AHRI Air-Conditioning, Heating, and Refrigeration Institute

Electricity, Electronics, and Wiring Diagrams for HVACR

Edward F. Mahoney
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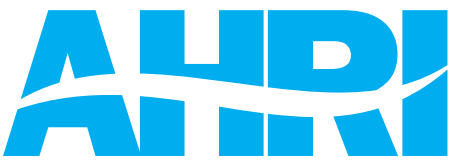
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This book is dedicated to my children, Kathleen McKee, Karen Wetzel, Timothy Mahoney, and Kimberly Nemeth.

I would like to thank Dianne Aucamp for always being there when typing is needed.

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Preface

This book is published in two main sections. The first section covers basic electricity and basic electronics related to the needs of air-conditioning refrigeration technicians. The second section of the book covers practical circuits and systems.

In the recent past, there has been an increase in the importance of electricity and electronics in the control and protection of air-conditioning and refrigerator devices.

It is not sufficient to cover electrical concepts lightly. Your career and success might well be based on how well you understand the material presented in the first section of this book.

With a firm foundation in basic concepts, the remainder of the book and the more complex circuits and problems that you will encounter in the field will not prove difficult.

If you master the basics, the rest is easy. This book provides you with the means to do just that.

New to this edition is information on:

- Kirchhoff's Laws and practical problems.
- Network Theorems and practical problems.
- Vector Diagraming.
- AC Circuit Analysis.
- Electronic Commutated Motors.
- Six Remote Control Thermostat connections

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UNIT 1

Electron Theory

OBJECTIVES

After completion and review of this unit, you should be able to:

- Relate electricity to things common in your environment.
- Picture in your mind electrons and electrons moving.
- Define the terms *voltage* and *current*.
- Recognize the difference between an open and a closed circuit.

The information presented in this unit is theoretical. *Theory* is a line of reasoning that is assumed to be correct. Theory may change from time to time as new information is gathered and new lines of reasoning are formed.

Electrical theory is highly developed at the present time and requires knowledge of higher mathematics for complete understanding. However, mathematical explanations of electricity are not the concern of this text; instead, an elementary approach to the electrical concepts, theories, and formulas that are essential to the air-conditioning and refrigeration technician will be provided.

It is suggested that this unit be read as a story. The material presented is good background information that will assist the reader in understanding the nature of electricity. With a good grasp of the nature of electricity, an air-conditioning and refrigeration technician will find troubleshooting an easier task.

THE STRUCTURE OF MATTER

A negatively charged, tiny object called an **electron** must be considered to understand the behavior of electricity. This consideration requires an investigation into the structure of matter—of what things are really made.

Imagine looking at a piece of copper under a microscope as the magnification is increased to an extremely high magnitude. It might be possible to see the actual construction of copper.

With the microscope at ×10 power, the copper (Cu) looks very much like copper (Figure 1–1). As the magnification is increased to ×100, the rough crystalline structure of copper is seen (Figure 1–2). It takes a large jump in magnification to ×10,000,000 before the beginning of atomic structure becomes evident, as seen in the bumpy surface shown in Figure 1–3. Finally, at a magnification of ×100,000,000, individual **atoms** are seen (Figure 1–4).

What is there to see? The center of a copper atom, the **nucleus**, consists of positively charged and neutral particles—**protons** and **neutrons**. Negatively charged particles, electrons, whirl in four orbits around the center. Electron theory is based on these negatively charged particles. An accepted representation of a copper atom is shown in Figure 1–5.

In the study of **electricity**, the electrons whirling around the nucleus are the center of interest.

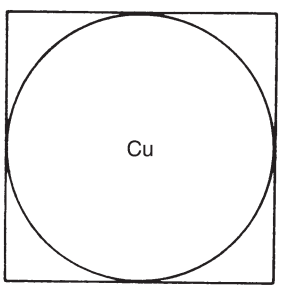


FIGURE 1–1 Plain copper (Cu).

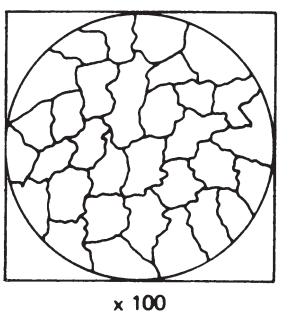


FIGURE 1–2 Copper crystal.

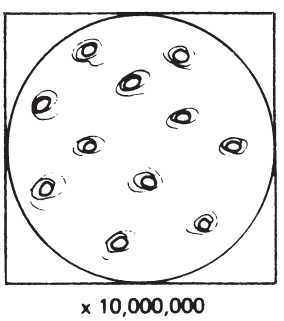


FIGURE 1–3 The atomic structure of copper.

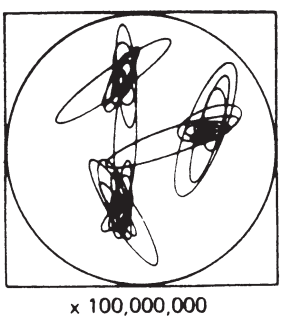


FIGURE 1–4 Copper atoms.

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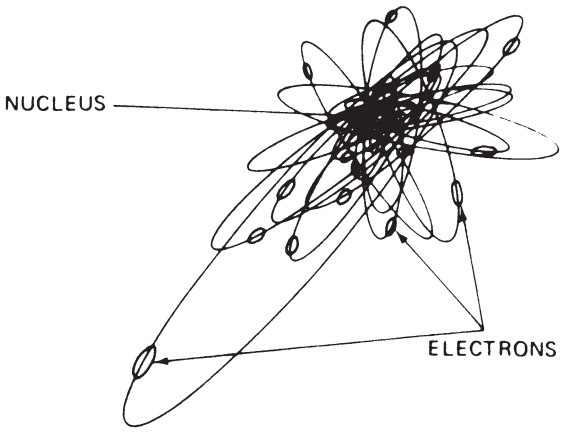


FIGURE 1–5 A copper atom.

Moving these electrons on command produces electricity that can be used to do work.

BOHR'S LAW

As scientists experimented with things of an electrical nature, they learned about the characteristics of electricity and about electrical phenomena. Physicist Niels H. D. Bohr (1885–1962) developed a model of electron, proton, and neutron arrangements to represent everything in the universe; this became known as Bohr's quantum theory of atomic structure. According to Bohr, an atom of hydrogen, the lightest known element, consists of one proton in the nucleus and one electron rotating around it (Figure 1–6). Bohr's theory of the hydrogen atom is regarded as the basis of modern atomic nuclear physics.

As we move up the atomic scale, heavier materials have a greater number of particles in the nucleus and a greater number of electrons whirling around that center. As the theory developed and is now understood, the arrangement of electrons in rings (orbits) around the nucleus is fixed:

1. In the first orbit around the nucleus, there can be no more than 2 electrons.
2. In the second orbit, the maximum is 8 electrons.
3. The third orbit has a maximum of 18 electrons.
4. The fourth orbit has a maximum of 32 electrons.

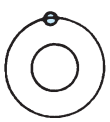


FIGURE 1–6 A hydrogen atom.

CONDUCTORS

As indicated, the number of electrons in each orbit around the nucleus of an atom is fixed. The number of electrons in orbit and the number of protons at the center determine the type of material.

Copper, for example, has a nucleus of 29 protons and 34 neutrons with 29 electrons rotating around it. According to the fixed arrangement of electrons, there are 2 in the first orbit, 8 in the second orbit, and 18 in the third orbit. This accounts for only 28 electrons. The remaining electron orbits alone in the fourth ring (see Figure 1–7). Because this electron is alone in the fourth ring, it is not held as strongly to the nucleus as are the other electrons. This electron is "free" to move whenever an outside force acts on it. Copper is a good conductor of electricity because each of the billions of tiny atoms in a copper conductor has one free electron ready to move when a force is applied to it. A reasonably small copper wire will pass a relatively large amount of electricity.

Another example of a good conductor is aluminum. The aluminum atom has a total of 13 electrons in three orbits. Two are in the first orbit, eight in the second orbit, and three in the third orbit (Figure 1–8). There are positions for 18 electrons in the third orbit. The three electrons in the third orbit are not tightly bound to the nucleus, and the third orbit can momentarily accommodate extra electrons. Aluminum, therefore, is a good conductor of electricity, but not as good as copper. If the same size of copper and aluminum wire is used, copper will conduct better. If weight and cost are factors to be considered, aluminum—a lightweight metal—is an excellent choice. Using wire of equal length and weight (not

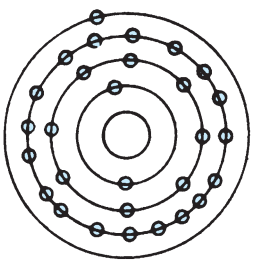


FIGURE 1–7 Electron configuration of a copper atom.

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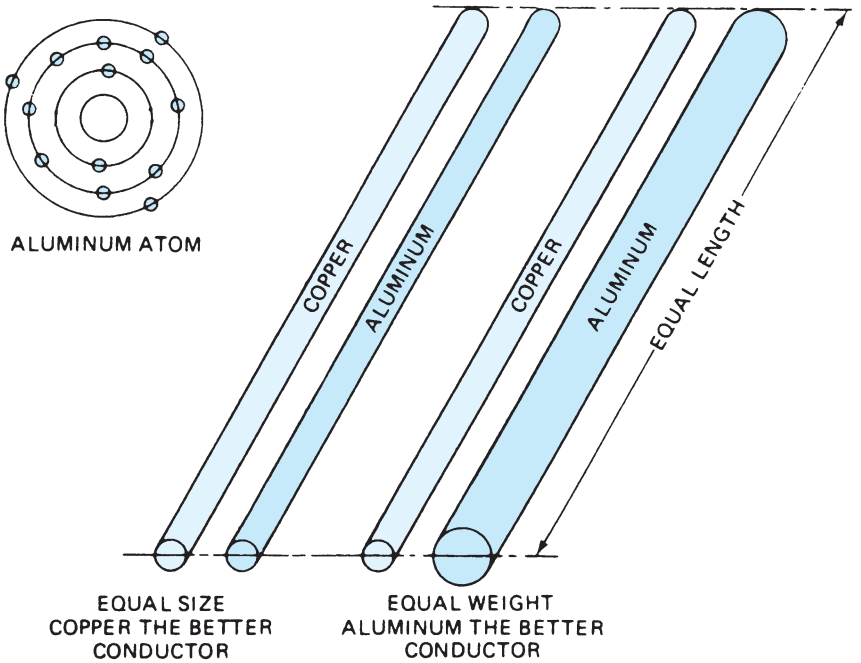


FIGURE 1–8 Relation of weight and size of aluminum and copper conductors.

size), aluminum will conduct electricity twice as well as copper. With equal weights, the aluminum wire will be much larger, of course.

THE BEHAVIOR OF ELECTRONS

After walking across a rug or sliding out of a car, you sometimes have the strange ability to cause an electric spark when you touch some other object. When you have that ability, you are electrically charged, or you carry an electric charge. This same type of electrical charge can be demonstrated by running a plastic comb through dry hair. The comb will attract lightweight objects, such as small scraps of paper or thread.

Static Electricity

The electricity that is obtained by rubbing certain materials together is called **static electricity**. It is called static because electrons are picked up on an item, and the electrical charge remains on the item until it touches some other object that does not have a like charge.

As experiments were performed on static electricity, it was found that two types of charges could be obtained, depending on the nature of the materials rubbed together: If two glass rods are rubbed with a silk cloth, they are charged alike and repel each other; if two hard-rubber rods are rubbed with wool, they are also charged alike and also repel each other.

CONCLUSION: *Like charges repel each other.*

If a charged glass rod is brought near a charged rubber rod, the glass rod and rubber rod will be attracted to each other. The charges on the rods are unlike each other, so they attract each other.

CONCLUSION: *Unlike charges attract each other.*

In order to classify the charges, they were given names. Benjamin Franklin (1706–1790), an American scientist, suggested **positive** and **negative** charges. The glass rods have a positive charge; the rubber rods have a negative charge.

Static electricity is electricity at rest.

Dynamic Electricity

Static electricity is not a practical form of electricity. The more practical form of electricity that is used to provide power and energy all over the world is **dynamic electricity**.

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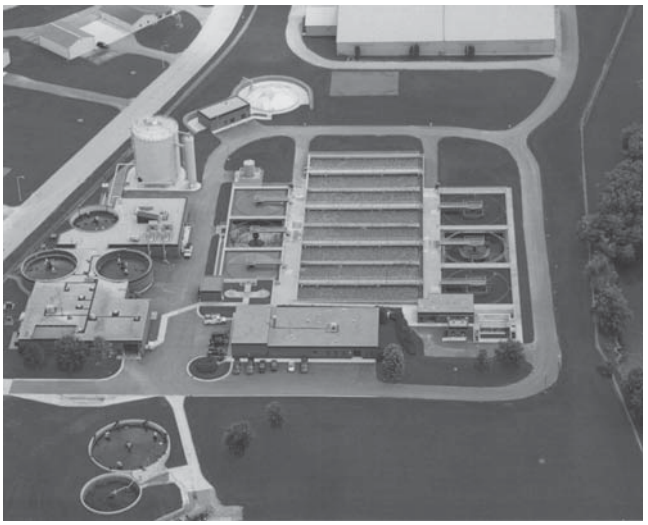


FIGURE 1–9 City of Beaver Dam wastewater treatment facility. (Photo courtesy of Applied Technologies, Engineers-Architects.)

Dynamic electricity is electricity in motion. In an automobile, the battery provides dynamic electricity, as does the **alternator** (generator). A power company uses water at high pressure behind dams to move large alternators that provide dynamic electricity. In some areas where there are no rivers for dams, large steam plants are used to turn alternators that generate dynamic electricity.

New kinds of power plants are being built throughout the country. Sewage, garbage, and process discharges of food plants are being used in combination or separately to produce electricity. One example of such an electrical plant is in the wastewater treatment facility and bioenergy system at Beaver Dam, Wisconsin (Figure 1–9). Inputs to the system are effluents from the sewer system of Beaver Dam along with whey permeate and processed wastewater from a nearby kraft Cheese plant.

The power plant produces approximately 800 kilowatts of bioenergy.

Another energy source that may be of greater importance in the future, geothermal energy, is presently being investigated. To tap this energy source, a deep hole is drilled into the earth to an area of intense heat. Water is introduced into the hole, where it is converted to superheated steam at the lower level. The steam returns to the earth's surface to operate turbines that rotate the electric alternators that provide electricity.

Regardless of the energy source, dynamic electricity is produced by generators or alternators converting mechanical energy into electrical energy.

VOLTAGE AND CURRENT

A well-developed understanding of the basic terms relating to dynamic electricity is necessary to troubleshoot air-conditioning and refrigeration electric systems effectively.

Voltage and *current* are terms associated with dynamic electricity. Voltage and current will be covered together, because it is not possible to obtain one without some of the other. **Voltage** is the pressure that causes electrons to move. **Current** is the movement of electrons.

The Compressor Analogy of Electricity

As is often the case, it is easier to understand a new subject when it is related to some past experience. The electrical phenomena will be related to an air-conditioning compressor system.

In this analogy, it is not necessary to be concerned with temperature changes in the refrigeration system; only the gas movement need be considered. Figure 1–10 shows a compressor with inlet (suction) and outlet (high-side, or discharge) lines attached. The lines are sealed at the ends so that no gas can enter or exit the system. When the compressor is not running, the system will be in balance with an equal number of gas molecules on either side. Balance is the state in nature that everything is trying to reach.

Figure 1–11 shows the compressor in operation. Some of the gas molecules are moved by the compressor from the suction line (on the left) to the discharge side (on the right). There is a relative excess of gas molecules in the discharge line (compression), causing a pressure difference between the two lines.

If a small pipe is connected from the discharge line to the suction line, as shown in Figure 1–12, some of the gas molecules will move through the pipe. There will be continuous movement of gas molecules through the system as long as the compressor is operating. The suction side of the system will continue to be under a vacuum, and the discharge side will continue at high pressure as long as the small tubing offers some restriction (resistance) to the movement (flow) of gas molecules through the system.

This system should seem reasonable to the student of refrigeration and air-conditioning technology because it is similar to the basic system most commonly associated with the refrigeration cycle. It is equally reasonable to use a similar system to understand how electricity works.

In Figure 1–13, an electric generator has been substituted for the compressor, and the air lines

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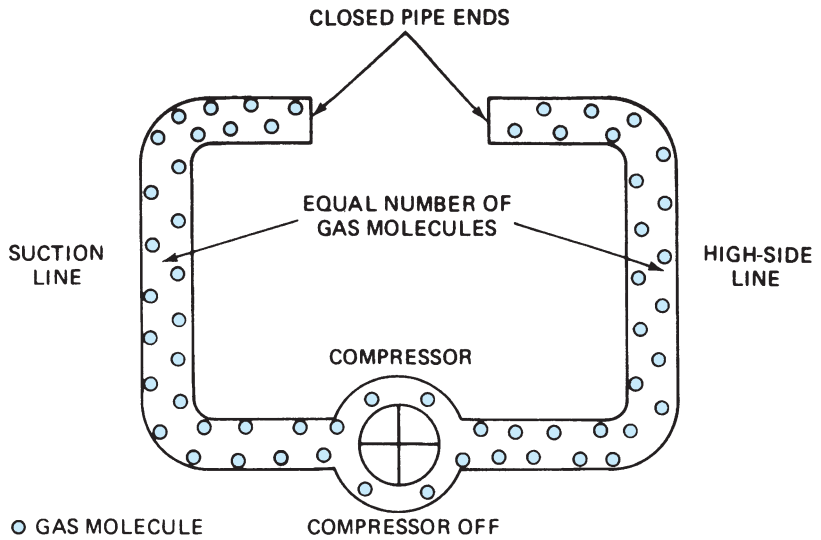


FIGURE 1–10 A balanced system.

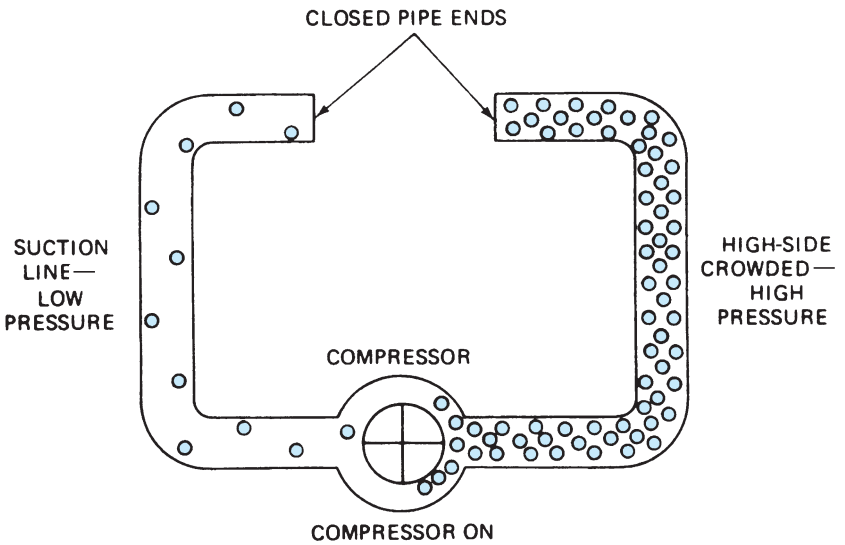


FIGURE 1–11 An unbalanced system.

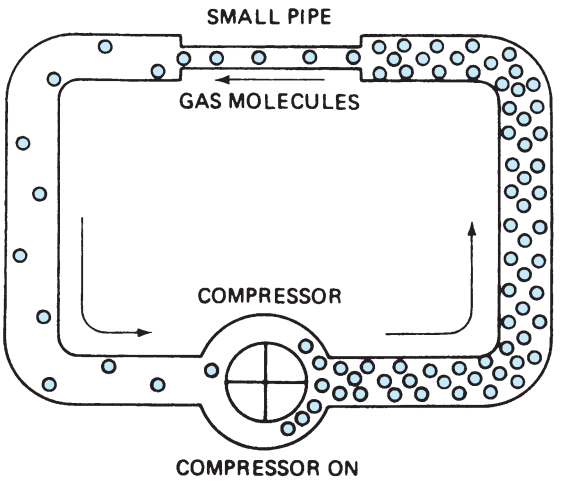


FIGURE 1–12 Molecule movement.

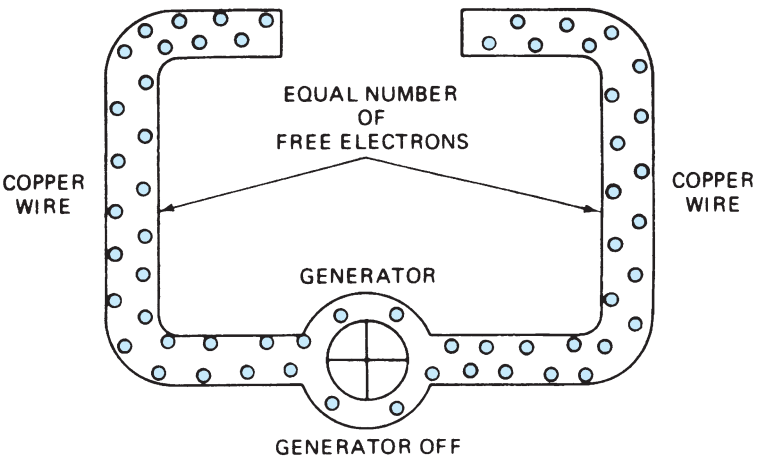


FIGURE 1–13 Electrical circuit in balance.

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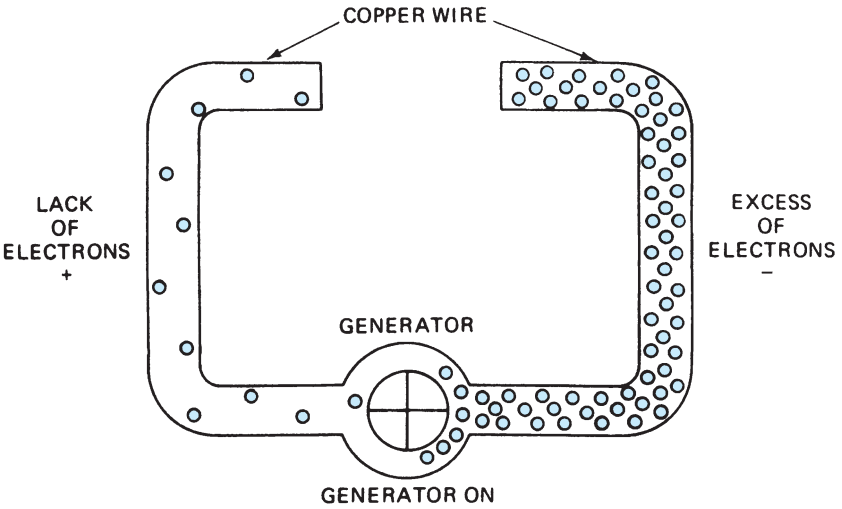


FIGURE 1–14 Unbalanced voltage.

have been replaced with copper wire. The circuit is open because there is no connection between the wire from the left side of the generator and the wire from the right side. Within the copper wire, there are a large number of copper atoms. Each atom has one free electron (easily moved) in its outer orbit.

The electrical generator, when running, is capable of moving electrons. This is similar to the compressor's ability to move gas molecules. How the generator moves electrons is covered in later units.

When the generator is not running, there are an equal number of free electrons in the wires on either side of the generator: The system is in balance. When turned on, the generator draws some of the free electrons from the left side and pushes them to the right side, as shown in Figure 1–14. The movement of electrons from one side to the other creates an unbalance. As long as there is an unbalance, there will be a pressure called voltage. The pressure is measured in **volts** and is exerted in an effort to try to balance the system. Another term for voltage is **electromotive force (EMF)**.

Because there is an excess of electrons on the right side, this side of the generator is negative (or we could say there is an absence of electrons on the left side). Because the nucleus of the copper atoms has not changed, the protons remain the same on both sides of the generator. The situation now is that there are more protons on the left side than electrons. Thus, the left side of the generator is positive. As long as the generator is operating, the system will remain unbalanced; voltage will exist between any point on the right side and any point on the left side.

If a voltage-measuring device (called a **voltmeter**) is connected across the open wire ends, the meter needle will move (Figure 1–15). This indicates the unbalance in electrical pressure that exists between the two points. Voltage is always measured between two points in a circuit. (See Unit 3.)

> ***WARNING:*** *Never connect a wire across the output terminals of a generator. The wire will short out the generator. It is used here only as a means of explanation.*

If a small wire is connected between the left side of the generator and the right side, some of

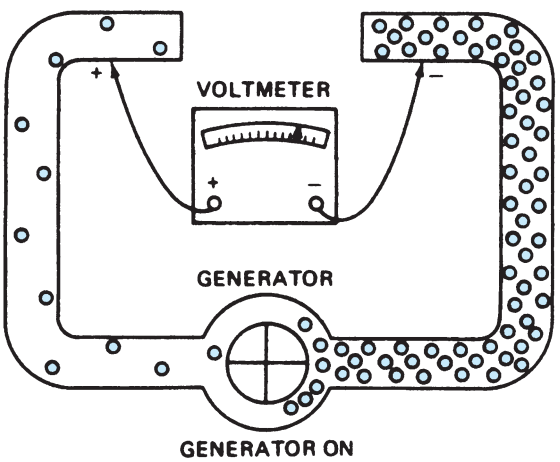


FIGURE 1–15 Measurement of voltage.

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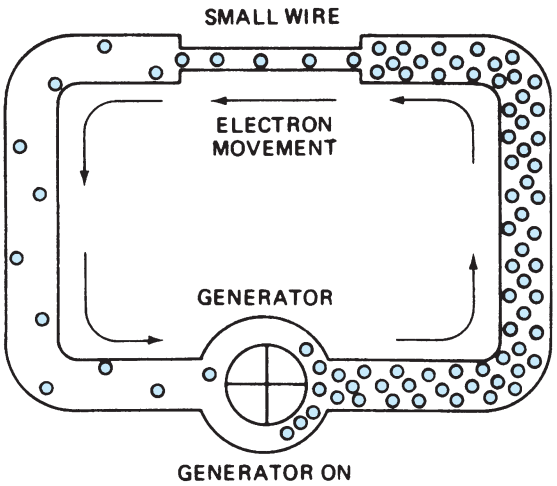


FIGURE 1–16 Electron flow, complete circuit.

the excess electrons will move from the right side through the wire to the left side (Figure 1–16). The generator will continue to move electrons, just as the compressor moves gas. An electric current will flow in the circuit as long as the circuit is complete and the generator is running. As long as there is an unbalance and a circuit, current will flow. Current, or electrons in motion, is measured in **amperes**, commonly referred to as **amps**. It takes 6,250,000,000,000,000,000 (6.25×10^{18}) electrons passing a point in one second to make 1 ampere. This quantity is called a **coulomb**.

Voltage is caused by an imbalance in electrons. It is not the electrons, but rather the electrons that have moved that create the unbalance. Similarly, the current in the circuit is the electrons in motion.

SUMMARY

- Whenever there is an unbalance in an electrical system, a pressure will exist trying to balance the system.
- In an electrical system the unbalance, or pressure between the two points in the system, is the electromotive force (EMF)—most often called voltage. Remember that voltage is measured between two points.
- If a circuit is provided between the unbalanced points, current (a movement of electrons) will flow through the circuit.
- If a circuit is not connected between the unbalanced points (an open circuit), no current will flow.

PRACTICAL EXPERIENCE

Required equipment A plastic or rubber pocket comb and paper

Exercise 1

1. Tear a small piece of paper into smaller pieces, approximately a half-inch (12–13 mm) square.
2. Pass the comb through your hair several times.
3. Place the comb near the pieces of paper.

Quiz

1. Did the comb attract the pieces of paper?
   a. If no, before proceeding, determine why not.
   b. If yes, proceed with question 2.
2. What do you think caused this attraction?
3. Is this exercise an example of static or dynamic electricity?
4. Explain your answer to question 3.

Exercise 2

1. On a wall-type air-conditioning unit, locate the power plug.
2. Observe the shape of the power plug.
3. Draw the shape of the power plug on a separate sheet of paper.
4. Locate the nameplate on the air-conditioning unit.
5. Find the voltage rating of the unit on that nameplate.
6. If the voltage rating of the unit is 120 volts (V), the power plug should be shaped like a large, standard home appliance plug such as the one shown in Figure 1–17. Is that the case?
7. If the voltage rating of the unit as indicated on the nameplate were 220 V at less than 15 amperes, the plug would be similar to the ones shown in Figures 1–18 and 1–19.

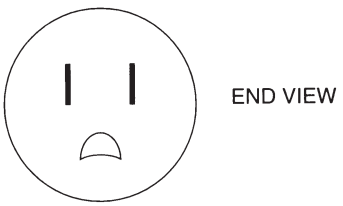


FIGURE 1–17 A 120 V power plug.

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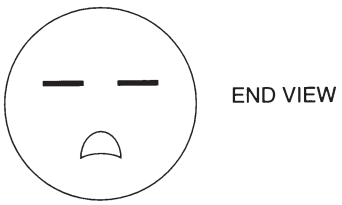


FIGURE 1–18 A 220 V power plug.

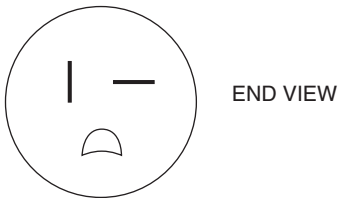


FIGURE 1–19 Another example of a 220 V power plug.

8. Examine other air-conditioning unit plugs.
9. Determine the voltage and current limitations of the plugs by their shape.
10. Check the air-conditioner nameplate for voltage and current levels.
11. Visit a hardware or home maintenance store. Check in the electrical department for different types of outlets and plugs and find their voltage and current rating.

REVIEW QUESTIONS

1. Static electricity is electricity at rest.
   T_____ F_____
2. Dynamic electricity is electricity in motion.
   T_____ F_____
3. Like charges repel each other.
   T_____ F_____
4. Unlike charges repel each other.
   T_____ F_____
5. Voltage is a pressure that causes electrons to move.
   T_____ F_____
6. Current is the movement of electrons.
   T_____ F_____
7. The natural state is for everything to be in a balanced condition.
   T_____ F_____
8. Current is measured in amperes.
   T_____ F_____
9. Electromotive force (EMF) is measured in volts.
   T_____ F_____
10. With equal size and length of conductors, copper is a better conductor than aluminum.
    T_____ F_____

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UNIT 2

Magnetism

OBJECTIVES

After completion and review of this unit, you should be able to:

- Understand the relationship of natural magnets and artificial magnets.
- Understand the relationship of magnetic polarity and magnetic fields.
- Understand the relationship of electromagnets and magnetic strength.

Magnets and magnetism are involved in many components of air-conditioning and refrigeration electrical circuits. Compressors are driven by electric motors that function through magnetism. Many electrical controls operate on magnetic principles. A basic understanding of magnetic principles and magnetic circuits will be helpful to all air-conditioning and refrigeration technicians.

NATURAL MAGNETS

Ancient peoples knew of the special properties of certain stones, notably those found in Magnesia, Asia Minor, that attracted small bits of iron. The stones are called **magnets,** after the location in which they were found. Because most ancient peoples had little scientific knowledge, the action of the magnets was attributed to magic. Natural magnets are stones with a high iron-ore content. Because of its special characteristics, this type of stone was given the name *magnetite.*

Around the year AD 1000, the property of natural magnets to point in a fixed direction was discovered. Because these stones were now useful in navigation, they were given a new name, **loadstone** (also spelled lodestone). The name loadstone means "leading stone" and is still used to indicate special iron ore with **magnetic** characteristics.

ARTIFICIAL MAGNETS

A piece of iron or steel can be magnetized by placing it in contact with a natural magnet or loadstone. Another method of producing an artificial magnet is to wrap a coil of wire around an iron or steel core and then pass an electrical current through the wire.

If the material being magnetized is hardened steel, it will retain its magnetism for a considerable length of time. If soft iron is used, a strong magnetism will appear during the magnetizing process, but little magnetism will remain after the magnetizing force is removed. **Permanent magnets** are made from hardened steel and other special alloys because of their useful characteristics. Soft iron or steel is used as the core of relays and solenoids, in which strong magnetism must be present only when current is flowing in the coils.

MAGNETIC POLARITY

If a piece of metal such as a steel bar is magnetized, the magnetic effects concentrate at the ends of the bar. These points of magnetic concentration are called the **poles** of the magnet. Away from the ends and around the bar, an invisible force is present, the effects of which can be seen if small bits of iron or steel are placed near the magnet. The invisible force around the magnet is called a **magnetic field**.

The planet Earth is a permanent magnet, with one end near the North Pole and the other near the South Pole (Figure 2–1). If a bar magnet is balanced near the center by a small thread, it tends to line up with Earth's magnetic field. One end of the bar magnet points north. It is therefore labeled the north-seeking pole and usually is marked with the letter *N.* The other end of the bar points south and is marked *S,* for south-seeking pole (Figure 2–2).

By definition, the magnetic field of a bar magnet is said to emerge from its north pole and to reenter the magnet at its south pole. Some lines will emerge from the sides of the magnet, but the major concentration is at the poles (Figure 2–3).

If two bar magnets are hung at their balance points and then brought together, the repelling and attracting forces can be demonstrated. In Figure 2–4, two magnets are hung from strings, and the repulsion of two like poles is shown. As the magnetic

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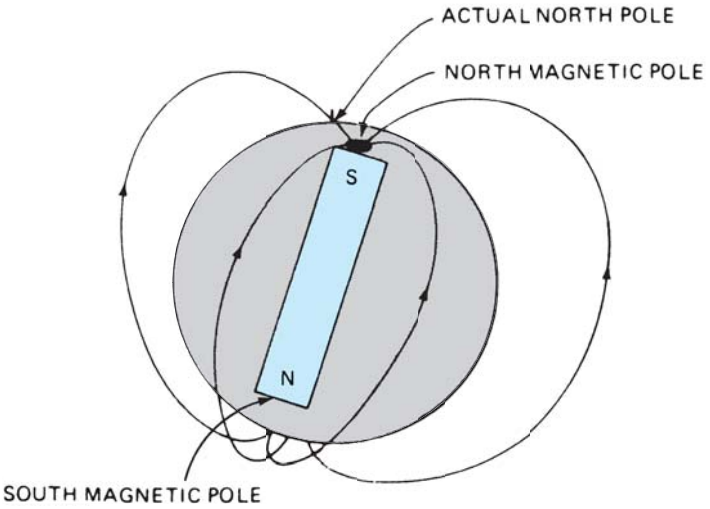


FIGURE 2–1 Earth as a magnet.

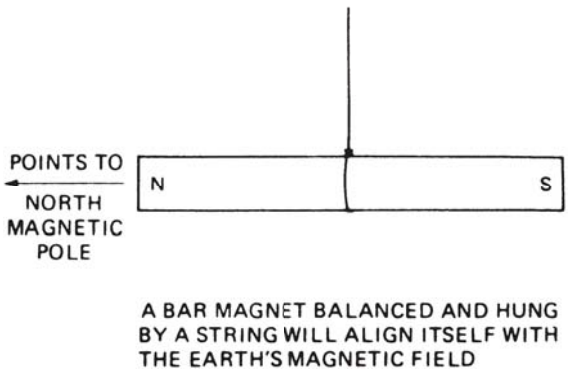


FIGURE 2–2 Bar magnet compass.

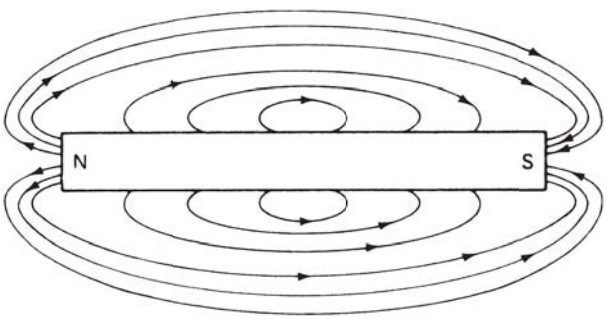


FIGURE 2–3 Magnetic field.

bars approach each other, the two north poles swing away from each other. In Figure 2–5, the attraction of two unlike poles is shown. As the two unlike poles approach each other, they are attracted to each other, as the pull on the strings indicates.

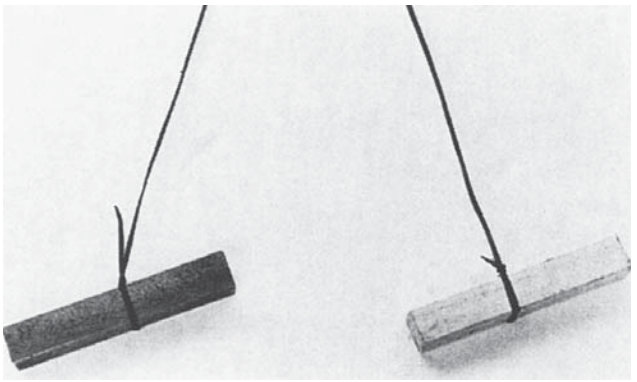


FIGURE 2–4 Like poles repel. (Courtesy of BET Inc.)

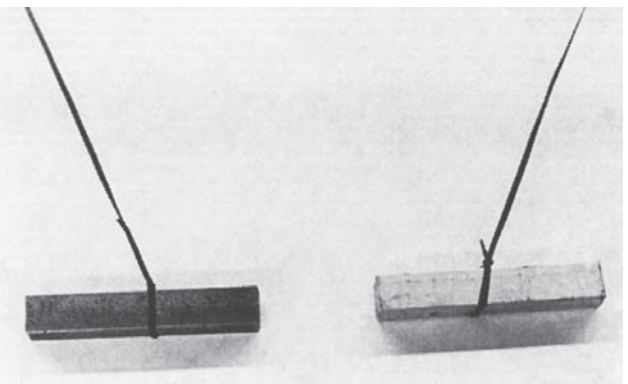


FIGURE 2–5 Unlike poles attract. (Courtesy of BET Inc.)

MAGNETIC MATERIALS

Most materials are not magnetic. Copper, aluminum, brass, wood, paper, and glass are examples of nonmagnetic materials. Magnetic fields will pass through these materials, but the material will not be magnetized. Some materials are magnetic; iron, steel, cobalt, and nickel are examples of magnetic materials. Many alloys of iron, cobalt, and nickel also provide excellent magnetic properties. Some of these alloys contain nonmagnetic materials, such as aluminum, but the final alloy is magnetic and, in most cases, very highly so.

MOLECULAR MAGNETS

In ordinary steel, each molecule of steel is a tiny, permanent magnet. In unmagnetized steel, the molecular magnets are arranged haphazardly throughout the metal (Figure 2–6). Because each molecular magnet is pointing in a different direction, the total

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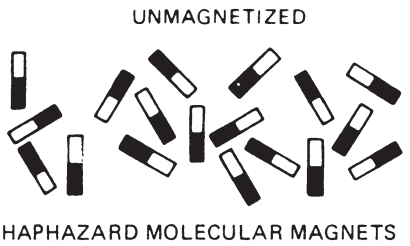


FIGURE 2–6 Molecular magnets.

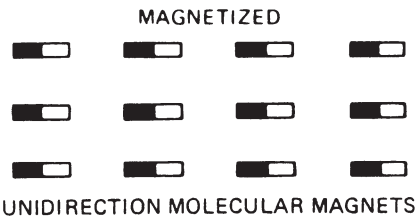


FIGURE 2–7 Aligned molecular magnets.

magnetic effect is zero. The steel is not a magnet and will not attract magnetic materials.

When steel becomes magnetized, the magnetizing process rotates the molecular structure (magnets) so that most molecules are pointing in the same direction. This arrangement is shown in Figure 2–7.

MAGNETIC FIELD

Although the magnetic field is invisible, its effect can be demonstrated. If a piece of paper is placed over a bar magnet and the paper is sprinkled with iron filings, a pattern will form. The magnetic force, or field, will arrange the filings in lines running from one end of the bar magnet to the other, as shown in Figure 2–8.

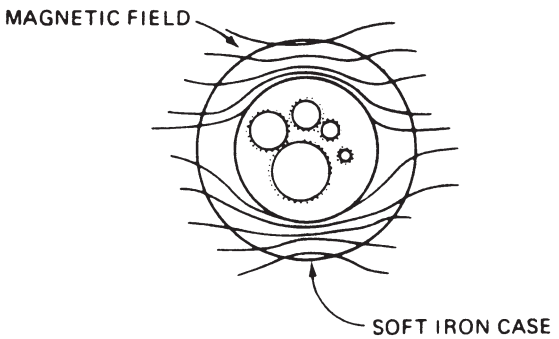


FIGURE 2–9 Magnetic shielding.

There are no insulators from magnetic fields. Magnetic lines of force can pass through all materials. They will be deflected or bent by other magnetic fields but not stopped or blocked.

The term *antimagnetic* is in most cases a play on words. A wristwatch, for example, may be marked antimagnetic. Because the delicate mechanisms within a watch may be very susceptible to magnetic fields, these small, delicate parts are protected by the frame of the watch, which is made of soft iron (Figure 2–9). Magnetic fields will pass through the iron frame rather than the hard steel parts. The small parts are protected, not because they are antimagnetic, but because the magnetic fields take the easiest path through the soft iron.

ELECTROMAGNETISM

As indicated previously, a magnet can be created by passing an electric current through a coil of wire. This can be explained by one of the basic tenets of electricity: A magnetic field exists around each electron in

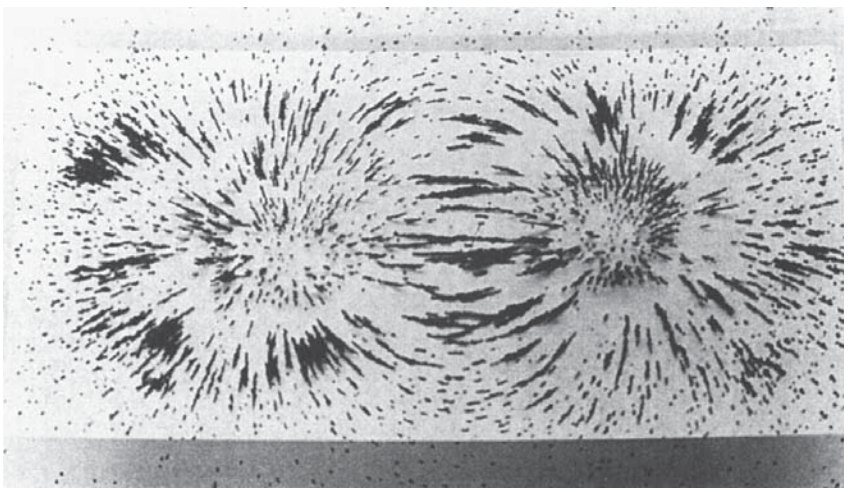


FIGURE 2–8 Iron filings show field around bar magnet. (Courtesy of BET Inc.)

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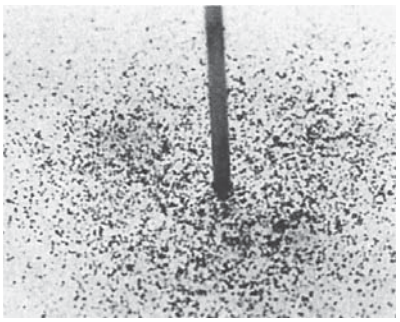


FIGURE 2–10(a) No current.

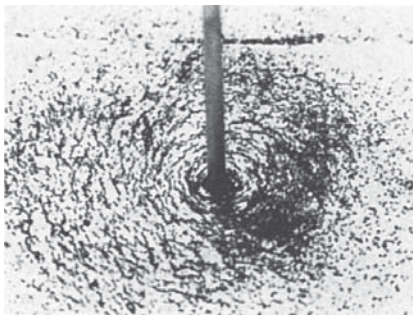


FIGURE 2–10(b) Current flow. (Courtesy of BET Inc.)

motion. When electrons move through a wire, the magnetic field set up around the wire is proportional to the amount of current in the wire. This is a basic relation between electricity and magnetism. The magnetic field around a wire carrying current is in the form of concentric circles (Figure 2–10 [a&b]).

The method for demonstrating the magnetic field around a wire is shown in Figure 2–11 (a&b). A wire carrying current is passed through a sheet of paper. Compasses placed on the paper demonstrate the existence of a magnetic field, as well as the direction of the field. The compass needles align themselves with the magnetic field.

Left-Hand Rule

If the direction of electron flow in a wire is known, the direction of the magnetic field around the wire can be determined by following the **left-hand rule**: Grasp the current-carrying wire in the left hand with the thumb pointing in the direction of electron flow. The fingers will point in the direction of the **magnetic lines of force** (Figure 2–12).

Electromagnets

If a current-carrying wire is formed into a loop or coil, the concentric lines of force will all be in the same direction through the center of the loop (Figure 2–13).

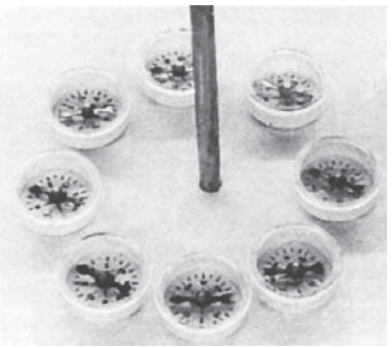


FIGURE 2–11(a) No current, compasses all point north. (Courtesy of BET Inc.)

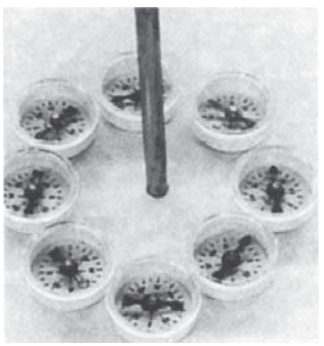


FIGURE 2–11(b) Electrons traveling down, compasses line up with magnetic field. (Courtesy of BET Inc.)

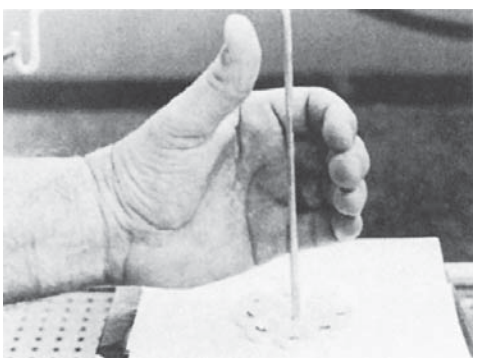


FIGURE 2–12 Demonstrating left-hand rule. (Courtesy of BET Inc.)

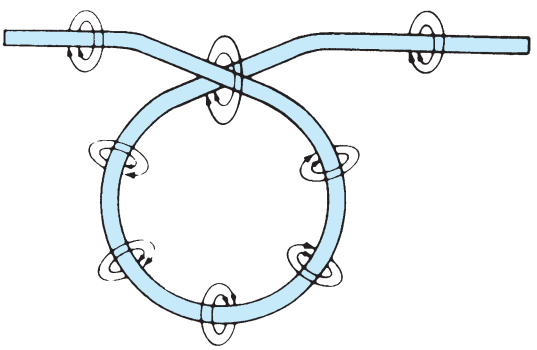


FIGURE 2–13 Magnetic field around wire. (Courtesy of BET Inc.)

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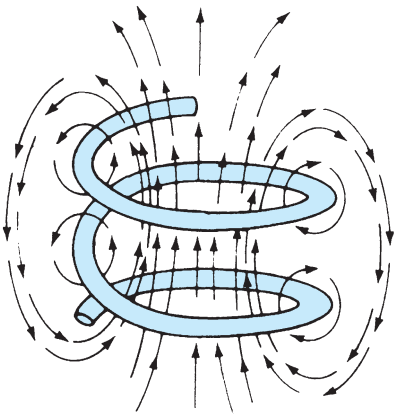


FIGURE 2–14 Field around coil.

If loops are placed close together, there will be a further concentration of lines of force. Some lines will merge and go around the combined loops, as shown in Figure 2–14.

If several turns of insulated wire are formed into a coil, lines of force will enter one end of the coil, pass through it, and emerge at the other end. The lines of force will be completed outside of the coil, as shown in Figure 2–15.

Magnetic Polarity of Electromagnets

The polarity of an electromagnet may also be determined by using the left-hand rule. The direction of electron current must be known in order to use the rule. Grasp the coil in the left hand with the fingers pointing in the direction of electron flow. The thumb will point in the direction of the lines of force through the center of the coil and to the north pole of the electromagnet (Figure 2–16).

Magnetic Strength of Electromagnets

The strength of an electromagnet depends on the size, length, material of the core, number of turns in the coil, and amount of current flowing through it. Other conditions being the same, an electromagnet with a soft iron core will be stronger than one with a core of steel.

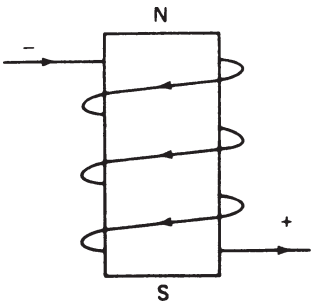


FIGURE 2–16 Left-hand rule.

If the direction of the field is known but the direction of electron flow is not, the rule can be used to determine the current direction. Grasp the wire with the left hand with fingers pointing in the direction of the magnetic lines. The thumb will point in the direction of electron flow.

Ampere-Turns

The magnetizing force of a coil is based on the ampere-turns (AT) of the coil. The ampere-turns of a coil are equal to the amount of current flowing through the coil multiplied by the number of turns. In Figure 2–17, the ampere-turn rating of different coil–current combinations is given.

The magnetizing force of a one-turn coil with 1 ampere (AMP) of current flowing through it is very weak: 1 ampere-turn. A two-turn coil with 5 amperes flowing through it has a magnetizing force 10 times stronger, or 10 ampere-turns. A five-turn coil with 2 amperes of current has the same magnetizing force, 10 ampere-turns. A three-turn coil with

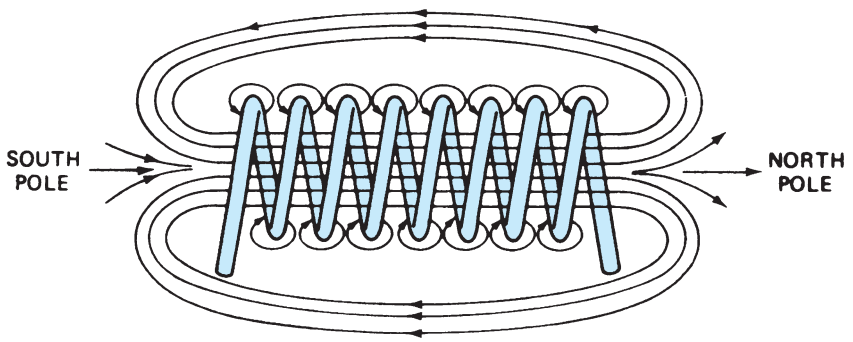


FIGURE 2–15 Concentration of magnetic lines.

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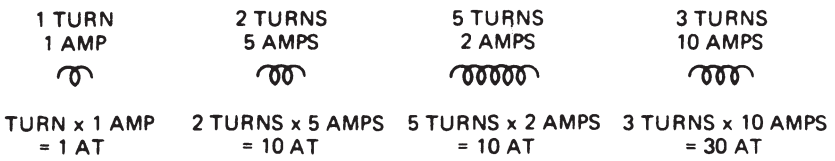


FIGURE 2–17 Ampere-turns.

10 amperes of current has the strongest magnetizing force of the group, 30 ampere-turns.

Iron Core Coils

When a magnetic material is used as the core of an electromagnet, the strength of the magnet is greatly increased. This is very important in the design of components such as electric motors, relays, and solenoids. With an iron core, a stronger magnet is obtained in a coil with the same current flow. This produces a stronger magnet at a lower operating cost. High-energy, efficient motors are those with more iron in the core and more windings in the coils. The higher initial cost is usually offset in a year or so by savings in operating costs.

A large number of devices that operate on the magnetic principle are found in air-conditioning and refrigeration electrical systems.

SUMMARY

- Permanent magnets are made with hardened steel.
- Soft iron is used in temporary magnets.
- Like poles of magnets repel each other.
- Unlike poles of magnets attract each other.
- There are no insulators for magnetism or magnetic lines of force.
- Soft iron is often used to shield items from magnetism by providing a better path for the magnetic lines of force.
- When an electric current flows in a wire, a magnetic field exists around the wire.
- When a current-carrying wire is formed into a loop or coil, the magnetic field is concentrated in the center of the loop.
- When an iron core is used as the core of a coil carrying an electric current, the magnetic field is greatly increased.

PRACTICAL EXPERIENCE

Required equipment A permanent magnet; copper, aluminum, and iron material; a screwdriver

Procedure

1. In sequence, place the magnet close to the copper, aluminum, and iron. Describe the action that took place as the magnet was placed close to the suggested materials.
2. Place the magnet at the screwdriver point. Did the magnet and screwdriver attract each other?
3. Stroke the screwdriver with a pole of the magnet from about 2 inches from the tip to the tip itself.
4. Place the tip of the screwdriver at the piece of iron. Is there an attraction exhibited? The action in steps 3 and 4 demonstrate the ease with which magnetic materials iron and steel may be magnetized.

Conclusion Certain magnetic materials, iron and steel, are easily magnetized when they come into contact with a magnet.

REVIEW QUESTIONS

1. With magnets, like poles (repel, attract) each other.
   T_____ F_____
2. The concentration of a magnetic field in a bar magnet is at the (side, ends) of the bar.
   T_____ F_____
3. Two adjacent wires carrying current in the same direction will (attract, repel) each other.
   T_____ F_____
4. Two adjacent wires carrying current in the opposite direction will (attract, repel) each other.
   T_____ F_____

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5. If a wire carrying current is formed into a loop or coil, the magnetic field will (increase, decrease).
   T_____ F_____
6. If a magnetic material, such as soft iron, is used as the core of an electromagnet, the strength of the magnet will (increase, decrease).
   T_____ F_____
7. Soft iron is used as the core of (permanent, temporary) magnets.
   T_____ F_____
8. Hard steel is used as the core of (permanent, temporary) magnets.
   T_____ F_____
9. (Nothing, glass) will isolate a material from magnetic lines of force.
   T_____ F_____
10. Electric motors containing more iron and windings are usually (cheaper, more expensive) to operate.
    T_____ F_____

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UNIT 3

Ohm's Law and the Electric Circuit

OBJECTIVES

After completion and review of this unit, you should be able to:

- Recognize resistors as components in electrical/electronic circuits.
- Recognize the schematic symbol for fixed resistors.
- Recognize the schematic symbol for variable resistors.
- Use Ohm's law to determine one of the three values—*voltage, current,* or *resistance*—when two of the values are known.

In Units 1 and 2, voltage and current were covered. Another factor is of equal importance in the study of electricity and electrical circuits: **resistance**. In the discussion of voltage and current, the following observation was made: When a generator is operating, electrons are pulled from the wire on one side and forced out on the wire on the other side. This creates an unbalance called voltage, shown in Figure 3–1. As long as the generator operates, it will maintain the unbalance, and a voltage will exist between the two wires.

Note in the circuit of Figure 3–1 that no wire connects the output wires of the generator. The resistance of air is extremely high and may be considered infinite. With such a high resistance, no current will flow.

If a small wire is connected between the ends of the original wires, a current will flow in the circuit, as shown in Figure 3–2. The amount of current that flows in the circuit depends on the type of material from which the wire is made, the size (diameter) of the wire, and its length. In the circuit in Figure 3–2, the small wire is said to offer resistance to the current flow. Although resistance is offered, current will flow.

The connecting wire in the circuit in Figure 3–3 is the same length and of the same material. However, the cross-sectional area is twice the size of the wire used in Figure 3–2. More current flows in the circuit in Figure 3–3 than in the circuit in Figure 3–2 because resistance is reduced. Actually, twice as much current flows when the larger wire is used.

The resistance of a wire depends on four things:

1. Material used to make the wire (available free electrons)
2. Cross-sectional area of the wire (size)
3. Length of the wire
4. Temperature (normally as temperature increases, resistance increases)

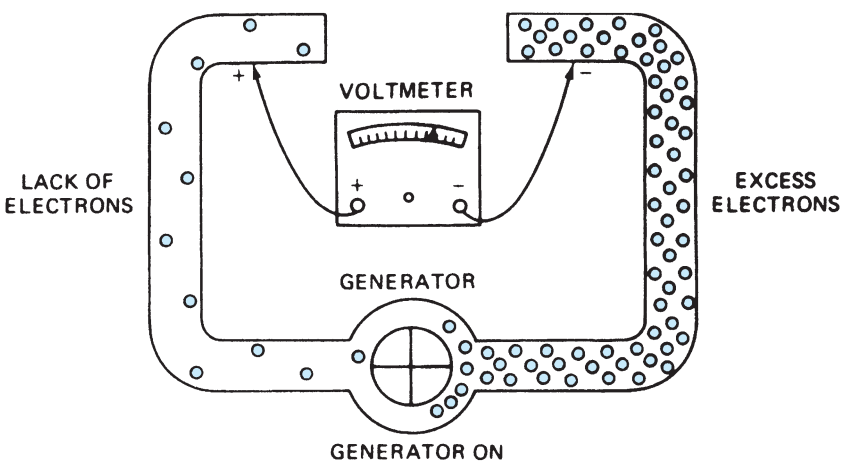


FIGURE 3–1 Generator producing voltage.

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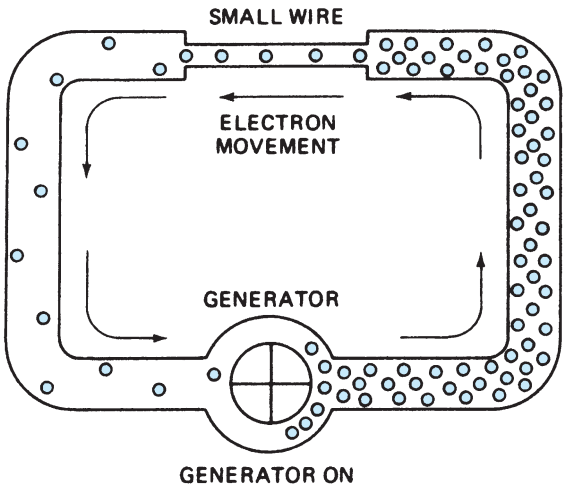


FIGURE 3–2 Current flow.

Resistors come in many shapes and sizes. Figure 3–4 shows four resistors: Three are different types of wire-wound power resistors, and one is a carbon resistor.

The physical size of a resistor relates to how much power the resistor can handle (how much heat the resistor can radiate or get rid of). The physical size of a resistor has nothing to do with its resistance value in ohms.

Another resistive element that may be familiar is the heat strip from an air-conditioning system (Figure 3–5). The component is made of nichrome wire that has been coiled to decrease the space needed to accommodate the total wire length. The heat strip is a resistive element.

COMPLETE ELECTRIC CIRCUITS

For current to flow in an electric circuit, the circuit must be complete. Another way of stating this is that current must be able to flow from the source through the load, back to the source, through the source back to the load, and so on.

In Figure 3–6, an electric generator is the energy source, and a lamp is the load. As long as the circuit is complete, current will flow from the generator (source) through the lamp (load) and back through the generator. There is a continuous path for current to flow in. It is a complete electric circuit.

If a switch is included in the circuit, the same current that flows through the lamp flows through the switch. Two conditions can exist. When the switch is **closed**, the circuit is complete and current can flow (Figure 3–7). When the switch is in the **open** position, the circuit is not complete (Figure 3–8). Current cannot flow through the open switch; therefore, current cannot flow through the lamp.

Figure 3–9 shows two circuits. Note the position of the switches. In both circuits, the switches and the lamp are connected in series. In the circuit in Figure 3–9a, if either switch A-1 or A-2 is open, the circuit is not complete: The lamp will not light. Similarly, in the circuit in Figure 3–9b, if either switch B-1 or B-2 is open, the circuit is not complete: The lamp will not light. A complete circuit may be made up of the generator, the load, and the connecting wires.

The connecting wires in a circuit are usually considered not to have resistance. Actually, wires do have resistance but for practical application, the

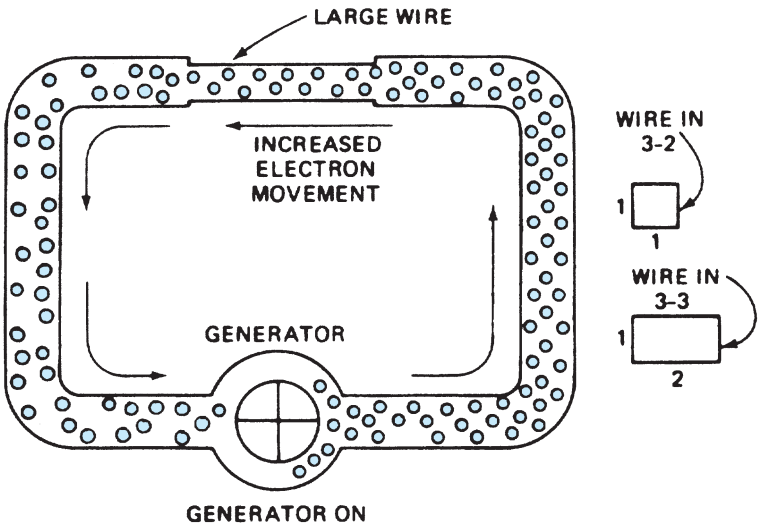


FIGURE 3–3 Increased current flow.

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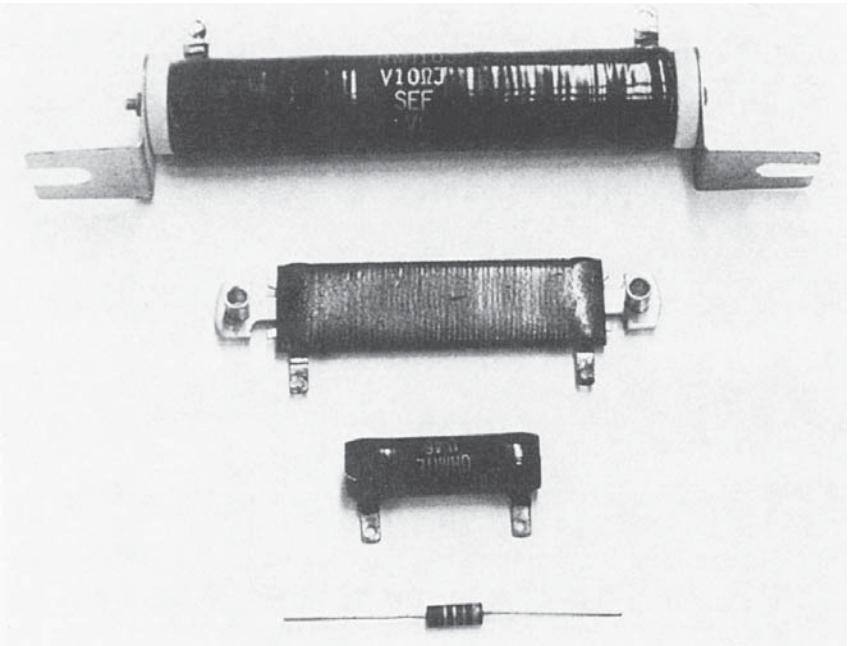


FIGURE 3–4 Resistors. (Courtesy of BET Inc.)

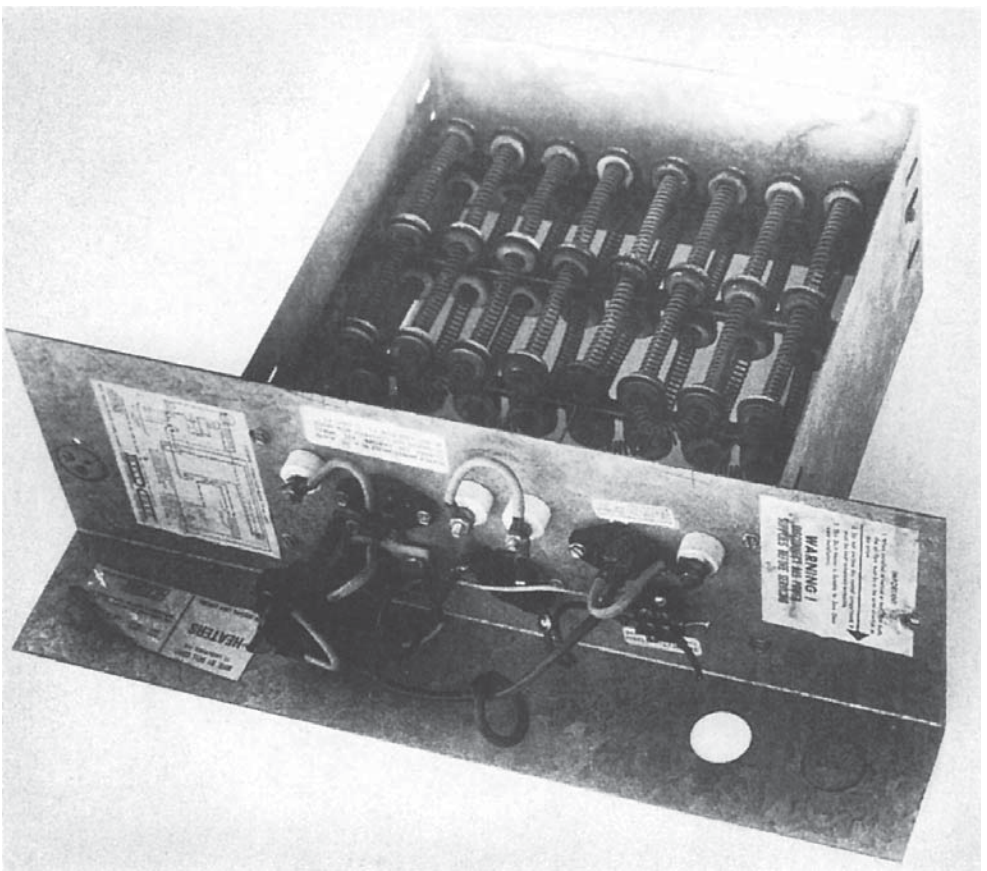


FIGURE 3–5 Heat strip. (Courtesy of BET Inc.)

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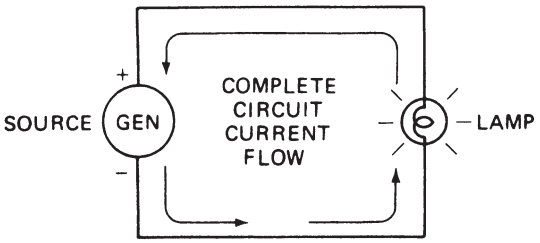


FIGURE 3–6 Complete circuit allows current flow. Lamp is lit.

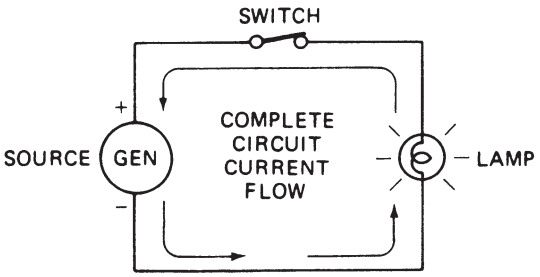


FIGURE 3–7 With a closed switch, the circuit is still complete. Lamp is lit.

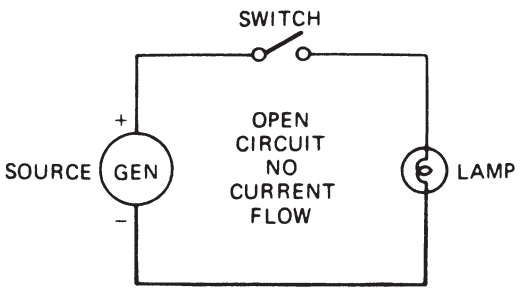


FIGURE 3–8 Open switch, no current flow. Lamp is not lit.

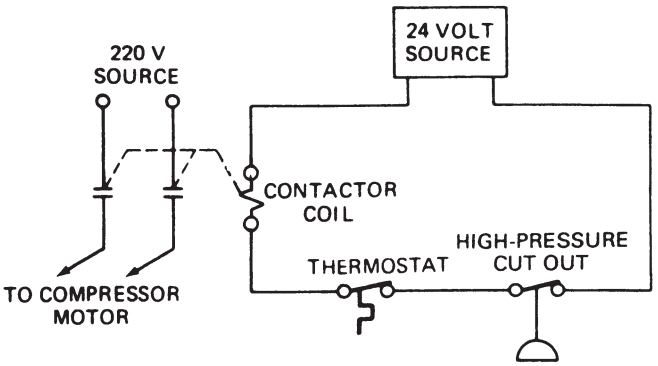


FIGURE 3–10 Low-voltage circuit controlling a high-voltage circuit.

resistance of wires (copper) is so small that it need not be considered in circuit calculation.

Electrically, both circuits in Figure 3–9 are the same. They are both series circuits. The same current must flow through each component of the circuit.

Figure 3–10 shows a simple control circuit for an air-conditioning compressor contactor. It is a series circuit. The contactor will be energized as long as 24 volts are available from the source and both the high-pressure cutout and the thermostat select switches are closed. If either switch should open, the circuit to the contactor coil will open, no current can flow in the circuit, and the contactor will de-energize and remove power from the compressor motor.

Consider Figure 3–11, a power source connected to a group of lamps. In this circuit, switch S1 is closed. There is a complete circuit from the A terminal of the generator through S1, through the lamp L1, to generator B and through the generator to A. The circuit is complete. Lamp L1 will be lit.

If switch S2 is closed, a complete circuit exists from generator A through S2, through lamp L2, and back through the generator. Lamp L2 will be lit.

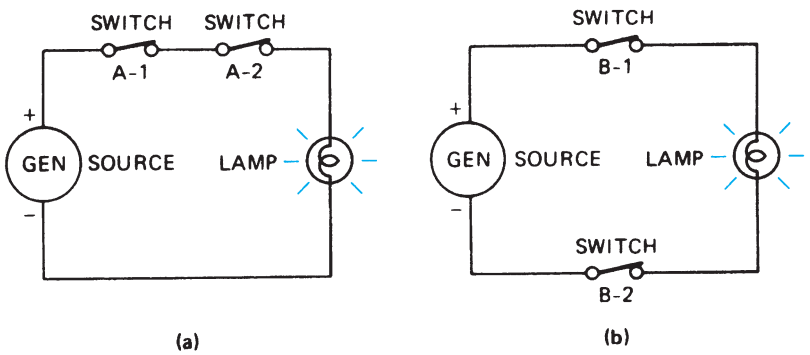


FIGURE 3–9 Switches may be located in different parts of the circuit.

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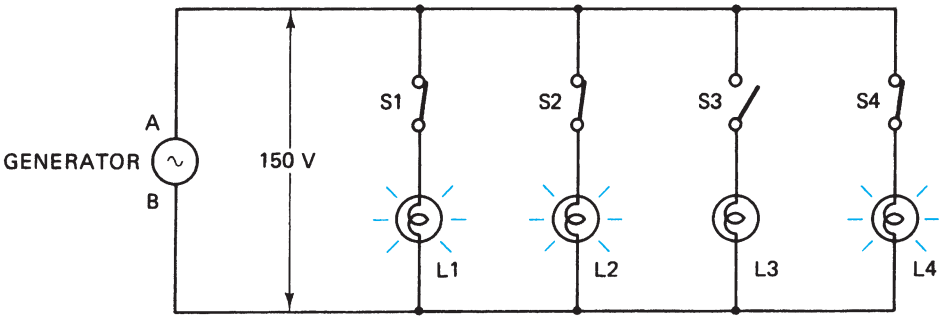


FIGURE 3–11 Parallel lamp circuit with individual switches.

When switch S3 is open, a complete path does not exist for current flow in the L3 lamp circuit. Lamp L3 will not be lit.

If switch S4 is closed, a complete circuit exists through S4, the lamp L4, and the generator. Lamp L4 will be lit.

If current is to flow in any electric circuit, a complete path must exist from the power source, through the load, and back to the power source.

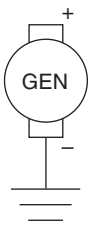


FIGURE 3–12 Negative terminal of the generator connected to the engine and chassis of the automobile to provide a *common* or *ground* connection.

Common or "Ground" Connection

In a standard electrical system, two wires are used to connect components to the power source. A wire connected to the A terminal of the generator is shown in Figure 3–11. Another wire is shown connected to the B terminal of the generator. These two wires are then connected to lamp and switches.

Another method of completing a circuit is to use a **common** or **ground** connection for one of the wires. A common or ground connection is usually used where there is a metal chassis or frame involved in the overall product.

An automobile is a good example of the use of a common or ground. In an automobile the chassis, frame undercarriage, and engine are all mechanically connected together. This forms one large electrical common connection. One side of the alternator or generator is directly connected to the engine block, which is common with the rest of the system. This can be seen on the schematic shown in Figure 3–12.

The completion of a circuit similar to the one in Figure 3–11 is shown in Figure 3–13. Current leaving the A terminal of the generator continues through the closed switches, the lamp, and finally reaches the ground. The ground, being metal, completes the path back to the B terminal of the generator.

In most situations, components in air-conditioning and refrigeration circuits use wires for both the supply and return sides of the power system, as shown in Figure 3–11. Keep in mind, however, that some systems may use a common electrical connection.

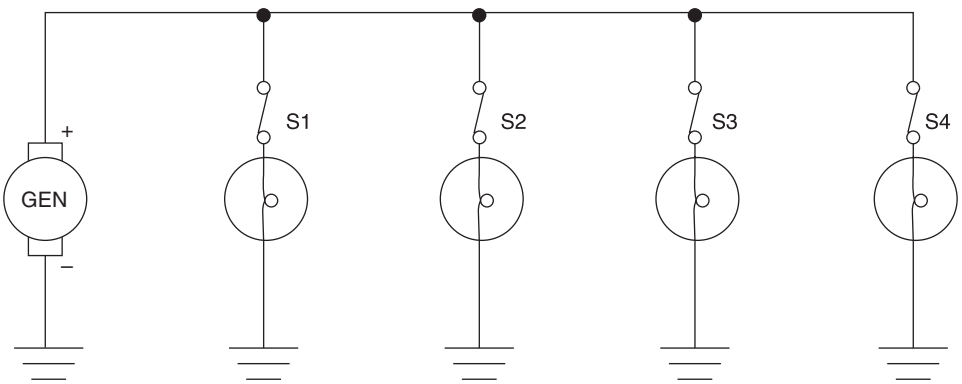


FIGURE 3–13 Lamps and switches connected in a circuit using common or ground as the return to the generator.

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This is apparent in many electronic systems; for example, a printed circuit board. The common is around the edge of the circuit board.

OHM'S LAW

The relationship of voltage, current, and resistance may be determined by a relatively simple formula known as **Ohm's law**. It was devised by a German physicist, Georg Simon Ohm, in 1848. He discovered that the current in any circuit is directly proportional to the voltage applied and is inversely proportional to the resistance.

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

or

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

or

$$E = I \times R$$

The following rules can be derived from Ohm's law:

1. If the resistance is kept the same and the voltage is increased, the current will increase.
2. If the voltage is kept the same and the resistance is increased, the current will decrease.

In honor of the discoverer of the law, the name of the unit used to measure resistance is the **ohm**; it is indicated by the Greek letter *omega* (Ω). The symbol for resistance is the letter R. The symbol for voltage is the letter E (from electromotive force [EMF]). The symbol for current is the letter I (from current intensity).

By using any one of the three forms of Ohm's law, when two factors are known in a circuit, the third factor can always be found.

EXAMPLE 1 (I is the unknown)

A 12-ohm resistor has 24 volts across it. How much current is flowing through it? (See Figure 3–14.)

Solution

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

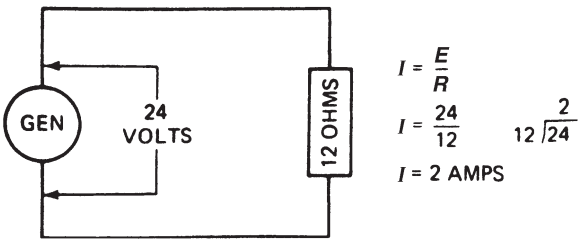


FIGURE 3–14 Using Ohm's law to determine current.

$$I = \frac{24}{12}$$

$$I = 2 \text{ amps}$$

Mathematically, the answer is 2 amperes. If an **ammeter** is connected in series with the 12-ohm resistor, as shown in Figure 3–15, the meter will indicate 2 amperes. ■

EXAMPLE 2 (E is the unknown)

A resistor of 60 ohms is connected across an electrical power source. An ammeter connected in series with the resistor indicates 2 amperes (Figure 3–16). What is the voltage of the power source?

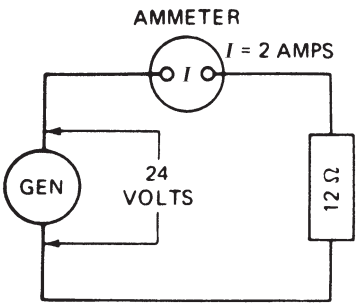


FIGURE 3–15 Connecting an ammeter to indicate current.

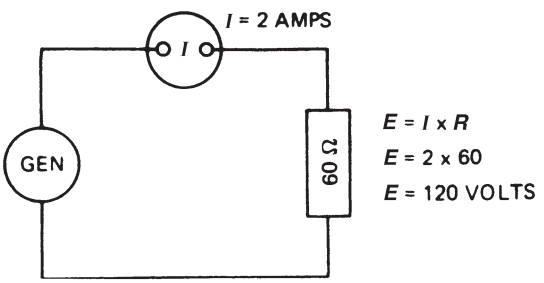


FIGURE 3–16 Using Ohm's law to determine voltage.

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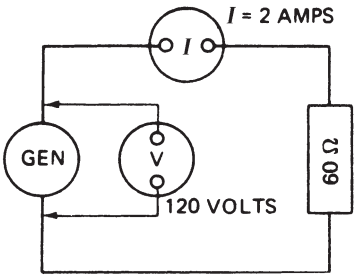


FIGURE 3–17 Measuring supply voltage.

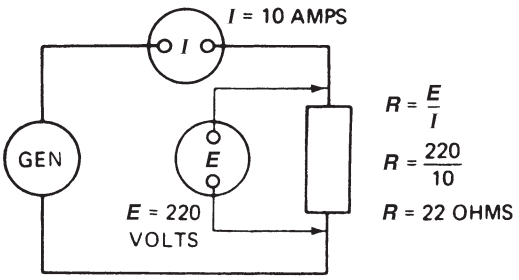


FIGURE 3–18 Measuring current flow.

Solution

$$E = I \times R$$
$$E = 2 \times 60$$
$$E = 120 \text{ volts}$$

Mathematically, the answer is 120 volts. If a voltmeter is connected across the power source, it will indicate 120 volts (Figure 3–17). ■

EXAMPLE 3 (R is the unknown)

A resistor is connected across a 220-volt power source. An ammeter connected in series with the resistor indicates 10 amperes (Figure 3–18). What is the value of the resistor?

Solution

$$R = \frac{E}{I}$$
$$R = \frac{220}{10}$$
$$R = 22 \text{ ohms}$$

Mathematically, the answer is 22 Ω. If an **ohmmeter** is connected to the resistive device, it will indicate 22 Ω (Figure 3–19).

In normal, everyday operations, the air-conditioning and refrigeration technician is not required to solve Ohm's law problems. An understanding of Ohm's law does, however, provide the means to a better understanding of electricity. A good understanding of electricity is important to the technician when troubleshooting equipment. ■

Open Circuit—Ohm's Law

Ohm's law is true for the whole circuit or any part of a circuit. Consider the circuit in Figure 3–20a. Switch S1 is closed. The resistance of the closed switch could be 0.001 ohm or even lower. The switch resistance is so low compared to the lamp resistance that the switch resistance does not effectively contribute to the total resistance of the circuit (144 ohms versus 144.001 ohms).

By Ohm's law, the current in the circuit is

$$I = \frac{E}{R}$$
$$I = \frac{120}{144}$$
$$I = 0.833 \text{ amperes}$$

In Figure 3–20b, switch S1 is open. The resistance of the open switch could be 100,000,000 ohms. The resistance of the lamp is insignificant when compared to the open switch resistance. The supply

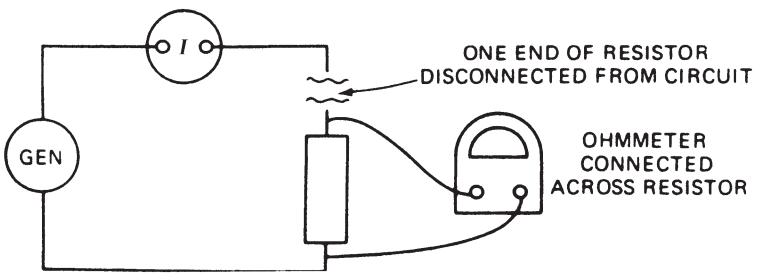
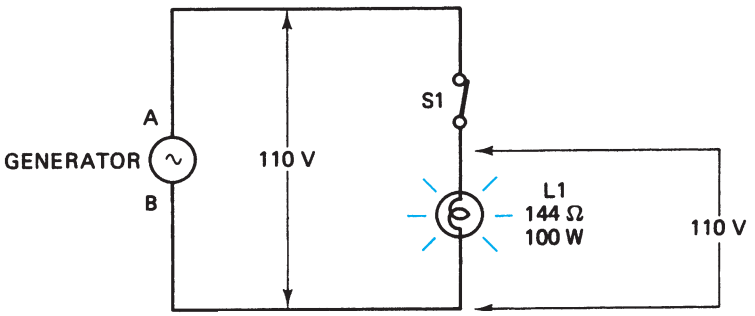


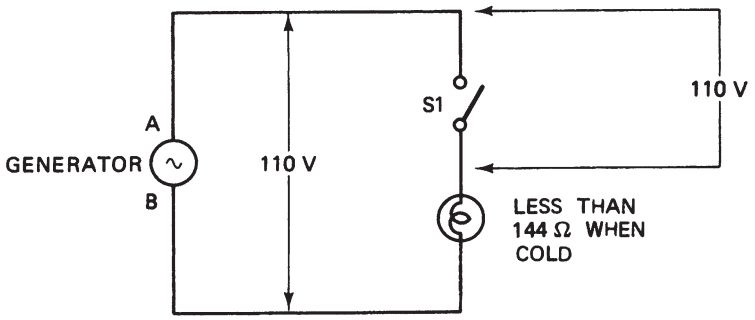
FIGURE 3–19 Using an ohmmeter to measure resistance.

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(a)

FIGURE 3–20(a) Closed switch has low resistance; voltage appears across the lamp.



(b)

FIGURE 3–20(b) Open switch has extremely high resistance; voltage appears across the switch.

voltage, 120 volts, will appear across the open switch. By Ohm's law, the current is

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

$$I = \frac{120}{100{,}000{,}000}$$

$$I = 0.0000000012 \text{ amperes}$$

Lamp L1 will not be lit, as there is too little current flowing through it. For all practical purposes, there is no current. (The actual resistance of the open switch would depend on a number of factors. One is air resistance. The resistance of air varies according to moisture content, among other factors.)

DIAGRAMS

Diagrams are used to provide circuit information. Four types of diagrams are particularly useful in showing component connection. They are (1) pictorial, (2) schematic, (3) ladder, and (4) wiring. Figure 3–21

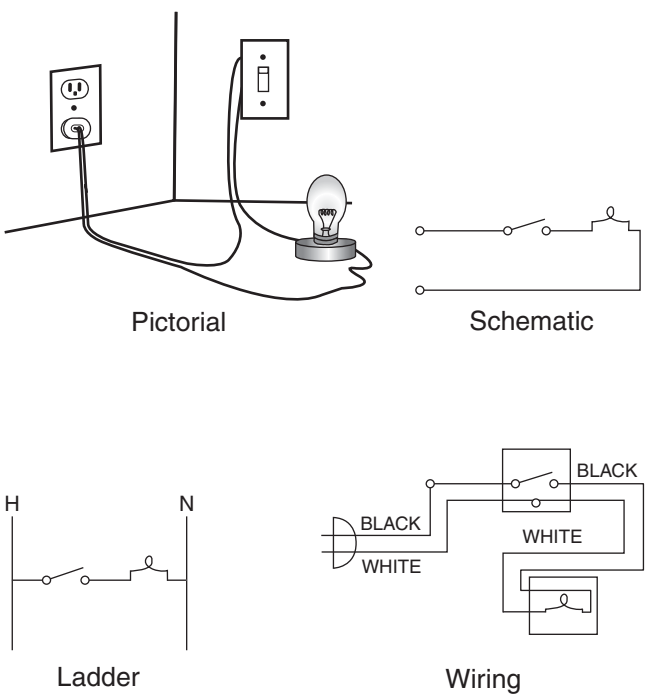


FIGURE 3–21 Types of diagrams.

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shows examples of the same circuit in the four diagram types. Some of the diagrams may look similar because the circuit is so simple. The difference will become more obvious as the circuits become more complex.

RESISTOR COLOR CODE

Normally, we are only interested in the resistance of loads such as motors, coils, and heaters. However, in electronic circuits and some other special applications, a device called a resistor (Figure 3–22) is used for the sole purpose of providing a resistance and providing no other function. You will find resistors on circuit boards, but you will usually not troubleshoot these boards down to the component level. But sometimes you will. For example, if you use your ohmmeter incorrectly, you can ruin it by blowing out one of the resistors. If you can find the failed resistor (usually by the burn mark around it), it can be replaced with a resistor of the same resistance value. The resistance value of a resistor can be determined from the colors of the four bands. Each different color stands for a different number, as follows:

Black	= 0
Brown	= 1
Red	= 2
Orange	= 3
Yellow	= 4
Green	= 5
Blue	= 6
Violet	= 7
Gray	= 8
White	= 9

The first colored band (closest to the end of the resistor) is read as the first number. The second band is read as the second number. The third band is read as the number of zeros that must be added to the first two numbers. The fourth band tells you the manufacturing tolerance of the resistor, with the following values:

Gold	= 5%
Silver	= 10%
None	= 20%

The manufacturing tolerance tells you how close the actual resistance of the resistor will be to the value that you read by the colors.

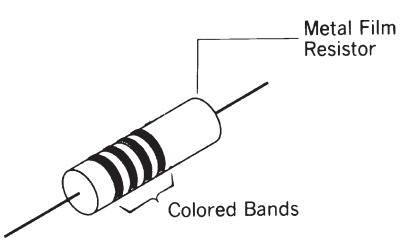


FIGURE 3–22 Color-coded resistor.

EXAMPLE 4

A burned-out resistor has the colors gray, red, orange, and gold. What value resistor will you buy to replace it?

Solution

The first band, gray, stands for 8. The second band, red, stands for 2. The third band, orange, stands for 3, which means three zeros. The value of the resistor is 82,000 ohms. The fourth band, gold, means that the actual resistance is within 5% of the 82,000 ohms that you just determined. ■

TROUBLESHOOTING

A practical troubleshooting situation could exist in the circuit shown in Figure 3–20a. Here the switch is closed, and the lamp should be lit.

But, if the lamp is not lit, there is a problem. The first procedure normally would be to replace the lamp with one that is known to be good. If the new lamp still does not light, troubleshooting to find the problem in the circuit is required.

1. Measure the supply voltage at the generator. The voltage between the output A and B terminals should be 110 volts.
2. Measure the voltage across the lamp socket.
   a. If there are 110 volts across the socket and the good lamp is not lit, the lamp socket is bad.
   b. If 110 volts are not present at the socket, measure the voltage at the switch.
   c. The voltage across the closed switch should be zero volts. If the voltage across the closed switch is 110 volts, the switch is bad.

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SUMMARY

- A complete circuit is necessary for current to flow.
- Ohm's law is the relationship between current, voltage, and resistance in an electric circuit.
- If two of the factors in Ohm's law are known, the third can always be found.
- Ohm's law is true for the entire circuit or for any part of the circuit.

PRACTICAL EXPERIENCE

Determine the value of the unknown in the following problems:

1. A 22-ohm resistive heater has 220 volts across it. How much current is flowing through it?
2. A resistor of 15 ohms has 11 amperes flowing through it. How much voltage is across the resistor?
3. The voltage measured across a heat strip is 220 volts. A clamp-on ammeter used on a line feeding this circuit indicates 9 amperes. What is the resistance of the element?

Conclusion The relationship between current, voltage, and resistance in a component is fixed by a law called Ohm's law. The formula may be stated in three ways:

1. The current flow through a component is equal to the voltage across the component divided by the resistance of the component.

$$I = E/R$$

2. The resistance of the component is equal to the voltage across the component divided by the current flow through the component.

$$R = E/I$$

3. The voltage across the component is equal to the current flow through the component multiplied by the resistance of the component.

$$E = I \times R$$

REVIEW QUESTIONS

1. The resistance of a piece of wire depends on four things. What are they?
2. In an electric circuit, if the resistance is kept the same and the voltage is increased, the current will (increase, decrease).
3. In an electric circuit, if the voltage is kept the same and the resistance is increased, the current will (increase, decrease).
4. If a 6-ohm resistor has 20 amperes flowing through it, the voltage across the resistor will be _____ volts.
5. If 24 volts is measured across an 8-ohm resistor, how much current must be flowing through it?
6. An ammeter connected in series with a resistor indicates 11 amperes. A voltmeter connected across the resistor indicates 220 volts. What is the value of the resistor?
7. What voltage is needed to cause 4 amperes to flow through a 110-ohm resistor?
8. If the voltage across a 15-ohm resistor is measured at 90 volts, how much current is flowing through the resistor?
9. If the voltage applied to a resistor is doubled, will the current double or decrease to one-half the original value?
10. What size resistor will cause a current of 3 amperes to flow when 120 volts is applied to it?

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UNIT 4

Resistance Circuits

OBJECTIVES

After completion and review of this unit, you should be able to:

- Recognize a complete circuit.
- Recognize a series circuit by component connections.
- Solve series circuit problems.
- Recognize parallel circuits are circuits in which the total line current splits into two or more paths before returning to the current source.
- Recognize series—parallel circuits are circuits in which some of the components of the circuit are connected in series and other components of the circuit are connected in parallel.
- Recognize Ohm's law is applicable to the whole circuit or the individual components of the circuit in both the parallel or series—parallel circuits.

In Unit 3, Ohm's law and its application to simple electric circuits were discussed. In this unit, the discussion will be expanded to cover Ohm's law as it relates to series circuits.

An example of a simple series circuit is the **relay** contacts of an air-conditioning compressor and the related compressor motor. (See Figure 4–1.) The contacts are in series with the motor. All the current that flows through the compressor must flow through the contacts. When the contacts are open, the circuit is open; no current flows through the compressor motor.

A more complete presentation of series circuits follows; the relationship between voltage, current, and resistance in a series circuit is covered in this unit.

WIRE RESISTORS

A common material used in the construction of wire-wound resistors is nichrome. Nichrome wire has a relatively high resistance for short lengths of wire. For example, 100 feet of nichrome wire could have a resistance of about 100 ohms. A practical, usable resistor can be made out of nichrome wire by winding it on a core of ceramic with terminals at either end (Figure 4–2).

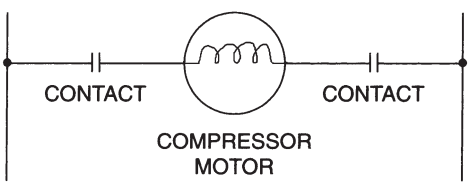


FIGURE 4–1 Contacts in series with compressor motor.

The circuit in Figure 4–3 consists of a source (a generator), connecting wires, and a load (a 100-ohm wire-wound resistor). According to Ohm's law, if the generator is producing 100 volts, then 1 ampere of current will flow in the resistor. A voltmeter connected across the resistor will read 100 volts.

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

$$I = \frac{100}{100}$$

$$I = 1 \text{ ampere}$$

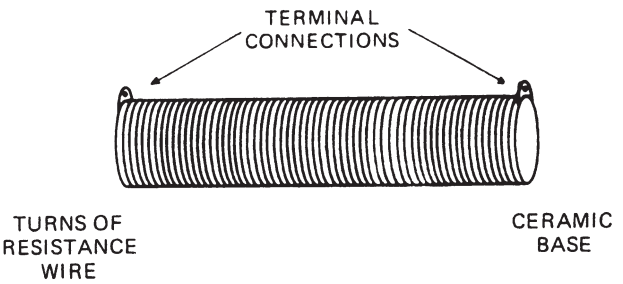


FIGURE 4–2 Wire-wound resistor.

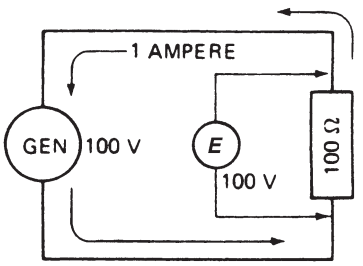


FIGURE 4–3 Single-resistor circuit.

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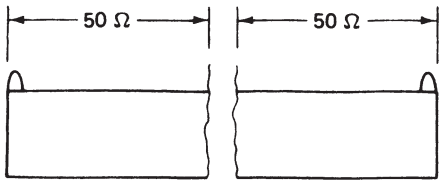


FIGURE 4–4 100-ohm resistor broken at the exact center.

If the resistor is broken at the exact center (Figure 4–4), there will be two resistors of 50 ohms each (two 50-foot lengths of the nichrome wire). The two broken ends of wire could be clamped together to remake the 100-ohm resistor (Figure 4–5). The two 50-ohm resistors, tied in series, make the 100-ohm resistor: 50 + 50 = 100.

The two reconnected 50-ohm resistor sections can be connected into the original circuit (Figure 4–6). This circuit is a **series circuit**. The same current, 1 ampere, flows through each of the 50-ohm resistor sections. Ohm's law may be used to calculate the voltage across R_1, the first resistor section.

$$E = I \times R_1$$
$$E = 1 \times 50$$
$$E = 50 \text{ volts}$$

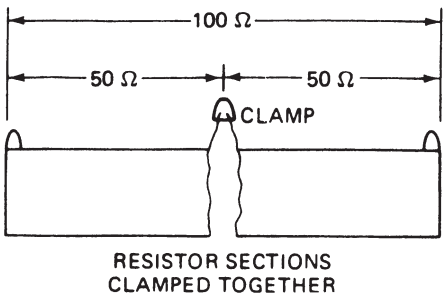


FIGURE 4–5 Two 50-ohm resistors joined together.

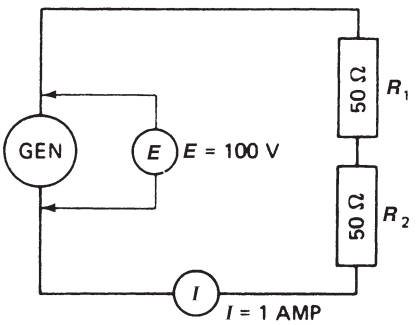


FIGURE 4–6 Two-resistor series circuit.

Ohm's law also is used to calculate the voltage across R_2, the second resistor section.

$$E = I \times R_2$$
$$E = 1 \times 50$$
$$E = 50 \text{ volts}$$

Note that the sum of the voltages across R_1 and R_2 equals the supplied voltage, 50 V + 50 V = 100 V. Also note that the total resistance, 100 ohms, is the sum of the individual resistors, 50 Ω + 50 Ω = 100 Ω.

LAWS OF SERIES CIRCUITS

We can now state the laws of series circuits.

1. The same current flows through each component of a series circuit.
2. The total voltage in a series circuit is equal to the sum of the voltages across the individual components.
3. The total resistance of a series circuit is equal to the sum of the resistances of the individual components.

EXAMPLE 1

A circuit consists of a 25-ohm resistor and a 50-ohm resistor connected in series across a 150-volt generator (Figure 4–7). Determine the current flow in the circuit and the voltage across each resistor.

Solution

The total resistance is equal to the sum of the individual resistances.

$$R_T = R_1 + R_2$$
$$R_T = 25 + 50$$
$$R_T = 75 \text{ ohms}$$

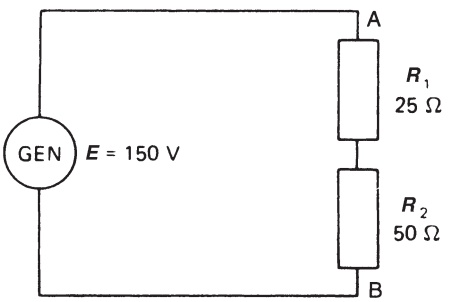


FIGURE 4–7 Circuits of 25 ohms and 50 ohms in series.

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Use Ohm's law on the whole circuit.

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

$$I = \frac{150 \text{ V}}{75}$$

$$I = 2 \text{ amperes}$$

Because the same current flows through each component, the voltage across each component may be determined by using Ohm's law.

$$E_{R_1} = I \times R \qquad E_{R_2} = I \times R$$

$$E_{R_1} = 2 \times 25 \qquad E_{R_2} = 2 \times 50$$

$$E_{R_1} = 50 \text{ volts} \qquad E_{R_2} = 100 \text{ volts}$$

The supply voltage is equal to the sum of the voltages across the individual components.

$$E_T = E_{R_1} + E_{R_2}$$

$$E_T = 50 + 100$$

$$E_T = 150 \text{ volts}$$ ■

EXAMPLE 2

Determine the value of each resistor, the voltage across each resistor, and the total resistance of the circuit shown in Figure 4–8. The generator supplies 240 volts; the ammeter indicates 4 amperes.

Solution

Solve for R_T, using Ohm's law for the whole circuit.

$$R_T = \frac{E_T}{I}$$

$$R_T = \frac{240}{4}$$

$$R_T = 60 \text{ ohms}$$

Solve for R_2.

$$R_2 = \frac{E_{R_2}}{I}$$

$$R_2 = \frac{80}{4}$$

$$R_2 = 20 \text{ ohms}$$

Solve for ER_3.

$$E_{R_3} = I \times R_3$$

$$E_{R_3} = 4 \times 5$$

$$E_{R_3} = 20 \text{ volts}$$

Solve for R_4.

$$R_4 = \frac{E_{R_4}}{I}$$

$$R_4 = \frac{40}{4}$$

$$R_4 = 10 \text{ ohms}$$

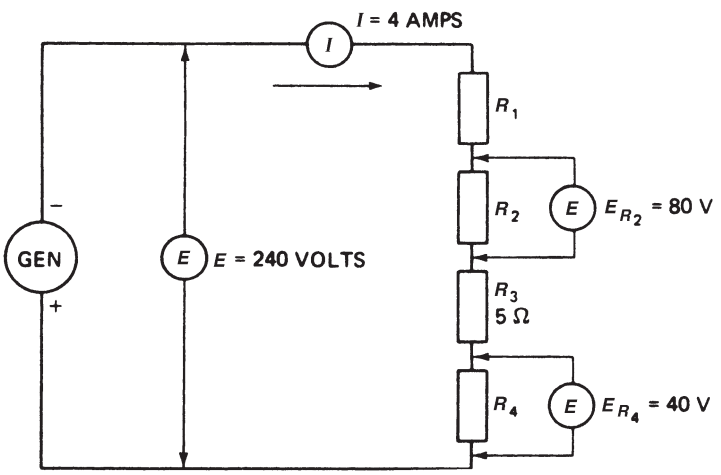


FIGURE 4–8 Using Ohm's law in series circuits.

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