

Modern Residential Wiring

10th Edition

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*Master Electrician
Member, International
Association of Electrical
Inspectors*



Based on the

2014 NEC®

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Introduction



Modern Residential Wiring provides you with a solid background of electrical principles and practices, as well as a thorough understanding of *National Electrical Code*[®] requirements. Once having mastered the information given here, you will be well equipped to design and install modern and safe residential wiring systems that meet the electrical power demands of the new millennium.

Modern Residential Wiring covers not only the “how” but the “why” of safe electrical wiring practice. Although the content is concerned primarily with residential installations, many of the same concepts and principles may be applied to commercial and industrial electrical construction.

The chapters are arranged in a logical sequence. The order of instruction follows the normal order in which the installation would be made. However, each chapter is designed to stand alone and may be studied independently to suit a specific need.

Modern Residential Wiring makes the study of electrical wiring easy. Even the most complicated procedures are simply explained and easy to understand. Procedures are explained step-by-step while the many illustrations are fully integrated into the easy-to-read text. The illustrations should be carefully examined as they will often clarify and explain the more difficult principles of electricity and the requirements of the *National Electrical Code*[®].

This new edition of *Modern Residential Wiring* is revised to be consistent with changes in the trade practices, materials, and the requirements of the 2014 *National Electrical Code*. It has been expanded to cover new areas and methods of residential wiring.

The principles of electricity remain fixed. The methods, materials, and tools of the trade are continuously evolving. *Modern Residential Wiring* presents both the fundamentals of electrical wiring and the latest practices used in the trade.

The author wishes to express his sincere appreciation to each of the individuals, organizations, and associations that provided input, assistance, and illustrative materials for the new edition. A special thanks to my wife, Linda, for her active assistance in the creation of this edition.

Harvey N. Holzman

Modern Residential Wiring

Chapter Components

CHAPTER 3
Tools for the Electrician



Objectives

- Select essential tools for residential wiring.
- Know the specialty tools available for subsequent applications.
- Discuss basic principles of tool use and care.

Technical Terms

Standard hammer
Box hammer
Cable ripper
Circuit tester
Conduit bender
Continuity tester
Diagonal cutter
Digital voltage tester
Electric drill
Electrical voltage tester
Electrician's hammer
Electrician's knife
Fish tape
Fishing rule
Ground pipe pliers
Hack saw
Hammer drill

Wrenching tool
Sucker
Soldering iron
Soldering paste (flux)
Screwdriver
Screwdriver
Steel tape
Surgeless level
Whetstone
Wire stripper

No electrician must have proper tools for a job. Tools must be kept in good repair, as they are not available or are in poor condition, time is wasted and good work is impossible. Invest in good-quality tools and take the time to inspect and care for them, so you will be able to rely on them for many years.

Setting Tools

Insulated tools have been treated to prevent conductivity at the edges for which the tool is used. Do not think that you can insulate a tool by dipping its handles in a polymer or wrapping them with tape. These methods create a weak and inconsistent thickness of insulation. If you must work on energized equipment, the cost of insulated tools is a small price to pay to prevent injury or death.

Objectives. Provide an overview of the chapter content and explain what should be understood on completion of the chapter.

Technical Terms. List of important technical terms introduced in the chapter. The terms in this list appear in **bold-italic type** when they first appear in the chapter.

Safety Note. Identify procedures that can result in personal injury or damage if the proper safety measures are not followed.

PVC and fittings, a special glue and primer are used. See Figure 4-25.

Attaching Fittings to PVC

1. Clean the inside of the fitting and the end of the conduit with a rag.
2. Dry-fit the fitting on the conduit to check the final position.
3. Remove the fitting.
4. Apply primer to the inside of the fitting and the outside of the conduit.
5. Apply cement to the ground areas.
6. Push the conduit into the fitting while turning the fitting a quarter turn.
7. Look at the seam for a bead of glue to indicate a proper amount of cement.

Note: NEC 250.17 requires conduit run underground to be sealed at joints prior to entering building.

Intermediate Metal Conduit

Intermediate metal conduit (IMC) is permitted for use in all atmospheric conditions and in all types of occupancies. Like its counterpart rigid metal conduit, IMC is available in 1/2" lengths. Each length of IMC is available to be properly connected and joined to other lengths or enclosures using the correct fittings. IMC is available with or without threads. Installation is the same as rigid metal conduit.

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Step 1 Mark primer to the inside of the fitting.

Step 2 Apply primer to the outside of the conduit.

Step 3 Mark glue to the inside of the fitting.

Step 4 Apply glue to the outside of the conduit.

Step 5 Push the conduit into the fitting. Turn the conduit 1/4 turn to spread the glue evenly.

Step 6 This is a common view of the completed assembly.

Figure 4-25 Follow these steps to make the PVC attachment stronger.

Procedures. Present installation or repair techniques in an easy-to-follow, step-by-step format. Procedures help promote a logical approach to common residential wiring tasks.

Learn More. Highlight organizations related to the topics discussed in the text. Their websites help to provide supplemental information.

Pro Tip. Supplemental information and hints related to the components or procedures discussed in the text.

Check Your Skills

For additional information concerning the use and care of hand tools, visit the **Wired Tool** website.

Review Questions

Answer the following questions using the information provided in this chapter.

1. List the three types of rules needed for measuring distance or length.
2. Four or Five? A cable ripper is used on a single conductor wire.
3. How is an electrician's hammer different from a standard claw hammer?
4. Which of the following statements is true when using cutting tools such as cable cutters and side cutters?
 - A. Never use more than maximum hand pressure.
 - B. Use a handle extender if the material does not cut easily.
 - C. It is acceptable to use a hammer to make the cutters cut the material.
5. _____ are used for holding, shaping, and cutting wire.

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96 Section 2 Introduction

Rigid Metal Conduit, Type RMC — Article 344

Location Allowed	Size	Maximum Burying Distance
Dry Hot Concrete	1/2" through 2"	

Rigid Metal Conduit

Rigid metal conduit (RMC) is galvanized and somewhat similar to water pipe. It is used for both indoor and outdoor applications. Inside and out, the conduit is smooth and can be cut, threaded, mated, and bent as necessary for proper installation. To cut RMC with a pipe cutter, follow the cutting procedure demonstrated in the previous EMF section. RMC must be firmly connected to items such as electrical outlet boxes, and panels with a threaded locknut and bushing. This solid connection is necessary because the conduit itself serves as the equipment grounding conductor. Thus, a separate equipment grounding conductor is not required when using RMC. Fittings should maintain a continuous ground throughout the system. See Figure 4-26.

Warning Labels
Section 344.40

Bushings. Where a conduit enters a fitting, or other enclosure, a bushing shall be provided to protect the wire from abrasion unless the design of the box, fitting, or enclosure is designed to provide such protection.



Figure 4-26 Rigid metal conduit is threaded at both ends and can be adapted to fittings and bushings.

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Review Questions. Designed to reinforce the material covered in the chapter.

Know the Code. A few *National Electrical Code* questions at the end of each chapter. These questions require a copy of the *NEC* and help the student become familiar with its overall layout.

Code Alert. Call attention to the *National Electrical Code* and possible local codes. Where possible, these notes relate directly to the content of the chapter. Specific codes may be cited, when applicable. It is essential that you refer to your local code to determine the requirements in your area.



Figure 4-4 A dual element fuse. A—Normal condition. B—Fuse opens from overload after a brief time delay. C—After an overload (C)—short melts, bulb element (D)—after a short circuit. (Batterman Division of Cooper Industries.)



Figure 4-5 Type 3 plug fuses (left) have a ribbon wire that Edison-base type fuses (right).

Plug fuses
Plug fuses are available in two varieties: Edison-base and Type 3. Figure 4-5. Plug fuses have a maximum rating of 30 amps. Fuses rated at 15 amps or less have a rectangular window, while higher rated fuses have a circular window. Figure 4-6.

Cartridge fuses
Cartridge fuses are used in fixed systems over 120 volts at 30 amps. There are two types of cartridge fuse construction: terminal type and knife-blade type. See Figure 4-7.

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Figure 4-4. Fuses rated by 15 amps or less have a rectangular window.

Plug fuses are listed by the following:

Caution. Warn readers of situations that may have an increased potential of injury.

overrating problem is eliminated by using a Type 3 fuse, which uses a wire-wire design. Type 3 fuses must be used on all new installations and for replacement installations. They are their classification of Type 3 fuses with specific adapters based on their ampere rating: 0–15 amps, 16–20 amps, and 21–30 amps.

Edison-Base Plug Fuses
Edison-base plug fuses have no inherent limit to the use of higher ampacity. For example, nothing prevents a 20-amp fuse from being installed in a 15-amp circuit. Using a fuse with an ampere rating higher than that of the circuit is a fire hazard.

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History Brief

OSHA

Congress created OSHA under the Occupational Safety and Health Act, which was signed by President Richard M. Nixon. Since its inception in 1971, OSHA has helped to cut workplace fatalities by more than 60 percent and occupational injury and illness rates by 40 percent.

Wiring Systems

Conductors for carrying electricity are commonly called wiring. A wiring system includes the wire, its insulating cover, a protective zone, and connectors that attach it to an electrical box. See Figure 4-4. In some systems, the protective covering and the electrical assemblies them on the job. In other cases, the protective covering is installed during manufacture.

Depending on the structure being wired, several different systems may be used. Regardless of the wiring system, it is important to have a continuous ground throughout every part of the system and every circuit. Refer to Chapter 5, *Grounding*, of this text for grounding requirements. All of these systems are adequate for most installations. Some cannot be used where there are unusual hazards such as extreme moisture, explosive gases, or volatile chemicals.

The wiring system selected depends on:

- Type of dwelling (style)
- Materials and type of construction used (brick, masonry, steel, post and beam, or platform)

Wiring. The wires installed in a building that provide the electrical power throughout.

Wiring system. An electrical installation, the materials and components used to deliver electricity from the service panel to electrical devices. The wiring system includes the wire, its insulating cover, a protective zone, and the connectors that attach it to electrical boxes.

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History Brief. Provide background information and help build an appreciation for the development of residential wiring and the electrical trade. This feature will help you gain greater perspective and understand the importance of safe and reliable wiring.

Running Glossary. Provides definitions of the important technical terms introduced on the page. It reinforces the terminology electricians will encounter on the job.

About the Author

Harvey Holzman is a master electrician licensed in the states of Texas, New York, and Kansas. He has over thirty years of experience installing, repairing, and upgrading electrical systems for residential and commercial customers. He is a long-time member of the International Association of Electrical Inspectors.

The National Electrical Code®

The most informative and authoritative body of information concerning electrical wiring installation in the United States, and perhaps the world, is the *National Electrical Code*® (*NEC*). It establishes a set of rules, regulations, and criteria for the installation of electrical equipment. Compliance with these methods will result in a safe installation.

The *NEC* is drafted by a team of experts assembled for this purpose by the National Fire Protection Association (NFPA). This team is formally called the *National Electrical Code* committee. They revise and update the *NEC* every three years. It is imperative that anyone installing electrical wiring obtains and studies the *NEC*. Articles and sections of the *NEC* are referred to throughout this text. Although certain portions, tables, and examples are directly quoted from its text, there is enough useful information in the *NEC* that not having it available would be a tremendous hindrance. The latest edition of the *National Electrical Code* can be purchased from the National Fire Protection Association by visiting their website.

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CHAPTER 2

Electrical Energy Fundamentals



Objectives

Information in this chapter will enable you to:

- Explain the electron theory for current.
- Explain conductors and insulating materials.
- Define and explain the difference between direct current and alternating current.
- Define basic electrical terms.
- Describe the makeup of an electrical circuit.
- Differentiate between series and parallel circuits.
- Apply Ohm's law to resistance, voltage, and current.
- Explain Ohm's law and give its formula.
- Apply the basic power formula to power, voltage, and current.
- Explain the basic power formula and give its formula.
- Explain electromagnetic induction.
- Discuss the operation of electric motors.
- Discuss electric power transmission.
- Explain the operation of transformers.

Technical Terms

Alternating current (ac)
Amperage (A)
Ampere
Anode
Atom
Battery
Basic power formula
Branch
Cathode
Circuit
Complex circuit
Conductor
Current
Cycles
Direct current (dc)
Dry cell
Electrical potential
Electrolyte
Electromagnetic induction
Electromotive force
Electrons
Energy
Equilibrium
Free electrons
Generator
Hertz
Insulator
Joules (J)
Kilowatt-hours (kWh)
Left-hand rule
Load
Neutrons
Ohms
Ohm's law
Parallel circuit
Power (P)
Primary winding
Protons
Resistance (R)
Secondary winding
Series circuit
Step-down transformer
Step-up transformer
Substation
Transformer
Voltage
Volt-amperes (VA)
Volts (V)
Wattage
Watts (W)
Watt's law
Wet cell
Windings
Work

Electron Theory

According to the electron theory, all matter is made up of atoms. An *atom* is the smallest particle of an element. If you take an atom apart, it will not be recognizable as its original element. You can look at each atom and say “This is the building block of copper” or “This atom is hydrogen.”

Each atom has a nucleus or center made up of *protons* (positively charged particles) and *neutrons* (particles with no charge). Negatively charged particles called *electrons* orbit the nucleus. See **Figure 2-1**. Electrons are attracted to the protons in the atom. This attraction keeps the electrons in orbit. There can be one or more electrons traveling around in any one atom and they can be at different distances from the nucleus in their orbital paths.

Electrons have the ability to travel from one atom to another. In some types of matter, electrons are tightly bound to the nucleus and travel only with great difficulty. In other types of matter, the bond is so relaxed that moving is easy. These easy-moving electrons are called *free electrons*.

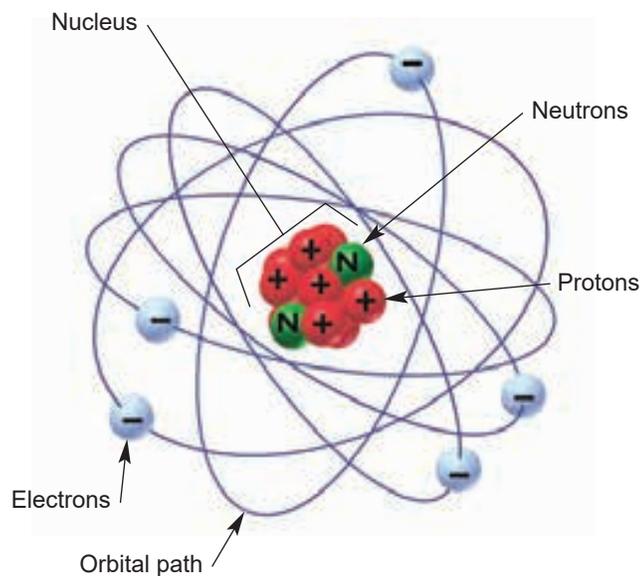


Figure 2-1. The basis of electricity is the atom, which is the foundation of all matter. In some elements, such as metals, orbiting electrons can easily be made to leave the atom and travel.

Electron Travel

A material in which electrons move easily is called a *conductor*. A material in which movement is difficult is called an *insulator*.

Pure metals, carbon, and most liquids are excellent conductors. Among good insulators are dry gases, glass, rubber, mica, silk, and cork. According to the commonly held electron theory, metals conduct electricity well because they have a great number of free electrons. In insulators, there are few, if any, free electrons; thus, little or no electricity is conducted.

Equilibrium

If a conductor, such as a wire, connects a negatively charged body to a positively charged body, the electrons will be attracted to the positive particles. Nature prefers everything to be neutral—equal numbers of positive and negative charges. As a result, electrons will flow from the negatively charged body to the positively charged body. See **Figure 2-2**. This flow is called *current*. Even if two negatively charged bodies are connected in this manner, free electrons will flow from the body with more electrons to the one with fewer electrons. Flow will continue until both bodies have an equal number of electrons. This balance is called *equilibrium*.

atom: The smallest particle of an element.

protons: The positively charged particles of an atom.

neutrons: The particles with no charge in the nucleus of an atom.

electrons: Negatively charged particles that orbit the nucleus of an atom.

free electrons: Electrons that are loosely bound to the nucleus of an atom and can easily leave to join other atoms.

conductor: A substance that allows electrons to flow freely through it; an object having good conductivity.

insulators: Substances that prevent electrons from flowing freely.

current: The flow of electrons.

equilibrium: When two connected bodies have the same number of electrons; a balanced condition.

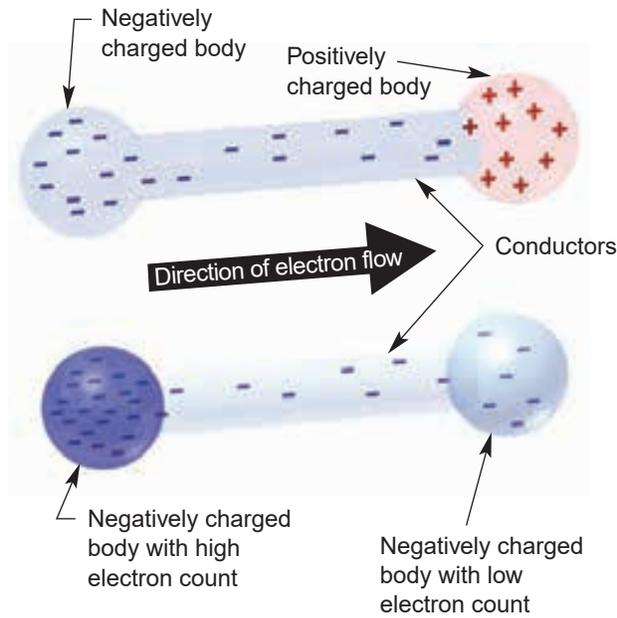


Figure 2-2. Electrons will move from a body with an excess of electrons to a body with fewer or no electrons, provided there is a path (conductor).

Electrical potential is the ability to provide free electrons. Bodies with different concentrations of free electrons are said to be at different potentials. In electricity, differences in potential are measured in units called *volts (V)*.

Types of Electric Current

There are two types of electric current, depending on the direction of the current flow. The first type is called **direct current (dc)**. In this type, current flows in one direction only. Direct current is used in battery-operated devices, such as radios, flashlights, and automobiles.

The second type of current, **alternating current (ac)**, continually reverses the direction of flow. This constant change in direction is represented by a sine wave, **Figure 2-3**. In the United States, the standard current is 60 *cycles*, also known as 60 *hertz* (60 Hz). Hertz is a term for frequency meaning “cycles per second.” The cycles occur at a frequency of 60 hertz. Thus, there are 60 complete cycles in every second. Notice that the direction changes twice in each cycle. This means that the current reverses its direction 120 times each second. This happens so rapidly that the changes generally cannot be

electrical potential: The ability to provide free electrons.

direct current (dc): A current that always flows in one direction.

alternating current (ac): A periodic current that continuously reverses direction.

cycles: A cycle is one complete repetition of a waveform or signal. The rate at which the signal repeats itself is expressed in cycles per second, or hertz.

Hertz (Hz): A unit of frequency that equals one cycle per second. Named after Heinrich Hertz.

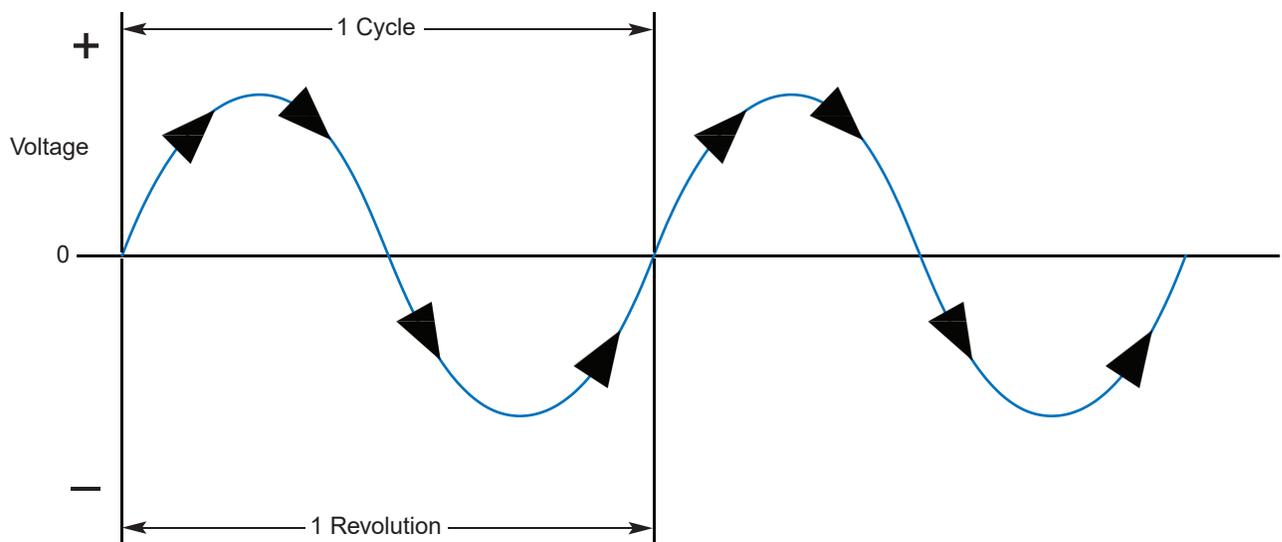


Figure 2-3. A cycle of alternating current is created by one complete revolution of the alternator.

History Brief

Evolution of Electrical Standards

North American electric systems did not use 120 volts ac (VAC) and 60 Hz in their early days. Thomas Edison was using and promoting dc power in his early electric distribution systems. There were problems with dc, however. It was not very easy to change the voltage, so transmitting more power meant higher current in the wires. The current became so high that wires were actually melting from being overloaded. Due to the high current, there were large losses due to voltage drop over short distances. It was also very inconvenient to use devices that required different voltages.

Nikola Tesla championed the use of ac systems. It was easy to change the voltage, so large amounts of power could be delivered by increasing the voltage and decreasing the current in the wires. With lower currents, the wires would not overheat and melt. Losses due to voltage drop were greatly reduced, meaning that electricity could be transmitted over much longer distances. Tesla had the backing of George Westinghouse, who also had the financial backing of John Jacob Astor and J. P. Morgan.

Edison tried to prove how unsafe the ac system was by holding public electrocutions of animals, including Topsy the Elephant. He went so far as to have two of his employees invent the electric chair to demonstrate how effective ac was at killing people. Ultimately, the Westinghouse ac system won the battle based on its technical superiority, and Edison's General Electric Company changed from dc to ac.

It is less clear how the frequency of 60 Hz was adopted, but it seems that it was a high enough frequency that the human eye could not see lightbulbs flickering at 60 Hz. Tesla had calculated that 60 Hz was the most effective frequency, but his early systems were originally 240 V. Other countries adopted 50 Hz because it was still too fast to see the flicker and it matched the 1 2 5 10 standard popular with the "metric countries."

detected, not even as flicker in an electric light. Various cycles and voltages have become the standard in different areas of the world.

Sources of Electrical Energy

To maintain a flow of electrons or electricity, it is necessary to have a source that is always at a greater electrical potential. That is, it always has an excess of free electrons that are ready to move along a conductor to where the electrical potential is less. The energy may be produced chemically, as with a battery, or mechanically, as with a generator.

Battery

A basic chemical device for providing electrical power is the voltaic cell. **Figure 2-4** shows a simplified cell made up of two metal plates suspended in a mild acid solution. The plates react chemically with the acid. Electrons on the surface of the copper plate are stripped away and travel to the zinc plate. Then the copper plate has fewer electrons and is positively charged. The copper plate becomes the positive pole, or *anode*. The zinc plate has excess electrons and becomes the negative pole, or *cathode*.

It is common practice to group a number of cells in a single container. See **Figure 2-5**. A group of cells is called a *battery*. A *wet cell* battery uses a liquid chemical. A *dry cell* battery uses a somewhat dry chemical paste. The liquid or paste is called an *electrolyte*. When the battery is connected to a circuit, current will flow through the circuit from the cathode to the anode.

Generator

A battery is just one of the ways to generate and drive an electrical current. A second method is with a generator. Driven by some mechanical

anode: The positive terminal of a battery.

cathode: The negative terminal of a battery.

battery: A group of voltaic cells that are connected in series or parallel, usually contained in one case.

wet cell: A battery that uses a liquid electrolyte.

dry cell: A battery that uses a chemical paste electrolyte.

electrolyte: The chemical that is a liquid or paste that allows the flow of electrons in a battery.

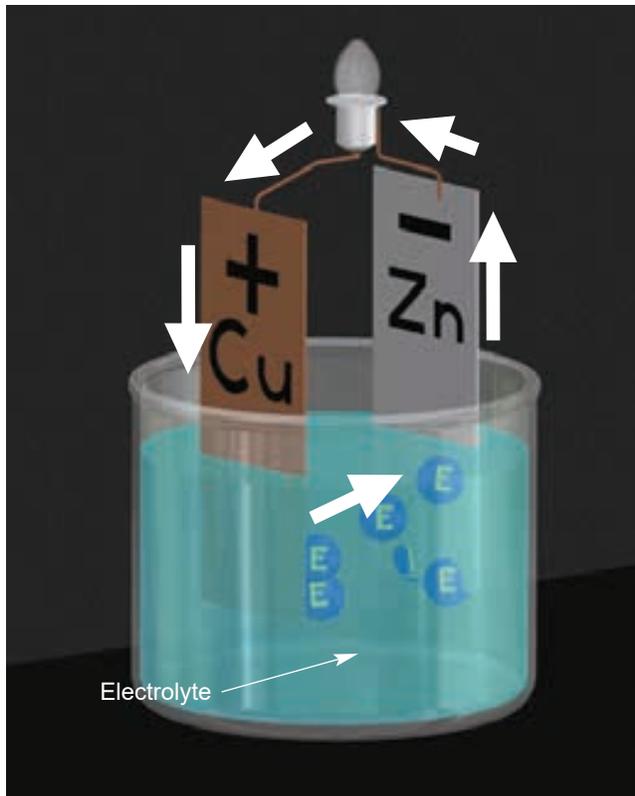


Figure 2-4. A simple wet cell can store electricity as a chemical solution. One electrode is made from copper and the other from zinc. Conductors and a lightbulb complete this simple circuit.

force, a *generator* is a device that creates differences in electrical potential between two electrical poles. It moves electrons from one terminal and deposits them on the other terminal. This is accomplished through electromagnetic induction. This process will be explained later as we discuss generators and alternators.

Measuring Electricity

Measuring electricity is essentially finding out how much, how fast, and with what force the electricity flows through a conductor. The terms or units used to measure electricity are amperage, voltage, resistance, and wattage. The full definition of these terms is vital not only to measuring electricity but to understanding its very nature.

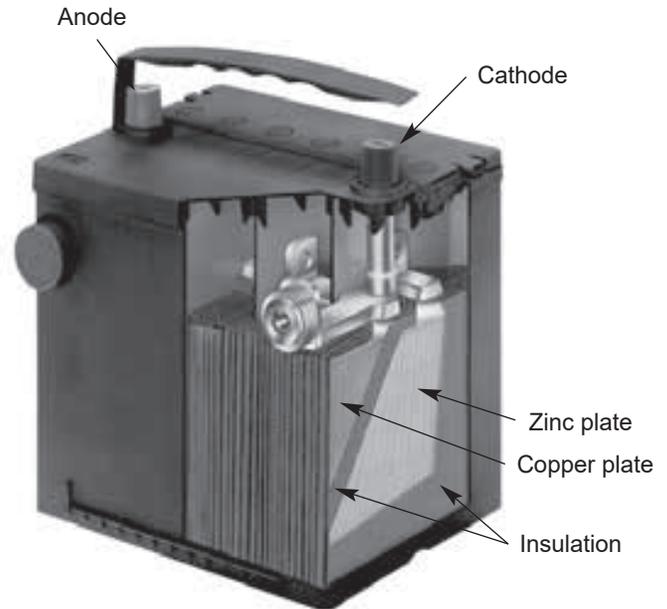


Figure 2-5. A group of wet cells connected electrically and suspended in electrolyte is called a battery. Batteries can supply a steady current of electricity. (East Penn Manufacturing Co., Inc., manufacturer of Deka Batteries, Lyon Station, PA)

Current

The flow of electricity, as you have learned, is called current. The rate of this flow is known as *amperage* (represented in equations by the letter I). The *ampere* (A), or amp, is the unit used when measuring current. The equipment where electricity enters a house is usually rated at 100 A or 200 A.

Voltage

The pressure (electrical potential) that moves electrons through a conductor is called voltage or *electromotive force* (E or *emf*). Its

generator: A device that uses electromagnetic induction to convert mechanical energy to electrical energy.

amperage: The measurement of the rate of flow of electrons.

ampere (A): The unit used in measuring amperage or current. Abbreviated as amp (plural amps). Named after André-Marie Ampère.

electromotive force (E or *emf*): The force that causes current to flow between two objects with different electrical potential.

unit of measure is the *volt (V)*. Most residential wiring is rated at 120 volts and 240 volts.

Resistance

The opposition to the flow of electrons through a conductor is called *resistance (R)* and is similar to friction. This electrical resistance is measured in units called *ohms (Ω)*. Like other forms of friction, resistance is responsible for creating heat and consequent loss of power. All devices that use electric power are forms of resistance.

Power

Power (P) is the rate of doing work and, in electricity, is measured in *watts (W)* or *volt-amperes (VA)*. Power determines how fast a certain amount of work can be done, or determines how fast a certain amount of *energy* is consumed by a load. Watts are relatively small units, and we often speak in terms of kilowatts (1,000 watts) and megawatts (1,000,000 watts).

Work

Work is a measure of how much power is applied (or consumed) over a period of time. Work is measured in *joules (J)*. One joule is one

watt-second. Electrical energy in particular is measured in power-time units called watt-hours or *kilowatt-hours (kWh)*. One kilowatt-hour is equivalent to 1,000 watts (power) being used for one hour (time). **Figure 2-6** is a summary of these electrical terms.

volt (V): The units of measurement of electromotive force caused by the difference in potential between two bodies. Named after Alessandro Volta.

resistance (R): The opposition to the flow of electrons through a conductor.

ohms (Ω): The units of measurement used to express resistance. Named after Georg Simon Ohm.

power (P): The rate of doing work. Electric power is measured in watts or volt-amperes.

watts (W): The units of measurement used in expressing power delivered to or consumed by an electrical device. Named after James Watt.

volt-amperes (VA): Very simply, volts multiplied by amps. The amount of power an electric system can provide or the amount of power an electrical device requires. Equivalent to watts in simple systems. Abbreviated as volt-amps.

energy: The ability to do work.

work: The process of changing energy from one form to another, or causing an object to gain or lose energy.

joules (J): A unit of electrical power. One joule equals one watt-second. Named after James Prescott Joule.

kilowatt-hours (kWh): A unit of electrical power. One kilowatt-hour is the equivalent of 1,000 watts being used for a 1-hour period.

Electrical Units and Measurements				
Electrical Property	Property Abbreviation	Measurement Units	Units Abbreviation	Named After
Electromotive Force or Potential or Voltage	EMF or E (do not confuse with energy)	Volts	V	Alessandro Volta
Current or Amperage	I	Amperes (Amps)	A	André-Marie Ampère
Resistance	R	Ohms	Ω	Georg Simon Ohm
Power or Wattage	P	Watts	W	James Watt
Energy or Work	E or W	Joules or Kilowatt-hour	J or kWh	James Prescott Joule

Figure 2-6. Nearly all units used to measure electrical properties are named after persons who made significant contributions in electrical research and discovery. There are many more electrical properties than those shown here. These are just the basic building blocks that are discussed in this chapter.

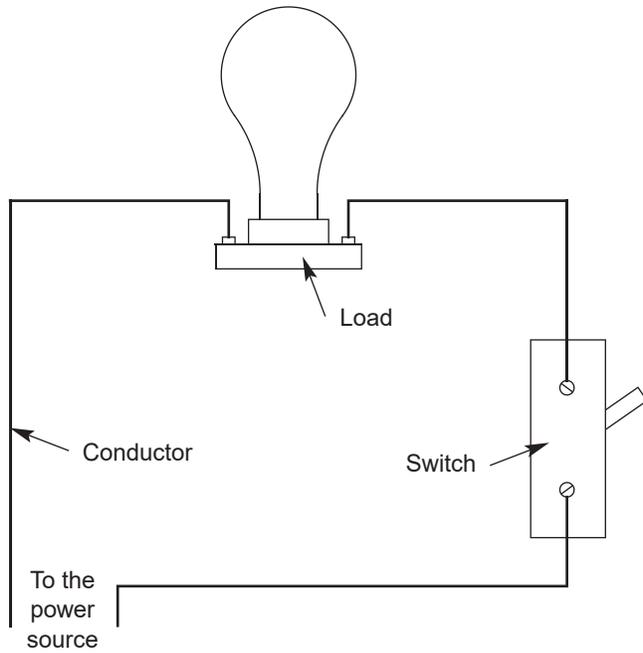


Figure 2-7. A simple electrical circuit includes a pathway (conductors), power source, load (light), and a switch.

Circuits

No electron flow will occur unless there is a pathway in which the electrons can move. In a water system, the pathway is the piping, which moves the water from storage to where it is used. In electrical devices, wires form the pathway, which is called a *circuit*, **Figure 2-7**. The circuit allows the electrons to flow through its conductors as long as the power source supplies electricity. A simple circuit consists of the following elements:

- **Power source.** For a residence, the power source could be considered the electrical generating stations. However, primary sources include small generators and batteries.
- **Conductors.** Wires provide a path for the current to travel.

circuit: The pathway over which electrons can move.

series circuit: A circuit having a single path for current flow.

- **Loads.** These are devices through which the electricity produces work.
- **Devices for controlling current.** These devices include switches, fuses, and circuit breakers.

Types of Circuits

The two basic types of electrical circuits are called series and parallel. A third, called a complex circuit, is a combination of these two.

Series circuit

In a *series circuit*, only one path is provided for the current to flow. The electricity flows through every device in the circuit. If one device is burned out, the circuit will not function. **Figure 2-8** is a simple diagram of a series circuit.

Apart from switches and fuses or circuit breakers that are used to control the flow of electricity, series circuitry is not practical for residential wiring. A simple example will explain why. Older Christmas tree lights were often wired in series. Current had to pass through every lightbulb for the string of lights to work. If one bulb burned out, all the lights went out. Finding the defective bulb was a trial-and-error

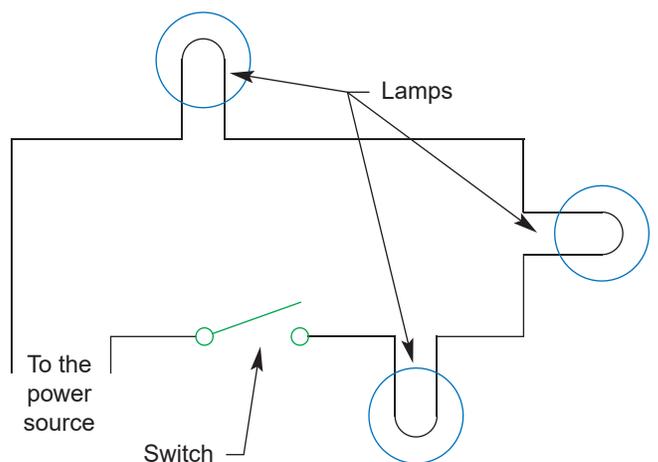


Figure 2-8. Simple diagram of a series circuit. The three lights are wired into the circuit so that if one were not working, the circuit would be open and all lights would go out.

operation. Each bulb had to be removed and tested. Residential circuits are set up so that a nonfunctioning load will not stop electrical current in the remainder of the circuit.

Parallel circuit

The *parallel circuit* has more than one path available for the current to flow, **Figure 2-9**. Like the series circuit, the parallel circuit has a complete path for the current to follow. Each path goes to a load that can operate independently of the other branches and loads in the circuit. If one load, such as a lamp, burns out, the other branches would continue to operate since a path still exists from one supply terminal through the circuit to the other supply terminal.

Under normal conditions, another advantage of parallel circuits is that the current draw of each branch affects only that branch. In a series circuit, current draw in one load affects the rest of the loads on the circuit. Loads such as lamps, heaters, or motors might not operate properly in a series circuit. Except for switches, fuses, and circuit breakers, all residential wiring is done in parallel.

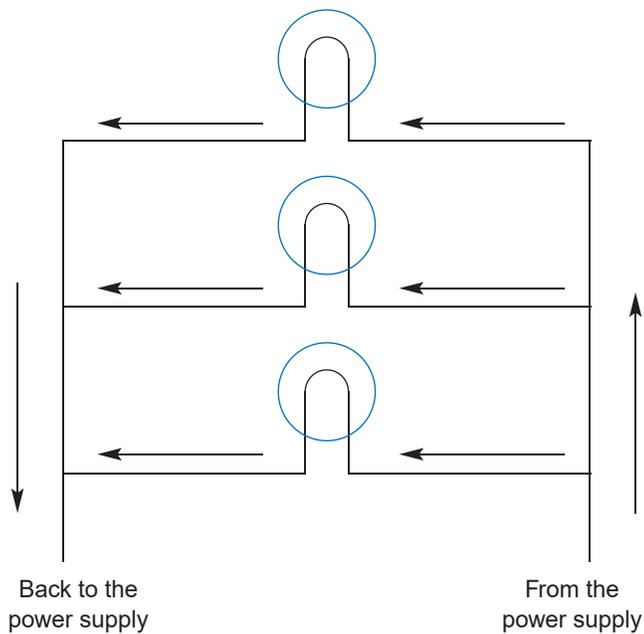


Figure 2-9. Parallel circuit diagram. Note that each lamp is on its own electrical path. Should one burn out when the circuit is closed, the others would remain lit.

Loads

In electrical systems, a *load* is any device that uses an electric current and converts the energy to another form. Loads include:

- Lamps and lightbulbs (convert electrical energy to light)
- Electric furnaces and space heaters (convert electrical energy to heat)
- Power tools and motor-driven appliances (convert electrical energy to mechanical energy)
- Radios, televisions, and other electronic devices (convert electrical energy to sound)

Each load is designed to operate at a specific voltage. A voltage rating is given with every device. It is important that the device be operated at its rating. Otherwise, the device can be damaged or destroyed. In some cases the entire circuit can be damaged. This is an important reason series circuits are not used in residential wiring.

Circuit Fundamentals

Electrical circuits consist of a source of electromotive force and one or more complete pathways of electron flow. Both dc and ac circuits require a definite pathway to be useful. A circuit normally consists of a power source, protective devices (fuses or circuit breakers), one or more loads, a switching device, and conductors.

Electrical Resistance— Ohm's Law

To understand circuit theory you must understand electrical resistance. Without it, electrical current could create neither heat nor light.

parallel circuit: A circuit with multiple paths available for current flow.

load: Device that converts electricity into another form of energy.

Georg Simon Ohm first explored resistance in 1827. He expressed the relationship between current, voltage, and resistance: *Current in a circuit is directly proportional to the voltage applied to the circuit and is inversely proportional to the resistance of the circuit.* This statement is called **Ohm's law**. This law can be applied to the entire circuit or to any part of the circuit.

Mathematically, the law takes the following form:

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

I is the current measured in amperes. E is the voltage or emf (electromotive force) measured in volts. R is the resistance measured in ohms.

Electrical Power— Basic Power Formula

A load in an electrical circuit consumes energy. The rate at which it consumes energy is called **power**. The relationship between power, voltage, and current was established by James Watt and is called the **basic power formula**, also known as **Watt's law**. It states that:

$$P = I \times E$$

where P is power measured in watts, I is current measured in amps, and E is emf measured in volts.

Series Circuits

A series circuit has only one loop or path. When devices such as resistors are in series, they are placed one after another so that the current flows through all of them in succession. The three resistors illustrated in **Figure 2-10** are in series arrangement.

Ohm's law: The law that states the relationship between voltage, resistance, and current.

Watt's law: The law that states the relationship between power, voltage, and current.

Series circuit rules

Series circuits follow certain rules that may be summarized as follows:

- Total resistance (R_T) is the sum of the individual resistances. Therefore, the total resistance of the series circuit in Figure 2-10 is:

$$\begin{aligned} R_T &= R_A + R_B + R_C \\ &= 1 \Omega + 2 \Omega + 3 \Omega \\ &= 6 \Omega \end{aligned}$$

- The current (amperage) of a series circuit is the same throughout. Thus, the total current (I_T) of the circuit is the same as the current running through each load. By applying Ohm's law, we can find the current in Figure 2-10:

$$I_T = I_A = I_B = I_C$$

$$I_T = \frac{E}{R_T}$$

$$= \frac{6 \text{ V}}{6 \Omega}$$

$$= 1 \text{ A}$$

Therefore, 1 A is not only the total amperage, but also the amperage flowing through each of the resistors.

- The total voltage at the source (V_T) is equal to the sum of the voltages at each of the resistances. The voltage at each load is calculated

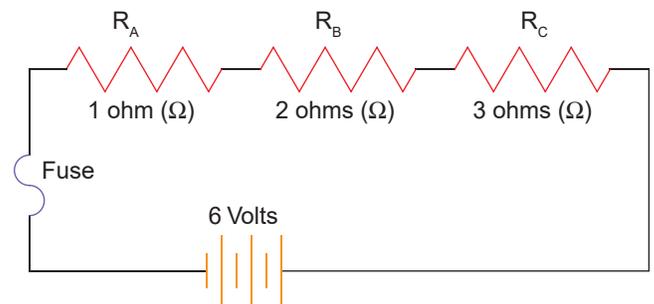


Figure 2-10. A simple series circuit. It has three resistors connected to form a single loop.

using Ohm's law:

Voltage of Resistor A =
Amperage A × Resistance A

$$\begin{aligned} E_A &= I_A \times R_A \\ &= 1 \text{ A} \times 1 \ \Omega \\ &= 1 \text{ V} \end{aligned}$$

Voltage of Resistor B =
Amperage B × Resistance B

$$\begin{aligned} E_B &= I_B \times R_B \\ &= 1 \text{ A} \times 2 \ \Omega \\ &= 2 \text{ V} \end{aligned}$$

Voltage of Resistor C =
Amperage C × Resistance C

$$\begin{aligned} E_C &= I_C \times R_C \\ &= 1 \text{ A} \times 3 \ \Omega \\ &= 3 \text{ V} \end{aligned}$$

The total voltage (E_T) can then be calculated by adding the voltages for all loads:

$$\begin{aligned} E_T &= V_A + V_B + V_C \\ &= 1 \text{ V} + 2 \text{ V} + 3 \text{ V} \\ &= 6 \text{ V} \end{aligned}$$

- A break anywhere in the circuit stops the electron flow in the entire circuit. This is the main disadvantage of series circuits.
- Ohm's law applies to any part of the entire series circuit.

Example: Using the circuit shown in **Figure 2-11**, find:

- The total resistance, R_T .
- The total current at the source, I_T .
- The voltages of resistors 1 and 3, E_1 and E_3 .

Solution:

- Add the individual resistances to find the total resistance, R_T :

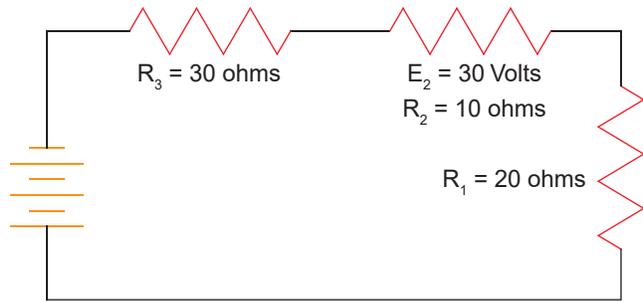


Figure 2-11. In this series circuit, find total resistance, total amperage, and voltage at two resistors.

$$\begin{aligned} R_T &= R_1 + R_2 + R_3 \\ &= 20 \ \Omega + 10 \ \Omega + 30 \ \Omega \\ &= 60 \ \Omega \end{aligned}$$

- The current in a series circuit is constant. Therefore, the total current (I_T) equals the current at resistor 2 (I_2). The current at resistor 2 can be found using Ohm's law:

$$\begin{aligned} I_T &= I_2 = \frac{E_2}{R_2} \\ &= 30 \text{ V} / 10 \ \Omega \\ &= 3 \text{ A} \end{aligned}$$

- The current through each resistor is equal to the total current (3A). Use Ohm's law to calculate the voltage at resistors 1 and 3:

$$\begin{aligned} E_1 &= I_1 \times R_1 \\ &= 3 \text{ A} \times 20 \ \Omega \\ &= 60 \text{ V} \end{aligned}$$

$$\begin{aligned} E_3 &= I_3 \times R_3 \\ &= 3 \text{ A} \times 30 \ \Omega \\ &= 90 \text{ V} \end{aligned}$$

You can also check to see if the total voltage is equal to the sum of the individual voltages:

$$\begin{aligned}
 E_T &= I_T \times R_T \\
 &= 3 \text{ A} \times 60 \Omega \\
 &= 180 \text{ V}
 \end{aligned}$$

$$\begin{aligned}
 E_T &= V_1 + V_2 + V_3 \\
 &= 60 \text{ V} + 30 \text{ V} + 90 \text{ V} \\
 &= 180 \text{ V}
 \end{aligned}$$

Parallel Circuits

As you learned earlier, a parallel circuit is an electrical circuit having two or more different conducting pathways. The term parallel, in electricity, does not necessarily mean physically or geometrically parallel, but simply alternate routes. Each of these alternate routes is called a *branch*. Parallel circuits are more commonly used in electrical circuitry for reasons that will become clear as we go on. **Figure 2-12** shows a simple parallel circuit containing three resistors. Arrows indicate the electron flow.

Parallel circuit rules

Like series circuits, parallel circuits follow certain rules:

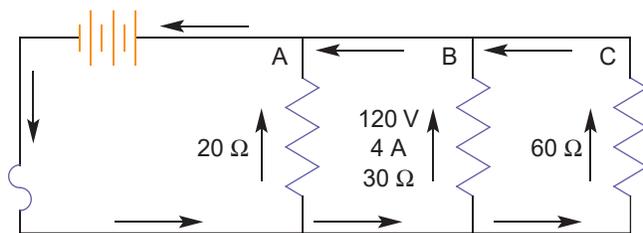


Figure 2-12. Parallel circuits provide numerous alternate routes for the electrons to follow. These routes are called branches.

branch: One of the pathways in a parallel circuit.

- A break or opening in any branch of a parallel circuit does not stop the flow of electrons to the remaining branches.
- The voltages across all branches of a parallel circuit are the same, and are equal to the voltage at the source. In Figure 2-12, the voltage in branch B is 120 V. Therefore, the total voltage and the voltage in branches A and C are also 120 V. Mathematically:

Source voltage = branch A voltage =
branch B voltage = branch C voltage

$$\begin{aligned}
 E_T &= V_A = V_B = V_C \\
 &= 120 \text{ V}
 \end{aligned}$$

- Ohm's law applies equally well to the total circuit or any of the loops or branches:

$$\begin{aligned}
 I_A &= \frac{E_A}{R_A} \\
 &= \frac{120 \text{ V}}{20 \Omega} \\
 &= 6 \text{ A}
 \end{aligned}$$

$$\begin{aligned}
 I_C &= \frac{E_C}{R_C} \\
 &= \frac{120 \text{ V}}{60 \Omega} \\
 &= 2 \text{ A}
 \end{aligned}$$

- The total current (I_T) is equal to the sum of the currents flowing through each of the branches. For Figure 2-12:

$$\begin{aligned}
 I_T &= I_A + I_B + I_C \\
 &= 6 \text{ A} + 4 \text{ A} + 2 \text{ A} \\
 &= 12 \text{ A}
 \end{aligned}$$

- The total resistance in a parallel circuit is the reciprocal of the sum of the reciprocals

of the separate resistances in parallel. Now, before throwing up our hands, let us look at this mathematically:

$$\frac{1}{R} \text{ total} = \frac{1}{R} \text{ branch A} + \frac{1}{R} \text{ branch B} + \frac{1}{R} \text{ branch C}$$

$$\frac{1}{R_T} = \frac{1}{R_A} + \frac{1}{R_B} + \frac{1}{R_C} \text{ which can be written as:}$$

$$R_T = \frac{1}{\left(\frac{1}{R_A} + \frac{1}{R_B} + \frac{1}{R_C}\right)}$$

Now use the resistance information from the circuit in Figure 2-12:

$$\frac{1}{R_T} = \frac{1}{20 \Omega} + \frac{1}{30 \Omega} + \frac{1}{60 \Omega}$$

Find a common denominator:

$$\frac{1}{R_T} = \frac{3}{60 \Omega} + \frac{2}{60 \Omega} + \frac{1}{60 \Omega}$$

$$\frac{1}{R_T} = \frac{6}{60 \Omega}$$

$$\frac{R_T}{1} = \frac{60 \Omega}{6}$$

$$R_T = 10 \Omega$$

Series-Parallel Combination Circuits

Practical circuits, for the most part, are far more difficult than those just outlined. Quite often, loads in a particular circuit are designed in both series and parallel configurations. When loads are arranged both ways in a single circuit, the circuit is called a *complex circuit*. An example of this type is shown in **Figure 2-13**. We will use this circuit to show the steps taken to simplify a complex circuit.

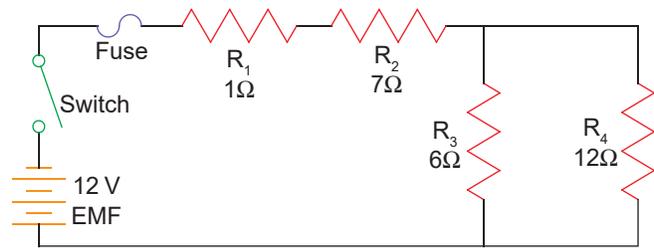


Figure 2-13. A complex circuit uses the advantages of both series and parallel circuits.

In the circuit shown, the source voltage is 12 V. The resistance of each component resistor is also given. First, we need to find the total resistance. To do this we must reduce the parallel resistances into an equivalent single resistance (R_{eq}) and add this resistance to the resistances arranged in series.

Equivalent resistance from parallel portion:

$$\begin{aligned} \frac{1}{R_{eq}} &= \frac{1}{R_3} + \frac{1}{R_4} \\ &= \frac{1}{6 \Omega} + \frac{1}{12 \Omega} \\ &= \frac{2}{12 \Omega} + \frac{1}{12 \Omega} \\ &= \frac{3}{12 \Omega} \\ \frac{R_{eq}}{1} &= \frac{12 \Omega}{3} \\ R_{eq} &= 4 \Omega \end{aligned}$$

We may draw a simpler equivalent circuit showing the equivalent resistance in series with R_1 and R_2 . See **Figure 2-14**. Now add this resistance to resistors 1 and 2 to find the total resistance:

$$\begin{aligned} R_T &= R_{eq} + R_1 + R_2 \\ &= 4 \Omega + 1 \Omega + 7 \Omega \\ &= 12 \Omega \end{aligned}$$

complex circuit: A combination of series and parallel circuits.

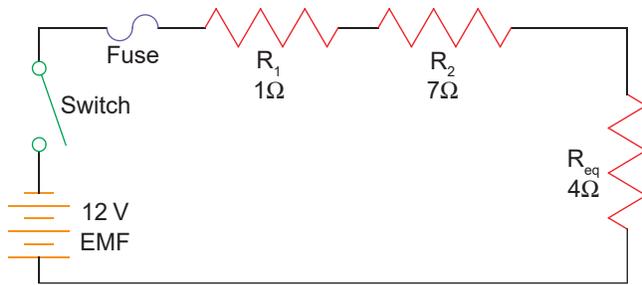


Figure 2-14. An equivalent circuit of Figure 2-13. R_3 and R_4 have been reduced to one resistance, R_{eq} .

Having found the total resistance, and given the total voltage, we can find the total current through the circuit using Ohm's law:

$$\begin{aligned} I_T &= \frac{E_T}{R_T} \\ &= \frac{12 \text{ V}}{12 \Omega} \\ &= 1 \text{ A} \end{aligned}$$

Next, find the voltages across each of the resistors. Since resistor 1, resistor 2, and the "equivalent resistor" are in series, the current at each resistor is the same as the total current (1 A). Using Ohm's law to calculate the voltage at resistors 1 and 2 and the voltage across the "equivalent resistance."

$$\begin{aligned} E_1 &= I_1 \times R_1 \\ &= 1 \text{ A} \times 1 \Omega \\ &= 1 \text{ V} \end{aligned}$$

$$\begin{aligned} E_2 &= I_2 \times R_2 \\ &= 1 \text{ A} \times 7 \Omega \\ &= 7 \text{ V} \end{aligned}$$

$$\begin{aligned} E_{eq} &= I_T \times R_{eq} \\ &= 1 \text{ A} \times 4 \Omega \\ &= 4 \text{ V} \end{aligned}$$

This is verified by the fact that the total voltage is equal to the sum of the various voltages in a series circuit.

All that remains is to find the portion of the total current (1 ampere) that goes through each of the parallel resistors. (Remember, $E_{eq} = E_3 = E_4 = 4 \text{ V}$.)

$$\begin{aligned} I_3 &= \frac{E_3}{R_3} \\ &= \frac{4 \text{ V}}{6 \Omega} \\ &= 0.67 \text{ A} \end{aligned}$$

$$\begin{aligned} I_4 &= \frac{E_3}{R_4} \\ &= \frac{4 \text{ V}}{12 \Omega} \\ &= 0.33 \text{ A} \end{aligned}$$

Again, verification comes from the fact that the total current (1 ampere) is equal to the sum of the current through each branch of the parallel resistors. Thus:

$$1 \text{ A} = 0.67 \text{ A} + 0.33 \text{ A}$$

Considered as a whole, electrical circuits are mostly of the complex type. The source voltage is carried by means of wires across every device, appliance, and branch circuit. These are connected in parallel.

Circuits Summary

Figure 2-15 is a summary of the various circuits discussed in this chapter. **Figure 2-16** is a simple aid to remembering Ohm's law. Simply cover the part you wish to find and you discover what to multiply or divide by. Thus, to find E , multiply R by I . To find R , divide E by I . To find I divide E by R .

Series Circuit—Parallel Circuit Network			
Electrical Property	Series Circuits	Parallel Circuits	Complex Circuits
Resistance (R) Unit: Ohm Symbol: Ω	$R_t = R_1 + R_2 + R_3$ Sum of individual resistances	$\frac{1}{R_t} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$	Total resistance equals resistance of parallel portion and sum of series resistors.
Current (I) Unit: Ampere Symbol: A	$I_t = I_1 = I_2 = I_3$ The same throughout entire circuit	$I_t = I_1 + I_2 + I_3$ Sum of individual currents	Series rules apply to the series portion of the circuit. Parallel rules apply to the parallel portion of the circuit.
Voltage (E) Unit: Volt Symbol: V, E	$E_t = E_1 + E_2 + E_3$ Sum of individual voltages	$E_t = E_1 = E_2 = E_3$ Total voltage and branch voltage are the same	The total voltage is the sum of the voltage drops across each series resistor and each of the branches of parallel portion of the circuit.

Figure 2-15. Characteristics of electrical circuits can be summarized as shown.

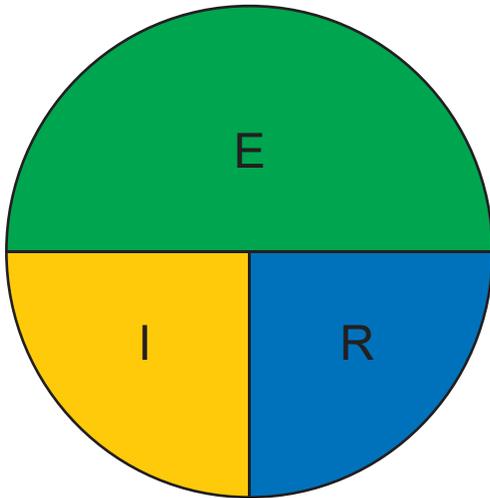


Figure 2-16. This drawing is an easy way to remember the mathematical relationships of Ohm's law. It will tell you when to multiply or divide.

Power and Work

Electrical power is a combination of current and voltage. It is actually current times voltage:

$$P = E \times I$$

Power expresses the rate at which electricity is being consumed regardless of the voltage or the current. For example, a 120 V air conditioner

drawing 10 A of current is using the same amount of power as a 240 V air conditioner that is only drawing 5 A of current. The power in both cases is 1200 W. Power indicates how fast a certain amount of work can be done.

Energy and work are almost the same thing. The work done equals the change in energy. Work (W) is a certain amount of power (P) applied (or consumed) for a certain period of time (t):

$$W = P \times t$$

Substituting $E \times I$ for P :

$$W = E \times I \times t$$

You have a 100 W lightbulb and you leave it turned on for 5 hours. The total power consumed is:

$$\begin{aligned} W &= P \times t \\ &= 100 \text{ W} \times 5 \text{ hrs} \\ &= 500 \text{ watt-hours} \end{aligned}$$

Now you change it to a 250 W lightbulb and you leave it turned on for 2 hours. The total power consumed is:

$$\begin{aligned} W &= P \times t \\ &= 250 \text{ W} \times 2 \text{ hrs} \\ &= 500 \text{ watt-hours} \end{aligned}$$

Both lightbulbs use the same amount of total energy. Because the second lightbulb is more powerful, it is brighter and it uses energy faster.

Electromagnetic Induction

In a battery, chemical action displaces the electrons and produces the current through a conductor. Current can also be produced by using magnetic fields.

Two men working independently discovered they could produce a flow of electrons in a wire by passing the wire through a magnetic field, **Figure 2-17**. Michael Faraday and Joseph Henry discovered *electromagnetic induction*, the process of producing an electromotive force

by varying the magnetic field surrounding a conductor. If you were to fashion the conductor into many loops (a coil), and rotate it between two magnetic poles, you would have a crude generator. See **Figure 2-18**.

The strength of the electron flow in a generator is increased by four factors:

- A greater number of turns (loops) of wire in the coil
- A faster speed of the conducting loop rotation
- An increased strength of the magnets
- Positioning the moving coil at right angles to the magnetic field lines of force (**Figure 2-19**)

electromagnetic induction: The process of producing an electromotive force by varying the magnetic field surrounding a conductor.

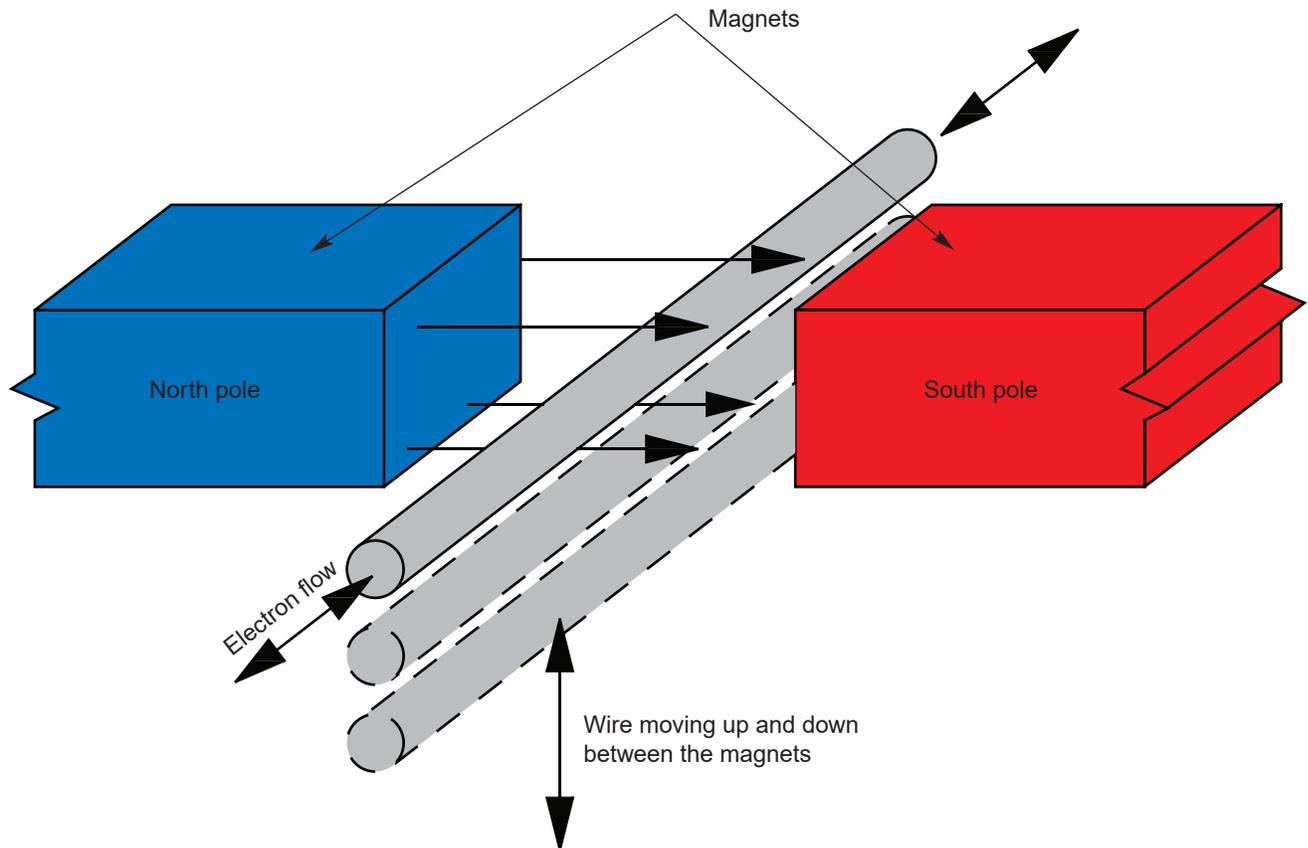


Figure 2-17. Moving a conductor up and down between the poles of a magnet displaces electrons in the conducting wire and causes the electrons to move through the conductor. This event is called electromagnetic induction.

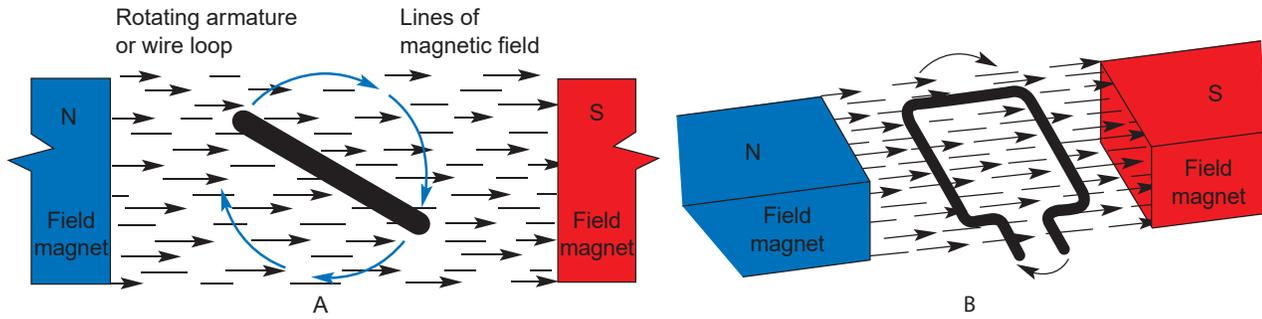


Figure 2-18. A simple generator. The rotating coil of wire has current induced in it as the loop cuts through a magnetic field created between the poles of the magnet. A—Straight-on view of a generator. Voltage would be low with the loop in this position. Wire would be cutting through the field at a sloping angle. B—Perspective view showing loop cutting the magnetic field at a right angle. Voltage is at its highest level at this point.

Generators and Alternators

Alternators, like generators, are rotating machines driven by some mechanical force. They use the electromagnetic induction principle to convert the mechanical force to electrical energy. There are ac generators and dc generators. The ac generator is usually called an alternator.

Direction of induced current

Current from a spinning generator will always move in a specified direction. You can determine this direction by knowing the *left-hand rule* for generators, **Figure 2-20**. Point your thumb, forefinger, and middle finger of the left hand at right angles to each other. According to the rule, the thumb is pointing in the direction the wire is moving, the forefinger is pointing

left-hand rule: A rule for determining the direction of flow in a conductor caused by electromagnetic induction. Also known as *Fleming's rule*.

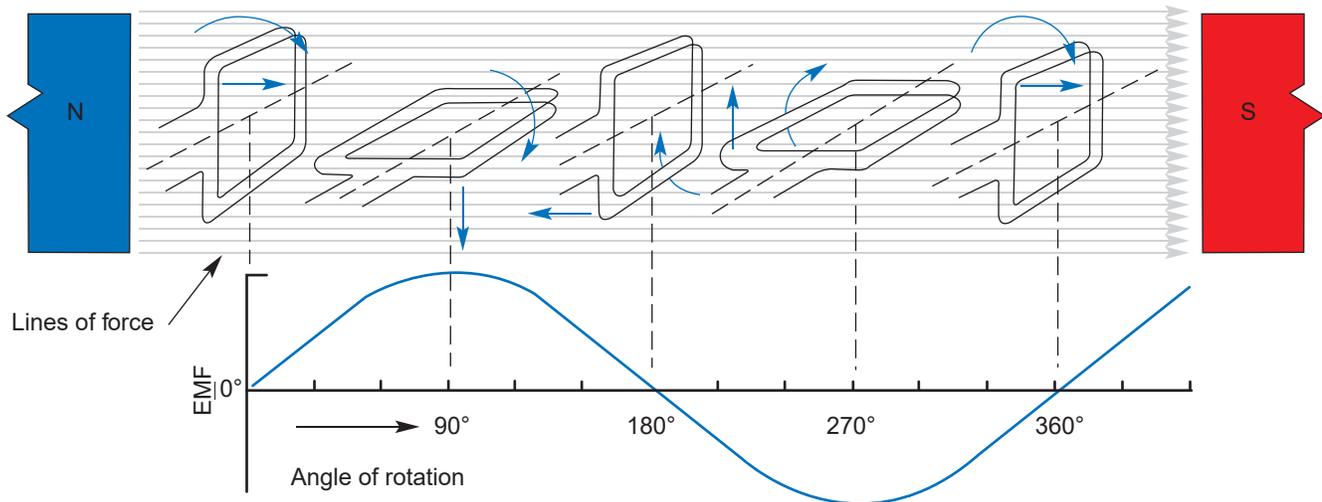


Figure 2-19. Voltage produced by the generator varies. Compare the position of the coil above with the sine wave below. Peaks in wave represent points of highest voltage during one complete rotation cycle.

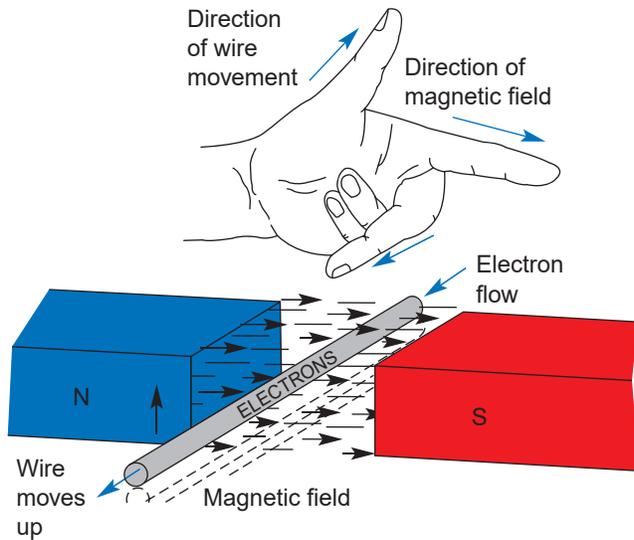


Figure 2-20. Left-hand rule for generators. If a wire is moving in the direction of the thumb and the magnetic field is moving in the direction of the forefinger (north pole to south pole), electric current is flowing in the direction of the middle finger.

in the direction of the magnetic field (north to south), and the middle finger is pointing in the direction of the induced electron flow. This statement is also known as *Fleming's rule*.

Alternating current generator

The ac generator, or alternator, consists of several distinct parts, **Figure 2-21**. Each has a specific function:

- **Coil or armature.** This part rotates. It has the conducting wire that cuts across a magnetic field. The electron flow begins in the coil.
- **Nonmoving magnetic poles.** These poles create the magnetic field. In some generators, the poles are magnetized by a portion of the generated electrical current.
- **Slip rings.** These metal rings are connected to the ends of the coil wires. The slip rings rotate with the coil and transfer the current to the brushes.

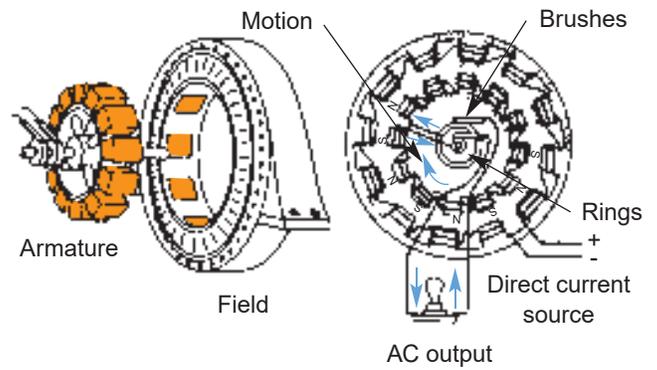


Figure 2-21. A commercial ac generator (alternator) looks much different from the simple sketches you have seen. This unit uses some of the current it produces to magnetize the field.

- **Brushes.** Two brushes are in contact with the slip rings and transfer current from the slip rings to the external circuit. One brush is in contact with each slip ring.

As the armature is turned, it cuts through the magnetic field created by the field magnets. Electrons flow through the wires of the armature. The electrons move into one of the slip rings, then to one of the brushes and, finally, into the external circuit. See **Figure 2-22**.

With every half-turn of the armature, the electron flow reverses, following the left-hand rule. Then the electrons flow out to the external circuit through the opposite slip ring and brush.

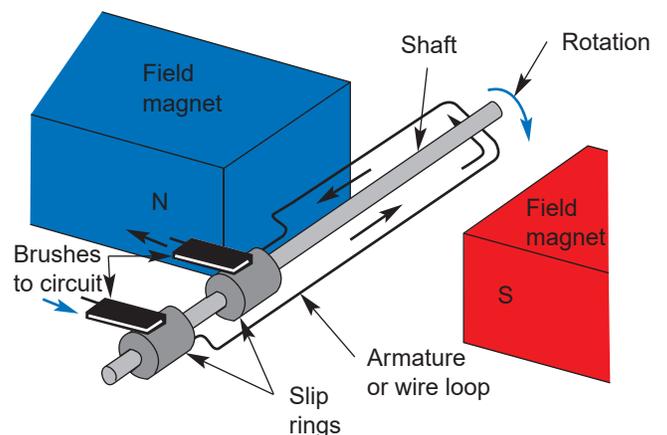


Figure 2-22. Basic elements of an alternator. The wire loop carries induced current. Electrons flow out through one brush, through the circuit, and back in through the other brush.

This creates the reversal of electron flow, which accounts for alternating current. The speed at which the generator is turned determines the frequency of the current. One complete turn is a cycle, and 60 turns each second creates 60 Hz electric current.

Direct current generator

The dc generator is similar in construction to the alternator except that the two slip rings are replaced by a single slip ring with two halves, commonly called a commutator. The two segments of the commutator are connected to the two ends of the armature, **Figure 2-23**, and rotate with it.

As the armature rotates, an alternating current is set up in the coil exactly as in the alternator. However, because the segments of the commutator change brushes every half-turn, the ac of the coil is changed into a pulsating dc in the external circuit, **Figure 2-24**.

Single-Phase and Three-Phase Electricity

An ac generator may produce either single-phase or three-phase electric power. A generator with a single armature coil produces

single-phase power. To produce three-phase power, the generator must have three armature coils.

The coils of a three-phase generator are located exactly 120° apart. During each turn of the rotor, voltage is created at three different intervals. The separate voltages or phases are said to be 120° electrically apart in time, or 120° out of phase.

Power plants generate three-phase power because it is more efficient. The electric power is converted to single-phase for residential use. Three-phase power is supplied to commercial and industrial customers for either of the following reasons. Three-phase power is necessary for high-demand applications and cost-effective where there are many motors. Three-phase motors are simpler, less expensive, and more powerful than single-phase motors.

Electric Motors

Electric motors, **Figure 2-25**, are like generators. They transform one kind of energy to another. While generators convert mechanical energy to electrical energy, electric motors change electrical energy to rotating mechanical energy.

A dc motor is constructed exactly like a dc generator. Rotation takes place when the

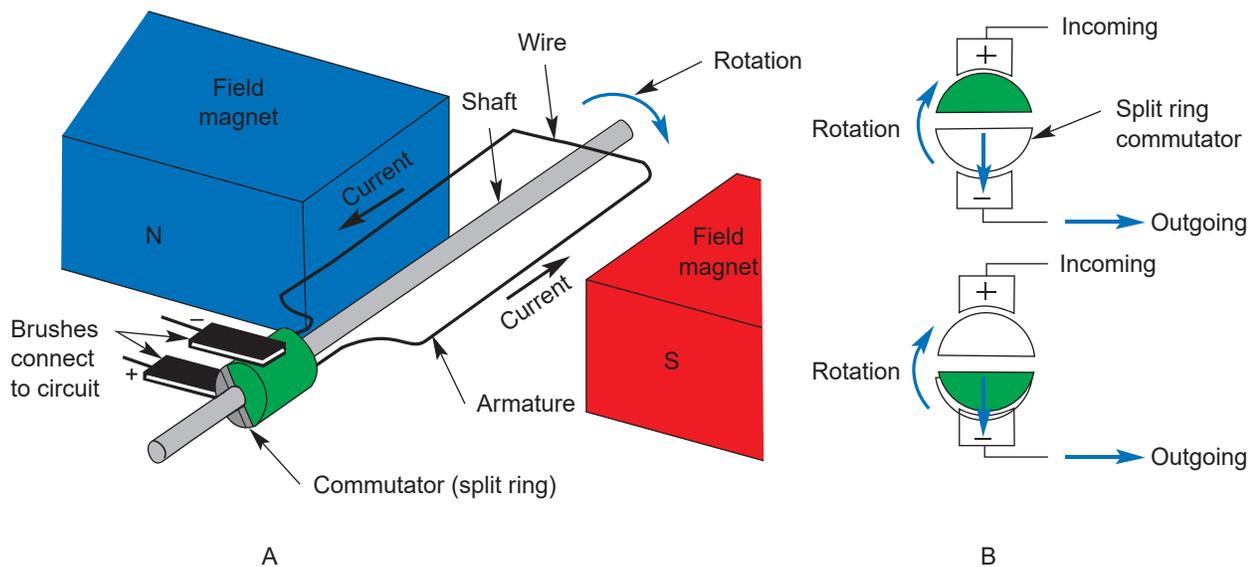


Figure 2-23. If you look at a simple dc generator, you can see why current always flows in the same direction. A—Each end of an armature coil connects to a different half of the commutator. B—As current reverses in the armature, opposite sides of the commutator contact the brushes so current always flows through the brushes in the same direction.

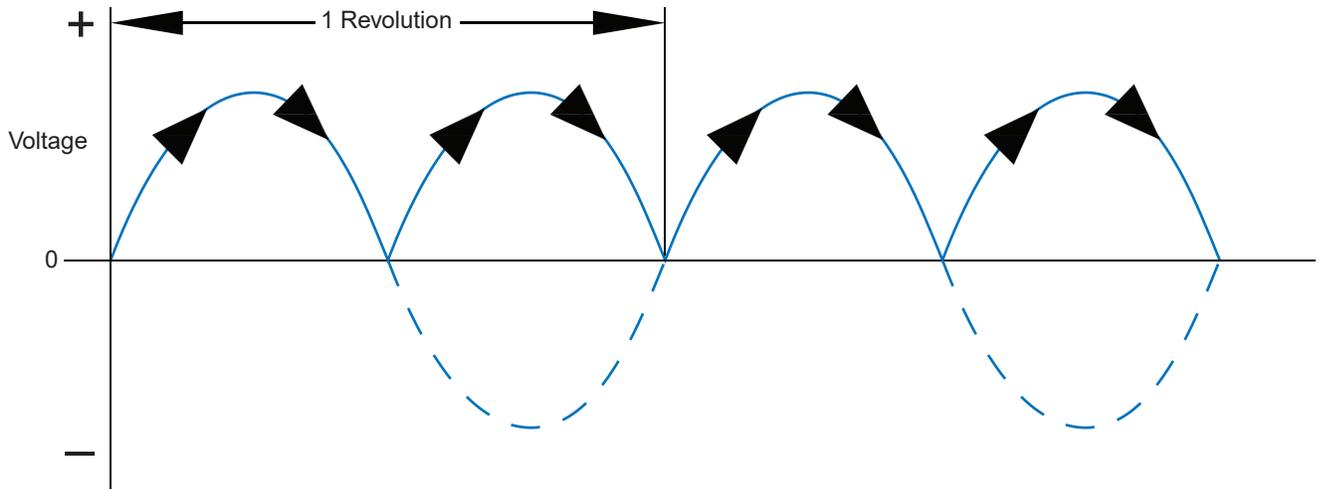


Figure 2-24. Typical dc current pulsates as shown in the wave pattern. The dotted line shows where the sine wave would go if it were alternating current.

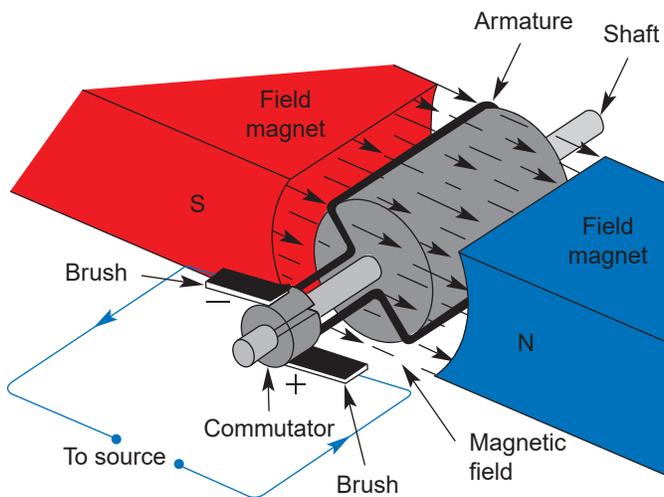


Figure 2-25. A dc motor is constructed in the same way as a dc generator.

polarity of the armature is in opposition to the poles of the field magnet. In other words, like magnetic poles in the motor repel each other to start the rotation. Constant shifting of the magnetic polarity keeps the motor spinning.

AC motors are somewhat different in construction, but their operation is similar. These motors will be discussed in a later chapter.

Transformers

A *transformer* is a device that uses electromagnetic induction to change the voltage as it transfers electrical energy from one circuit to another. Basically, a transformer is made up of two coils of wire wrapped around an iron core, **Figure 2-26**. There is no connection between the two coils of wire. Each is linked to a different circuit. These coils are commonly known as *windings*.

The coil that is connected to the power source side of a transformer is called the *primary winding*. The coil connected to the load side is

transformer: A device that transfers electrical energy from one circuit to another, usually at a different voltage, through electromagnetic induction.

windings: The coils of wire in an electrical device. Windings are used in generators, motors, and transformers.

primary winding: The winding of a transformer that creates a magnetic field and is connected to the power source side.

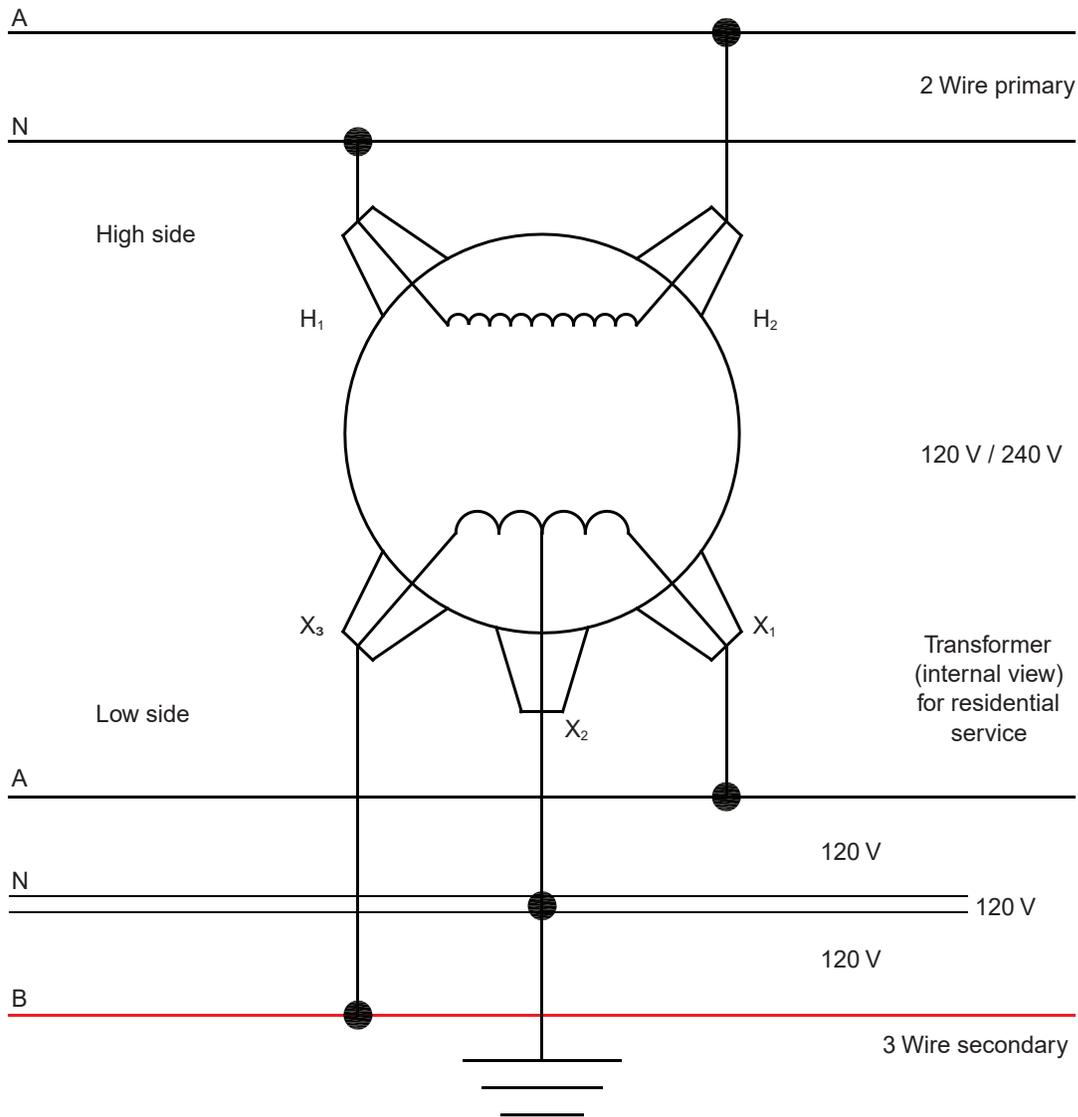


Figure 2-26. Simple diagram of a transformer. The coil of wire on the primary side creates a magnetic field. A current is induced in the secondary coil at a different voltage.

called the *secondary winding*. The current in the primary winding creates a magnetic field that induces current in the secondary winding.

Voltage out of a transformer is directly related to the number of turns of wire in the windings. If there are more turns in the secondary winding than in the primary, the voltage out will be greater than the voltage in. Such a transformer is called a *step-up transformer* because the voltage steps up, or increases, from the primary to the secondary. In fact, the change in voltage from primary to secondary is directly proportional to the change in number of wire turns.

$$V_{out} = \frac{V_{in} \times N_{sec}}{N_{pri}}$$

Suppose that the incoming electrical power is at 110 volts on a transformer that has 100

secondary winding: The transformer winding connected to the load.

step-up transformer: A transformer that steps up, or increases, the voltage exiting the transformer.

turns on the primary coil and 600 turns on the secondary coil. The secondary has six times as many turns as the primary. Therefore, the output voltage will be six times greater.

$$V_{out} = 110 \text{ V} \times \frac{600}{100}$$

$$V_{out} = 660 \text{ V}$$

In a *step-down transformer*, the secondary coil has fewer turns than the primary coil. Therefore, the output voltage is less than the input voltage.

Electrical System Overview

Electricity is generated at large power stations. These stations have huge generators that are spun by a turbine. High-pressure steam causes the turbine to spin by blowing past the

turbine blades. A turbine looks like dozens of fans all connected to the same shaft. If you think of the wind causing a windmill to turn, then you have the right idea. The steam is produced by boiling water in a boiler. The heat for the boiler can come from many sources. Natural gas, coal, oil, and uranium (nuclear fuel) are the most common sources.

Most electrical power is generated at 24,000 V and is stepped up to 132,000 V, 238,000 V, or 345,000 V at the power station. The electricity is sent out to substations over high-voltage cable. See **Figure 2-27**. A *substation* is a collection of transformers, located away from the power station, that lowers the voltage of the electrical power and redistributes it along another set of conductors (distribution lines). Before being brought into homes, the voltage is further reduced to 120 V and 240 V, **Figure 2-28**.

step-down transformer: A transformer that steps down, or decreases, the voltage exiting the transformer.

substation: A collection of transformers that changes the voltage of the electrical power and redistributes it along another set of conductors.

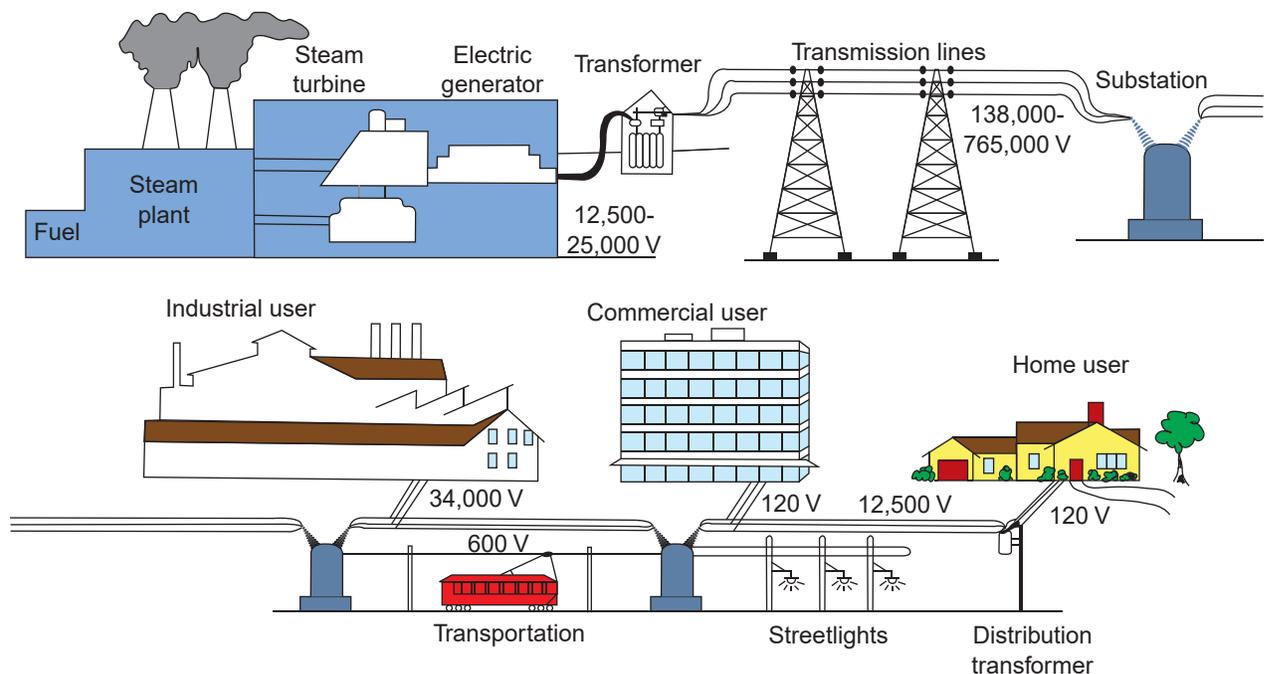


Figure 2-27. Electric power used in residences is generated in power stations and transmitted over long distances through high-voltage lines. Before it is brought into a house, voltage is reduced to 240 or 120 volts.



Figure 2-28. A 240/120 V step-down transformer. This type of transformer is used to reduce voltage to levels that can be used in houses. This transformer is rated at 37.5 kVA or 37.5 kW.

From the point of generation up to the service transformer, the power is all three-phase power. Your service transformer is connected to one of the three phases, while your neighbors' transformers are connected to other phases. The houses are split up among the different phases in order to keep the load on each phase balanced.

The power enters your house through the *service entrance*, which is where the electric meter is located. The electric meter records the amount of power you use each month. The electric company reads the meter every month, and charges you for the amount of energy used.

After passing through the electric meter, the power passes through the main disconnect switch or panel. This is where the power is divided up into branch circuits for the different parts of your house. The panel contains circuit breakers, which will shut off the power if a

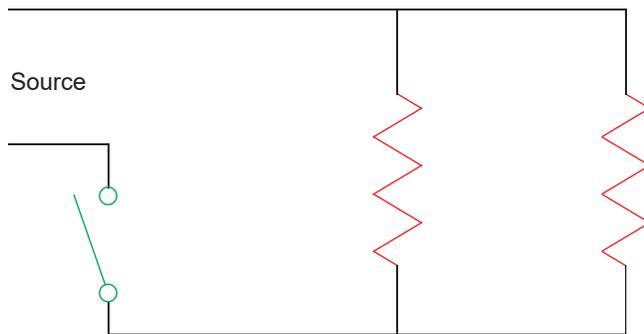
circuit becomes overloaded. Individual conductors are connected to each circuit breaker and are further connected to the light switches, devices, equipment, and receptacles in your house. The electricity thus reaches your lights, stereo, computer, toaster, and other devices that convert it into forms of useful energy.

Review Questions

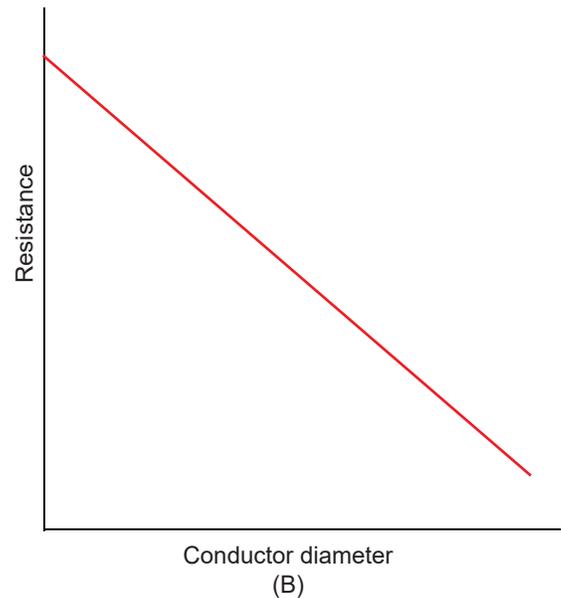
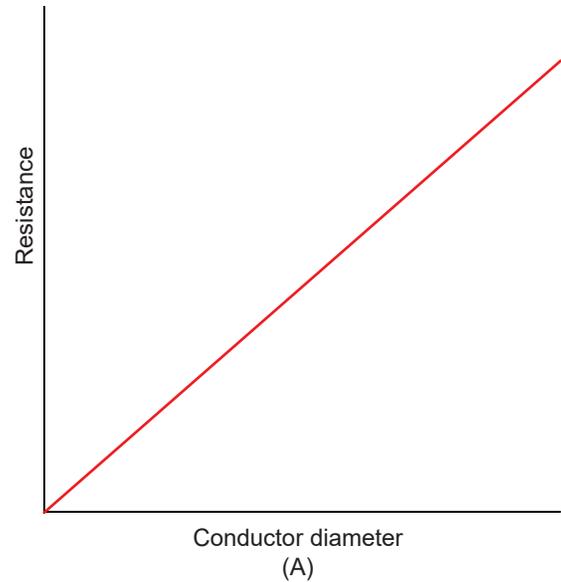
Answer the following questions using the information provided in this chapter.

1. Electricity is a form of _____.
2. Substances that allow electricity to pass through them easily are called _____, whereas those that block the electron flow are called _____.

3. The two types of electric current we use are called _____ current and _____ current.
4. A(n) _____ is a pathway for electric current.
5. In a(n) _____ circuit, current must go through every device in the circuit or it will not work.
6. The loads in the circuit shown are connected in (series, parallel).



7. What did Faraday and Henry discover?
8. In what important way do ac and dc generators differ?
9. Explain the left-hand rule.
10. A transformer uses _____ principles to increase or decrease voltage between an electrical power source and its load.
11. Ohm's law relates resistance, _____, and _____ in an electrical circuit.
12. The _____ relates power, voltage, and current in an electrical circuit.
13. A series circuit has a current of 2 amperes. What is the source voltage, if the total resistance is 6 ohms?
14. Which of the following graphs would best express the correct relationship of resistance to other conductor characteristics:



15. What is the total amperage of a parallel circuit having a total resistance of 12 ohms and a source voltage of 24 volts?
16. *True or False?* Ohm's law applies to series, parallel, and complex circuits.
17. *True or False?* Power is the rate of doing work.
18. Electrical energy is measured in units called _____ .
 - A. joules
 - B. watts
 - C. horsepower
 - D. kilowatt-hours

Know the Code

A copy of the NEC 2014 is required to answer these questions.

1. The first issue of the *National Electrical Code* was published in what year?
2. The *National Electrical Code* is published by what organization?
3. What is the primary purpose of the *National Electrical Code*?