Study Unit

Electrical Fundamentals

By

Ed Abdo

About the Author

Edward Abdo has been actively involved in the motorcycle and ATV industry for more than 25 years. He received factory training from Honda, Kawasaki, Suzuki, and Yamaha training schools. He has worked as a motorcycle technician, service manager, and Service/Parts department director.

After being a chief instructor for several years, Ed is now the Curriculum Development Manager for the Motorcycle Mechanics Institute in Phoenix, Arizona. He is also a contract instructor and administrator for American Honda's Motorcycle Service Education Department.

Preview

In your previous study units, you've learned about the components of a motorcycle and ATV engine and how they affect engine operation. You've also learned about lubrication and cooling systems. This study unit is the first of three that will concentrate on the subject of electricity. The text will show you the basics of electricity, where electricity comes from, and how we measure electricity. In the following study units, we'll discuss charging systems, ignition systems, and other electrical circuits that will be found when working on a motorcycle or an ATV.

When you complete this study unit, you'll be able to

- Explain how a basic circuit operates
- Describe the electron theory of electrical operation
- Describe the conventional theory of electrical operation
- Explain the difference between voltage, current, and resistance in a circuit
- Calculate voltage, current, and resistance using Ohm's Law
- Describe how to use a multimeter to measure voltage, resistance, and current
- Describe how an electromagnet works
- Explain what a diode is and how it works

Contents

Electrical Fundamentals

INTRODUCTION

Since electricity can't normally be seen, many technicians in the motorcycle and ATV industry know little about it and are somewhat afraid of it. Electricity isn't a difficult subject area to learn as long as you understand the basics of how electricity works. We assure you that you don't have to be an electrical engineer with a background in the theory of electrical systems in order to competently service the electrical systems on modern motorcycles or ATVs. However, for you to understand why something isn't functioning properly, you must first know how it works. The technician who understands how electrical systems produce, conduct, store, and use electrical energy will find it easier to locate and correct problems in these systems. Therefore, in this study unit we'll discuss the fundamentals of electricity, including the terms used in this field, and cover some of the devices used to measure electricity.

As you probably know, electrical theory and its application can be very complex. In this study unit we're going to give you a general understanding of electricity and how it works. While you should understand the basic theory and facts presented here, you won't be expected to become an electrical genius and memorize electrical formulas and theories. In fact, we'll try very hard to make learning about electricity and electrical systems fun!

BASIC PRINCIPLES OF ELECTRICITY

The typical motorcycle or ATV electrical system has many different paths through which electricity can flow. The four major electrical systems found are

- Starting systems, which are used on many motorcycles and ATVs to rotate the engine to start it
- Ignition systems, which provide for high-energy sparks to ignite the fuel-and-air mixture inside of the engine's combustion chamber
- Lighting systems, which are used to power the lights as well as operate other electrical equipment on the machine
- Charging systems, which are used to produce the electricity that the above systems require, and to recharge the battery which is used to store the electricity

Besides these major systems, there are also many other electrical subsystems. Let's take a closer look at electricity by first looking at some electrical theories, a battery, and a simple circuit.

Electricity and the Electron Theory

Scientists now generally accept the *electron theory* concerning the nature of electricity. All matter is composed of *molecules*, and each molecule contains two or more *atoms*. Atoms, in turn, are made up of *neutrons*, *protons*, and *electrons*. It's the arrangement of these particles that makes materials such as liquids, solids, and gases differ from one another.

The core of the atom, called the *nucleus*, contains protons and neutrons. Protons have a positive electrical charge and neutrons are neutral, meaning that they have no electrical charge. Electrons have a negative charge and rotate around the nucleus of the atom. Atoms normally have an equal number of protons and electrons, and therefore an equal number of positive and negative electrical charges. These charges cancel each other out, resulting in an atom with no positive or negative electrical charge. When an atom has more protons than electrons, it's positively charged. When an atom has more electrons than protons, it's negatively charged (Figure 1).

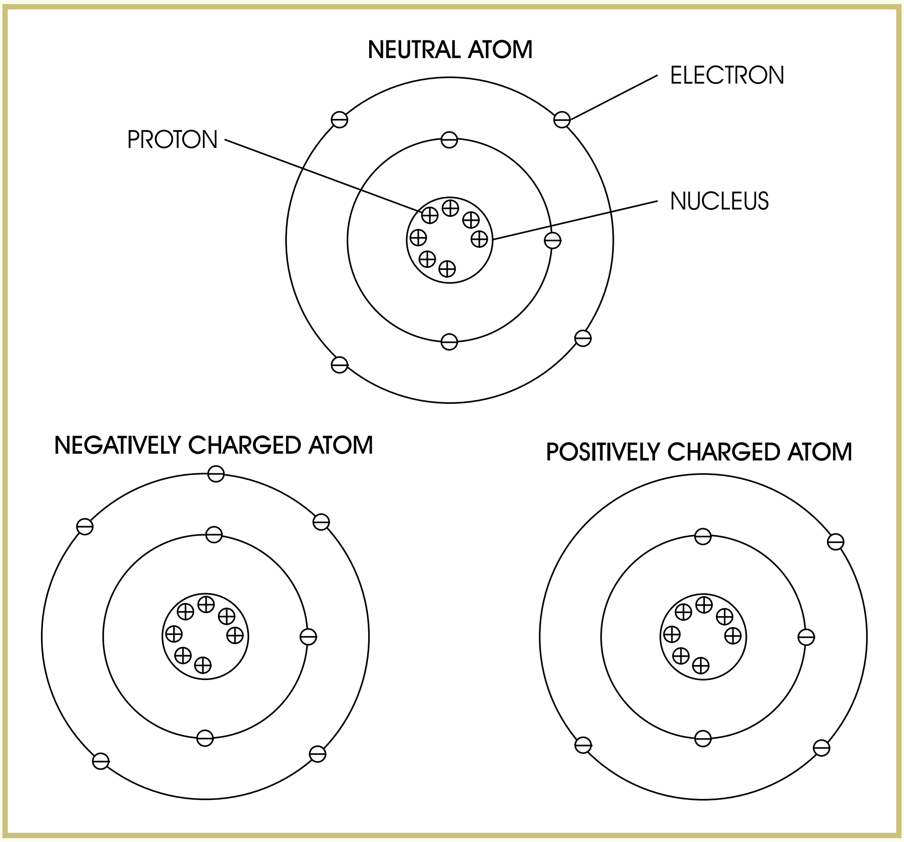


FIGURE 1—A neutral atom has an equal number of protons and electrons. A positively charged atom has more protons than electrons. A negatively charged atom has more electrons than protons.
(Courtesy of American Suzuki Motor Corporation)

Atoms which make up different kinds of material have different numbers of electrons and protons. For example, a carbon atom has only 12 protons and 12 electrons, while a uranium atom has 234 protons and 234 electrons.

In some materials, the electrons are tightly bound in orbit around the nucleus of the atom and aren't free to travel to other atoms. This condition exists in materials that are poor conductors of electricity. In other materials, the orbits of the electrons are relatively large and the electrons are able to travel to other atoms. Such materials are good electrical conductors (Figure 2). The orbits of the electrons in copper are large and the electrons can move relatively easily; so copper conducts electricity well. For this reason, most electrical circuits use copper wire as the conductor through which the current flows.

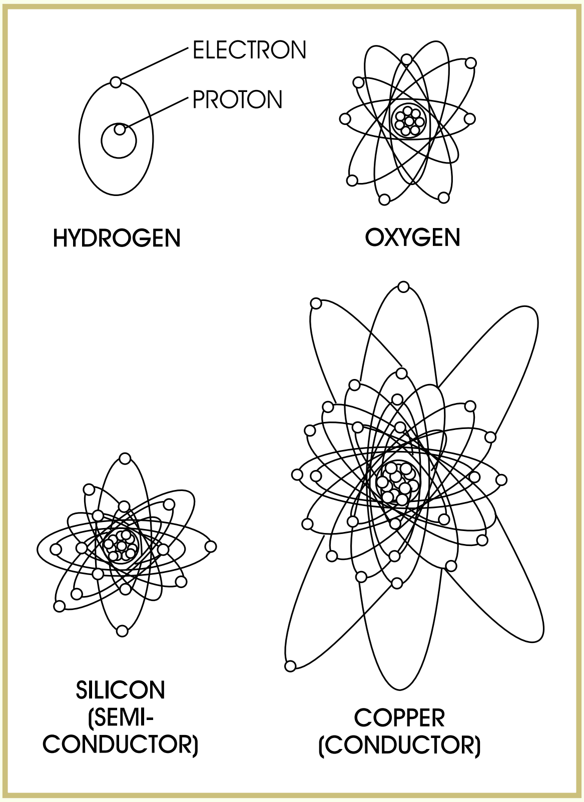


FIGURE 2—Hydrogen and oxygen are poor conductors; silicon is a semiconductor; and copper is a good conductor. (Courtesy of American Suzuki Motor Corporation)

When an atom is positively charged or negatively charged, the condition (excess number or lack of electrons) will cause a flow of electrons from one atom to another. The idea of removing electrons from an atom may seem strange. However, we remove electrons from atoms all the time without realizing it. For example, if you shuffle across a carpet and then touch a metal surface, what usually happens? You probably receive a small shock, and maybe even see a spark. This occurs because, as you scuffed your shoes along the carpet, you actually rubbed free electrons off the carpet. Your body held onto these electrons, and you became negatively charged. When you touched the metal surface, the free electrons from your body transferred to the metal, restoring your body to a neutral charge. The discharge of electrons from you to the metal caused the small shock that you felt.

Thus, you can see that it's not impossible to get electrons moving from one place to another. However, it's easier to get electrons moving in some materials than in others. The structure of an individual atom will determine how easily an electron can be removed from it. For example, in Figure 2, you saw that the structure of the hydrogen atom makes it very difficult to remove an electron from its orbit. So, it's very difficult to produce a flow of electricity in hydrogen. However, in a copper atom, the outermost electron can easily be dislodged from its orbit. Therefore, it's very easy to get a flow of electricity moving in copper.

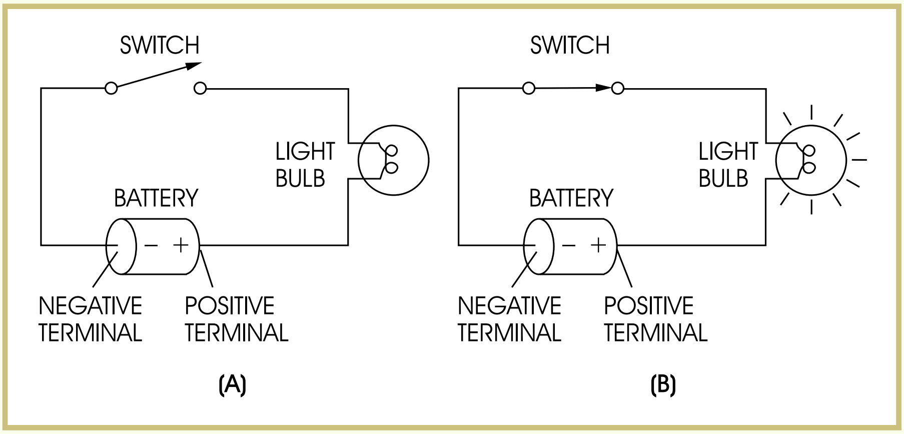
Any substance in which electrons can move freely is called an electrical conductor. Copper, silver, gold, and other metals are good electrical conductors. (In fact, silver and gold are better electrical conductors than copper, but because silver and gold are so expensive, they aren't used to make electrical wires in motorcycles or ATVs.) Materials in which the electrons are tightly bonded to the nucleus are called insulators. Plastic, nylon, ceramic, and other similar materials are very resistant to the flow of electricity and are classified as insulators.

A Battery

Electricity is an invisible form of energy that can be transformed into magnetism, light, heat, or chemical energy. Because we know how to control electrical energy, we can use it to perform many jobs. You may be wondering, what exactly is electricity? *Electricity* is a natural force produced by the movement of electrons. In the circuit shown in Figure 3, moving electrons come from the battery. A *circuit* is a complete electrical path. (Circuits will be discussed later in this study unit.) The battery produces a flow of electrons that moves through the wires to light the flashlight bulb.

Note that the battery has two different ends. The end of the battery that's labeled with a negative, or minus, sign ( ) is called the *negative terminal*. The opposite end of the battery that's labeled with a positive, or plus, sign (+) is called the *positive terminal*. The negative terminal of the battery has a negative charge, as it contains too many electrons. The positive terminal of the battery has a positive charge, as it contains too few electrons.

FIGURE 3—This figure shows a simple circuit. In A, the circuit is open. In B, the circuit is closed.

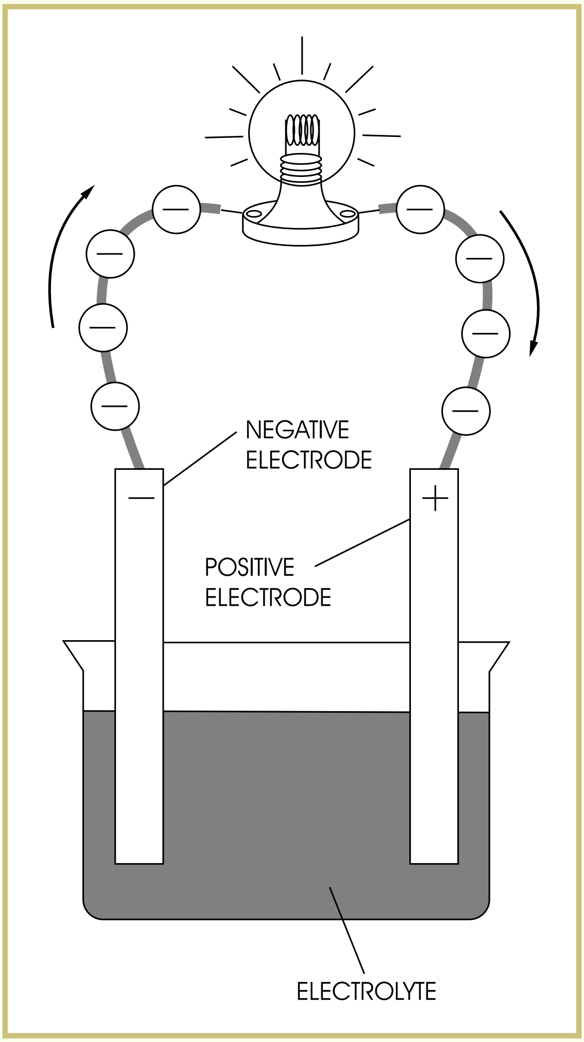


The negative and positive charges in a battery are produced by a simple chemical reaction. Figure 4 shows a simplified diagram of the parts of a battery. The battery terminals, or *electrodes*, are two strips of lead. Each electrode is made from a different type of lead. When the strips of metal are placed into the electrolyte solution, a chemical reaction occurs. *Electrolyte* is a chemical compound which, when molten or dissolved in certain solvents (usually water), will conduct an electric current. As a result of this reaction, a negative charge forms on one electrode and a positive charge forms on the other electrode.

You've probably heard the phrase "opposites attract." This phrase holds true with electricity. Opposing electrical charges (positive and negative) strongly attract each other and try to balance each other out. Because of this attraction, whenever too many electrons are in one place, the electrons will try to move to a place where there are fewer electrons. This is the basic operating principle of a battery. The negative terminal of a battery has a high concentration of electrons, while the positive terminal has very few electrons. So, the electrons at the negative battery terminal will be drawn toward the positive battery terminal. But to actually move from the negative terminal to the positive terminal, the electrons need a path to follow. We can create a path for the electrons by connecting a wire between the battery terminals. (Batteries are discussed in more detail in a future study unit.) By attaching the wires, we actually build a circuit.

In the simple circuit shown in Figure 3, electrons flow from the negative battery terminal to the positive terminal through the conductors that are attached to them. Note that the flow of electricity produced by the battery will continue as long as the chemical reaction in the battery keeps up. After some time, the chemical reaction in the battery will stop and the battery will stop functioning. At that point the battery will need to be recharged or replaced. This is why motorcycles and ATVs have charging systems.

FIGURE 4—In this illustration of a battery, a chemical reaction takes place between the electrodes and the electrolyte solution. This chemical reaction produces an electrical charge on each of the electrodes.



Circuits

There are four requirements to complete a typical circuit—a power source, conductors, a load, and a switch. A *power source* is simply a source of electrical power. The power source in a common household circuit is typically provided by a wall outlet. The power source in a motorcycle electrical circuit is a battery. The *conductors* are the wires that carry the electricity. In order to use the electrons to perform useful work, we've connected a light bulb to the circuit, which is our load. A *load* is any device, such as a light bulb or an appliance, that we want to run with electricity. The *switch* is the device used to turn the circuit on and off.

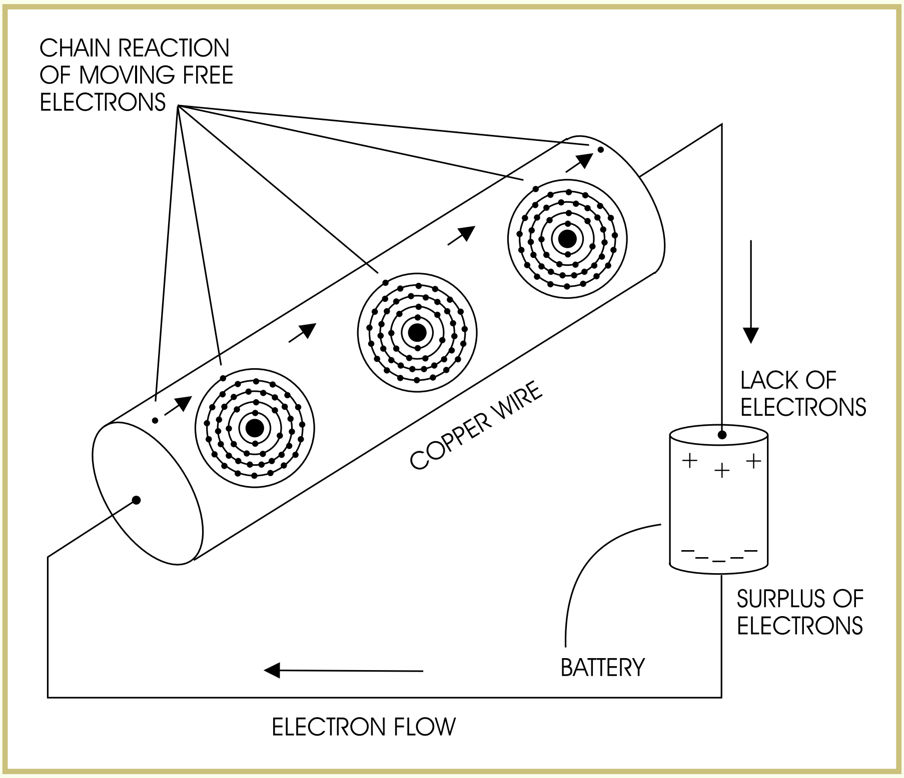
Circuits may be closed or open. In a closed circuit, when the switch is turned on, electrical power from the power source flows through an unbroken path to the load, flows through the load, and then returns back to the power source. In other words, when we turn the switch on, electrons from the negative battery terminal travel to the positive battery terminal. This flow of electrons through a circuit is called *electric current*. In contrast, in an open circuit, the switch is turned off, which breaks the path of the circuit so power doesn't reach the load.

A simple flashlight circuit is shown in Figure 3. The power source in this circuit is a battery. The conductors are copper wires. The load is a light bulb. In Figure 3A, the switch is open (in the OFF position). The electrical circuit is therefore open, and power can't flow through the wires to reach the bulb. In Figure 3B, the switch is closed (in the ON position). This circuit is complete, and electricity flows through the wires to reach the bulb, causing the filament to heat up and glow. The simple circuit that we've just described is known as a *series circuit*. We'll discuss the different types of circuits later in this study unit. You should note that all electrical systems can be broken down to simple circuits very similar to the circuit that we've just discussed!

Electron Flow in a Circuit

Let's take a closer look at how electrons flow in an electrical circuit. Figure 5 shows a simple series circuit in which a copper wire is attached to a battery. One section of the copper wire is enlarged so that you can see how electrons flow through the wire.

FIGURE 5—A section of the conductor in this illustration has been enlarged so that you can see how electrons flow through the wire. A free electron from the battery enters the wire. The free electron then creates a chain reaction within the wire where free electrons bump other electrons from the outer shell of the atoms. Remaining free electrons are drawn to the positive side of the battery, completing the circuit.



In the figure, the circuit is closed, and the electrons from the negative battery terminal are drawn to the positive terminal. Remember that the outermost electron in each copper atom is easily dislodged from its orbit. An electron is drawn from the negative battery terminal into the copper conductor wire. This electron then collides with a free electron in a copper atom, bumping a free electron and taking its place. The displaced free electron moves to a neighboring copper atom, bumps a free electron out of the copper atom's orbit, and takes its place. As this chain reaction continues, free electrons bump their neighbor out of orbit, taking their place. This chain reaction of moving electrons is called *electric current*.

In reality, of course, atoms are much too small to see, so we can't follow the movement of just one electron through a wire. Many millions of copper atoms make up a single strand of wire. When a circuit is closed, millions of electrons move through the wire at the same time, at a high rate of speed. The more electrons moving through a circuit, the higher the current in the circuit.

Types of Circuits

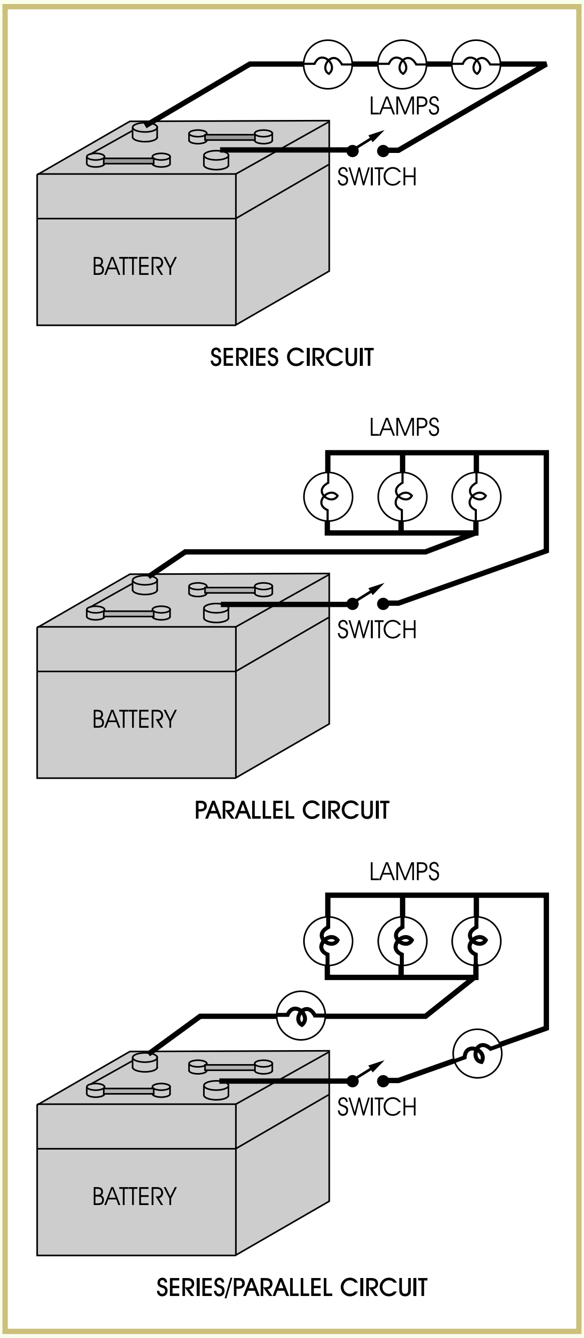
As we discussed earlier, there are different types of circuits used in electrical systems. We've already talked about one simple electrical circuit—the series circuit. A *series circuit* (Figure 6) is a circuit that has only one path back to its source. In a series circuit, if one light bulb burns out, the whole circuit shuts down since there's no path for the electricity to continue to flow. A *parallel circuit* (Figure 6) is a circuit that has more than one path back to the source of power. In a parallel circuit, if a light bulb burns out, it won't have any effect on the other bulbs because they each have a separate return path to the source of power. A popular type of circuit that you'll find on motorcycles and ATVs is a combination of the series and the parallel circuit, called the series/parallel circuit. The *series/parallel circuit* (Figure 6) contains a load in series and a parallel load in the same circuit.

Unwanted Circuit Conditions

There are different electrical circuit conditions that have an adverse effect on electrical systems. These circuit conditions are opens, shorts, and grounds.

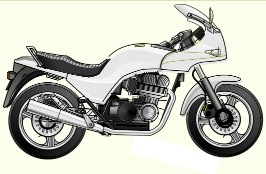
As you already know, an *open circuit* is a circuit that has an incomplete path for current to flow. An example of an open circuit is a broken wire or a blown light bulb. A *short circuit* is a circuit that has developed a path to the source of power before it reaches the load in the circuit. A short circuit will blow fuses in the circuit as well as damage wires and components in the electrical system. A *grounded circuit* is a circuit that allows the power to flow back to the source after the load, but before the means of control.

FIGURE 6—A Series, Parallel, and Series/Parallel Circuit



The Conventional Theory of Electricity

The *conventional current flow theory* states that the electrons within a conductor flow from the positive terminal to the negative terminal of an electrical energy source. The flow in this theory is the opposite of the electron theory. Almost all motorcycle and ATV service manuals use the conventional current flow theory when describing their electrical systems. Since the conventional theory is the most commonly used theory in the motorcycle and ATV industry, from now on, we'll use this theory when describing the electrical circuits used on these machines.



Road Test 1

At the end of each section of *Electrical Fundamentals*, you'll be asked to check your understanding of what you've just read by completing a "Road Test." Writing the answers to these questions will help you review what you've learned so far. Please complete *Road Test 1* now.

1. What are the four major electrical systems found on most motorcycles and ATVs?

   ____

2. Electrons have a _______ charge.
3. A _______ could cause a blown fuse.
4. Explain, in simple terms, the electron theory of electricity.

   ____

   ____

5. A _______ has no charge.
6. What are the four items needed to make up a typical circuit?

   ____

7. What are the names of the three particles that make up an atom?

   ____

8. Explain, in simple terms, the conventional theory of electricity.

   ____

   ____

9. _______ is a common material used in an electrical system to conduct electricity.
10. Define a series/parallel circuit.

   ____

   ____

Check your answers with those on page 41.

UNITS OF ELECTRICITY

Throughout this study unit, you'll learn terms that are used in connection with electrical systems, and learn some basic formulas. Some important terms you should know are *current*, *voltage*, and *resistance*, which are the three basic units of measurement in electrical and electronic circuits. We'll discuss these units next.

Current (Amperes)

As you've already learned, when a complete conducting path is present between two opposing electrical charges, electrons will flow between the two points. *Current* is the rate of flow of electrons through a conductor. Current is measured in units called amperes, or amps, which is often abbreviated *A*. For instance, the quantity 3 amperes would be abbreviated *3A*. In other electrical-related work, electrical drawings, diagrams, and mathematical formulas, the letter *I* is used to represent current. Small amounts of current can be measured in milliamperes, which is abbreviated *mA*. One milliampere of current is equal to one-thousandth of an ampere, or 0.001A of current.

Voltage (Volts)

Now, let's look at the electrical quantity called voltage. Remember that in a battery, one terminal has a negative charge and the other terminal has a positive charge. Whenever a positive charge and a negative charge are positioned close to each other, a force is produced between the two charges. This force is called *electrical potential*. Electrical potential is simply the difference in electrical charge between the two opposing terminals. Electrical potential can also be thought of as the amount of electrical pressure in an electrical system. The bigger the difference between the two opposing charges, the greater the electrical potential will be. *Voltage* is a measurement of the amount of electrical potential in a circuit. Voltage is measured in units called volts, which is often abbreviated *V*. For instance, the quantity 12 volts would be abbreviated *12V*. In electrical diagrams and mathematical formulas, voltage is usually represented by the letter *E*.

Resistance (Ohms)

The last electrical quantity we'll look at is called resistance. *Resistance* is a force of opposition that works against the flow of electrical current in a circuit. You've already seen that current flows easily through copper wires in a circuit. However, frayed wires, corroded connections, and other obstructions will reduce the flow of electrons through a circuit. That is, the circuit will resist the flow of current through it. When a lot of resistance is present in a circuit, more voltage is needed to increase the flow of electrons moving through the circuit. Resistance is measured in units called *ohms*, which is often abbreviated with the Greek letter omega, represented by the symbol Ω. In electrical diagrams and mathematical formulas, the letter *R* is usually used to represent resistance. Motorcycle and ATV service manuals often provide electrical specifications in ohms. A service manual may tell you, for example, that the resistance you should be able to measure between the leads on a charging system stator should be .2Ω. (Note that we'll discuss charging systems, their components, specifications, and how to measure circuit quantities in more detail in an upcoming study unit.)

Ohm's Law

The values of resistance, current, and voltage have a very important relationship in a circuit. The amount of current flowing through a completed circuit is directly proportional to the voltage applied to the conductor. This relationship between resistance, current, and voltage is known as *Ohm's Law*. Ohm's law states that a resistance of one ohm (1Ω) permits a current flow of one ampere (1A) in a circuit that has a source voltage of one volt (1V). This relationship that's summarized by Ohm's law is expressed with the mathematical formula

Voltage (E) = Current (I) × Resistance (R)

Two useful variations of the Ohm's law equation are

Current (I) = Voltage (E) ÷ Resistance (R)

Resistance (R) = Voltage (E) ÷ Current (I)

To help you understand how to use these equations, let's look at the following example. If you have a circuit that draws 3 amps of current from a 12-volt battery, how much resistance is in the circuit? To solve this equation, simply install the known measurements in the formula as follows:

Resistance (R) = 12 (E) ÷ 3 (I)

The answer is 4 ohms. Ohm's law is a very useful formula that you should know. The Ohm's law formula is frequently used to analyze circuits and troubleshoot problem areas. By using these three given variations of the Ohm's law formula, it's easy to find the proper voltage, resistance, and current values for any circuit.

You should note that as the resistance in a circuit increases, the current decreases. Conversely, if the resistance in a circuit decreases, the current increases. All circuits are designed to carry a particular amount of current. In fact, many circuits are protected by fuses that are rated at an amperage value that's just slightly higher than the current value of the circuit. Thus, if a problem develops in a circuit, the circuit will draw too much current from the battery and the fuse's elements will melt (the fuse will blow), creating an open in the circuit. This design prevents any further damage from occurring.

The Relationship Among Current, Voltage, and Resistance

You may better understand the relationship among current, voltage, and resistance in an electrical circuit if we compare a circuit to a simple water flow example (Figure 7). Using Figure 7, we can make the following comparisons:

- The water pipes form a path for the water to follow. The water pipes are similar to the conductors in the adjacent electrical system.
- The water valve turns the flow of water on and off. The water valve is similar to the switch in the electrical system.
- The water wheel is being operated by the flow of water. The waterwheel is similar to the light bulb (the load) in the electrical circuit.
- The water reservoir (the water source) is similar to the battery (the power source) in the electrical circuit.
- The flow of water is similar to the flow of electrons. The amount of flow would be the current.
- The water pump is the pushing force that causes the water to flow into the pipes, just as voltage does in the electrical circuit.

In Figure 7A, both the water system and the electrical circuit are turned off. Both the water valve and the electric switch are in the off position, so no water or current flows. The water wheel doesn't turn and the light bulb doesn't illuminate. In Figure 7B, in the water system, the water valve is turned on. Water is pumped out of the reservoir and into the pipes; the water flows through the pipes, turns the water wheel, and then returns to the reservoir. With the electrical circuit, the switch is also turned on. Electric current flows out of the battery through the wires, lights the bulb, and returns to the battery. In this example, you can think of resistance as being like a blockage or a clog in the water pipe. If some debris were stuck in the pipe, the flow of water through the pipe would be reduced. Similarly, excessive resistance in an electrical circuit reduces the flow of current through the circuit.

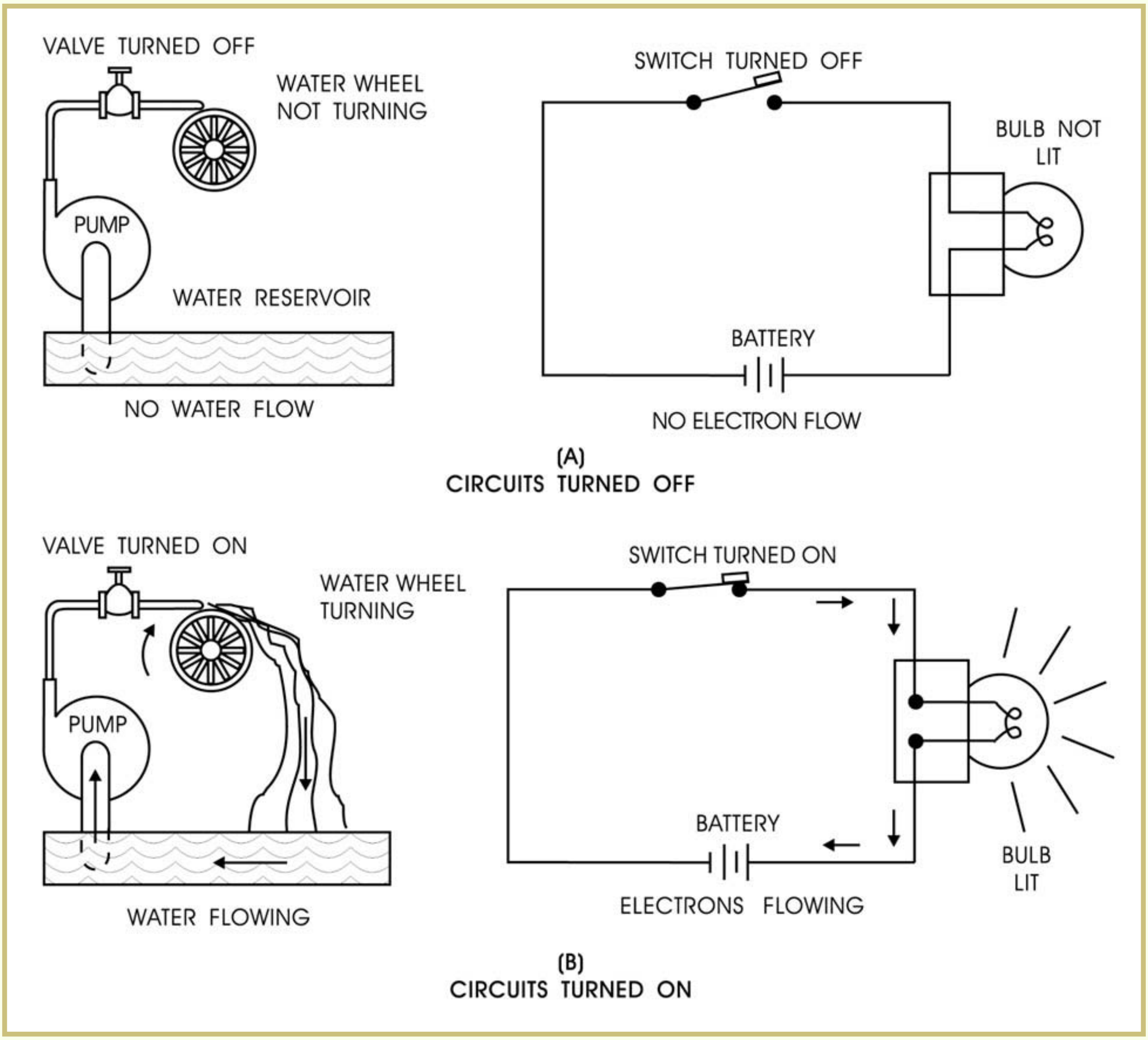


FIGURE 7—The basic principles of electricity can be easily visualized when you compare an electrical circuit to a water system.

AC/DC Voltage and Current

There are two different types of current—direct current and alternating current. It's important that you understand the differences between these two types of current.

Direct current (DC) is the flow of electrons in one direction only. A DC voltage reading is nonvarying and is usually produced by a battery or a DC power supply unit. For example, if we were to graph a DC voltage of 6 volts over a period of time, the graph would appear as shown in Figure 8. Whatever the voltage value, a DC voltage remains constant and unchanging over time.

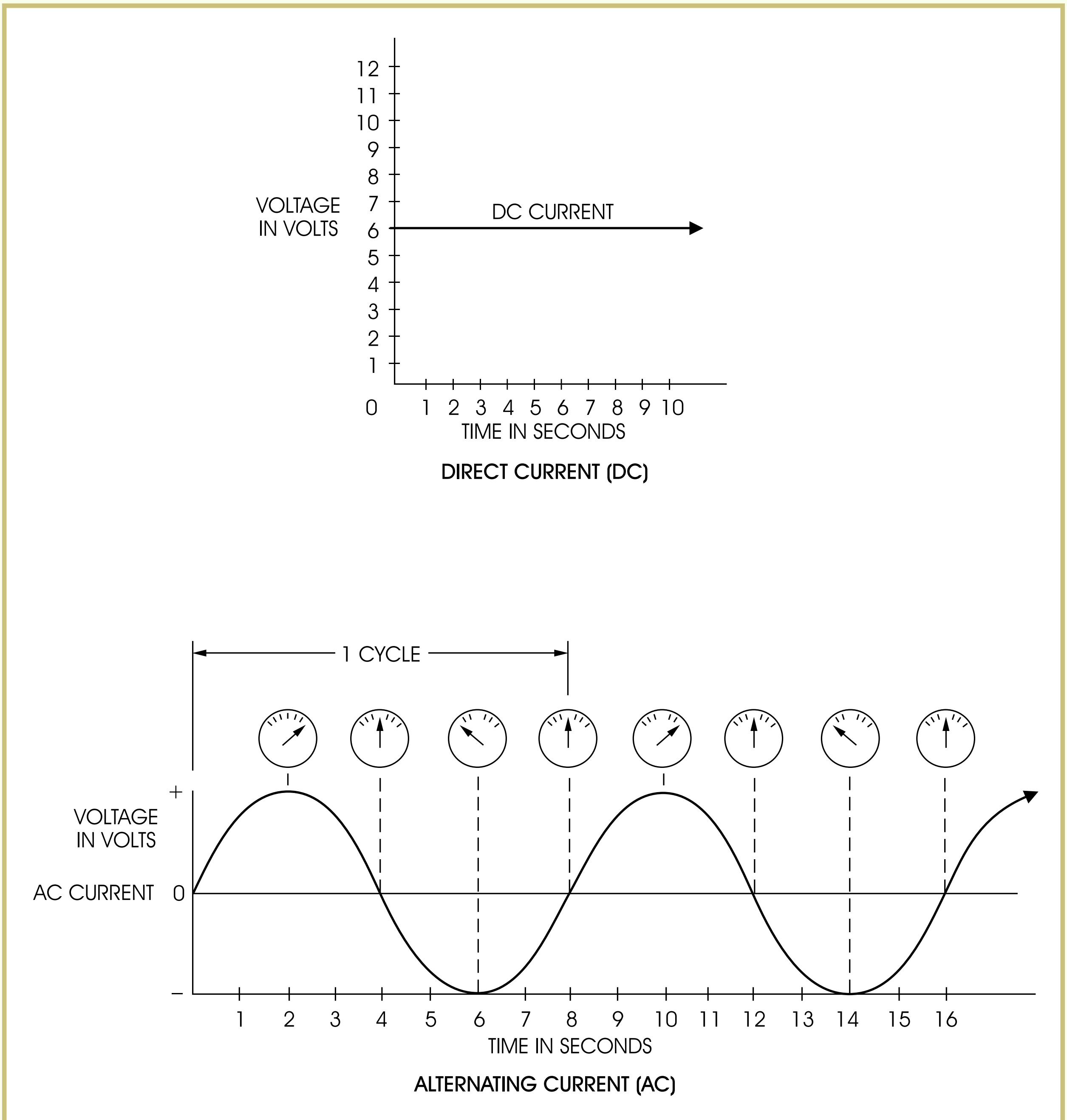


FIGURE 8—A DC voltage level remains constant over time, whereas an AC voltage level changes over time.

In contrast, *alternating current (AC)* is the flow of electrons first in one direction, and then in the opposite direction (Figure 8). Alternating current reverses direction continually and is produced by an AC voltage source. Alternating current is the type of current found in household electrical systems and wall outlets. Motorcycles and ATVs also produce AC in various ways. (We'll discuss alternating current in more detail in upcoming study units.) In Figure 8, the alternating current starts at zero, then rises to a maximum positive value. At the maximum positive point, the current reverses direction and falls back to zero. The current continues to drop until it reaches the maximum negative value. The current then reverses direction again and rises back to zero. One complete transition of the current from zero to the positive peak, down to the negative peak, and back up to zero is called a *cycle*. These alternating current cycles repeat continuously as long as the current flows. As related to motorcycles and ATVs, there are three key items needed to produce AC voltage—a magnetic field, a conductor, and motion. These items will be explained later in this study unit.

ATVs that don't have a battery use AC voltage and current for their lighting and ignition systems. Machines that use a battery use the DC voltage produced by the battery to power the starter, lights, horn, and other accessories. These machines also use AC voltage to keep the charging system working properly.

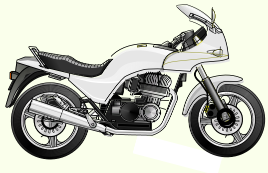
Common Electrical Quantities

Table 1 has common electrical quantities, their abbreviations, and their values. You should become familiar with these abbreviations, as you'll see them in different areas of a service manual when working with the electrical systems on motorcycles and ATVs.

Table 1

ELECTRICAL QUANTITIES

Unit	Abbreviation	Value
Ampere	A	1 ampere
Milliampere	mA	0.001 ampere
Volt	V	1 volt
Kilovolt	KV	1,000 volts
Millivolt	mV	0.001 volt
Megavolt	MV	1,000,000 volts
Ohm	Ω	1 ohm
Megohm	MΩ	1,000,000 ohms
Kilohm	kΩ	1,000 ohms



Road Test 2

1. What are the three basic units of measurement associated with electricity?

   ____

2. The unit of measurement for resistance is _______.

3. As the resistance in a circuit increases, the current will _______.

4. *True or False?* Voltage can be thought of as the pressure forcing current through a wire.

5. The abbreviation "AC" stands for _______.

6. The abbreviation "DC" stands for _______.

7. Define, in simple terms, Ohm's law.

   ____

   ____

8. How much current will flow through a 12-volt circuit that has a resistance of 2 ohms?

   ____

9. A 12-volt circuit has 6A of current. How much resistance does the circuit have?

   ____

10. *True or False?* The force produced between a positive charge and a negative charge is called electrical properties.

Check your answers with those on page 41.

ELECTRICAL METERS AND MEASUREMENTS

Although we can observe the effects of electricity, such as a glowing light bulb, we can't see the flow of electrons that we call electricity. We can however, use various meters to observe the action of electric current in a circuit.

Electrical Meter Displays

When you begin working with electrical meters, you'll notice that there are two basic types of readouts, or displays, that meters use to present the information—analog and digital. The function of these two types of meters is the same (displaying electrical information), but the way in which the data is displayed is different.

Analog Electrical Meter

The display of an analog electrical meter has a movable pointer and a scale (Figure 9). The meter is usually enclosed in a case and has terminals (test leads), which connect to jacks on the front of the case. Often a red jack indicates a positive terminal and a black jack is negative.

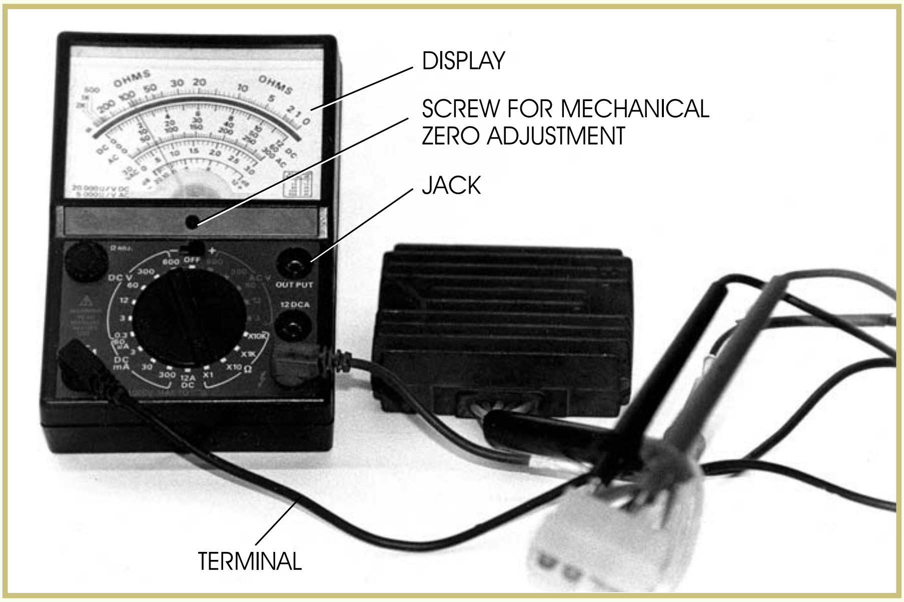


FIGURE 9—An Analog Electrical Meter

Most analog meters have scales from zero up to some maximum number. Some meters may have zero centered in the middle of the scale with numbers on the right and left. Most analog meters have what's called a *mechanical zero adjustment*. This means that by turning a screwdriver inserted into a small screw on the front of the meter, the pointer can be adjusted so that it's exactly over the zero on the scale. (During this adjustment the meter shouldn't be connected to any circuit.) The amount of movement of the pointer is called *pointer deflection*.

Digital Electrical Meter

The display of a digital electrical meter has a numeric readout (Figure 10). Like the analog meter, the digital meter is also enclosed in a case and has positive and negative terminals (test leads) which connect to jacks on the front of the case.

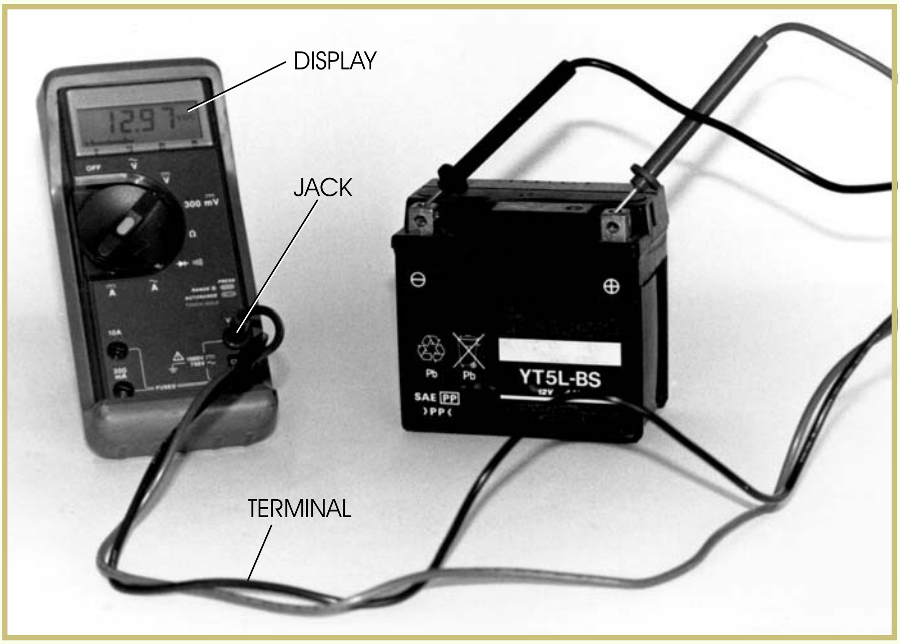


FIGURE 10—A Digital Electrical Meter

Electrical Meter Types

As you work with electrical meters, you'll also find that there are four types of meters—voltmeter, ammeter, ohmmeter, and multimeter. Keep in mind that the display of these meters may be either analog or digital. We'll discuss the use of these meters next.

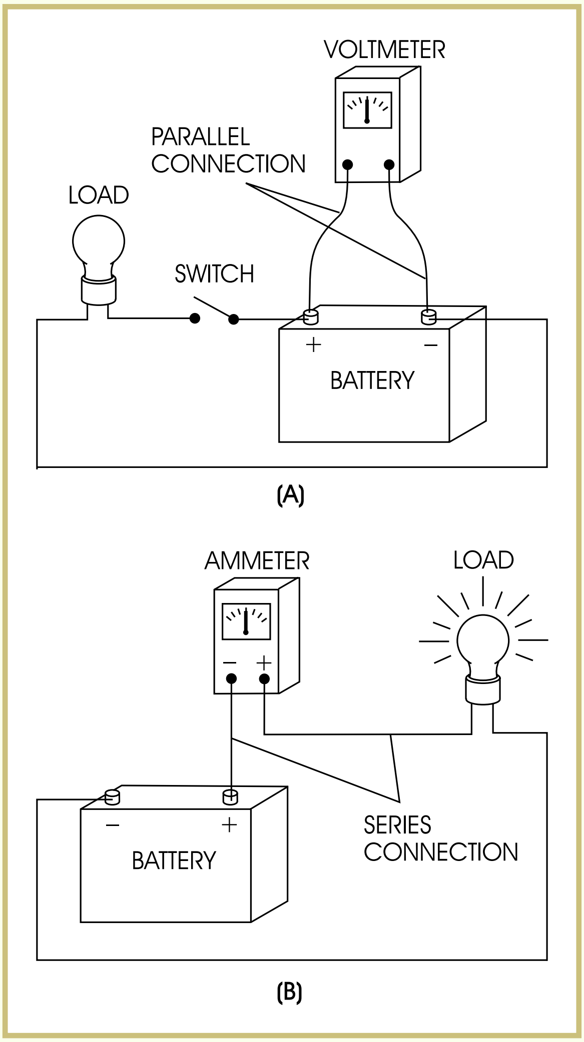
Voltmeter

Voltmeters are used to measure the voltage, or potential difference, between two points. A voltmeter can be used to check voltage at any point in a circuit. Remember that voltage is like pressure and exists between two points; it doesn't flow like current. Therefore, a voltmeter isn't connected in series, but must be connected across a circuit, or in parallel. A parallel connection is shown in Figure 11A. There are both AC and DC voltmeters. We'll discuss how to measure AC and DC voltages, currents, and resistances a little later in this section of the study unit.

Ammeter

Ammeters are used to measure the current flow through a circuit. As we discussed before, current is measured in amperes (or amps). The scale of an ammeter shows the number of amps in a particular circuit. Unlike a voltmeter, ammeters are always connected in series in a circuit as shown in Figure 11B. An ammeter must be connected in series because the entire current must flow through both the circuit and the ammeter. Like voltmeters, there are both AC and DC ammeters.

FIGURE 11—In A, the voltmeter is connected in parallel to check the voltage of the battery. In B, the ammeter is connected in series to check the current of the draw of the light bulb.



Ohmmeter

Ohmmeters are used to measure the resistance of a circuit or component by applying a known voltage to the circuit and measuring the resulting current. Ohmmeters usually have a built-in power supply (often a battery) which supplies the voltage to test the part. Thus, when connecting an ohmmeter to a circuit, you must be certain the power source is removed from the circuit. It's best to completely disconnect the battery before using an ohmmeter.

Multimeter

A *multimeter* is a meter that combines the testing capabilities of a voltmeter, ammeter, and ohmmeter into one meter. The multimeter is the most common electrical testing instrument and is often referred to as a *volt/ohmmeter (VOM)*. The meter shown in Figure 10 is an example of a multimeter. A dial on the front of the multimeter is used to select what you want to measure—voltage, current, or resistance. Multimeters will also have a mode selector switch that can be set for the quantity being measured (such as DC amps or AC volts). Some meters will also have a range selector switch that can be used when a wide range occurs in the quantity being measured. For example, one model of multimeter has multiple DC voltage ranges: 0–10 volts, 0–100 volts, and 0–1,000 volts. When the selector switch is in the 10V position, the meter will only measure from 0 to 10 volts. Note that when a multimeter is set to read resistance, it can be called an ohmmeter. When it's set to measure voltage, it's called a voltmeter. When it's set to measure current, it's called an ammeter.

Operating Electric Meters

Next we'll cover the basic information you should know about operating the meters we've discussed thus far.

Measuring AC

The connection of the positive and negative terminals of an AC voltmeter or ammeter doesn't matter because, as you'll recall, AC current is constantly reversing itself. Therefore, the positive and negative terminals are constantly alternating from positive to negative and negative to positive.

When measuring AC voltage, certain requirements must be met:

1. Whenever you're checking for any kind of voltage (AC or DC), the meter must be connected in parallel to the circuit.
2. You should recall that to produce AC voltage, you must have three items—a magnet, a conductor, and motion. To get an AC voltage reading, there must be engine motion. That is, the crankshaft must be turning.

Measuring DC

The connection of the positive and negative terminals of a DC voltmeter or ammeter is important. The terminals must be correctly connected.

When measuring a DC circuit with an analog meter, you must be sure to connect the meter so that the negative terminal of the meter is connected in the circuit toward the negative terminal of the battery. Likewise, the positive terminal of the meter must be connected in the circuit toward the positive terminal of the battery. If the meter is improperly connected, it will read exactly opposite of the actual measurement!

When working on motorcycles and ATVs, the only current readings that you'll take will be for DC current. Be sure to hook the meter up in series when checking for DC current. Also be sure to hook the meter leads up correctly. One way to verify that the leads are correctly hooked up is to turn the power on after the meter is attached and look at the reading while the engine isn't running. The meter must read a negative number if the key is on and the engine is off. If the meter is reading a positive number, simply switch the meter leads and check again. NEVER electric start a motorcycle or ATV engine while the ammeter is hooked up in series to the battery. The meter isn't designed to handle the large amount of amperage that the starter motor requires to turn the engine over, which will almost certainly damage the meter.

Measuring Resistance

As we discussed earlier, whenever you're using an ohmmeter, it's very important to first disconnect the component being tested from the rest of the electrical system. In other words, isolate and de-energize the component. If you don't isolate the component from the rest of the electrical system, you may risk damaging your meter. You may also receive a false resistance reading, as there may be other resistance in the circuit that you're about to test.

Using a Multimeter

You could destroy a multimeter if you use it improperly. Here are some basic steps you should know about how to operate a multimeter.

1. Determine what you want to measure (voltage, current, or resistance).
2. Set the meter up to the proper unit of measurement (volts, amps, or ohms).
3. Attach the test leads to the meter.
4. Select the quantity you want to measure by turning the dial.
5. Holding the two test leads, touch the probes to two points in a circuit.
6. Read the resulting information on the meter's display.

Note that this is a basic description of the operation of a multimeter. The actual operation of a digital multimeter is somewhat more involved, and electrical safety precautions must be observed. We've included some additional information on multimeters in Appendix A of this study unit.

As a general note, when you're using meters, you need to ensure that they're properly connected to the circuit being tested. Improper connection can result in an incorrect measurement and, in some cases, damage the meter. It's also important that you learn to read the scales on each meter properly, since errors can occur here, too.

Reading Electric Meters

Voltmeters and Ammeters

Both voltmeters and ammeters are easy to read. They're just about the same except that one is read in volts and one is read in amperes. The highest number on the scale is called the *full scale value* and indicates the maximum voltage or current the meter can measure. With an analog meter, if the pointer deflects to one of the major divisions on the scale, it's easily read. If it rests between these divisions, you'll have to use the small-scale divisions to determine the correct reading. If the pointer falls between the small-scale divisions, you'll have to estimate the correct reading.

A type of ammeter commonly used in connection with motorcycle work is a 20-0-20 DC ammeter. This meter has a scale with a zero in the center and the number 20 on the far right and left of the scale. Thus, 20 amps is the full scale value, or maximum amperage, that can be measured with this instrument. The pointer rests over the zero when no amps are being measured. When current is being measured, the position of the pointer to the right or left of the zero not only tells you the rate of current flow, but also whether current is flowing into or out of the battery. (Note that we're referring to a DC ammeter. The pointer would have no meaning on an AC ammeter since AC current is constantly reversing its direction of flow.) If the needle points to the right side of the scale, it indicates a flow of direct current into the battery. In other words, the battery is being charged. If the needle points to the left side of the scale, it indicates that current is flowing from the battery. In other words, the battery is being discharged. Let's try some examples.

- On a motorcycle, AC current flows from an alternator to the battery where it's then stored (Figure 12). Before it reaches the battery, it flows through a *rectifier* which changes the current from AC to DC. Therefore, to check the current, you would connect a DC ammeter between the rectifier and the battery. If you wanted to test the current or voltage between the alternator and the rectifier, you would use an AC meter. In this example, our ammeter is reading a current of about 17 amps. The battery is being charged.
- If an ammeter were connected between the lights and the battery on our motorcycle (with the engine and charging system off), the ammeter would read a current of about 3 amps (Figure 13). The battery is being discharged.

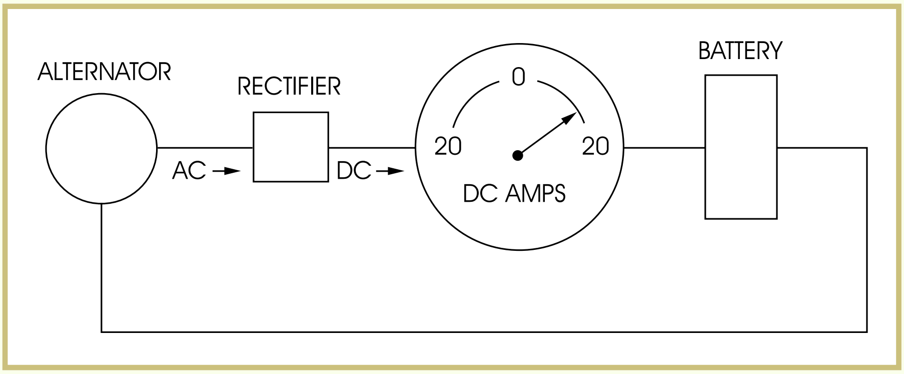


FIGURE 12—This ammeter is measuring a current flow into the battery at a rate of about 17 amps.

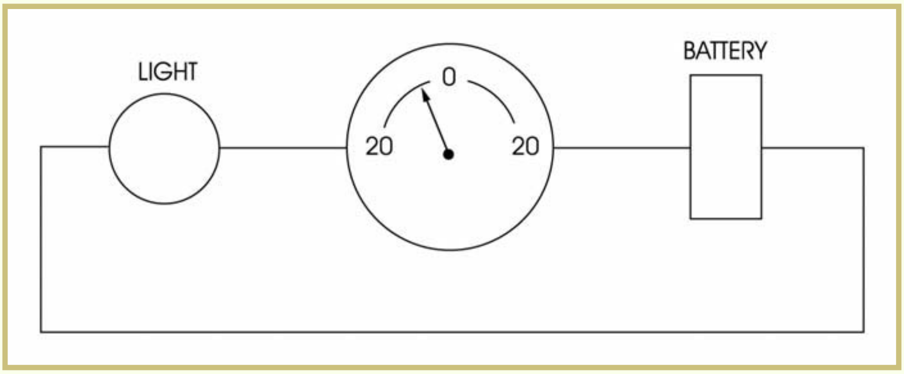


FIGURE 13—This ammeter is measuring a current discharge of about 3 amps from the battery to the lights.

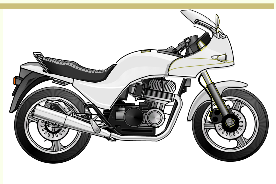
Ohmmeters

As you learned earlier, the scales on most voltmeters and ammeters are linear. In contrast, ohmmeters have a nonlinear scale. There are different types of ohmmeter scales. One common scale is read from right to left, but the values of the major scale divisions aren't always the same at all points on the scale (Figure 14). On the scale shown in Figure 14, each major division mark between 0 and 20 has a value of 5 ohms. Between 20 and 100, each major division equals 10 ohms. On the far left, each major division has a value of 1000 (1K) ohms. Therefore, when you're reading this scale, you must first determine the value of the major divisions on the part of the scale you're concerned with and then the value of the smaller divisions.

On the far left of the scale is the symbol ∞. This symbol stands for infinity and indicates that the resistance being measured is too high to be measured with this meter. The needle also rests on the ∞ mark when no resistance is being measured because there's infinite resistance between the test leads when they aren't touching anything. When you touch the test leads together, the pointer should move to the zero mark, indicating no resistance between the leads. If the meter doesn't read zero, you can adjust it to read zero.

FIGURE 14—Resistance is measured using the nonlinear scale of the multimeter.

Road Test 3



1. What are the three requirements to produce AC voltage?

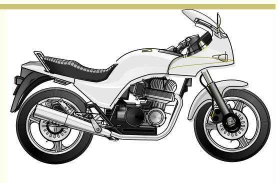
____

2. *True or False?* Voltmeters are connected in parallel.

3. What should be done to an electrical component before you check for resistance?

____

(Continued)



Road Test 3

4. When measuring a DC circuit with an analog ammeter, you must be sure to connect the ammeter so that the _______ terminal of the ammeter is connected to the negative terminal of the battery.

5. *True or False?* An analog meter has a moving pointer.

6. A _______ can test for voltage, amperage, and resistance.

7. The symbol ∞ stands for ________.

8. What does "VOM" stand for?

   ____

9. *True or False?* It doesn't matter how the meter leads are connected when checking for AC voltage.

10. Which type of ammeter is commonly used in testing motorcycle and ATV electrical systems—AC or DC?

   ____

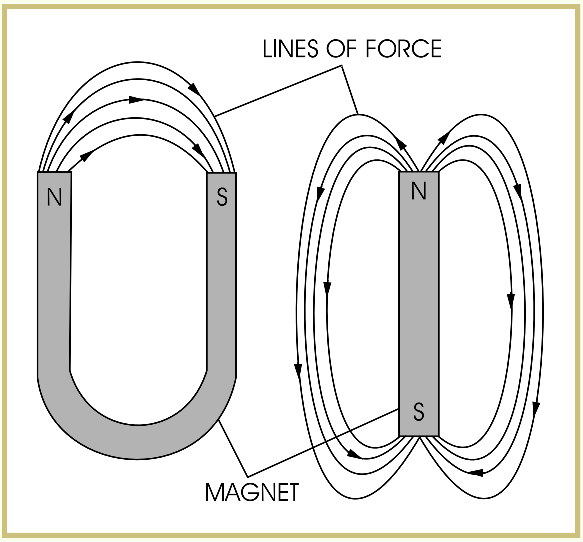
Check your answers with those on page 41.

MAGNETISM

Magnetism, like electricity, is a force we can't see. However, like electricity, we can observe its effects. The exact explanation of magnetism isn't completely understood, and most of this field is well beyond the scope of this study unit. However, it's important for you to understand some basic information about magnets so that you can better understand how alternators and generators produce electricity.

Many years ago, scientists discovered that fragments of iron ore attracted each other. Researchers also found that when a magnetized iron bar was suspended in the air, one end would always point north. This was called the North Pole of the magnet. The opposite end of the bar became the South Pole of the magnet. It was also found that when a piece of nonmagnetized metal, such as steel, was rubbed over a magnetized metal, the magnetic properties of the metal were transferred to the steel. The area affected by a magnet is called the *field of force* or *magnetic field* (Figure 15). Note that the "lines" of force, or flux lines, as they're sometimes called, are for illustrative purposes only—we can't actually see the lines.

FIGURE 15—Magnetic Lines of Force



As with electricity, one important property of magnets you should know is that opposites attract. When opposite poles of a magnet or magnets are placed near each other, they'll attract each other. Conversely, when two like poles are placed together, they repel each other. This is because the lines of force are going in opposite directions. Another property of magnets is that when a nonmagnetic substance (such as a piece of wood) is placed in a magnetic field, the lines of force aren't deflected. Magnetic forces pass through nonmagnetic materials!

There are three different types of magnets.

- A *natural magnet*, called magnetite, which comes in rock form. Magnetite is a weak magnet and isn't used in any motorcycle or ATV.
- A *permanent magnet*, which is man-made of different metal alloys. It's very strong and long-lasting. Permanent magnets are commonly found in different parts of motorcycles and ATVs.
- An *electromagnet*, which is also man-made, is another commonly found magnet. An electromagnet consists of a coil wound around a soft iron or steel core. The core becomes strongly magnetized when current flows through the core and becomes almost demagnetized when the current is interrupted; hence the term electromagnet, as it combines electric current with magnetic properties. We'll discuss electromagnetism in detail next.

Magnetic Forces

Electromagnetism

The concept of electromagnetism is very important to the operation of electrical systems used in motorcycles and ATVs. *Electromagnetism* is the magnetic effect produced when an electric current flows through a conductor (wire). When the current flows through the wire, the wire becomes surrounded by a magnetic field (Figure 16). The magnetic field is strongest in the space immediately surrounding the conductor.

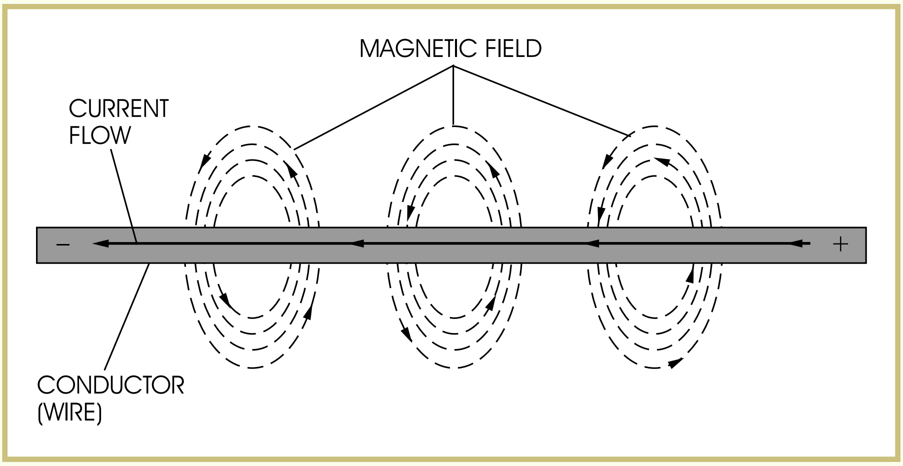


FIGURE 16—When current flows through wire, a magnetic field is produced.

The force of electromagnetism has many interesting and highly useful applications. If an insulated piece of conductor wire is looped around an iron bar to form a coil, the resulting device is called a magnetic coil. When current flows through a magnetic coil, each separate loop of wire develops its own small magnetic field. The small magnetic fields around each separate loop of wire then combine to form a larger and stronger magnetic field around the entire coil. The coil develops a North Pole and a South Pole. The magnetic field at the center of a magnetic coil is stronger than the fields above or below the coil (Figure 17). An electromagnet is generally much stronger than a magnetic coil of a similar size.

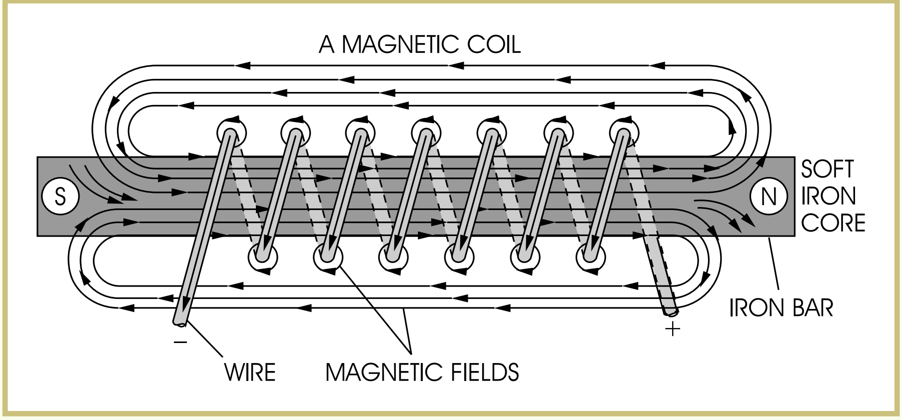


FIGURE 17—A magnetic field can become highly concentrated when an iron core is installed in a coil of wire.

Magnetic Induction

When a conductor (wire) is moved through a magnetic field so that it passes across the lines of force, an *electromotive force (EMF)*, or potential voltage, is induced in the wire. If the wire is part of a complete electrical circuit, current will flow through the wire. This important fact is the basis for the various kinds of AC-producing generators used in motorcycles. This kind of generator may also be called an alternator or flywheel magneto. We'll explain electrical generating systems in greater detail in another study unit, but for now it's important for you to understand that each is based on the same principle. That principle is that when an electrical conductor is passed through a magnetic field (or a magnetic field is moved past an electrical conductor), an electric current, or voltage, is induced through the conductor wire. This effect is called the *generator action of magnetic induction*. (Note that current won't flow through the wire until the wire is connected in a complete circuit.)

Mutual Induction

The final electromagnetic property we'll look at is called mutual induction. If two conductors are placed close together, and current is applied to one of the conductors, a voltage will be induced in the other conductor. This occurs because when two conductors are physically close to each other, the energy in the "live" conductor will stimulate the other conductor to become energized, too. This effect is called *mutual induction*, and it can be used to operate ignition coils. Note that if the conductors are moved apart from each other, the effect of mutual induction will become less effective. If the conductors are moved far enough apart, the energy of the "live" conductor won't be strong enough to influence the second conductor, and the mutual induction effect will stop.

In an upcoming study unit, we'll show you how the principle of mutual induction is used to help operate a motorcycle and ATV engine ignition system.

AC Generator Operation

The generator action of magnetic induction is the basic property that's used to operate motorcycle and ATV charging systems. We'll explain this property using Figure 18 as a guide which shows an AC charging system. A permanent magnet is suspended within a soft iron frame, which completes the circuit for the permanent magnet's lines of force. The soft iron core becomes a temporary magnet, concentrating lines of magnetic force around the coil of wire in the magnetic field to produce an electric current. The coil (better known as a *stator* in a charging system) is made up of many loops of conductor wire. As the magnet rotates, the magnetic polarity of the soft iron frame is reversed. With each 180° of rotation, the magnetic lines of force around the soft iron frame collapse and then reestablish themselves in the opposite direction. Each time the lines of force collapse and rebuild, the coil of wire within the magnetic field cuts them and an electric current is produced.

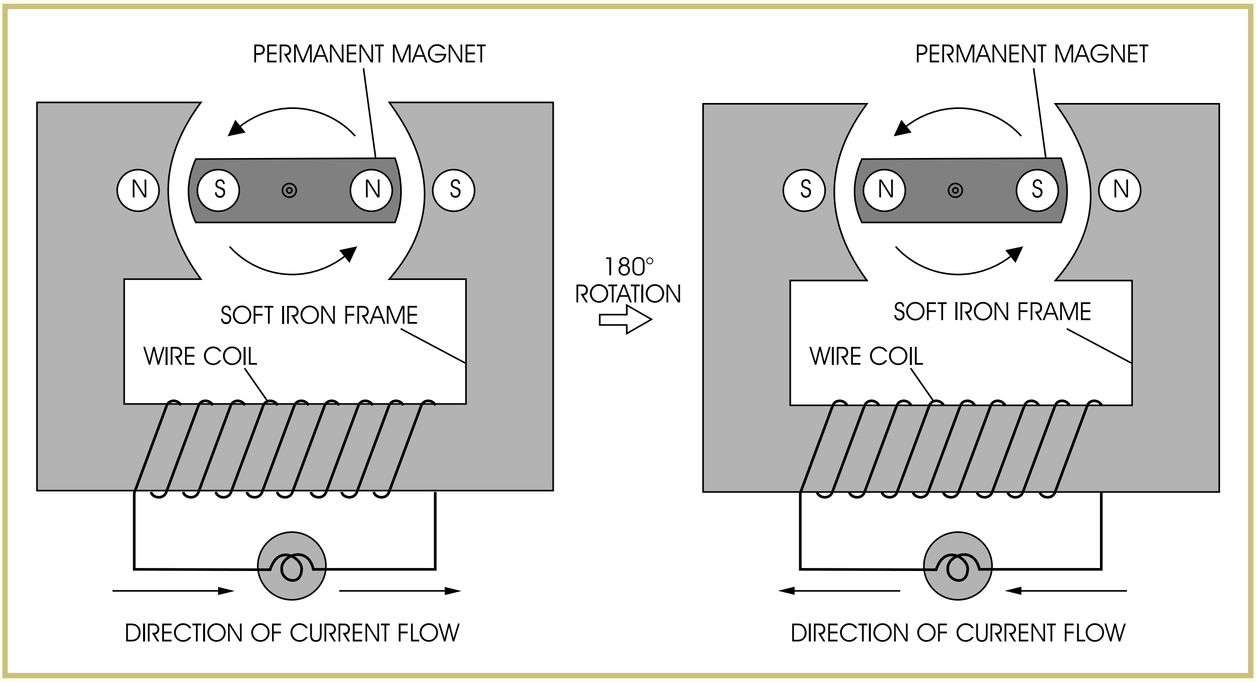


FIGURE 18—In this AC generator, as the magnet rotates, the induced current reverses. (Copyright by American Honda Motor Co., Inc. and reprinted with permission)

The voltage and current produced by the simple generator shown in Figure 18 would be quite low. But if we wound many loops of wire into a coil and rotated the coil in the magnetic field, a much larger voltage and current would be produced. This is the arrangement in a real AC generator. The amount of voltage and current produced by a generator is based on three things:

- The number of turns in the coil and the diameter of the wire
- The strength of the magnetic field
- The speed at which the wire coil passes by the magnets

Many motorcycle and ATV engines use AC generator action of magnetic induction to power their ignition systems. For example, in some ignition systems, coils are placed underneath the flywheel or outside (next to the edge) of the flywheel. Magnets are embedded in the edge of the flywheel so that when the flywheel spins, the magnets pass by the coils and generate the necessary voltage and current to operate the ignition system. We'll discuss these systems in more detail in a future study unit.

All motorcycles and ATVs that contain batteries use the AC generator action of magnetic induction to charge their batteries. In such machines, generators or alternators charge the batteries, and the energy from the batteries is then used to power the electrical systems. We'll also discuss these systems in more detail later in another study unit.

Solenoids

Some electromagnets have special movable cores. This type of electromagnet is called a *solenoid* or *relay*. Inside the solenoid coil, the core is a movable, round piece of metal called a *plunger*. When a solenoid coil is energized by a flow of current, the resulting magnetic field moves the plunger in the coil. When the flow of current stops, a spring above the plunger forces the plunger back into its original position. Solenoids are used in electrical starter systems, as well as in many safety devices on motorcycles and ATVs. Solenoids are designed in one of two ways.

1. A *normally open solenoid* is a solenoid that doesn't allow current flow unless the solenoid is activated. This type of solenoid is found in electric starting systems and allows a high current flow after a very small current flow activates the solenoid.
2. A *normally closed solenoid* is a solenoid that allows current to flow unless the solenoid is activated. This type of solenoid will be found in safety devices such as kickstand safety devices and creates an open circuit after a very small current flow activates the solenoid.

Electromagnetism in Motors

You've just learned that when a conductor moves through a magnetic field, a voltage is produced in the conductor. Now, suppose that a current-carrying conductor is placed in a magnetic field. What happens? Well, the interaction between the magnetic field and the moving electrons in the conductor causes a physical force to be applied to the conductor. If the conductor is free to move, this physical force will cause the conductor to move for as long as the conductor current and the magnetic field are maintained. This property is called the *motor action of electromagnetic induction*.

The motor action of electromagnetic induction is shown in Figure 19. In this figure, a conductor (wire) is connected to a battery to form a complete circuit. Current is already flowing in the conductor when it's placed in a magnetic field between two magnets. The reaction between the magnetic field and the moving electrons in the conductor causes the conductor to move upward as shown by the arrow in the figure.

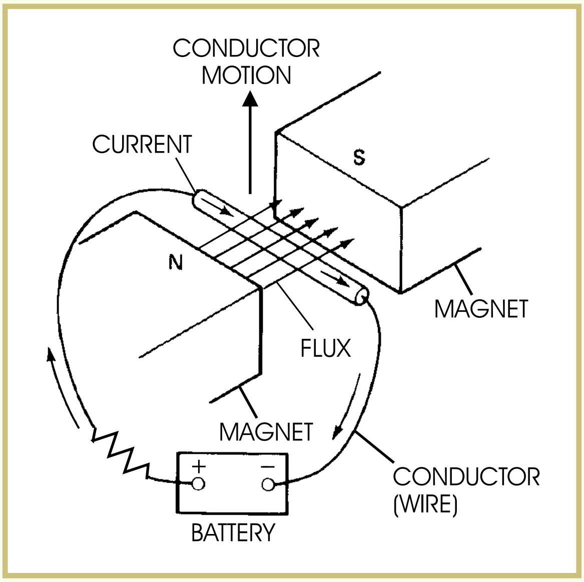


FIGURE 19—Because the current-carrying conductor has been placed in a magnetic field, the motor action of electromagnetic induction causes the conductor to move upward.

The motor action of electromagnetic induction is the basic property that's used to operate electric starter motors. The parts of an electric starter motor are shown in Figure 20. In a starter motor, the *armature* is a rotating component that's mounted on a shaft and positioned between the motor's field magnets. Loops of conductor wire, called *armature windings*, are connected to the armature's *commutator*. Note that for simplicity, only one winding is shown in the figure. The *brushes* are electrical contacts that slide over the surface of the commutator as the armature rotates. The brushes are connected to an electrical power source outside the motor (usually a battery). Electrical wires, called *field windings*, are wound around the field magnets. When current flows into these wires, the field magnets become electromagnets and produce a powerful magnetic field inside the motor. When current is applied to the brushes, the current moves through the brushes and into the commutator and armature windings. The current flowing through the armature windings produces magnetic fields around the windings. The interaction of all these powerful magnetic forces causes the armature to spin. The output shaft of the armature is connected outside the motor to a machine or load to perform useful work. An actual disassembled electric starter motor for a motorcycle is shown in Figure 21.

FIGURE 20—When the field windings are energized, the field magnets produce a magnetic field in the motor. When current flows through the armature windings, magnetic fields are produced around the windings. The interaction of these fields causes the armature to rotate.

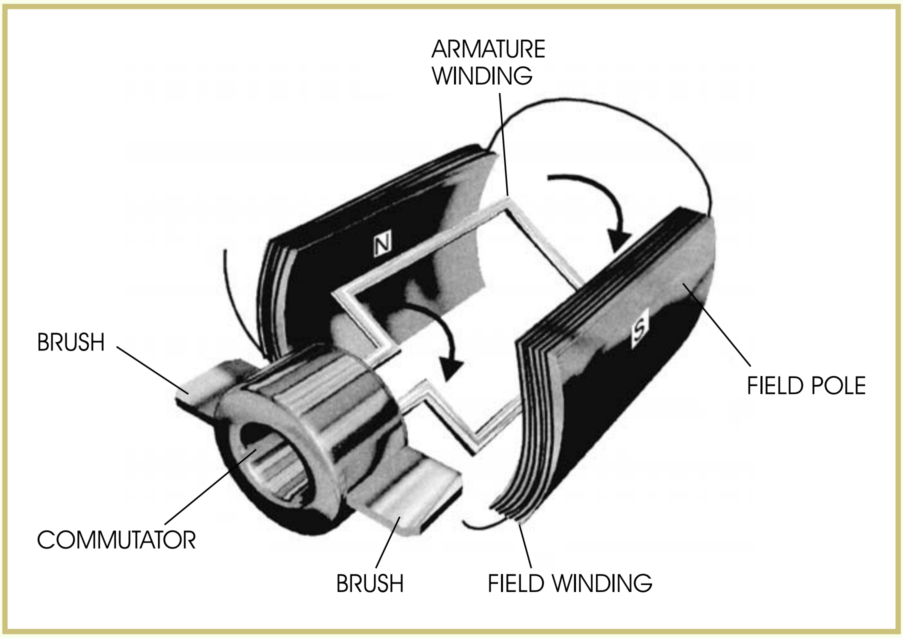
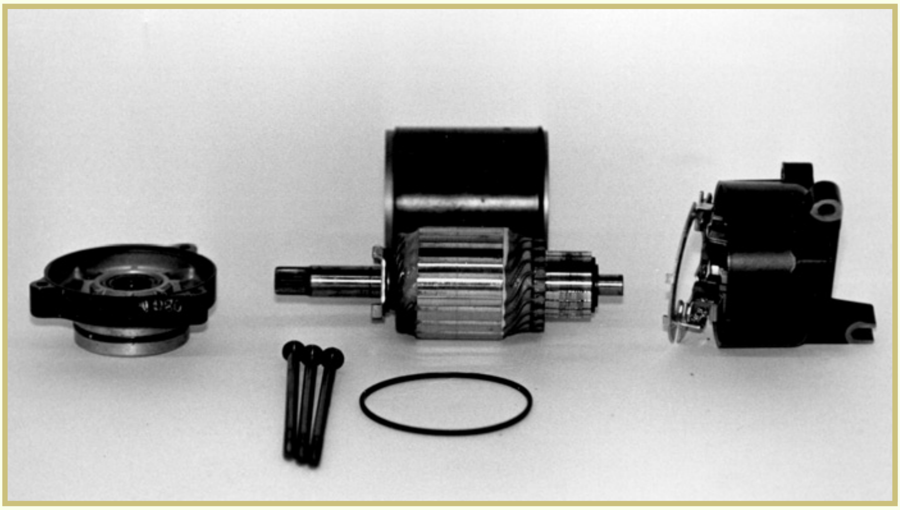
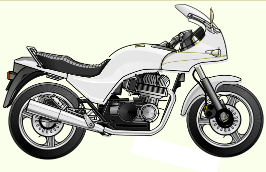


FIGURE 21—A Disassembled Electric Starter Motor



Many motorcycles and ATVs contain small electric motors in their starter systems. The output shaft of the electric motor in such a system would generally be connected to gears that engage the crankshaft. The spinning motion of the electric motor's armature would be transferred through these gears to the crankshaft of the motorcycle or ATV engine. (*Note*: Some people may use the word "motor" when talking about either the electric starter motor or the motorcycle or ATV engine. Don't confuse the starter motor with an engine!)

Road Test 4



1. The area around a magnet is called a _______.
2. What would happen if you were to put two North Poles of a magnet together?

   ____

3. What would happen if you were to put a North and South Pole of a magnet together?

   ____

4. An electromagnet that has a movable core is called a _______.
5. An ignition coil works off of the process of _______ induction.
6. *True or False?* A permanent magnet is man-made.

Check your answers with those on page 41.

BASIC ELECTRONIC DEVICES

Now that you have a basic understanding of electrical and magnetic principles, let's take a brief look at some electronic devices.

Let's start by reviewing a few terms. You'll remember that a conductor, such as copper wire, is a material that allows electrical current to flow through it easily. An insulator, such as plastic or nylon, is a material that resists the flow of electricity through it. There are other materials called *semiconductors* which, as the name implies, allow some flow of electricity through them. We'll talk about this material next.

Semiconductors

A *semiconductor* is a substance whose electrical conductivity is between that of a conductor and an insulator. A semiconductor's electrical conductivity also increases as its temperature increases. Silicon, germanium, and selenium are common semiconductor materials that are used to make electronic components.

Semiconductor devices are manufactured in laboratories under very special conditions. The semiconductor materials are specially processed and combined to form electronic devices such as diodes and transistors. (We'll discuss these electronic devices next.) Because of the way semiconductor materials are processed during manufacturing, the finished diodes and transistors are capable of controlling the flow of electrons. So, as a result of these special manufacturing processes, the conducting and insulating properties of semiconductor materials can be used to perform useful work in a circuit.

Electronic Components

Electronic devices contain components that are used to control the flow of electrons in a circuit. Many different electronic components are used in circuits, but we'll look just at the most common ones used in motorcycle and ATV electrical systems. These devices are the diode, Zener diode, transistor, and silicon-controlled rectifier (SCR).

Diode

A *diode* (Figure 22) is a simple electronic device that has two terminals. A diode can have many shapes, but is often shaped like a small cylinder. The two terminals are thin wires that protrude from the ends of the cylinder. The two terminals are called an *anode* and a *cathode*. In a battery or electronic device, the anode is the positive (+) terminal, whereas the cathode is the negative ( ) terminal. Remember that in our conventional theory, our electrons and current flow from positive to negative.

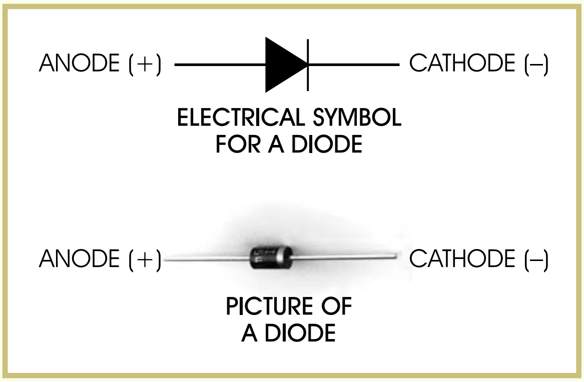
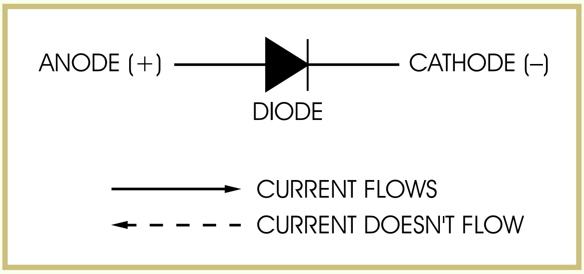


FIGURE 22—This illustration shows a line drawing of a diode as well as the electrical symbol for a diode.

When a positive voltage is applied to the anode end of a diode, electric current moves through the diode and exits at the cathode end. In this situation, the diode acts like a conductor. When a positive voltage is applied to the cathode end of a diode, the diode resists the flow. Current won't flow through the diode. In this situation, the diode acts like an insulator. Diodes allow current to flow through them in one direction only. The electrical symbol for a diode, shown in Figure 23, illustrates this principle. The diode is sometimes called a "one-way valve" in a circuit.

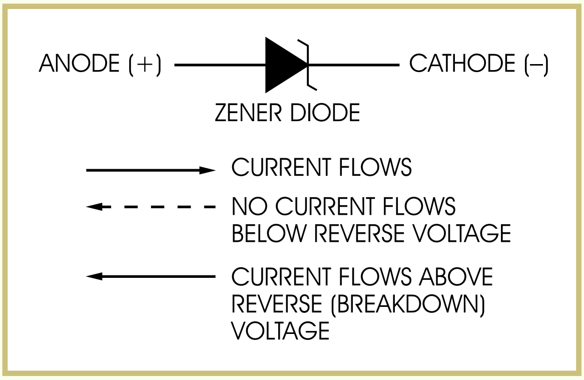
FIGURE 23—A diode will allow electrical flow in only one direction. (Copyright by American Honda Motor Co., Inc. and reprinted with permission)



Zener Diode

Like a regular diode, a Zener diode allows current to flow in one direction. However, the Zener diode will also allow current to flow in the opposite direction if the voltage exceeds a predetermined value called the *breakdown voltage* (Figure 24). At the breakdown voltage, the diode becomes conductive. The voltage drop across the diode remains constant and independent of current. This characteristic makes the Zener diode useful for voltage regulation.

FIGURE 24—A Zener diode allows current to flow in the reverse direction under certain circumstances. (Copyright by American Honda Motor Co., Inc. and reprinted with permission)



Transistor

A transistor is another type of electronic device that's used in electrical systems. A *transistor* is a semiconductor device. Transistors are used to control the flow of current in a circuit.

A transistor has three wire terminals—the *base*, the *collector*, and the *emitter*. There are two types of transistors—*PNP* and *NPN* (Figure 25). With PNP-type transistors, when a positive voltage is applied to the emitter and negative voltage to the collector, almost no current flows from the collector to the emitter. However, if the emitter voltage is raised slightly higher than the base voltage, and a small amount of current flows from the emitter to the base, a large amount of current flows from the emitter to the collector (Figure 26). With NPN-type transistors, almost no current flows when a positive voltage is applied to the collector and a negative voltage to the emitter. When a small amount of current flows from the base to the emitter, a large amount of current flows from the collector to the emitter (Figure 26).

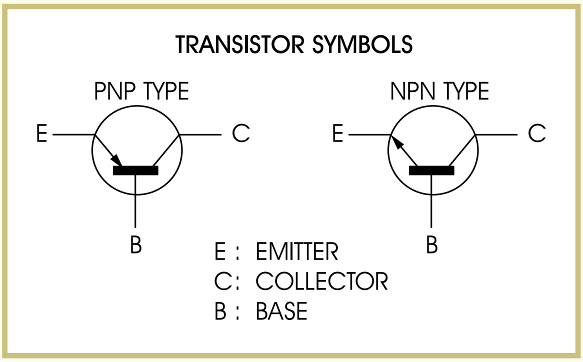


FIGURE 25—The electrical symbols of the PNP and NPN transistor types are shown here. (Copyright by American Honda Motor Co., Inc. and reprinted with permission)

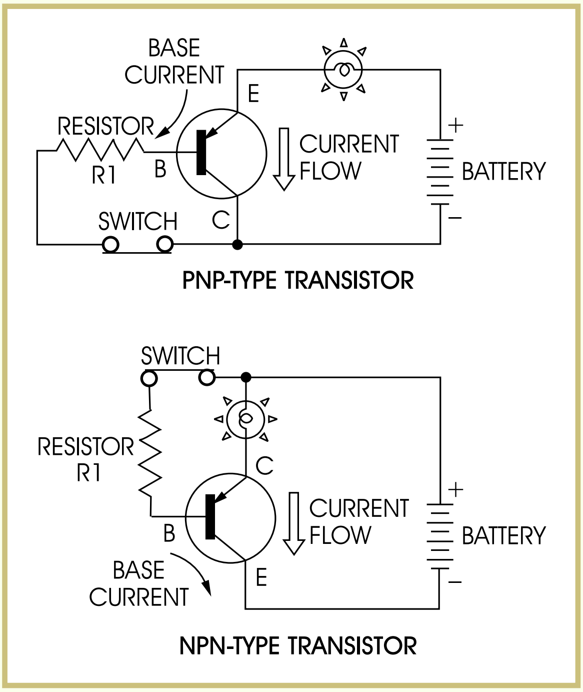


FIGURE 26—The circuitry of the PNP and NPN transistors and their power flow are shown here. (Copyright by American Honda Motor Co., Inc. and reprinted with permission)

Transistors resemble switching devices. The transistor is turned on, allowing collector-to-emitter current to flow when there's base current, and turned off when no base current exists.

Silicon-controlled Rectifier (SCR)

A *silicon-controlled rectifier (SCR)* is another type of semiconductor component. SCRs are used as switching devices in electronic circuits. An SCR, or thyristor as it's often called, has three terminals—the anode, the cathode, and the gate (Figure 27). Note in Figure 27 that the construction of an SCR is similar to that of a diode, except that an SCR has an additional terminal—a gate.

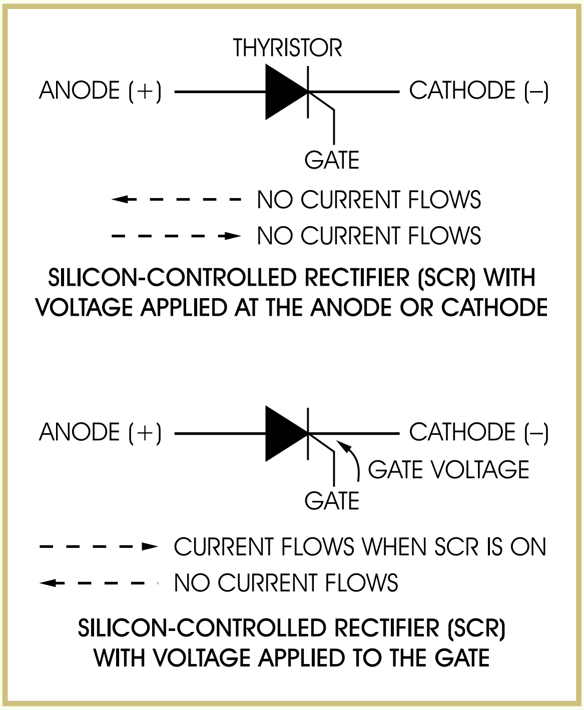
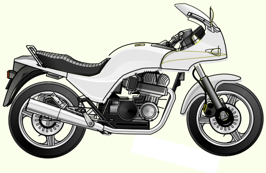


FIGURE 27—An SCR, or thyristor, is a diode with a gate that allows current to flow only when voltage is applied to the gate. (Copyright by American Honda Motor Co., Inc. and reprinted with permission)

Unlike a diode, an SCR will block current in both directions. If you apply a voltage across an SCR, current won't flow. If a small amount of voltage is applied to the gate of an SCR, however, current will flow through the SCR in the forward direction (Figure 27). Current will continue to flow until the voltage is removed from the gate. Thus, an SCR can be switched on and off by applying a voltage to the gate.

In an upcoming study unit, we'll look at how these electronic components function in electronic ignition system and charging system circuits.



Road Test 5

1. In simple terms, define a *semiconductor*.

2. *True or False?* Another name for an SCR is a thyristor.

3. What are the three terminals on a transistor?

4. What makes a Zener diode different from a diode?

Check your answers with those on page 42.

Road Test Answers

1

1. Starting, ignition, lighting, charging
2. negative
3. short circuit
4. The path of current flows from negative to positive.
5. neutron
6. Source, conductor, load, switch
7. Proton, electron, neutron
8. The path of current flows from positive to negative.
9. Copper wire
10. A circuit that contains a load in series and a parallel load

2

1. Current, voltage, resistance
2. ohms
3. decrease
4. True
5. alternating current
6. direct current
7. 1 ohm of resistance permits 1 amp of current flow in a circuit that has a source of 1 volt.
8. 6 amps
9. 2 ohms
10. False

3

1. Magnet, conductor, motion
2. True
3. Isolate it.
4. negative
5. True
6. multimeter
7. infinity
8. Volt/ohmmeter
9. True
10. DC

4

1. magnetic field
2. They would repel each other.
3. They would attract each other.
4. solenoid or relay
5. mutual
6. True

5

1. A substance whose electrical conductivity is between that of a conductor and an insulator
2. True
3. Emitter, base, collector
4. A Zener diode allows current to flow in the opposite direction when the breakdown voltage is reached.

Appendix A

SAFETY PRECAUTIONS WITH THE MULTIMETER

Electrical devices and circuits can be dangerous. Safe practices are necessary to prevent shock, fires, explosions, mechanical damage, and injuries resulting from the careless or improper use of tools.

Perhaps the greatest hazard is electrical shock. Electricity affects the body by overriding brain impulses and contracting muscles. Therefore, a current through the human body in excess of 10 milliamperes can paralyze the victim and make it impossible to let go of a “live” conductor.

Your skin can have approximately one thousand times more resistance to the flow of electricity when dry, which would be in the vicinity of several hundred thousand ohms. When moist or cut, the skin’s resistance may become as low as several hundred ohms. In this circumstance, even so-called safe voltages as low as 30 or 40 volts might produce a fatal shock. Naturally, the danger of harmful or fatal shock increases directly as the voltage increases. You should be very cautious, even with low voltages. **Never assume a circuit is dead, even though the switch is in the OFF position.**

General Safety Rules for Electricity and Electronics

Safe practices will protect you and those around you. Study the following rules.

- Don’t work when you’re tired or taking medicine that makes you drowsy.
- Don’t work in poor light.
- Don’t work in damp areas.
- Use approved tools, equipment, and protective devices.
- Don’t work if you or your clothes are wet.
- Remove all rings, bracelets, and similar metal items.
- Never assume that a circuit is off. Check it with a device or piece of equipment that you’re sure is operating properly.
- Don’t tamper with safety devices. Never defeat an interlock switch. Verify that all interlocks operate properly.
- Keep your tools and equipment in good condition. Use the correct tool for the job.

- Verify that capacitors have discharged. Some capacitors may store a lethal charge for a long time.
- Don't remove equipment grounds. Verify that all grounds are intact.
- Don't use adapters that defeat ground connections.
- Use only an approved fire extinguisher. Water can conduct electric current and increase the hazards and damage. Carbon dioxide (CO_2) and certain halogenated extinguishers are preferred for most electrical fires. Foam types may also be used in some cases.
- Follow directions when using solvents and other chemicals. They may explode, ignite, or damage electrical circuits.
- Certain electronic components affect the safe performance of equipment. Always use the correct replacement parts.
- Use protective clothing and safety glasses.
- Don't attempt to work on complex equipment or circuits without proper training. There may be many hidden dangers.
- Some of the best safety information for electrical and electronic equipment is the literature prepared by the manufacturer. Find it, read it, and use it!
- When possible, keep one hand in your pocket while working with electricity. This reduces the possibility of your body providing an electrical path through the heart.

Any of the above rules could be expanded. As your study progresses, you'll learn many of the details concerning proper procedures. Learn them well because they're the most important information available. Remember, always practice safety; your life depends on it.

MULTIMETER OPERATION

You should follow these safety guidelines.

- Never operate a multimeter unless the battery cover is in place and fully closed.
- Never connect a source of voltage with the function switch in the OHM (Ω) position or the DIODE position.
- Don't replace the battery or fuse unless the test leads have been disconnected and the power is OFF.
- When making current measurements, make certain the multimeter is connected in series with the load. Never connect the meter in parallel to measure current. To do so can result in blowing the overload protection fuse or damaging the device being tested.

Controls and Terminals

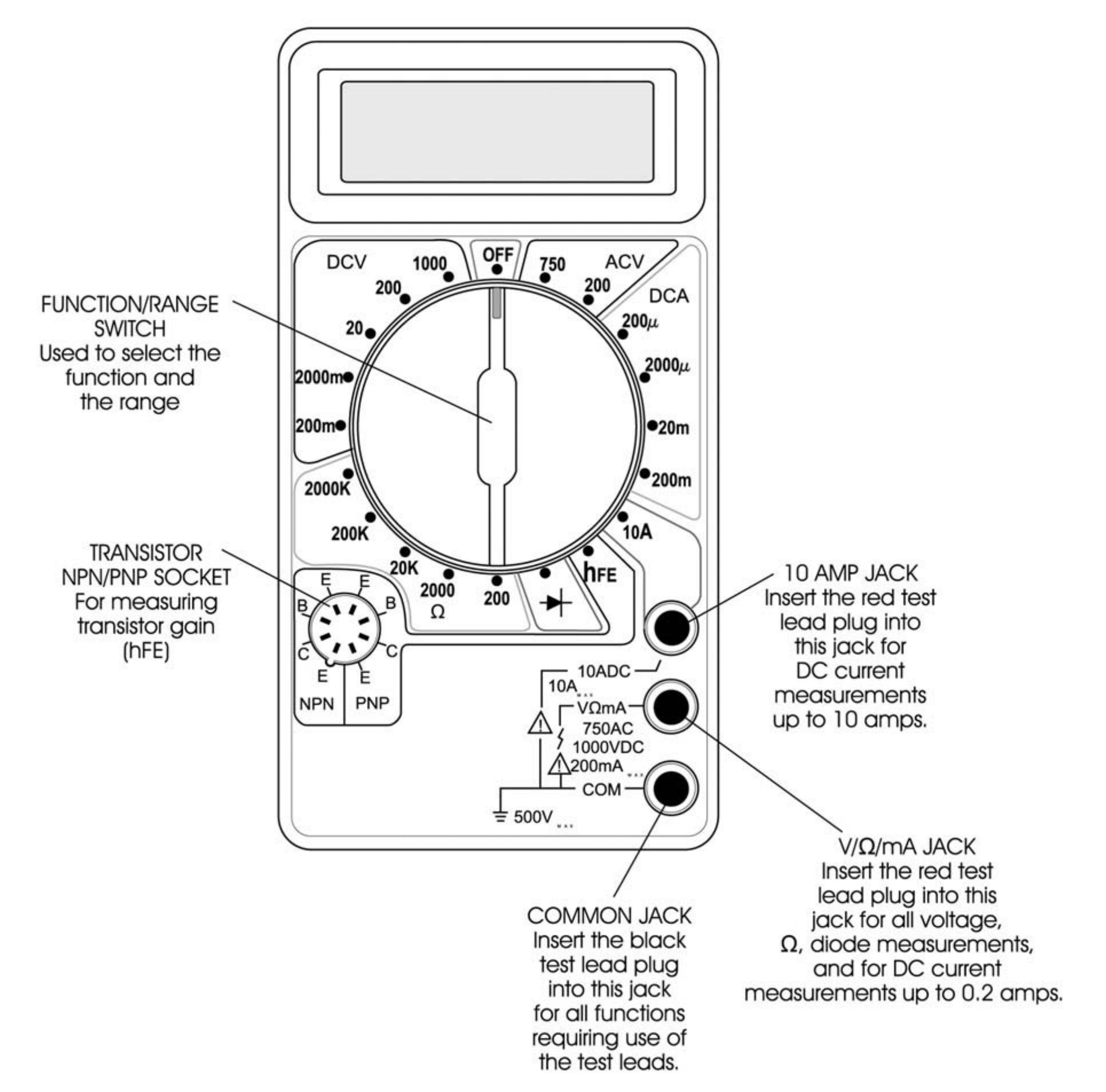


FIGURE A—Digital Multimeter Front Panel

Resistance Measurements

Resistance Measurement Procedure

Resistances into the megohm range can be measured with a multimeter. The multimeter can also be used for measuring the continuity of practically every electrical device made. The procedure is as follows:

1. Remove all sources of power from the device or resistor being tested.
2. Insert the test leads into the meter.
3. Select the Ω range and connect the test leads across the resistor under measurement as shown in Figure B.

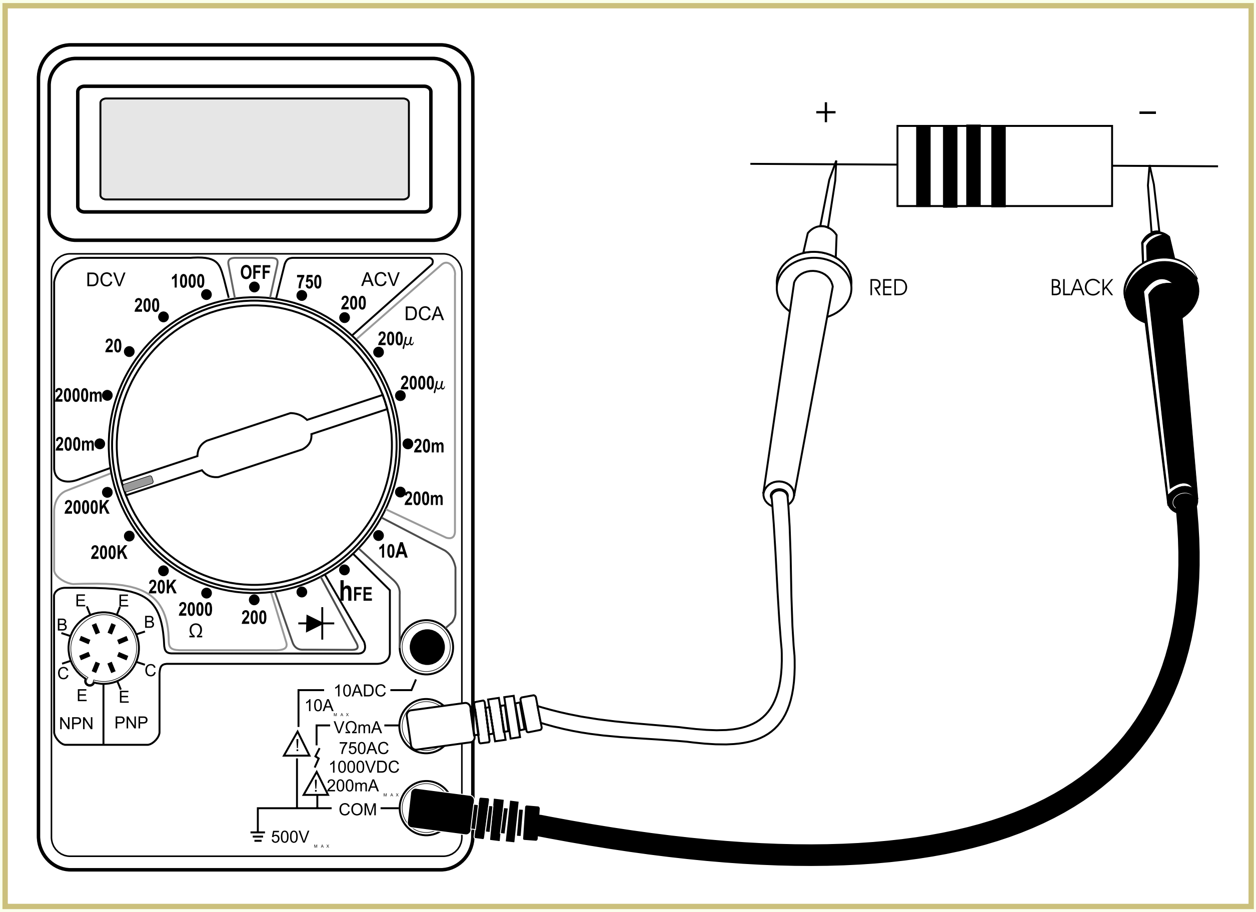


FIGURE B—Resistance Measurement Setup

CAUTION: NEVER apply voltage or current to the test leads when the function/range switch is in Ω position. A good habit is to always check the function/range switch position before making measurements.

Note: After resistance measurements are made, ALWAYS turn the function/range switch to the OFF position. This will help prevent the meter from being damaged and increase the life of the battery.

DC Voltage Measurement

DC Voltage Measurement Procedure

1. Insert the test leads into the meter.
2. Select a higher VDC range than you anticipate measuring. For example, to measure 700 VDC, select the 1000 VDC range. If the magnitude of voltage isn't known, select the highest range.

WARNING: Use extreme caution to avoid contact with the circuit when measuring voltage.

3. Connect the test leads across the source or device being measured as shown in Figure C. Voltage value will appear on the digital display along with the voltage polarity.
4. Reduce the setting until a usable reading is obtained.
5. Disconnect the test leads.

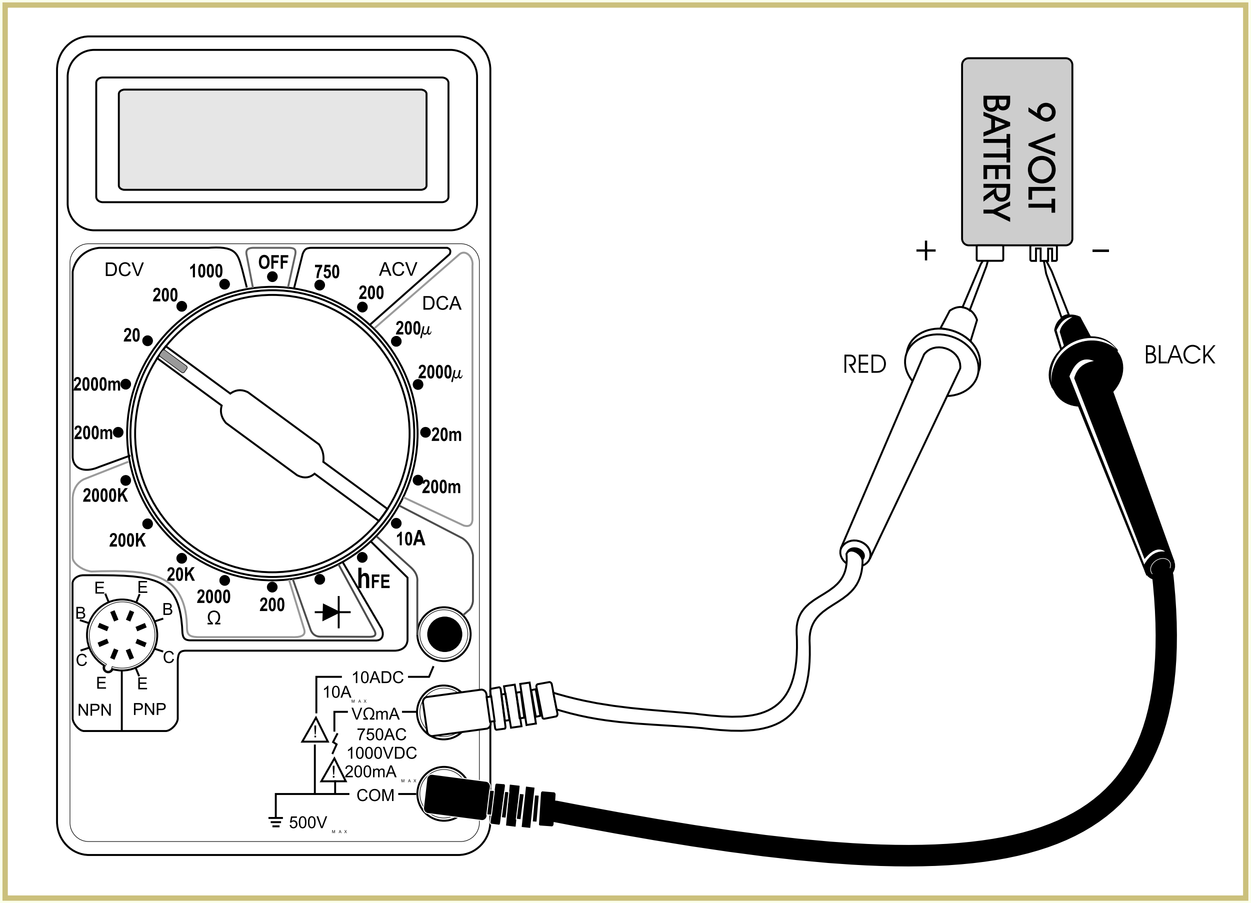


FIGURE C—DC Voltage Measurement Setup

AC Voltage Measurement

AC Voltage Measurement Procedure

1. Insert the test leads into the meter.
2. Select a higher VAC range than you anticipate measuring. For example, to measure 120 VAC, select the 200 VAC range. If the magnitude isn't known, select the highest range.

WARNING: Use extreme caution to avoid contact with the circuit when measuring voltage.

3. Connect the test leads across the source or device being measured as shown in Figure D. The voltage value will appear on the digital display.
4. Reduce the range until a satisfactory reading is obtained.
5. Disconnect the test leads.

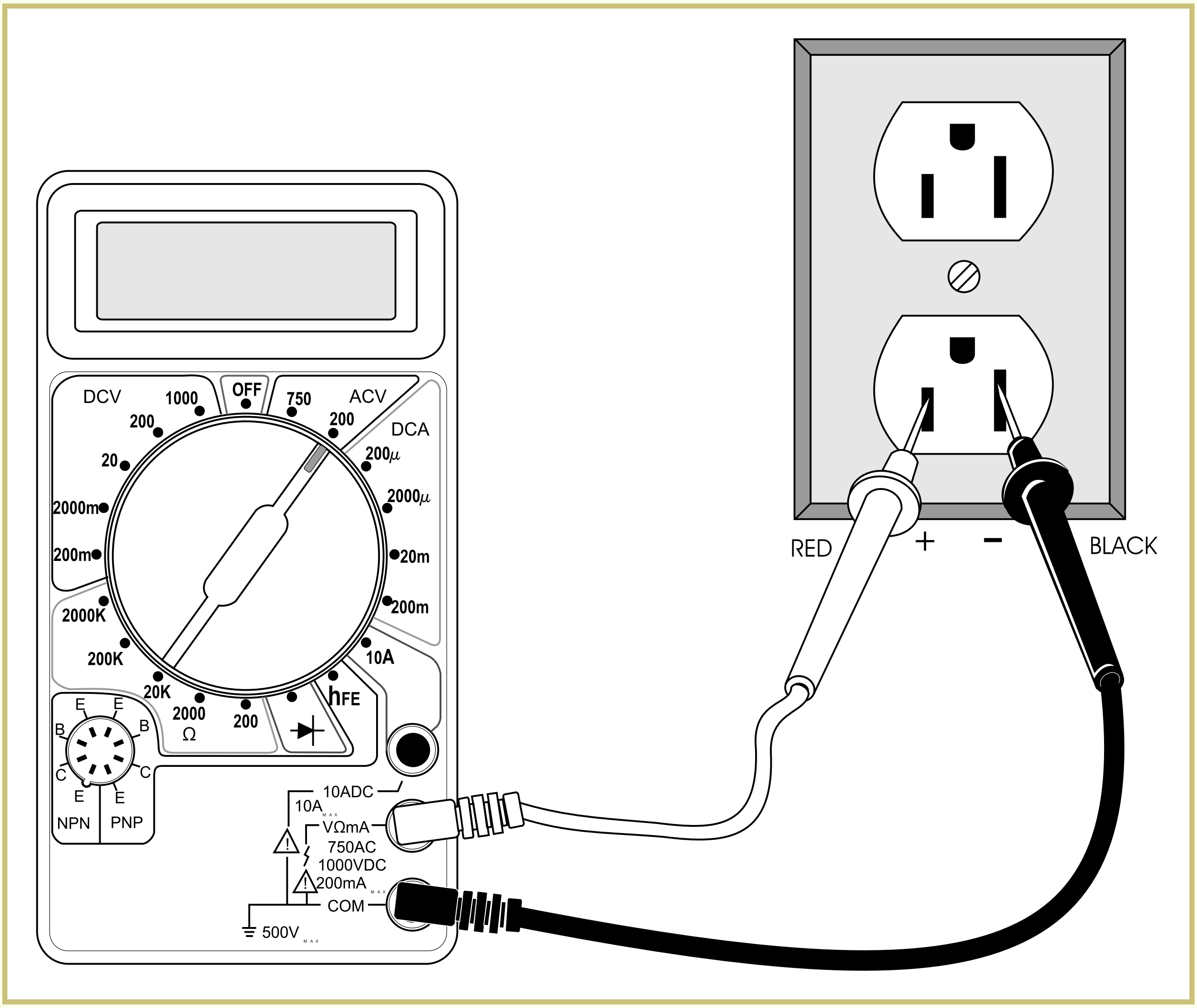


FIGURE D—AC Voltage Measurement Setup

DC Current Measurement

DC Current Measurement Procedure

1. Insert the test leads into the meter.
2. Turn OFF the power to the device being measured.
3. An ammeter **must be placed in series** with the branch circuit through which the current is to be measured. To do this, open the branch at some convenient point and connect one test lead to each side of the break as shown in Figure E.

CAUTION: Always place an ammeter in series with the circuit. Never place it across or in parallel with the circuit. Doing so can cause a short circuit to the source and can damage the multimeter.

4. Select a higher DCA range than you anticipate measuring. If the magnitude of the current isn't known, select the highest range and reduce the setting until a satisfactory reading is obtained.
5. Read the current value and polarity on the display.
6. De-energize the circuit, disconnect the test leads, and restore the circuit to its pretest condition.

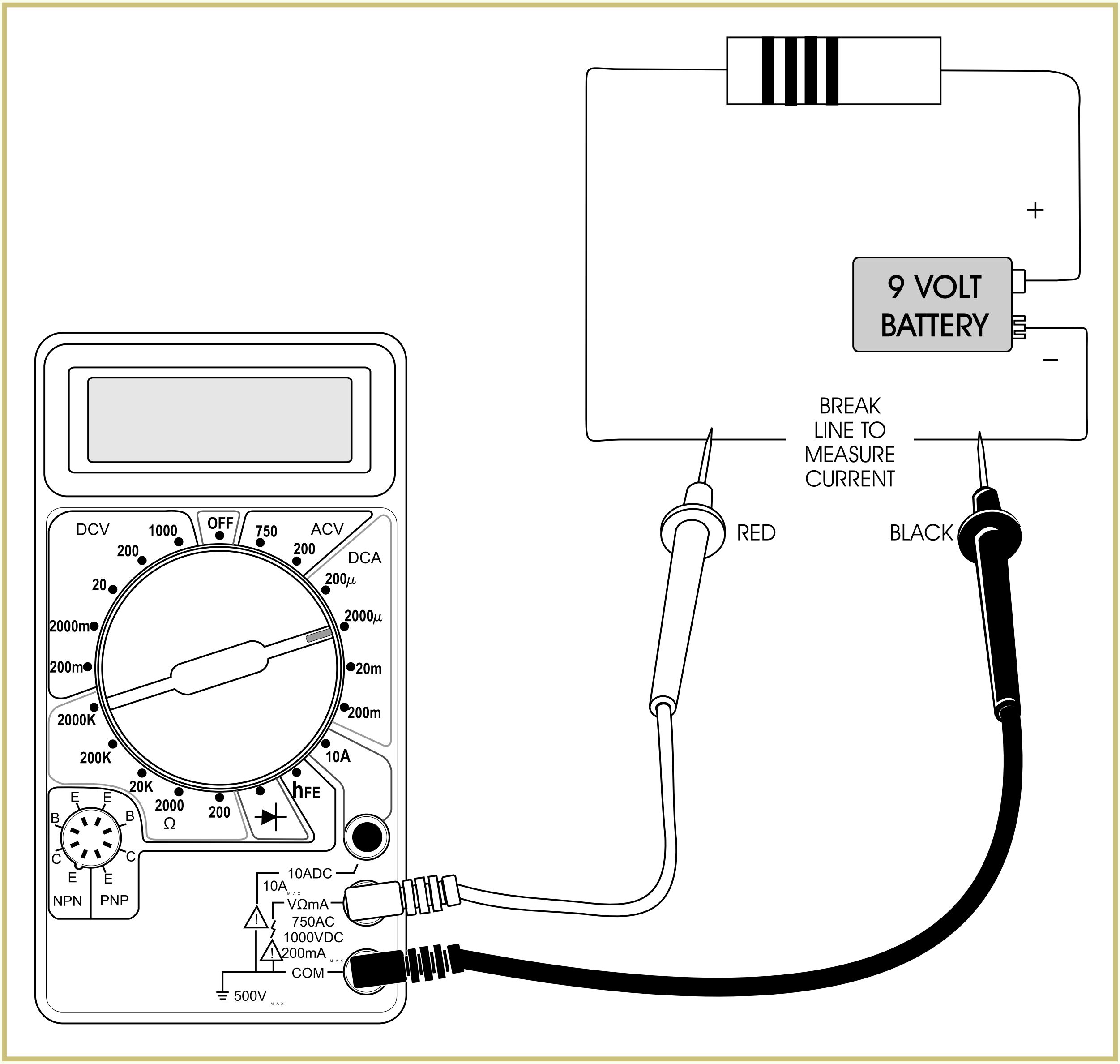


FIGURE E—DC Current Measurement

Appendix B

ELECTRICAL FUNDAMENTALS QUICK REFERENCE

Electrical Theory

To use the multimeter effectively, you need a working knowledge of the fundamentals of electricity.

Electric current consists of charged particles flowing through a conductor either in one direction (direct current) or alternately, first in one direction and then in the other (alternating current). These charged particles are known as electrons. The amount of current is proportional to the number of these particles passing any one point in the conductor each second.

The amount of current passing through a conductor is expressed in amperes (or amps). A milliampere (mA) is one-thousandth of an ampere, and a microampere (μA) is one-millionth of an ampere. Resistance is comparable to friction and determines the current that flows in a conductor with a given applied force. The resistor can be a long wire, an electric light, a motor winding, the heating element of a toaster or broiler, etc. The amount of resistance is expressed as ohms (Ω). A kilohm (kΩ or K) is one thousand ohms, and a megohm (MΩ or meg) is one million ohms.

To force these electrons through the wire, there must be an electromotive force (EMF). This EMF is often referred to as voltage (DC or AC). Measurements of EMF or voltage are made in units called volts. Sources of this voltage can be the battery in an automobile, a dry-cell battery, or the alternators supplying voltage to the home. The 60 Hz (Hertz) AC frequency is standard in the United States. Because power is dissipated when current flows through a resistance, a voltage source is generally considered a power source.

An electric circuit consists of an electromotive force (voltage) to drive electrons (current in units of amperes) through a resistance (ohms). The voltage supply always has two terminals, one supplying the electrons and the other receiving them. If a resistor or wire connects these two terminals, a current flows through the resistor or wire.

Ohm's Law

The volt, ohm, and ampere are related to each other in a simple formula known as Ohm's law:

Voltage = current × resistance, or $E = I \times R$

This law can be stated in three ways, depending upon which two of the three factors are known and which factor is to be found.

1. Voltage = current × resistance
2. Current = voltage ÷ resistance
3. Resistance = voltage ÷ current

For example, if a current of 5 amps flows through a resistance of 40 ohms, the voltage across that resistor, according to formula 1, is

Voltage = current × resistance

= 5 amps × 40 ohms = 200 volts

If a voltage of 200 volts across a 40-ohm resistor is measured, the current passing through the resistor is determined by formula 2. Thus,

Current = voltage ÷ resistance

= 200 volts ÷ 40 ohms = 5 amps

If it's found that when applying 200 volts, 5 amps pass through an unknown resistor, the value of the resistor can be calculated from formula 3. Thus,

Resistance = voltage ÷ current

= 200 volts ÷ 5 amps = 40 ohms

Power

When consumers buy electricity, they buy power.

The unit of power is the watt. A simple formula for relating watts to voltage and current is

Power = voltage × current, or

Watts = volts × amps

Thus, if there are 5 amps going through a resistor, due to a voltage of 200 volts, the power consumed by the resistor is

$$
\begin{aligned}
\text{Power} &= \text{voltage} \times \text{current} \\
&= 200 \text{ volts} \times 5 \text{ amps} \\
&= 1000 \text{ watts}
\end{aligned}
$$

It should finally be noted that 1000 watts = 1kw.

These measurements, plus an understanding of the nature of electricity, are essential to anyone working with electricity. The user of the multimeter should have some knowledge of the operation and mechanics of the particular circuits and/or the device being tested.

FIGURE F—Basic Electrical Terms and Abbreviations

ELECTRICAL TERMS	
DC	direct current
AC	alternating current
amp	ampere
Ω	ohm
m	milli = 1/1000
µ	micro = 1/1,000,000
K	Kilo = 1000
M	Mega or Meg = 1,000,000
Hz	Hertz (cycles per second)

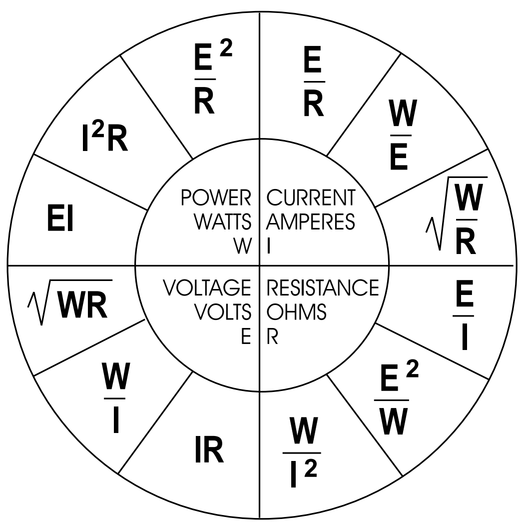
OHM'S LAW

$$E = I \times R$$

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

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

FIGURE G—Ohm's Law Wheel



Note that when you're performing calculations with Ohm's law, the variable *E* stands for the voltage in volts, the variable *I* stands for current in amperes, and the variable *R* stands for resistance in ohms. If the problem you need to solve contains other units (such as millivolts, microamperes, or megohms), you'll need to convert those values to volts, amperes, and ohms before you use them in the Ohm's law formula. The following conversion table can help you make these conversions.

CONVERSION TABLE

From	To	Multiply By
volts	millivolts	1000
millivolts	volts	0.001
volts	microvolts	1,000,000
microvolts	volts	0.000001
volts	kilovolts	0.001
kilovolts	volts	1000
volts	megavolts	0.000001
megavolts	volts	1,000,000
amperes	milliamperes	1000
milliamperes	amperes	0.001
amperes	microamperes	1,000,000
microamperes	amperes	0.000001
ohms	kilohms	0.001
kilohms	ohms	1000
ohm	megohms	0.000001
megohms	ohms	1,000,000
ohms	microhms	1,000,000
microhms	ohms	0.000001

Appendix C

ELECTRICAL REFERENCES

This appendix covers the basic electrical symbols and electrical terms with which you should become familiar.

Electrical Symbols

The symbols shown in Figure H are the most common type of electrical symbols used on motorcycles and ATV wiring diagrams.

Electrical Terms

The following terms are often found in material related to electrical repairs. Your job as a technician will be much easier if you know and understand these terms. For ease of reference, they're listed in alphabetical order.

AC. Abbreviation for "alternating current," which is electricity that reverses direction and polarity while flowing through a circuit. Examples: 110 volts AC in a household reverses direction and polarity 60 times per second (60 Hz).

alternator. An AC "generator" that uses magnetic induction to produce electricity. A revolving magnet and stationary stator windings are used. The current produced is AC.

amperes. Commonly called "amps," which are electrical units of current flow through a circuit (similar to gallons per minute of water through a hose).

amp hour. Discharge rate of battery in amperes times hours.

armature. A group of rotating conductors which pass through a magnetic field. The current produced is usually DC after passing through a commutator device.

battery. A chemical device used to store electrical power. Within the battery, a chemical reaction takes place which produces a voltage potential between the positive and negative terminals.

bench test. Isolated component inspection.

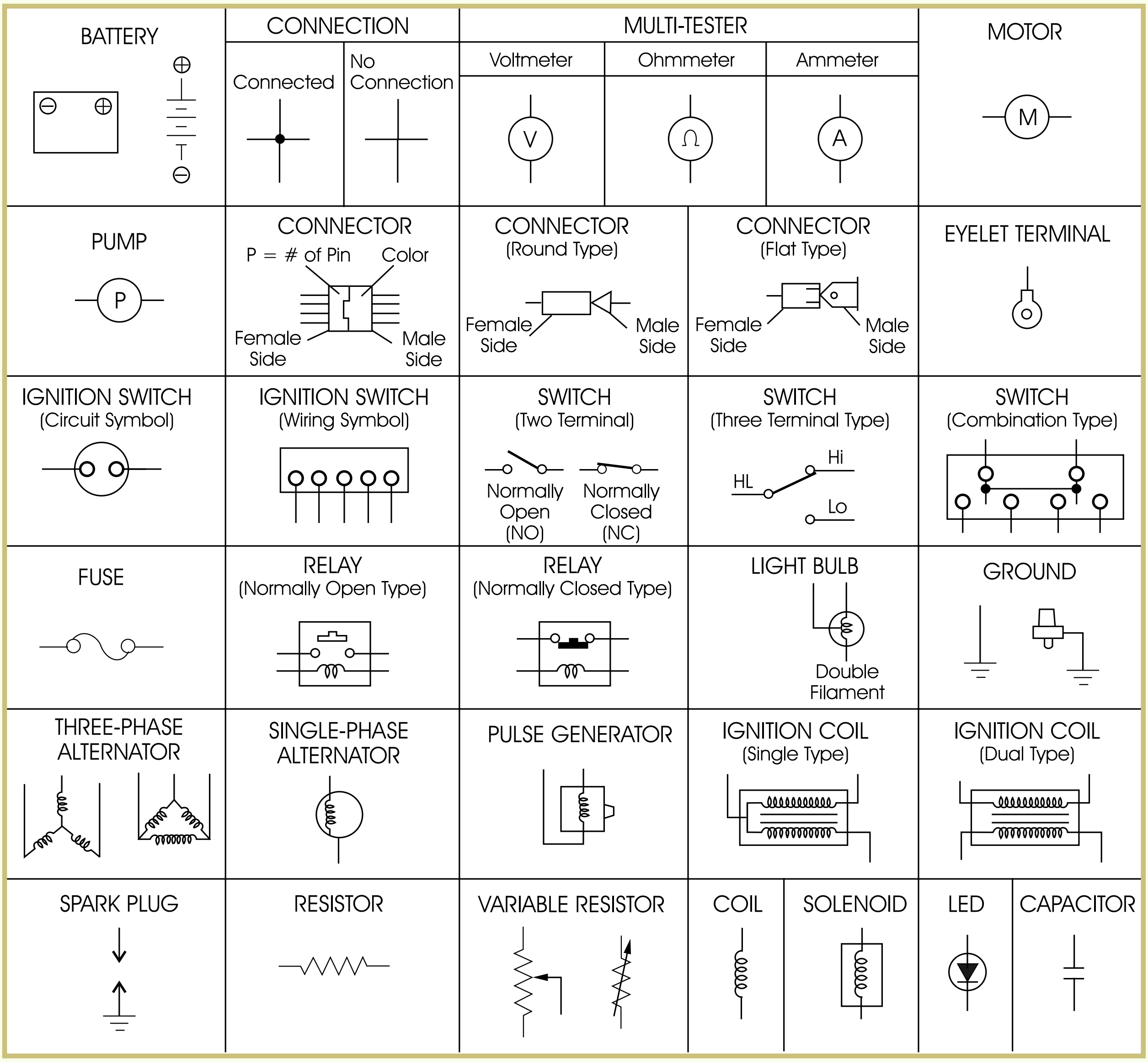


FIGURE H—The Most Common Electrical Symbols

capacitor (condenser). A component which, in a discharge state, has a deficiency of electrons and will absorb a small amount of current and hold it until discharged again.

circuit. Composed of three items: a power supply, load, and completed path.

circuit breaker. Heat-activated switch that interrupts current when overloaded. A circuit breaker can be reset and replaces the function of a fuse.

coil. A conductor looped into a coil-type configuration which, when current is passed through, will produce a magnetic field.

conductor. A wire or material (such as a frame) which will allow current to flow through it with very little resistance.

continuity. Having a continuous electrical path.

current. The flow of electrons in a circuit.

DC. Abbreviation for "direct current," which means that the current will only flow in one direction—from positive to negative (conventional theory).

dielectric. Nonconductor or insulator.

diode. A semiconductor often used in a rectifier on motorcycles. A diode has the characteristic of allowing current to pass through in only one direction. Thus it's used to change AC to DC current.

dynamic. Spinning or rotating in motion. Refers to making a test when the component is in use.

electricity. The flow of electrons through a conductor.

electron. The revolving part or moving portion of an atom. The electrons moving from atom to atom is electrical current.

electrolyte. The sulfuric acid and distilled water solution that batteries are filled with at setup.

electromagnet. A coil of wire which is wound around a soft iron core which acts as a magnet when current is passed through it.

electromotive force (EMF). The pressure of electrons in a circuit (also known as *voltage*). Created by difference in potential between positive and negative terminals of power supply. Also called pushing force of electricity.

electrolysis. The movement of electrons through an electrolyte solution. A battery charges and discharges through electrolysis. Electroplating (chroming) is an example where electrolysis is used to move and deposit metals from one electrode to another. In cooling systems, contaminated (tap water) coolant becomes an electrolyte, allowing electrolysis and the deposition of metal oxide scale on cooling system components.

free electron. An electron in an atom's outer orbit, which is held only loosely within the atom. Free electrons can move between atoms.

field coil. The field coil is an electromagnet. The flux lines may be used for generating electricity, for electric motor operation, or for operating a solenoid/relay.

fuse. A short metal strip that's protected by a glass or plastic case which is designed to melt when current exceeds the rated value.

flux lines. All the magnetic lines of force from a magnet.

ground. A common conductor used to complete electrical circuits (negative side). The ground portion of motorcycle electrical systems is often the frame.

ignition. The spark produced by the high-tension coil by which the spark plug "ignites" the air-and-fuel mixture.

insulator. See *dielectric.*

lines of force. Refers to a magnetic field whose lines run from its North Pole to its South Pole. (Also see *flux lines*.)

load. Anything that uses electrical power such as a bulb, coil, or spark plug.

magnetism. The characteristic of some (ferrous) metals to align their molecules. The alignment of the object's molecules will cause the object to act as a magnet. Every magnet has both a North and South Pole. Like polarities repel, opposites attract. Around every magnet there's a magnetic field which contains lines of force.

magnetic induction. When a conductor is moved through a magnetic field, electricity will be "induced" into the conductor when the flux field cuts through the conductor.

no-load test. A dynamic test with the component insulated or disconnected from its main system.

NPN. A transistor in which the emitter and collector layers are N-type and the base layer is P-type (Negative, Positive, Negative).

permeability. Ability of material to "absorb" magnetic flux (can be temporary or permanent—see *reluctance*).

pole. The North "Pole" or South "Pole" of a magnet. Also refers to the lugs (iron cores) of a stator around which the AC generator's wires are wound.

polarity. In magnets, polarity is north and south; in electricity, polarity is positive and negative.

PNP. Transistor in which the emitter and collector layers are P-type and the base layer is N-type (Positive, Negative, Positive).

rectifier. (See *diode*.) Changes AC to DC. Usually a group of 4 or 6 diodes comprises a "bridge rectifier."

regulator. Used to limit the output of a generator or alternator.

resistance. The opposition offered to the flow of current in a circuit.

rotor. The revolving magnets or electromagnets which form the magnetic field in an alternator or ignition signal generator.

reluctance. "Resistance" to magnetism. (Also see *permeability*.)

reluctor. Magnetic field interrupter used as a signal generator in ignition systems.

silicon. A material used in the construction of semiconductors. Because of its characteristics, the material allows current flow only under certain prescribed conditions.

sine wave. A graphic depiction of the form of alternating current usually taken from an oscilloscope.

SCR. An abbreviation for silicon-controlled rectifier, which is an electronically controlled switch. (See *thyristor*.)

selenium. Similar to silicon materials in characteristics; it's also used as a rectifier on older models.

solder. Tin/lead alloy with rosin core used to form lower-resistance connections of electrical components or wires.

static. Stationary. Usually a test made of a stationary component rather than a bench test.

stator. A stationary conductor (usually several coils of wire). When magnetic flux cuts the stator windings, a voltage potential is induced in the windings.

switch. A device which opens or closes an electrical circuit.

schematic. A wiring diagram showing the components and circuitry in detail.

thermo-switch. A bimetallic switch which, when heated, opens or closes a circuit.

thyristor. An electronically controlled switch which opens when signaled at the gate and closes after current flow falls.

unloaded. See *no-load test*.

valence electrons. See *free electrons*.

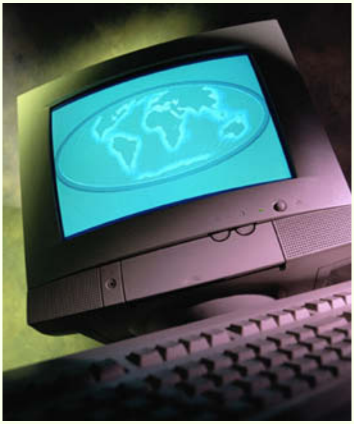
voltage. See *electromotive force*.

watt. The unit of electric power; $W = E \times I$ (Wattage = Voltage × Current).

wire gauge. Wire diameter. Usually specified by an AWG (American Wire Gauge) number. The smaller the number, the larger the wire diameter.

wiring diagram. Similar to a schematic, but less in detail. A wiring diagram usually shows components in block form rather than illustrating their internal circuitry.

Zener diode. Similar to a standard diode, but allows current flow in the reverse direction when the breakdown voltage is reached ("Zener Voltage").



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