

# 101 BASICS SERIES

## LEARNING MODULE 2: FUNDAMENTALS OF ELECTRICITY



Cutler-Hammer

**EATON**

## WELCOME

Welcome to Module 2, Fundamentals of Electricity. This module will cover the fundamentals of electricity in a practical way, and will not be complicated by complex theory and mathematical calculations. The module will present a number of different topics. You will be introduced to information that will be used in later modules.

Like the other modules in this series, this one presents small, manageable sections of new material followed by a series of questions about that material. Study the material carefully, then answer the questions without referring back to what you've just read. You are the best judge of how well you grasp the material. Review the material as often as you think necessary. The most important thing is establishing a solid foundation on which to build as you move from topic to topic and module to module.

## A Note on Font Styles

Key points are in bold.

Glossary items are italicized and underlined the first time they appear.

## Viewing the Glossary

You may view definitions of glossary items by clicking on terms and words that are underlined and italicized in the text. You may also browse the Glossary by clicking on the Glossary bookmark in the left-hand margin.

# FUNDAMENTALS OF ELECTRICITY

## WHAT YOU WILL LEARN

We will **start with an overview** to introduce you to the main points about these devices, and the parts that make them. Then we will **step through each of these topics** in detail:

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## INTRO- DUCTION TO ELECTRICITY

The technical term electricity is the property of certain particles to possess a force field which is neither gravitational nor nuclear. To understand what this means, we need to start simply.

Everything, from water and air to rocks, plants and animals, is made up of minute particles called atoms. They are too small to see, even with the most powerful microscope. **Atoms consist of even smaller particles called protons, neutrons and electrons.** The nucleus of the atom contains protons, which have a positive charge, and neutrons, which have no charge. Electrons have a negative charge and orbit around the nucleus. An atom can be compared to a solar system, with the nucleus being the sun and the electrons being planets in orbit.

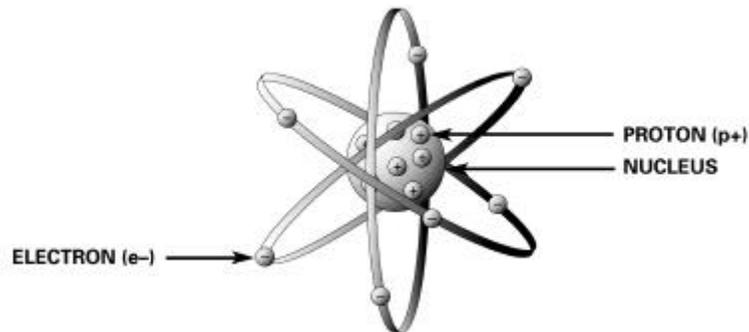


FIGURE 1: PARTS OF AN ATOM

Electrons can be freed from their orbit by applying an external force, such as movement through a magnetic field, heat, friction, or a chemical reaction.

A free electron leaves a void, which can be filled by an electron forced out of its orbit from another atom. As free electrons move from one atom to another, an electron flow is produced. **This electron flow is the basis of electricity.**

The cliché, “opposites attract,” is certainly true when dealing with electrical charges. Charged bodies have an invisible electrical field around them. When two like-charged bodies are brought close together, they repel each other. When two unlike charged bodies are brought closer together, their electrical fields work to attract.

### Characteristics

When we look at the flow of electricity, we need to look at its characteristics. There are three main characteristics of electricity:

- Current (symbol I)
- Voltage (symbol E or V)
- Resistance (symbol R)

## Current

The flow of free electrons in the same general direction from atom to atom is referred to as current and it is measured in amperes (“amps” or “A”). The number of electrons that flow through a conductor’s cross-section in one second determines amps. Current can be expressed in a number of different ways, such as:

Quantity	Symbol	Decimal
1 milliampere	1 mA	1/1000 A
1 ampere	1 A or 1 amp	1 ampere
1 kiloampere	1 kA	1000 amperes

When discussing current, the direction of current flow needs to be considered. There are two different theories about this:

- Conventional Flow
- Electron Flow

**Conventional Flow:** This theory states that electrons flow from positive to negative. Benjamin Franklin theorized this when very little was known about electricity. It states that an invisible fluid known as electricity tended to flow through a wire from the positive to the negative. Ben’s theory became the convention (hence the term “conventional current”) in electrical theory, mathematics, textbooks and electrical equipment for the next hundred years.



FIGURE 2: CONVENTIONAL FLOW

**Electron Flow:** This theory states that electrons flow from negative to positive. When more was known about the behavior of electrons, **scientists discovered that electrons actually flow from negative to positive**. Since electrons are negatively charged, it follows that they are attracted by positively charged bodies and repelled by negatively charged bodies.



FIGURE 3: ELECTRON FLOW

**Current  
(continued)**

Despite the fact that it has been positively determined that electron flow is the correct theory, the conventional flow theory still dominates the industry. Either theory can be used as long as the orientations are correct. Conventional flow will be used from this point on in these training modules unless otherwise stated.

**Voltage**

Voltage is the force that is applied to a conductor to free electrons, which causes electrical current to flow. It is measured in volts or "V". Current will flow in a conductor as long as voltage, the electrical pressure, is applied to the conductor. Voltage is expressed in a number of ways:

Quantity	Symbol	Decimal
1 millivolt	1 mV	1/1000 volt
1 volt	1 V	1 volt
1 kilovolt	1 kV	1000 volts

There are two methods that voltage forces current to flow:

- Direct Current
- Alternating Current

**Direct current:** With this method, the voltage forces the electrons to flow continuously in one direction through a closed circuit. This type of voltage is called Direct Current (DC) voltage. Batteries and DC generators produce DC voltage.

**Alternating current:** With this method, voltage forces electrons to flow first in one direction, then in the opposite direction, alternating very quickly. This type of voltage is called Alternating Current (AC) voltage. A generator is used to produce AC voltage. The voltage generated by utility companies for our home, factories and offices is AC voltage.

# FUNDAMENTALS OF ELECTRICITY

## Voltage (continued)

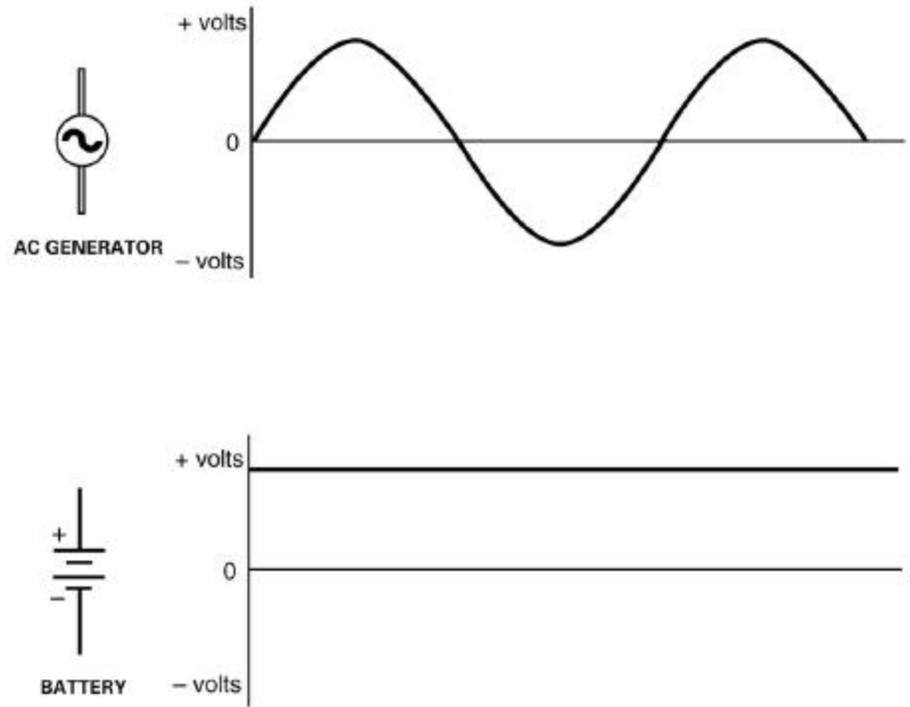


FIGURE 4: AC AND DC CURRENT

## Resistance

This is the third characteristic of electricity. The restriction to the flow of electrons through a conductor is called resistance and it is measured in *ohms* and abbreviated " $\Omega$ ", the Greek symbol Omega. Resistance is expressed in a number of ways:

Quantity	Symbol	Decimal
1 ohm	1 $\Omega$	1 ohm
1 kilohm	1k $\Omega$	1000 ohms
1 megohm	1M $\Omega$	1,000,000 ohms

### Resistance (continued)

In general, there are four factors that affect the amount of resistance in a conductor:

- Material
- Length
- Cross-Sectional Area
- Temperature

**Material:** We know that the amount of electron flow depends upon how readily particular atoms give up their electrons and accept new electrons. Materials that permit this are called conductors. Copper, silver and aluminum are considered good conductors.

Materials that don't readily give up electrons, which restricts the flow, are called *insulators*. Rubber, glass and porcelain are considered good insulators.

Conductors and insulators perform a very important team function. An electrical cord to a lamp, for example, has a copper wire conductor on the inside with a rubber-coating insulator around the outside. Free electrons flow along the copper wire to light the lamp while the rubber coating keeps the free electrons inside to prevent shock and other problems.

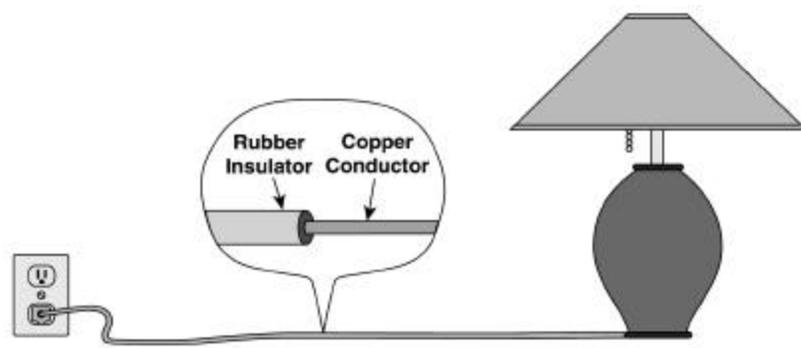


FIGURE 5: CONDUCTORS AND INSULATORS

**Length:** The longer the conductor, the more resistance in the conductor.

**Resistance is increased or decreased in proportion to the conductor's length.** For example, a 2-foot long conductor would have twice the resistance of a one-foot long conductor.

### Resistance (continued)

**Cross-Sectional Area:** As the cross-sectional area of a conductor increases, the resistance decreases, and vice versa. For example, if the **area of a conductor is doubled, the resistance is cut in half.**

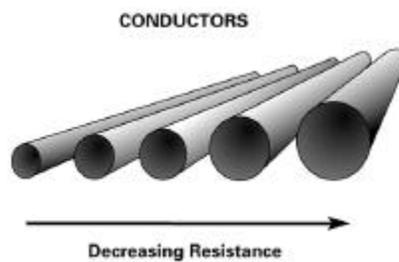


FIGURE 6: CONDUCTOR CROSS-SECTIONAL AREA

**Temperature:** Usually when the **temperature of a conductor increases, the resistance increases.** The temperature factor is not as predictable as the other factors, but it must be considered when dealing with electricity.

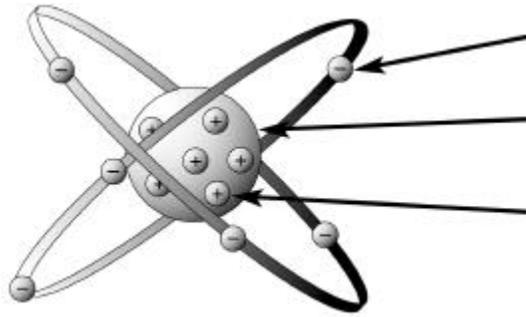
## REVIEW 1

Answer the following questions without referring to the material just presented. Begin the next section when you are confident that you understand what you've already read.

1. Atoms are larger than electrons.

TRUE    FALSE

2. Identify the parts of the atom indicated.



a. \_\_\_\_\_

b. \_\_\_\_\_

c. \_\_\_\_\_

3. Electrons are naturally repelled by the positively charged nucleus of the atom.

TRUE    FALSE

4. A free electron results when it is forced out of its \_\_\_\_\_.

5. The flow of electrons from one atom to another is the basis of electricity.

TRUE    FALSE

6. A good conductor of electricity permits a very free movement of electrons. Name two good conducting materials: \_\_\_\_\_ and \_\_\_\_\_.

7. Electric current flows in a conductor because it is forced to by \_\_\_\_\_.

8. One kilovolt (1 kV) is equal to 100 volts.

TRUE    FALSE

9. Resistance is measured in \_\_\_\_\_.

10. Usually, the higher the conductor temperature, the easier it is for electricity to flow in the conductor.

TRUE    FALSE

## OHM'S LAW

There is a definite relationship between the three primary electrical characteristics: current, voltage and resistance. A German mathematician, George Simon Ohm, formulated this relationship in the 19th century. His law (*Ohm's Law*) stated that **current is directly proportional to voltage and inversely proportional to resistance**. The following formula was derived from that law:

$$\text{Current} = \text{Voltage}/\text{Resistance} \quad \text{or} \quad I = E/R$$



**Current (I) in amps: Voltage (E) in volts: Resistance (R) in ohms**

FIGURE 7: OHM'S LAW

Ohm's Law is the basic formula used in all AC and DC electrical circuits. So if you know two of the three characteristics, you can calculate the third one.

Electrical designers use it to determine how much voltage is required for a certain load, like a motor, a computer, or even a house full of appliances.

## DC Circuits

We can use a simple DC circuit here to demonstrate Ohm's Law. Before we do any calculations, however, let's briefly discuss the symbols that will be used in our circuit diagrams.

**Voltage Symbol:** The terminals of a battery are symbolically indicated on an electrical drawing by one or more pairs of lines. The longer line represents the positive terminal, and the shorter line the negative terminal.

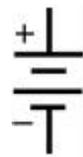


FIGURE 8: VOLTAGE SYMBOL (BATTERY)

**Resistance Symbol:** Resistance is represented in one of two ways: either an open rectangle or a zigzag line. Resistance in a circuit can take the form of many different components from light bulbs to motors. Most of these components have their own unique symbols. For now, we will use the zigzag line symbol to represent the loads.

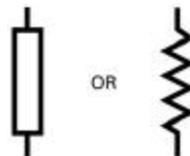


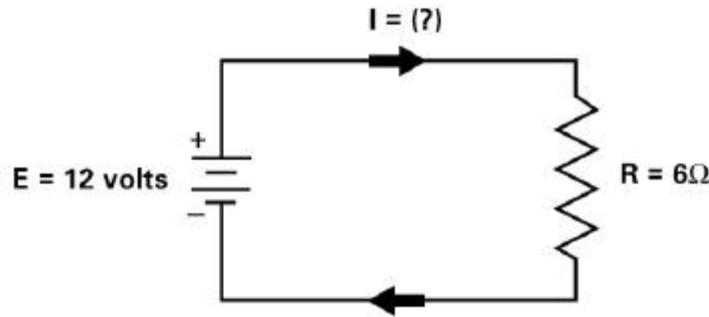
FIGURE 9: RESISTANCE SYMBOL (RESISTOR)

# FUNDAMENTALS OF ELECTRICITY

## Series Circuits

Using the simple circuit shown, assume that the voltage supplied is 12 volts, and the resistor provides six ohms of resistance. To determine the current, use the following formula.

$$I = \frac{E}{R} \quad \text{or} \quad \text{Current (amps)} = \frac{\text{Voltage (volts)}}{\text{Resistance (ohms)}}$$



CALCULATION
$I = \frac{E}{R}$
$I = \frac{12 \text{ volts}}{6\Omega}$
<b>I = 2 amperes</b>

FIGURE 10: FORMULA FOR CURRENT

## IN THE WORKPLACE

Another example of a simple DC circuit is a flashlight. Batteries in the flashlight provide the DC voltage source, the inside of the battery case usually acts as the conductor, and the lamp bulb is the load.

The flashlight has an ON and OFF switch which controls the flow of electricity. Since there must always be a complete path for current to flow, the switch stops the flow when it is in the OFF position. Why? Because the circuit is open when the switch is OFF. When the switch is ON, the circuit is complete and current flows, lighting the bulb.

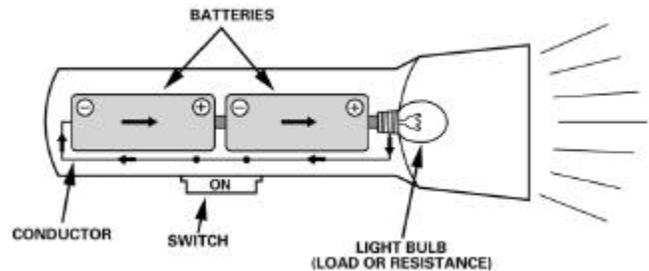


FIGURE 11: A SIMPLE DC CIRCUIT

The simple circuits above are called *series circuits*, which means all loads are connected one after another in a series. If a conductor or a load is broken, it opens the circuit. This condition does not allow the current to complete the circuit and makes the entire circuit dead.

A good example of this is the old design for holiday lights. If one bulb was burned out, the entire string would not light.

## Series Circuits (continued)

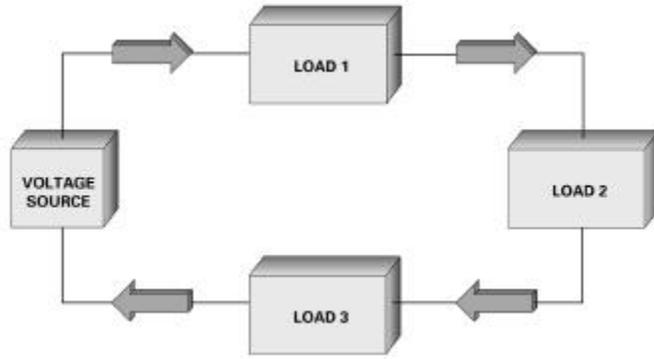
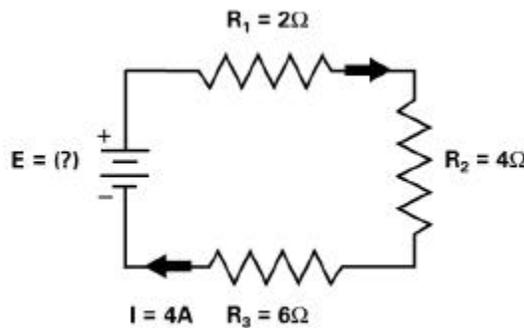


FIGURE 12: SERIES CIRCUIT

Take a look at the next series circuit. The voltage is unknown, but can be calculated using Ohm's Law,  $E = IR$ . The current ( $I$ ) is four amps as shown, but the resistance has to be calculated. **In a series circuit, when more than one resistance is in the circuit, the resistances are added together to get the total resistance ( $R_T$ ).** The  $R_T$  is 12 ohms. Given these two values and Ohm's Law, the voltage is 48 volts.



CALCULATION 1
$R_T = R_1 + R_2 + R_3$
$R_T = 2\Omega + 4\Omega + 6\Omega$
$R_T = 12\Omega$
CALCULATION 2
$E = IR_T$
$E = 4A \times 12\Omega$
$E = 48 \text{ volts}$

FIGURE 13: FORMULA FOR VOLTAGE

Now is a good time to talk about how current and voltage behaves in a series circuit. The current value is the same in every part of the circuit. An ammeter can verify this.

**Voltage, on the other hand, does not remain constant throughout the circuit.** Voltage values can be measured across each resistor or load. This is called the voltage drop. The total voltage ( $V_T$ ) is equal to the sum of all the voltage drops in that circuit. A voltmeter can verify this. The formula is:

$$(V_T) = V_1 + V_2 + V_3 \dots$$

## Parallel Circuits

In *parallel circuits*, the loads are connected across the power line to form branches. The loads operate independently of each other, and therefore a break in any one branch does not prevent the line voltage from being applied to the remaining branches. The result is that one path (branch) can be open with the load not receiving current without the other loads being affected, as in the newer strings of holiday lights.

Current has a number of paths to follow. If all paths are available, **the current divides itself between the branches back to the source**. If a path is open, the current divides between the remaining available paths and goes back to the source.

Parallel circuits are used in the majority of industrial, commercial and residential applications of electricity.

The next two circuit illustrations show three resistors in parallel. The only difference between the two circuits is the resistor values. To use Ohm's Law to solve the equations, you need to know how resistance, current and voltage behave in parallel circuits.

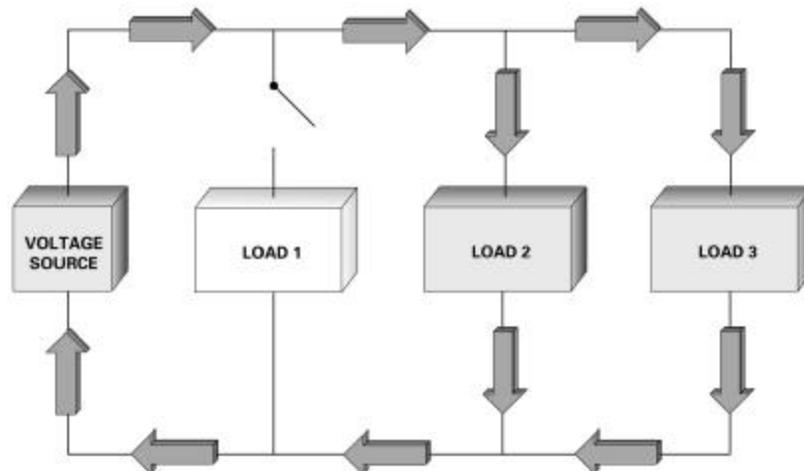


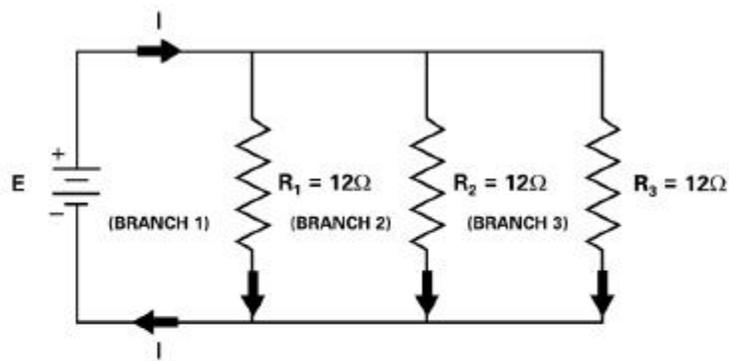
FIGURE 14: PARALLEL CIRCUIT

## Parallel Circuits (continued)

The total resistance ( $R_T$ ) of a parallel circuit decreases as more branches are added. The total resistance of a parallel circuit is always less than the resistance of any of its branches and is therefore less than the value of the lowest resistance in the circuit. To determine total resistance ( $R_T$ ) two different formulas are used:

- Resistors with equal values
- Resistors with unequal values

**Resistors with Equal Values:** This  $R_T$  is determined by dividing the value of one of the resistors by the total number of resistors in the circuit. Using this formula, the total resistance for the first circuit is calculated to be four ohms.



CALCULATION	
$R_T =$	$\frac{\text{One Resistor Value}}{\text{Total Number of Resistors}}$
$R_T =$	$\frac{12\Omega}{3}$
$R_T =$	$4\Omega$

FIGURE 15: RESISTORS WITH EQUAL VALUE

**Parallel Circuits  
(continued)**

**Resistors with Unequal Values:** Calculating  $R_T$  is more complicated and is shown below:

$$R_T = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}}$$

As a point of interest, the  $R_T$  for this circuit is  $1.09\Omega$ .

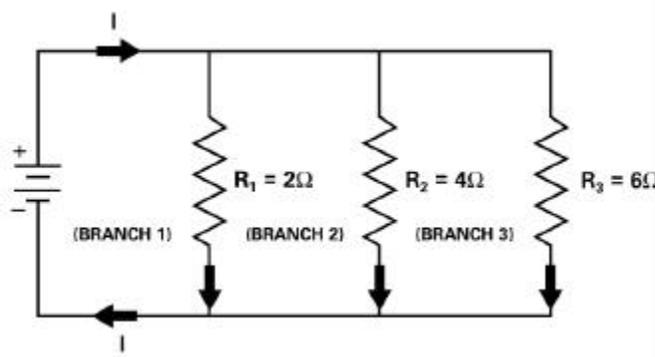


FIGURE 16: RESISTORS WITH UNEQUAL VALUE

To determine current, you need to find the total current, which is the sum of all currents in all the branches. The following simple formula represents the total current ( $I_T$ ), while the illustration offers a demonstration.

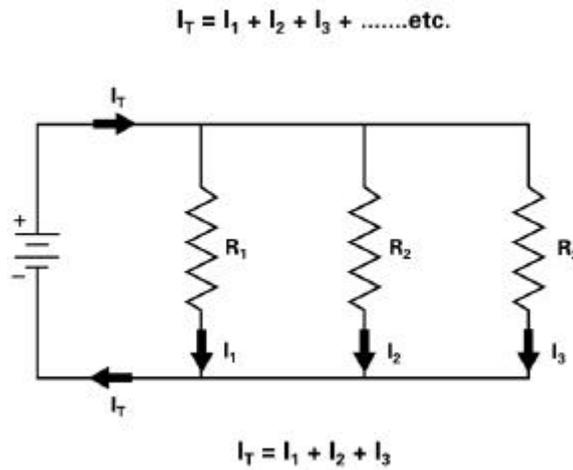


FIGURE 17: TOTAL CURRENT FORMULA

To determine the individual branch currents, it is necessary to know whether or not all the resistors have the same value.

## Parallel Circuits (continued)

**Current with Equal Resistor Values:** The current divides equally. Divide the total current by the total number of branch resistors to determine the current flowing through each branch. The following illustration and calculation demonstrate this procedure.

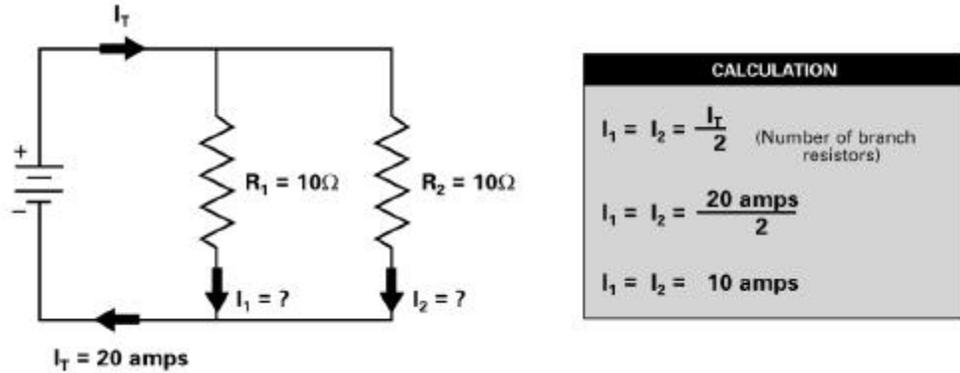


FIGURE 18: CURRENT WITH EQUAL RESISTORS

**Current with Unequal Resistor Values:** The current is greater through the branch with the least resistance.

**Parallel circuit voltage is easy to determine because it is the same across each resistor and/or load.** The illustration shows a parallel circuit with voltmeters indicating the voltage across each resistor to be the same as the source battery.

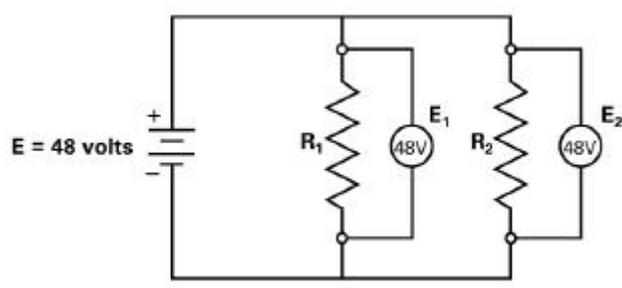


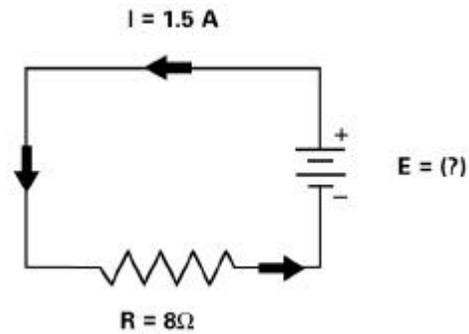
FIGURE 19: PARALLEL CIRCUIT VOLTAGE

## REVIEW 2

Answer the following questions without referring to the material just presented. Begin the next section when you are confident that you understand what you've already read.

1. Draw the Ohm's Law Triangle.

2. Using Ohm's Law, calculate the voltage of the battery in the simple circuit shown.  $E = \underline{\hspace{2cm}}$  volts

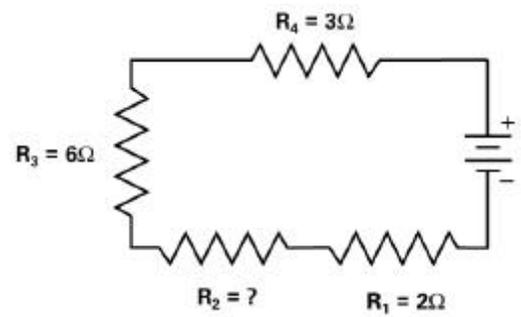


3. A circuit in which all the loads are connected by one continuous flow of electrical current is called a \_\_\_\_\_ circuit.

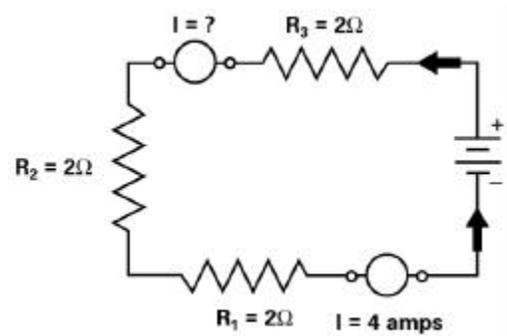
4. The current flow in a parallel circuit divides between all the open branches (paths) in the circuit.

TRUE      FALSE

5. The resistance of resistor R2 in the following DC series circuit is \_\_\_\_\_ ohms when the total circuit resistance ( $R_T$ ) is 18 ohms.



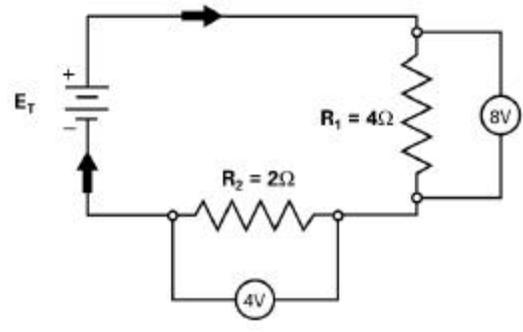
6. Ammeter 2 ( $A_2$ ) will read \_\_\_\_\_ amperes in the following DC series circuit.



## FUNDAMENTALS OF ELECTRICITY

### REVIEW 2 (continued)

7. The voltage of the source battery (ET) in the following DC series circuit is \_\_\_\_\_ volts.



8. If there is a break in any part of a series circuit, the entire circuit will be dead.

TRUE    FALSE

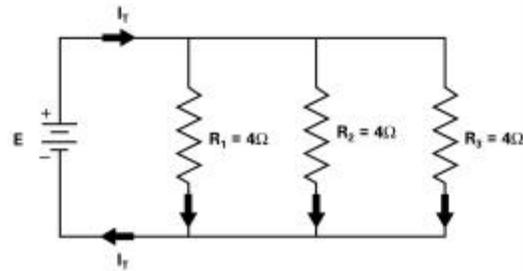
9. One advantage of a parallel circuit over a series circuit is that the parallel circuit provides more paths for current to flow.

TRUE    FALSE

10. The total current in a parallel circuit equals the sum of all branch currents.

TRUE    FALSE

11. Which resistor would have the most current flowing through it in the following parallel circuit?  
\_\_\_\_\_



## AC VOLTAGE

### Magnetism and Electro-magnetism

Magnetism and basic electricity are so closely related that one can not be studied at length without involving the other. There are three general relationships that exist between them:

- Current flow will always produce some form of magnetism.
- Magnetism is by far the most commonly used means for producing or using electricity.
- The peculiar behavior of electricity under certain conditions is caused by magnetic influences.

The importance of magnetism plays a key role in circuit protection and control devices. This importance will become apparent as you go through the different modules.

Let's talk about the main source of magnetism, a magnet. Every magnet has three common properties:

1. They attract and hold iron.
2. They all have two poles, one north and one south.
3. They will assume close to a north-south alignment, if permitted to move.

Every magnet is surrounded by a magnetic field that consists of flux lines or lines of force that extend into space from one end of the magnet to the other as well as inside the magnet. The north and south poles attract one another because the poles are opposites. It also holds true that two like poles repel one another.

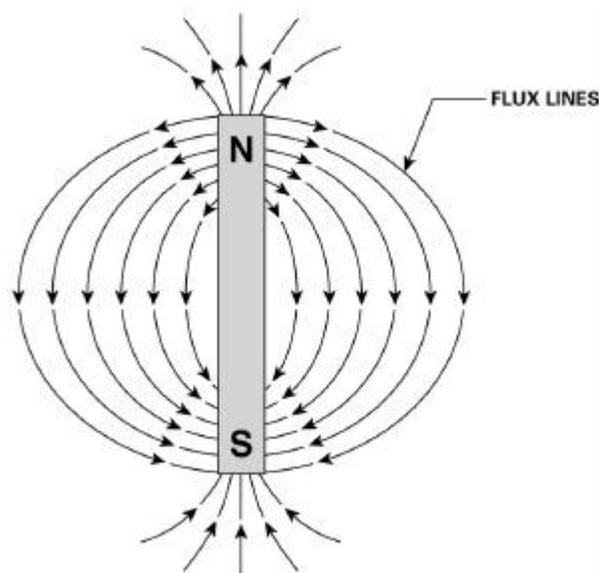


FIGURE 20: MAGNETIC FIELD

### Magnetism and Electromagnetism (continued)

Even though flux lines are invisible, their effects can be shown by a simple demonstration. When a sheet of paper is placed on a magnet and iron filings are loosely scattered over it, the filings arrange themselves along the flux lines. They leave the north pole and enter the south pole.

There are two types of magnets: *permanent magnets* and *electromagnets*. Permanent magnets retain their magnetism after a magnetizing force has been removed. The interaction of electric current and a magnetic field creates electromagnetism. Electromagnets are similar to permanent magnets, except they do not retain their magnetism when the electricity is removed, and they can be made stronger.

To make a typical electromagnet, take an iron rod and wrap it with insulated wire. The iron rod is called a “core”. When the wire is connected to a battery, electric current flows through the wire. This current magnetizes the iron core. This creates a north and south pole. When one or both ends of the wire at the battery are disconnected, the current flow stops. The core loses its magnetism.

Changing the direction of the current flow can reverse the poles of an electromagnet. To change the direction, just interchange the wire connections. This is because the battery produces DC voltage, which flows in one direction.

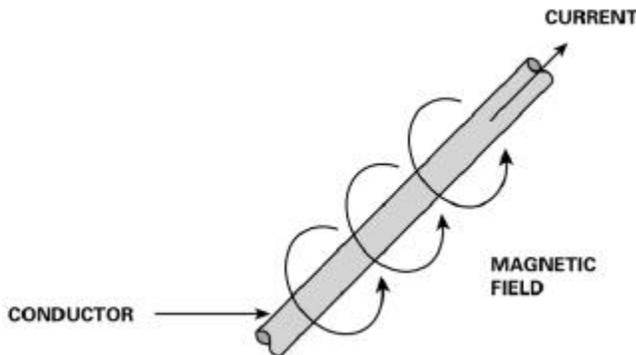


FIGURE 21: ELECTROMAGNET

**Alternating current changes directions on its own.** As the current direction changes, the electromagnet poles change.

Unlike the permanent magnet, the direction of the flux lines are not constant. They are related to the direction of current flow through the conductor.

## Magnetism and Electromagnetism (continued)

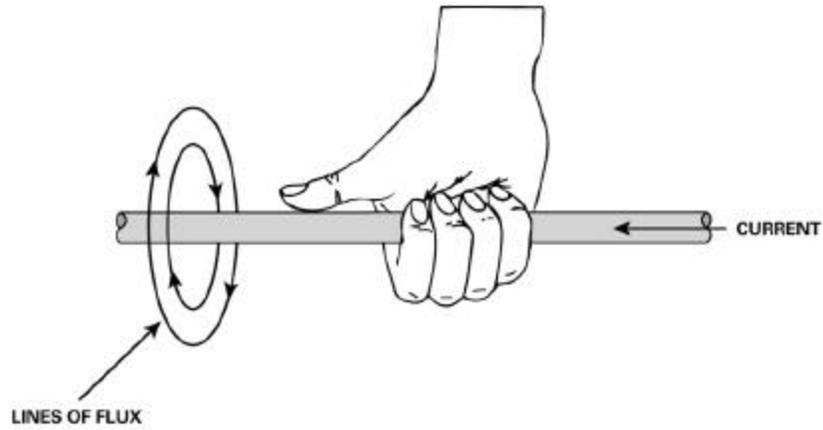


FIGURE 22: RIGHT-HAND RULE

The relationship between current flow and flux lines can be demonstrated using the *right-hand rule*. A current carrying conductor is held with the right hand and the thumb pointing in the direction of the current flow. Wrap the fingers around the conductor. The fingers point in the direction of the lines of flux.

**This right-hand rule is followed when using conventional flow, but when electron flow is used, then the left-hand rule would be used.** This rule is the same as right-hand rule except you do everything with your left hand. When we deal with motors in a later module, we will use left-hand rule, because of the way motors react with the magnetic flux and current.

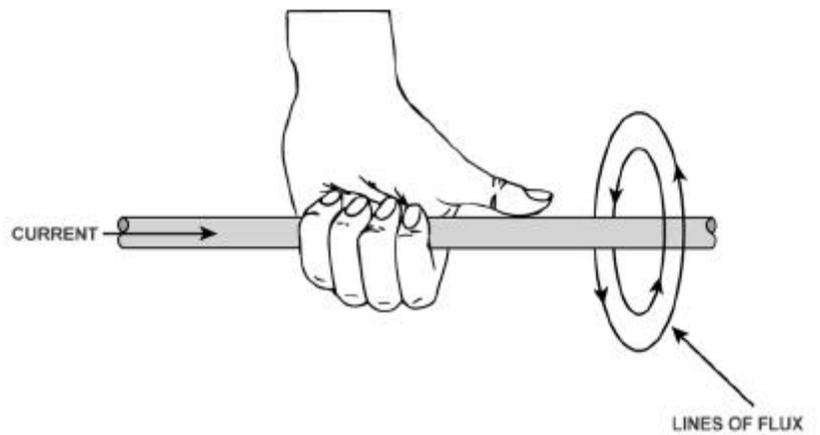


FIGURE 23: LEFT-HAND RULE

## Magnetism and Electromagnetism (continued)

Finally, if current in two parallel conductors is flowing in opposite directions, the magnetic fields would also flow in opposite directions, and a natural repulsion is created. The degree of repulsion depends on the magnitude of the current.

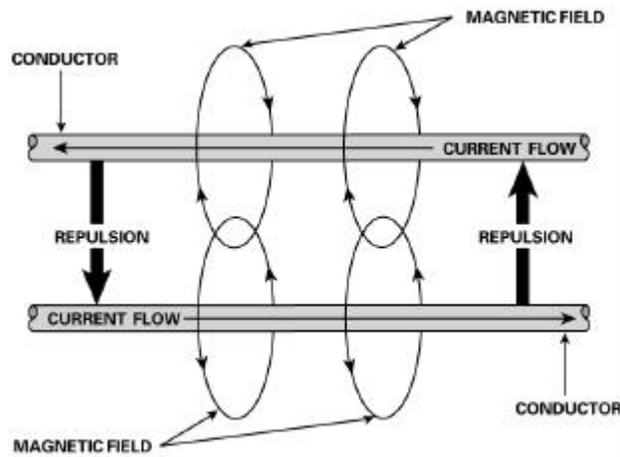


FIGURE 24: PARALLEL FLOW

These basic electromagnetic principles led to the invention of a wide variety of electrical devices such as the previously mentioned motors, generators, solenoids, tripping devices and circuit breakers.

## Alternating Current (AC)

As stated previously, there are two types of voltages: DC and AC. To this point we have been focusing on DC. DC voltage is very simple, straight forward and is created by batteries and DC generators.

Now let's focus on AC voltage. A generator or alternator is used to produce AC voltage. AC is generated by utility companies and transmitted to our homes, factories, stores and offices.

AC voltage is used for many reasons, but one of the main reasons is it can be stepped up or down by a *transformer*. This permits the transmission lines to operate at high voltages and low currents for maximum efficiency. The consumer can then step down the voltage to the desired level.

## Sine Waves

An AC generator converts mechanical energy into electrical energy. The theory of magnetism is what allows the generator to produce AC voltage. This is because a current carrying conductor produces a magnetic field around itself. A changing magnetic field produces voltage in a conductor. Likewise, if a conductor lies in a magnetic field, and either the field or conductor moves, a voltage is induced in the conductor. This effect is called *electromagnetic induction*.

## Sine Waves (continued)

Below is a simple AC generator with a single loop of wire and a magnetic field for simplicity. The figure shows the loop of wire rotating in a clockwise direction through the magnetic field of the magnets. This will show how a sine wave graphically represents AC voltage and current.

The coil will cover a 360-degree rotation and show what happens at different points in the rotation. The rotating coil is divided into black and white halves to keep track of the coil's position.

### Step 1: Starting point at 0 degrees

With the coil at 0 degrees and no rotation, no voltage is generated and no portion of the sine wave appears on the horizontal and vertical axes.

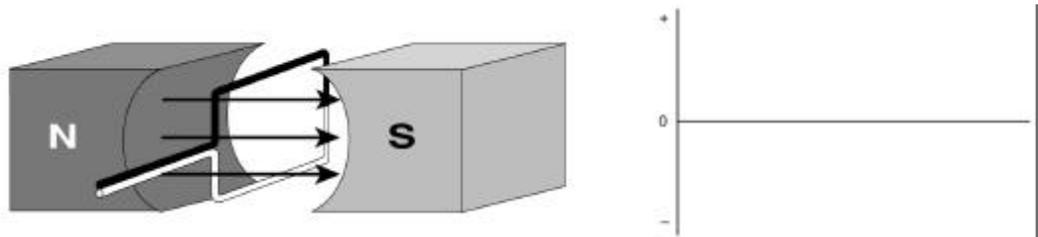


FIGURE 25: 0 DEGREES

### Step 2: Generation from starting point 0 degrees to 90 degrees

As the coil rotates from 0 to 90 degrees, it cuts more and more lines of flux. As the lines of flux are cut, voltage is generated in the positive direction.

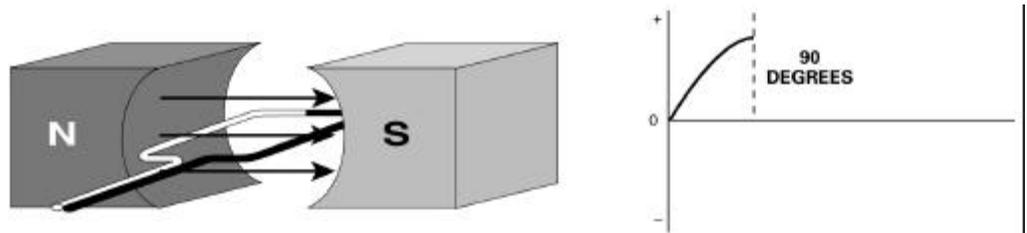


FIGURE 26: 90 DEGREES

## Sine Waves (continued)

### Step 3: Generation from 90 to 180 degrees

As the coil continues to rotate, it cuts fewer and fewer lines of flux. Therefore, the voltage generated goes from maximum back to zero.

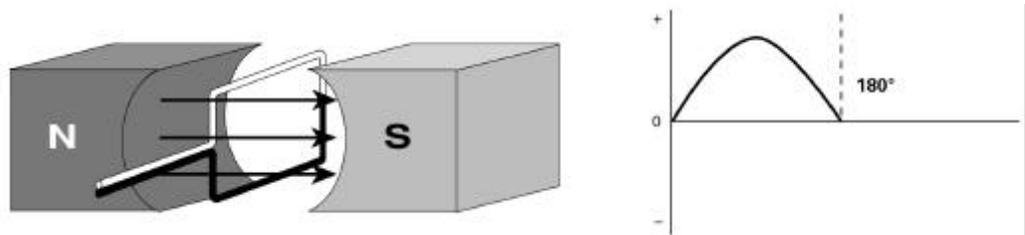


FIGURE 27: 180 DEGREES

### Step 4: Generation from 180 to 270 degrees

This is similar to Step 2 except voltage is now generated in the negative direction.

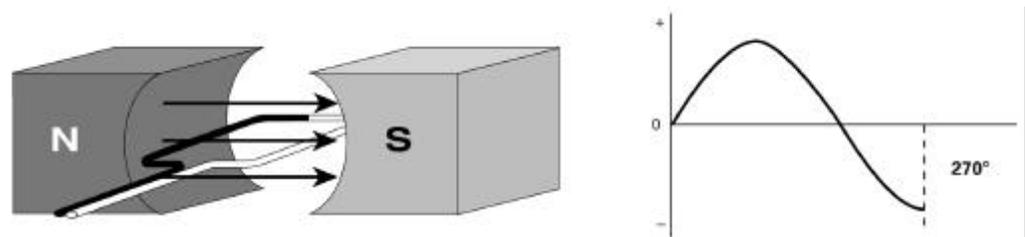


FIGURE 28: 270 DEGREES

### Step 5: Generation from 270 to 360 degrees

This is similar to Step 3 except the voltage is still negative. Once it reaches 0 degrees, one complete 360-degree revolution has been completed. At this point, the coil is back to its original starting position and one cycle has been completed. If the coil continues to rotate, the cycle will continue to repeat.

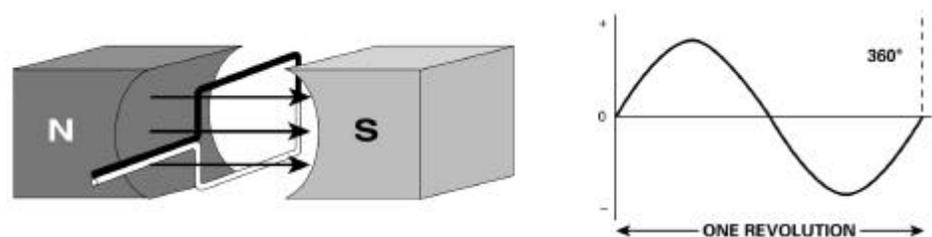


FIGURE 29: 360 DEGREES

AC goes through many of these cycles each second. The number of cycles per second is called the *frequency*. In the U.S., AC is generated of 60 hertz. This means that 60 cycles are completed every second. Frequency will be discussed in more detail in later modules.

## AC vs. DC

Now let's graphically compare an alternating current wave, and a direct current wave.

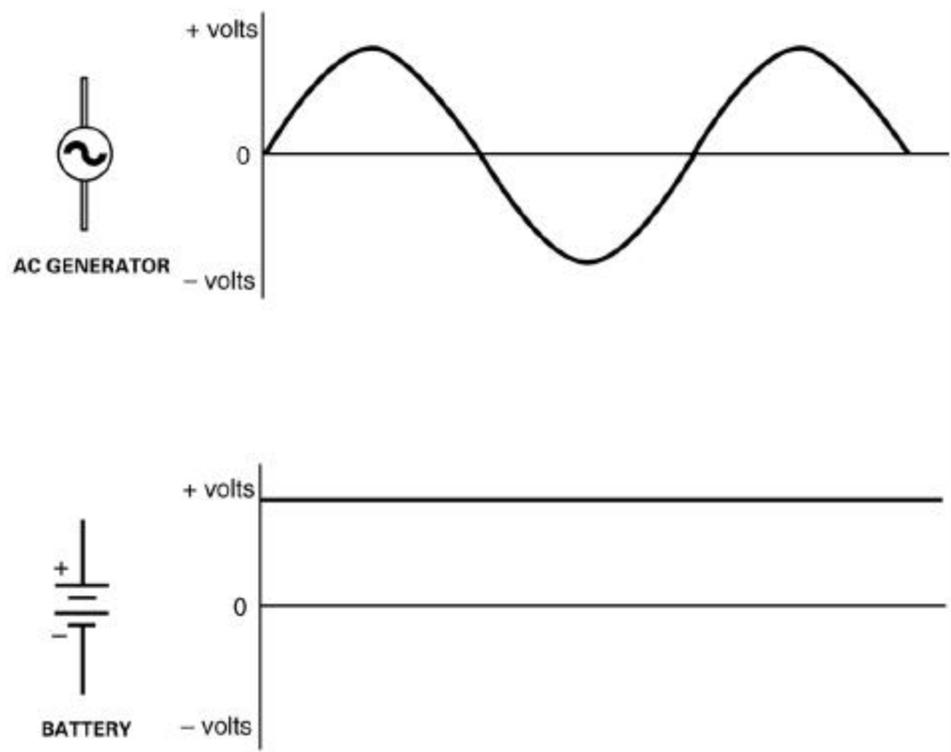


FIGURE 30: AC VERSUS DC

The AC sine wave varies constantly in direction (polarity) and magnitude. Usually, the DC wave is considered to be a steady, non-varying, uni-directional wave. The direction (polarity) of an AC wave generally reverses on a cyclical basis, that is, the wave takes on both positive and negative values, alternately.

## AC Voltage — Single-Phase and Three-Phase

AC can be *single-phase* or *three-phase*. Single-phase is used for small electrical demands such as in the home. Single-phase is what we have been discussing.

Three-phase is used where large blocks of power are required in commercial and industrial facilities. Three-phase is a continuous series of three overlapping AC cycles. Each wave represents a phase, and is offset by 120 degrees.

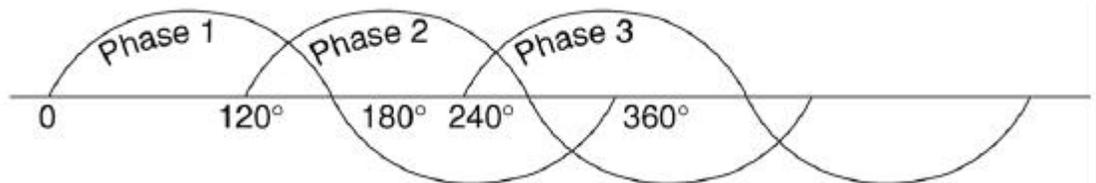


FIGURE 31: THREE-PHASE SINE WAVE

## Sine Wave Values

You learned earlier in this module that the sine wave represents the rise and fall of voltage and current in an AC circuit over time. There are several values that can be determined from the sine wave.

**Peak Value:** The peak value of a sine wave occurs twice each cycle, once at the positive maximum value and once at the negative maximum value.

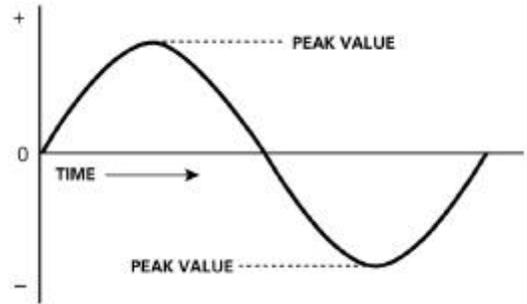


FIGURE 32: PEAK VALUE

**Peak-to-Peak Value:** The peak-to-peak value is the value of voltage or current between the positive and negative peaks.

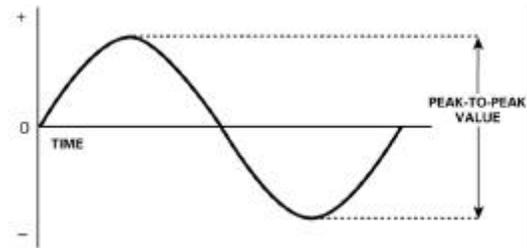


FIGURE 33: PEAK-TO-PEAK VALUE

**Instantaneous Value:** The instantaneous value is the value at any one particular time from zero to the peak value.

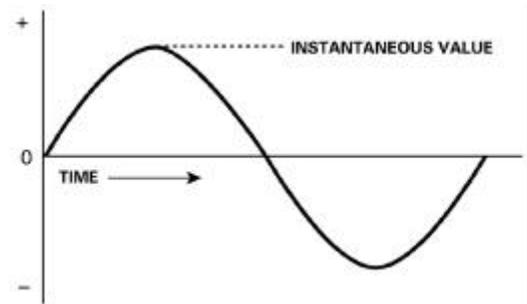


FIGURE 34: INSTANTANEOUS VALUE

## Sine Wave Values (continued)

**Effective Value:** As would be expected, there are a number of different values of voltage with alternating current constantly changing. The effective value was developed as a way to translate the varying values into a constant equivalent value for AC. This is known as the RMS value (root-mean-square).

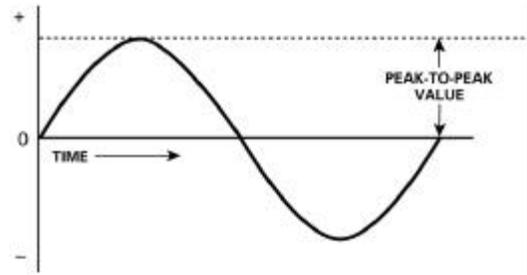


FIGURE 35: EFFECTIVE VALUE

The average home uses 120 volts, which is the RMS value. The effective value works out to be about .707 times the peak value. The formula is as follows:

$$\text{RMS} = .707 \times \text{peak}$$

Insulation is designed, for example, to deal with the peak value as well as the effective value. Calculate the peak value by multiplying the effective value by 1.41. In the average home example just given, the peak value would calculate out to be approximately 169 volts.

This formula is arrived by the following means:

$$\text{Peak} = \frac{1}{\text{RMS} \times .707}$$

$$\text{Or peak} = \text{RMS} \times 1.414$$

$$\text{So peak is } 120 \times 1.414 \text{ or } 169\text{V}$$

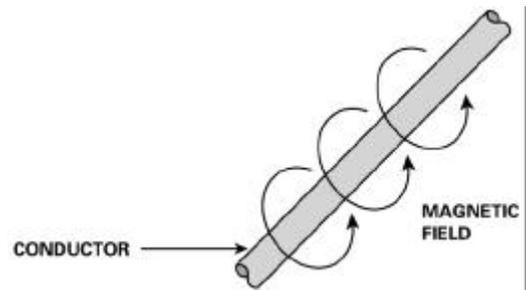
## REVIEW 3

Answer the following questions without referring to the material just presented. Begin the next section when you are confident that you understand what you've already read.

1. Name two characteristics that are common to every magnet.  
\_\_\_\_\_ and \_\_\_\_\_
2. A magnetic field consists of flux lines. Flux lines are also referred to as lines of \_\_\_\_\_.
3. Electromagnetism is an interaction between a magnetic field and a voltage source.

TRUE    FALSE

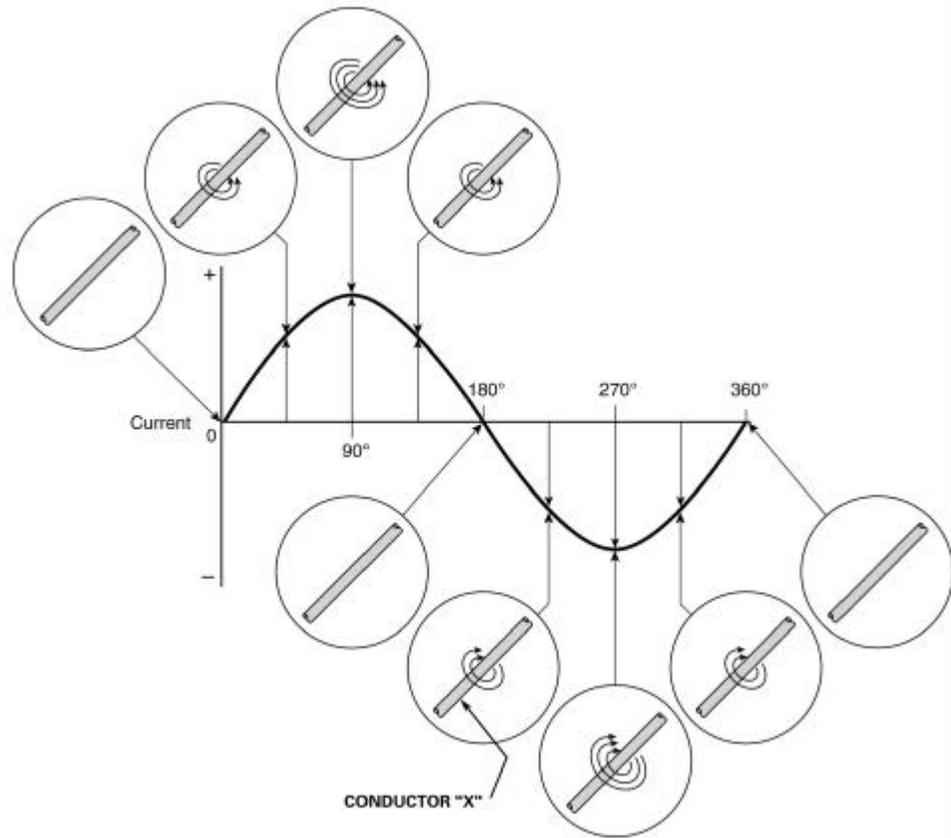
4. Use the right hand rule to determine what direction the current is flowing in the conductor shown to the right. Draw an arrow on the conductor to show your choice of direction.



5. A sine wave is used to represent alternating voltage as well as alternating current.  
  
TRUE    FALSE
6. With alternating current, electrons flow back and forth, changing direction very quickly.  
  
TRUE    FALSE
7. The number of cycles alternating current goes through in one second is known as the \_\_\_\_\_.

## REVIEW 3 (continued)

8. On the illustration below, indicate what direction current is flowing in the conductor marked "X" by drawing an arrow in or near the conductor, showing the direction. (Use Conventional Flow Theory.)



9. The peak value of an AC voltage or current occurs twice each cycle.

TRUE    FALSE

10. Another name for effective value relative to AC current or voltage is \_\_\_\_\_ value.

11. If we know the RMS is 240 volts and it is approximately .707 times the peak voltage, what would be the approximate peak voltage for this effective voltage?

### ELECTRIC POWER

#### Calculating Power

When discussing electricity, we need to address the issue of power.

Power is the rate at which work is performed, or the rate at which energy is expended. Work is often expressed in joules. In electrical terms, one joule of work is accomplished when a voltage of one volt causes one coulomb of electrons to pass through a circuit. When this amount of work is accomplished in one second, it is equal to one *watt*. A watt is the basic unit of power. One watt is also defined as the amount of work that is accomplished when a voltage of one volt causes one ampere of current to pass through a circuit. This relationship between power, voltage, and current is expressed by the following formula:

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

or

$$P = E \times I$$

In terms of other Ohm's Law components, the formula for power can be represented in two other ways as follows:

$$P = I^2 R \text{ or } P = E^2/R$$

Where:

**Power = P = Watts = volt-amperes (VA)**

**I = amperes**

**R = ohms**

**E = volts**

A great deal of our electrical equipment is rated in watts. The rating gives you an idea of how fast the electrical equipment converts electrical energy into things like heat and light.

## Calculating Power (continued)

Consider a 50-watt household bulb and a 100-watt household bulb. If both bulbs are rated for 120 volts like most household bulbs, Ohm's Law can be used to calculate the resistance of the bulb and then the current flowing through the bulb.

The calculations show us that the 100-watt bulb has less resistance and, therefore, more current flow. This shows that the 100-watt bulb converts electric energy faster, performs more work, gives off more light/heat, and uses more energy.

## IN THE WORKPLACE



50 WATT CALCULATIONS	
$P = \frac{E^2}{R}$	
$R = \frac{E^2}{P}$	(Transposed from previous formula)
$R = \frac{(120 \text{ volts})^2}{50 \text{ watts}}$	
$R = 288\Omega$	
-----	
$I = \frac{E}{R}$	
$I = \frac{120 \text{ volts}}{288\Omega}$	
$I = .416 \text{ amps}$	

100 WATT CALCULATIONS	
$R = \frac{E^2}{P}$	
$R = \frac{(120 \text{ volts})^2}{100 \text{ watts}}$	
$R = 144\Omega$	
-----	
$I = \frac{E}{R}$	
$I = \frac{120 \text{ volts}}{144\Omega}$	
$I = .833 \text{ amps}$	

FIGURE 36: WHICH BULB "WORKS" MORE?

## Kilowatt

For your electric company to determine how much to charge each customer each month, they simply read from the meter the amount of power that was consumed over that period of time. Since electricity is consumed at a rather high rate, it is impractical to talk or calculate in terms of watts. You probably are familiar with the terms kilowatt and kilowatt-hour from looking at an electric bill. A kilowatt, abbreviated kW, is equal to 1,000 watts. A kilowatt-hour, abbreviated kWh, is equivalent to 1,000 watts consumed in one hour.

**One kilowatt = 1kW = 1000 watts**

**One megawatt = 1MW = 1,000,000 watts**

Charges for electricity used in your home are calculated by multiplying the kilowatt-hours used by the rate per kilowatt-hour charged by your electric utility. (See Module 15, Power Management, for more information.)

## FUNDAMENTALS OF ELECTRICITY

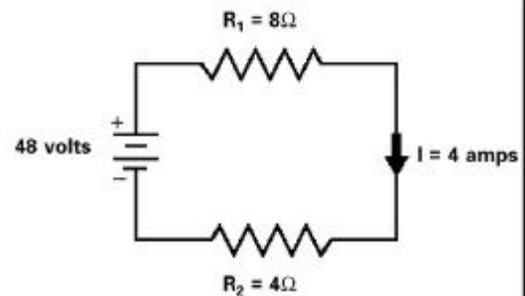
### REVIEW 4

Answer the following questions without referring to the material just presented.

1. The rate at which work is done is called \_\_\_\_\_ and is measured in \_\_\_\_\_.
2. There are three common formulas used for calculating power. List the formulas here:

$P =$  \_\_\_\_\_  $P =$  \_\_\_\_\_  $P =$  \_\_\_\_\_

3. Power is measured in watts (or kilowatts) and equals \_\_\_\_\_.
4. Use one of the formulas for power to calculate the power consumed in the following circuit.



5. A 100-watt light bulb costs more to use than a 50-watt light bulb because more current flows through the 100-watt light bulb and more power is consumed.

TRUE      FALSE

6. A kilowatt-hour (kWh) is equivalent to \_\_\_\_\_ watts consumed in \_\_\_\_\_.

**GLOSSARY**

<b>Alternating Current</b>	Voltage forces electrons to flow in one direction and then quickly alternate to the opposite direction.
<b>Ammeter</b>	A device to measure amperes (current).
<b>Ampere</b>	Unit of current.
<b>Conductor</b>	A material that permits a very free exchange/movement of electrons from one atom to another.
<b>Conventional Flow</b>	This theory states that electrons flow from positive (+) to negative (-).
<b>Current</b>	The flow of electrons in the same direction from atom to atom.
<b>Direct Current</b>	Voltage forces the electrons to flow continuously in one direction.
<b>Electromagnets</b>	Do not retain their magnetism after a magnetizing force is removed.
<b>Electromagnetic Induction</b>	The creation of voltage in a conductor from movement of the conductor or the magnetic field.
<b>Electron Flow</b>	This theory states that electrons flow from negative (-) to positive (+).
<b>Frequency</b>	The number of cycles in one second of alternating current. Expressed in hertz (Hz). For example, 60 Hz is 60 cycles in one second.
<b>Insulators</b>	Materials that don't readily give up electrons, thereby restricting the flow of current.
<b>Ohm</b>	Unit of resistance.
<b>Ohm's Law</b>	Current is directly proportional to voltage and inversely proportional to resistance.
<b>Parallel Circuits</b>	Loads are connected across the power line to form branches.
<b>Permanent Magnets</b>	Retain their magnetism after a magnetizing force is removed.
<b>Resistance</b>	The restriction to the flow of electrons.
<b>Right-Hand Rule</b>	A current carrying conductor held in right hand will indicate the direction of lines of flux.

## FUNDAMENTALS OF ELECTRICITY

<b>RMS Value</b>	Root Mean Square Current is also referred to as effective current and is the square root of the average of all the instantaneous currents (current at any point on a sine wave) squared.
<b>Series Circuit</b>	All loads in the circuit are connected one after the other.
<b>Single-Phase</b>	A continuous single alternating current cycle.
<b>Three-Phase</b>	A continuous series of three overlapping AC cycles offset by 120 degrees.
<b>Transformer</b>	A device used to raise (step up) or lower (step down) a voltage level.
<b>Volt</b>	Unit of force applied to a conductor to free electrons, to cause electrical current flow.
<b>Voltage</b>	The force applied to a conductor to free electrons, causing electrical current to flow.
<b>Voltage Drop</b>	Voltage value as measured across each resistor or load.
<b>Voltmeter</b>	A device to measure voltage.
<b>Watt</b>	The basic unit of power, indicating the amount of work accomplished when one volt causes one ampere to pass through a circuit.

## REVIEW 1 ANSWERS

1. True
2.
  - a. Electrons
  - b. Neutrons (Nucleus)
  - c. Protons
3. False
4. Orbit
5. True
6. Any two of the following:
  - Copper
  - Silver
  - Aluminum
7. Voltage
8. False
9. Ohms
10. False

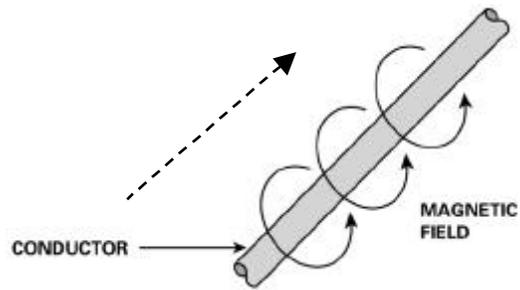
## REVIEW 2 ANSWERS

1. 
2. 12
3. Series
4. False
5. 7
6. 4
7. 12
8. True
9. True
10. True
11. Current is the same

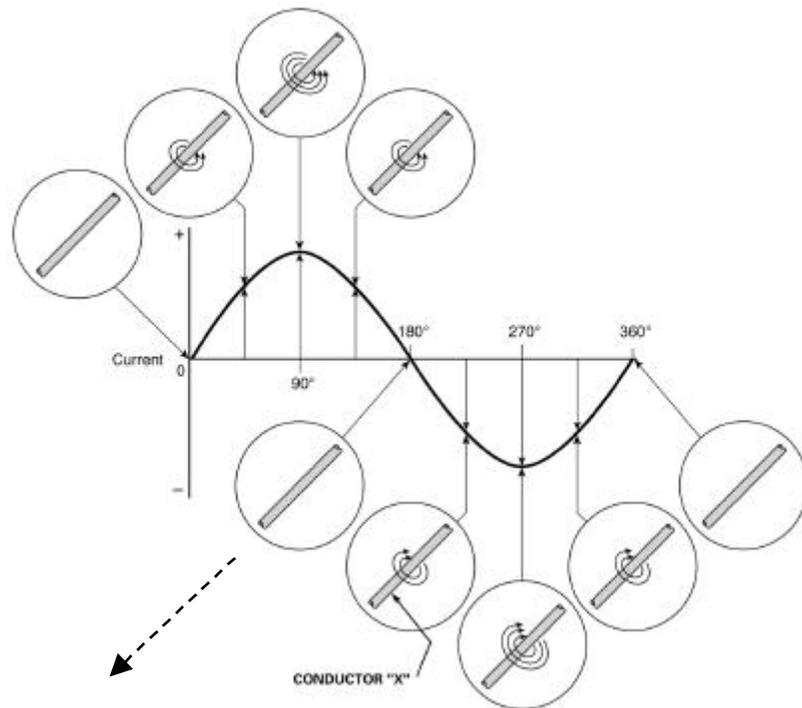
## FUNDAMENTALS OF ELECTRICITY

### REVIEW 3 ANSWERS

- Any two of the following:
  - Have two poles
  - Assume a north-south position
  - Attract and hold iron
- Force
- False
- 



- True
- True
- Frequency
- 



### REVIEW 3 ANSWERS (continued)

9. True
10. Root; Mean; Square; (RMS)
11. 338 Volts

### REVIEW 4 ANSWERS

1. Power; Watts
2.
  - $P = E \times I$
  - $P = I^2R$
  - $P = E^2/R$
3. Volt-Amperes (VA)
4. 192 watts
5. True
6. 1000; One hour

## Cutler-Hammer

Milwaukee, Wisconsin U.S.A.

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