transistor. A **transistor** is a semiconductor device that amplifies and acts as an electronic switch. The transistor is tiny and uses very little energy. Transistors rapidly replaced vacuum tubes in electronics. Scientists began using transistors to solve problems in mathematics. That led to the development of today's computers.

Semiconductors are materials with properties that fall between insulators and conductors. They conduct better than insulators, but not as well as conductors. Silicon and germanium are common semiconductor elements. A process called *doping* adds impurities to the pure semiconductor element. This increases its conductivity. Arsenic and gallium are two elements commonly added as impurities.

Some impurities add extra electrons that are free to move about the crystal. This produces an *n-type semiconductor*. Other impurities take away electrons. This produces a *p-type semiconductor*. Unfilled *valence* (VAY-lence) shells result, leaving positive sites in the semiconductor crystal. These positive sites are called *holes*.

The holes have a strong attraction for electrons. Valence electrons from nearby atoms can "fall" into the hole, leaving another hole where it had been. Movement of electrons from one hole to the next makes the holes appear to move in the opposite direction. Conduction through the p-type semiconductor is by holes. Conduction through the n-type semiconductor is by electrons.

Junction Diodes

When a semiconductor crystal is half n-type and half p-type, a *pn junction* is formed between the two regions. Figure 15-13 shows a pn junction device known as a *junction diode*. The n-region has many conduction electrons. The p-region has many holes.

Because of this junction, electrons can flow through the semiconductor in only one direction, from n-type to p-type.

The primary use of a junction diode is to *rectify* current, or to change ac into dc. Computers or televisions would not operate practically with batteries. Therefore, diodes are wired into their circuits to rectify the current. In this way, such devices can be supplied with direct current from a source of alternating current.

Uses and Types of Transistors

Transistors have two main uses. They are used to boost or amplify electronic signals. They also act as electronic

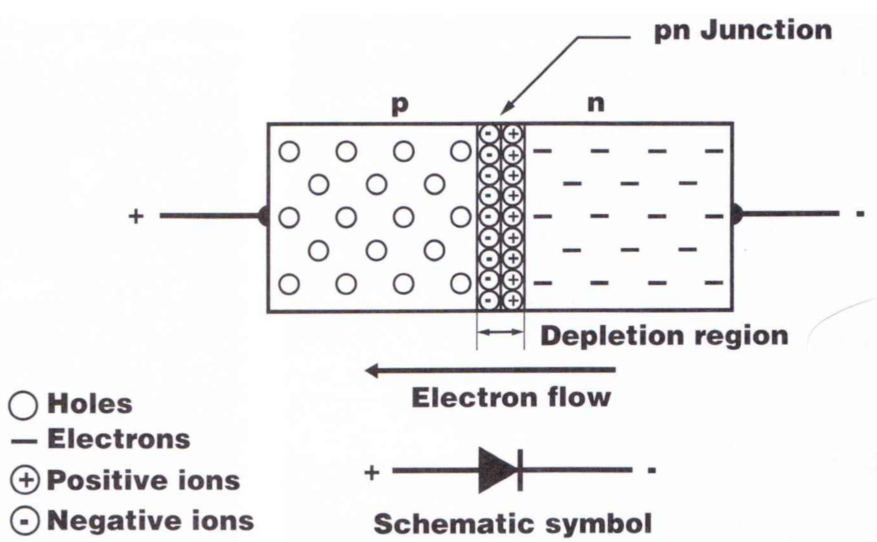


Fig. 15-13 Block diagram of a junction diode. Its schematic symbol is shown below. Electrons can flow in only one direction, from the n-region to the p-region.

switches. For example, they are used to amplify signals in microphones, radios, televisions, and hearing aids. They are used as switches in computers.

There are two basic types of transistors: npn and pnp. Both have three layers of semiconductor materials: a thin center section, called a *base*, and two thicker outer layers. One layer is called an *emitter*. The other layer is called a *collector*. Wire leads are joined to each of these layers. Fig. 15-14.

The pn junction is basic to the operation of transistors as well as diodes. A *forward-bias voltage* (negative of source connected to the n-region of an npn, positive of source connected to the p-region) is applied to the base-to-emitter leads. At the same time, a *reverse-bias* voltage is applied across the collector-to-emitter

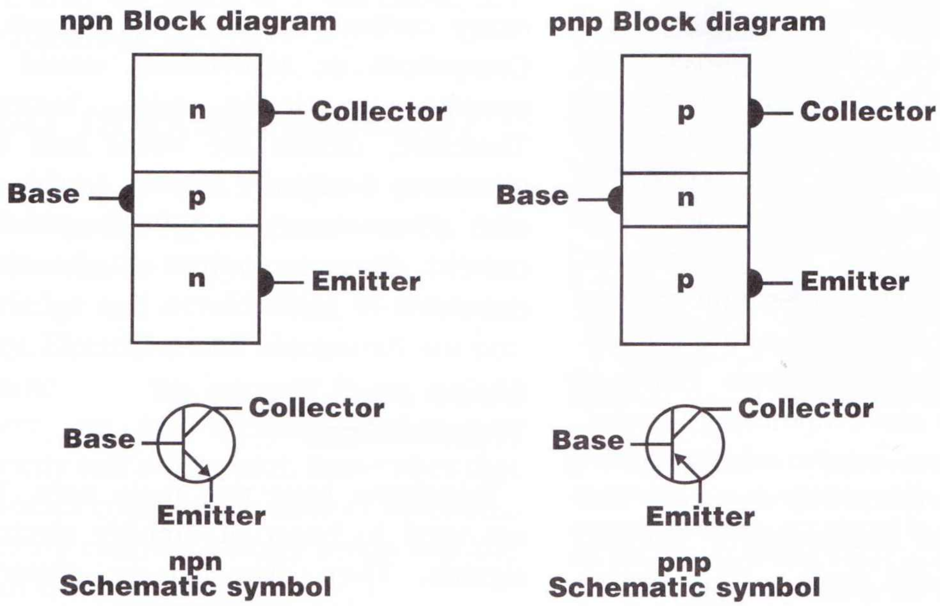


Fig. 15-14 Block diagrams and schematic symbols for npn and pnp bipolar junction transistors.

leads. Current then flows across the forward-biased, emitter-base junction into the base region. The flow of current carriers into the emitter allows current to flow from collector to emitter.

Increasing the base current slightly by increasing the forward-bias voltage causes a much larger collector-to-emitter current. This principle makes the transistor useful as an amplifier. A small input current can control a much larger output current.

In computers, transistors are used to create *logic gates*. Logic gates open and close like electronic switches. They control the flow of electrons at lightning speeds. Computers operate on the *binary number system*. This means that they use 1s and 0s to represent numbers and characters. In the "on" state, the transistor represents the digit 1. The "off" state represents the digit 0. Computers process information by adding, subtracting, multiplying, and dividing the binary 1s and 0s.

ELECTRONIC SYSTEMS

Electronic systems are devices that work together to control, monitor, and measure changes. To work, electronic systems must have *inputs, processes*, and *outputs*.

The input can be a sensor that converts a command into an electrical signal. The input to your oven is your setting of the oven at a certain temperature.

The process is the action that accomplishes a result. For example, in a streetlight control circuit, a photoresistor energizes a relay that switches on the streetlight.

The output is the result of the process. For example, when the battery in your smoke detector is low, it may begin to flash.

IMPACTS

Systems powered by electronics and electricity impact all areas of modern life. Such systems have provided many of the tools we need to earn a living. They have also increased our options for entertainment and travel. The positive impacts of electricity have far outweighed any negative impacts. Fig. 15-15.

THE FUTURE

Electrical engineers face the challenge of increasing the power of a device while limiting its size. This pattern has been present in the development of the radio, the television, the computer, and the cellular phone. Can you think of others?

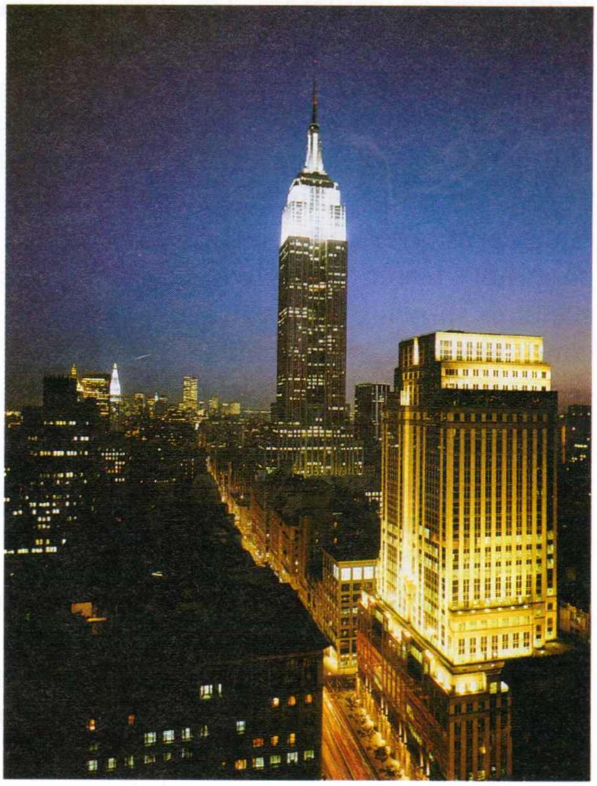


Fig.15-15 The full range of invention is shown by the electrical and electronic devices used in a large city.

CAREERS IN Electronics

ELECTRICAL AND ELECTRONIC ENGINEER

Growing developer of aerospace, automotive and military-embedded control products is in need of engineers to perform digital and analog electronic circuit design and real-time software programming. Bachelor's degree in electrical engineering required. Please send resume to: P.O. Box 361665, Monroe, MI 65389, or E-mail at ecc@ecc.com.

COMPUTER SERVICE TECHNICIAN

The ideal candidate will have the ability to test, troubleshoot, and resolve hardware problems on personal computers. Effective customer skills needed. Prefer one or two years of formal training in electronics with knowledge of computers. Will work without supervision. Submit your resume to: General Credit Insurance Company, 3201 Beachwood Parkway, Orlando, FL 33238.

ELECTRONICS TECHNICIAN

We are a premier printing company expanding our Akron facility and seeking an electronics technician. Responsible for assisting in the design, fabrication, troubleshooting and maintenance of our electrical/electronic manufacturing equipment. Computer programming and problem-solving skills necessary. Interested candidates should forward a resume to: Human Resources, Sealtight Company, 1978 Main Akron Road, Akron, OH 65230.

ELECTRONIC DRAFTER

Electronics manufacturing firm needs drafter to prepare detailed drawings and blueprints for electronic equipment. Draw wiring diagrams, circuit board assembly diagrams, schematics, and layout drawings. Send resume and list of references to: Technical Electronics, Inc., P.O. Box 7022, Chicago, IL 60032.

COMPUTER SALES REPRESENTATIVE

Computer retail company has grown to include corporate sales division. Challenging opportunity for self-motivated individual to solicit new business while managing existing accounts. Prefer one year of sales experience and PC proficiency. Must have strong organizational, customer service and communication skills. We offer competitive compensation package. Send or fax resume to: American Computer Corporation, 24295 Beechwood Avenue, Cleveland, OH 62240. Fax: (614) 888-3200.

Linking to the WORKPLACE

Advances in technology and manufacturing have impacted our lives. List five electronic products developed in the past ten years that have affected the workplace. How did these products change the ways in which jobs were performed?

Chapter 15 Review

SUMMARY

- A battery creates voltage by means of a chemical reaction. A generator creates voltage by means of electromagnetic induction.
- When a voltage is applied to a conductor, the current that moves through the conductor is directly proportional to the applied voltage. This relationship is known as Ohm's law.
- In a series circuit, components are connected one after another. In a parallel circuit, components are arranged in separate branches.
- A diode allows current to flow through a circuit in only one direction.
- A transistor controls a large output current with a small input current or voltage.

CHECK YOUR FACTS

1. Draw and label the parts of an atom. Identify the charges of particle.
2. What force causes electrons to flow?
3. Why are the electrons in the outer shell of the atom more likely to flow than electrons in the inner shells?
4. Describe two common sources of electromotive force.
5. Explain how Ohm's law describes the relationship among voltage, current, and resistance.
6. How did the invention of transistors affect the development of electronics?
7. Identify and describe the organization of the two main types of circuits.
8. Describe the operation and uses of diodes.
9. What design feature do all electronic systems have in common?
10. Describe the operation and uses of transistors.

CRITICAL THINKING

1. Describe how a toaster works in terms of input, process, and output.
2. Superconductors are materials that have very low resistance to electron flow. To achieve this, these materials are subjected to very low temperatures. What effect do you think low temperatures might have on electron flow and resistance? Explain your answer.
3. Describe how you would design an electronic fan that turns on when the temperature reaches 88°F.
4. Describe how doping changes the resistance of a conductor.