ARRL Amateur Radio Education
& Technology Program

Unit 3 Communication Electronics

INTRODUCTION:

Man has been communicating in many different ways over the years. It is only in the last 100 years that electronic means have been used. Just about all modern communications are based on electronics so it only stands to reason, any study of communication should include a study of electronics. You don't have to be an electronics technician to understand radio communications but it's important to have an understanding of basic electronic theory.

There is much for you to learn, and most of the material presented in this unit may be new to you. We will start with a description of working with large and small numbers. We will then touch on the metric system of measure. Many of the measurements we will make in electronics are based on *metric units*, so an understanding of this measuring system is important. Then we'll cover some basic *electrical principles*. Here you'll learn what voltage, current, conductors and insulators are and how they work. Then we'll move on to electronic fundamentals, where you will learn about *direct* (dc) and *alternating* (ac) currents. You will also learn about how alternating current applies to *inductance* and *capacitance*. To get the most from this unit, you should take one section at a time. Study the material is each section and really know it before you go on to the next section. The sections build on each other, so you may find yourself referring to sections you've already studied form time to time. If you find you are having problems understanding the material, let your teacher know. Don't be afraid to ask questions!

The vocabulary list, found in the index, will introduce you to the definitions of many new term you will meet in this unit. Don't be afraid to turn back to look up the meaning of words you are not sure of. It is important to understand that you will probably not remember everything you read in this unit, the first time through. Use this unit as a reference and go back to review the material.

This unit contains some drawings and illustrations to help you learn the material. Pay attention to these graphics, and you'll find it easier to understand the text. If you have trouble understanding parts of this unit, ask your teacher or another experienced ham for help. Many other books can help too. ARRL's *Understanding Basic Electronics* is written for students with no previous electronics background. You will see references to this text as you read through the material. To study more advanced theory, use the ARRL handbook from the technical library that came as part of your Amateur Radio Education & Technology Program.

Remember! Take it slowly, section by section. Before you know it, you'll have learned what you need to know. You then will be ready to experiment with radio electronics and expand you learning. You might even want to help others with their learning.

Section 3.1

WORKING WITH LARGE AND SMALL NUMBERS:

Modern electronics often uses numbers that are either quite large or very close to zero. At either extreme, it is difficult to write the numbers because of all the zeros. Even the most careful person will occasionally drop a zero, or add an extra one when calculating with such numbers. *More information is available in Understanding Basic Electronics – Chapter 2.*

For Large Numbers!

Suppose you want to multiply 250,000 times 500,000. You can see how easily you could skip a zero or get the numbers out of line when you are doing the multiplication. See **Figure 3.1**. With this many zeros in the answer (125,000,000,000) it is just too easy to make a mistake – even with a few commas are thrown in to help you count the zeros.

Figure 3.1

There's an easier way to keep track of all the zeros, though. Every time you multiply a number by 10, you just move the decimal point one place to the right and add another zero. So you can represent a number by writing its digits up to the last *nonzero* digit. Then multiply that part by ten for every zero you omitted. In our example, 250,000 becomes 25 X 10 X 10 X 10 X 10. (you may not think this is much better right now, but be patient for a minute.)

If we multiply a number by itself several times, we say that the number is "*raised to a power.*" If we raise 10 to the second power we say the number is 10 squared, or write it as 10^2. The 2 is an exponent of 10. Remember that this just means 10 X 10, or 100.

Going back to our example, we can write the first number in our multiplication problem (250,000) as 25 X 10 X 10 X 10 X 10. Using the "power of 10" idea, you also can write this as 25 X 10^4 because we have 10 multiplied by itself four times.

$$\boxed{250{,}000 = 25 \times 10^4}$$

Remember that you just move the decimal point one place to the right (and a zero) every time you multiply by 10. Then we can "expand" 25 X 10^4 back out to the normal form by writing 25 followed by four zeros (250,000). This means that the exponent, or power of 10, always tells us how many places to move the decimal point. The second number in our example (500,000) becomes 5 X 10^5. When we write a number with a power of 10, we express it in *exponential notation*. As another example, we could write the number 670,310,000 as 67031 X 10^4.

$$\boxed{5 \times 10^5 = 500{,}000}$$

For Small Numbers!

For numbers less than one, getting closer and closer to zero, we have a similar situation. In this case the number has many zeros right after the decimal point, such as 0.0000045. If it seems to you that dividing by 10 has the same effect as moving the decimal point to the left one place, you're right! And if you're also wondering, "Gee, does that mean I can write 0.0000045 as 0.45 ÷ 10 ÷ 10 ÷ 10 ÷ 10 ÷ 10 or as 45 ÷ 10 ÷ 10 ÷ 10 ÷ 10 ÷ 10 ÷ 10 ÷ 10?" the answer is Yes! You can write this number either way.

If we write the nonzero part of the number as 45, then we must divide by 10 seven times to get the original number. So we can combine the divided-by-ten factors as a power of 10, or 10^7. Then we can write $45 \div 10^7$. (Notice that we also could write this as $0.45 \div 10^5$ or $4.5 \div 10^6$). If you prefer, you can write the number as a common fraction:

$$\frac{45}{10^7}$$

$$\boxed{0.0000045 = 4.5 \times 10^{-6} = 45 \times 10^{-7}}$$

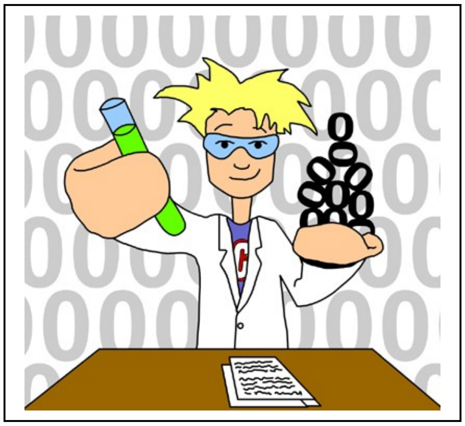
Short Cut:

There is a nifty little trick that we often use when working with exponents. If the power of 10 is in the denominator (the bottom part) of the fraction, we can move it into the numerator (the top part) just by changing the sign of the exponent. So instead of writing $45 \div 10^7$ to show that we mist divide by 10 seven times, we can write it as $45 \text{ X } 10^{-7}$. Now the –7 tells us to move the decimal point seven places to the left to write the number in its expanded form. If we move the decimal point two places to the left, so it is just before the 4, then it still has five places to go, and we have $0.45 \text{ X } 10^{-5}$.

So the rule is if the power of 10 is a positive number, the decimal point moves to the right. If the power of 10 is a negative number, the decimal point moves to the left.

← **Negative Numbers** $5.204 \times 10^{-5} = 0.00005204$	**Positive Numbers** → $4.025 \times 10^{7} = 40{,}250{,}000$
Move the decimal point to the left when expanding negative powers of 10.	**Move the decimal point to the right when expanding positive powers of 10.**

Scientific Notation:



There is a special form of exponential notation, called *scientific notation.* Numbers expressed in scientific notation always have a single nonzero digit before the decimal point. The remaining nonzero digits come after the decimal point, followed by the power of 10.

Here are a few examples:

We can write 40,250,000,000 as $4025 \text{ X } 10^7$ or any number of other forms that include a power of 10. In each case we would say the number is in exponential notation. One possible way to write the number is as 4.025 X 10^{10}. We say the number is in scientific notation when it has this form.

More information on Scientific Notation is available in Chapter 2 of Understanding Basic Electronics.

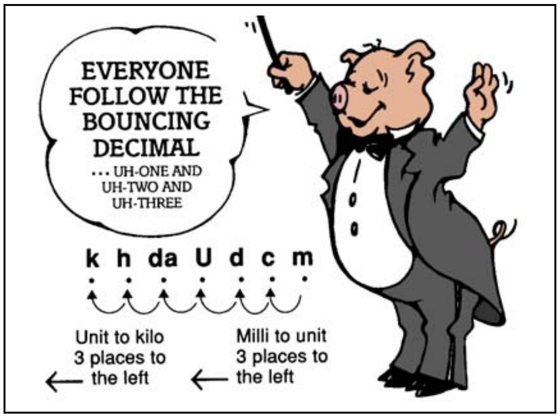
THE METRIC SYSTEM:

To start, lets look at the metric system. Why the metric system? This simple system is a standard system of measurement used all over the world. All the units used to describe electrical quantities are part of the metric system.

In the US, we use a measuring system known as the US Customary system for many physical quantities, such as distance, weight and volume. In this system, there is no logical progression between the various units. For example, we have 12 inches in 1 foot, 3 feet in 1 yard, and 1760 yards in 1 mile. For measuring the volume of liquids, we have 2 cups in 1 pint, 2 pints in 1 quart and 4 quarts in 1 gallon. To make things even more difficult, we use some of these same names for different volumes when we measure dry materials! As you can see, this system of measurements can be very confusing. Even those who are very familiar with the system do not know all the units used for different types of measurements.

It is exactly this confusion that led scientists to develop the orderly system we know today as the metric system. This system uses a basic unit for each different type of measurement. So how does the metric system work? Well, for example, the basic unit of length is the *meter*. The basic unit of volume is the *liter*. The unit for mass (or quantity of mater) is the *gram*. The Newton is the metric unit of force, or weight, but we often use the gram to indicate how "heavy" something is. We can express larger or smaller quantities by multiplying or dividing the basic unit by factors of 10 (10, 100, 1000, 10,000 and so on. These multiples result in a standard set of *prefixes*, which can be used with all the basic units. These same prefixes can be applied to any of the basic units in the metric system. Even if you come across some terms you don't know, you will be able to recognize the prefixes.

We can write these prefixes as powers of 10. The power of 10 (called the exponent) shows how many times you must multiply (or divide) the basic unit by 10. For example, we can see from the table that kilo means by 10^3. Lets use the meter as an example. If you multiply a meter by 10 three times, you willhave a kilometer (1 m x 10^3 = 10 x 10 x 10 = 1000 meters, or 1 kilometer.) If you multiply one meter by 10 six times, you have



a megameter. (1 meter x 10^6 = 1 m x 10 x 10 x 10 x 10 x 10 x 10 = 1,000,000 meters or 1 megameter.) It all comes down to the power of equations.

Notice that the exponent for some of the prefixes is a negative (-) number. This indicates that you must *divide* the basic unit by 10; you will have a decimeter. (1 meter x 10^{-1} = 1 m ÷ 10 = 0.1 meter, or 1decimeter.) When we write 10^{-6}, it means you must divide by 10 six times. (1 meter x 10^{-6} = 1 m ÷ 10 ÷ 10 ÷ 10 ÷ 10 ÷ 10 ÷ 10 = 0.000001 meter, or 1 micrometer.)

We can easily write very large or very small numbers with this system. We can use the metric prefixes with basic units, or we can use powers of 10. Many of the quantities used in basic electronics are either very large or very small numbers, so we use these prefixes quite a bit. You should be sure you are familiar at least with the following prefixes and their associated powers of 10: giga, mega, kilo, centi, milli, micro and pico.

Let's try an example. For this example, we'll use a term that you will run into quite often in your study of electronics: *hertz.* Hertz (abbreviated Hz) is a unit that refers to the *frequency* of a radio or television wave. We have a receiver dial calibrated in kilohertz (kHz), and it shows a signal at the frequency of 28,450 kHz. Where would a dial calibrated in hertz show this signal? The basic unit of frequency is the hertz. That means that our signal is at 28,450 kHz x 1000 = 28,450,000 hertz. There are 1000 hertz in a kilohertz, so 28,450,000 divided by 1000 gives us 28,450 kHz.

How about another one? If we have a current of 3000 milliamperes, how many amperes is this? Milli means multiply by 0.001 or divide by 1000. Dividing 1000 milliamperes by 1000 give us 3 amperes. The metric prefixes make it easy to use numbers that are a convenient size simply by changing the units. It is certainly easier to work with a measurement given as 3 amperes that as 3000 milliamperes.

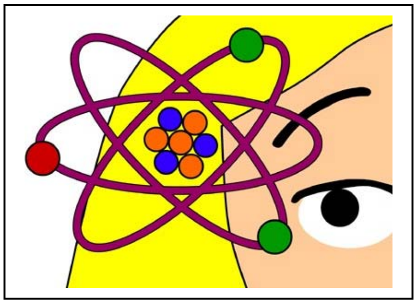
Notice that it doesn't matter what the units are or what they represent. Meters, hertz, amperes, volts, farads or watts make no difference in how we use the prefixes. Each prefix represents a certain multiplication factor, and that value never changes.

With a little practice you should begin to understand how to change prefixes in the metric system. First, write the number and find the proper power of ten and then move the decimal point to change to the basic unit. Then divide by the multiplication factor for the new prefix you want to use. With a little more practice you'll be changing prefixes with ease.

For practice with metrics, go to Activity Sheets # 1 and 2.
For more information on the metric system see Understanding Basic Electronics – Chapter 4.

Section 3.2
BASIC ELECTRICAL PRINCIPLES:

Information on Basic Electrical Principles is available in Understanding Basic Electronics – Chapters 7,8 & 9



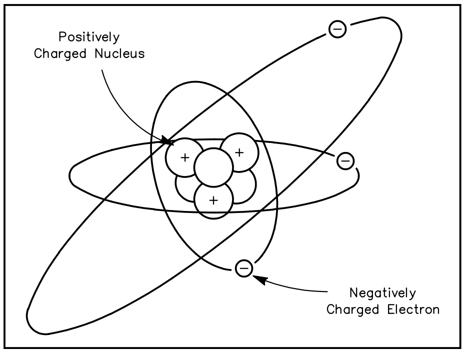
Electricity:

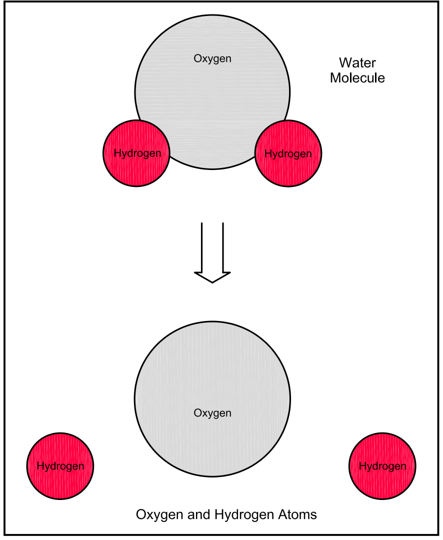
What is electricity? Can you describe it? What does it look like? Where does it come from? Electricity is the force behind our space-age civilization. It's one of nature's greatest powers. Yet, it's a mystery to most people. We use it in our work and play, but what is it? In this section you will learn the answers to these questions and have a better understanding of what electricity is and how to make good use of it's mysterious powers.

To understand electricity we must first understand the basic structure of nature itself. We need to know what our world is made up of and how it all relates. So to begin we will discuss the make of the basic building block of nature, the *atom.*

Inside Atoms:

Everything you can see and touch is made up of *atoms*. Atoms are the "building blocks" of nature. Atoms are very small. So small we cannot see them. Atoms are made up of even smaller particles called *subatomic particles*. There are three types of subatomic particles that make up the atom. In the center, called the *nucleus*, there are *protons*, positively charged particles, and *neutrons*, which have no charge. Circling around the nucleus is the negatively charged *electron.*



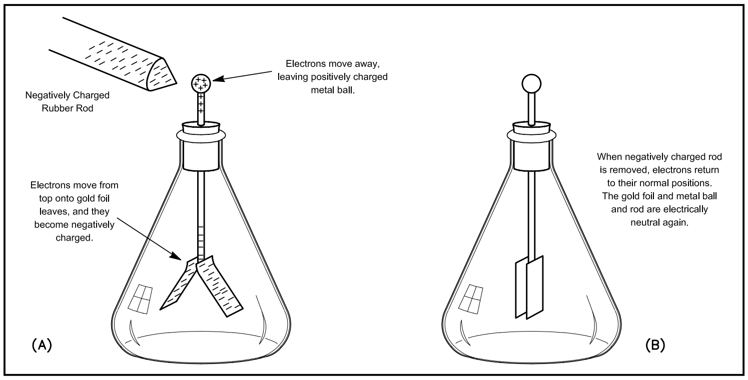


Scientists have identifies more than 100 different kinds of atoms. The number of positively charged particles in the atom determine what type of element the atom is. Different kinds of atoms combine to form various kinds of materials. For example, a hydrogen atom has one positively charged particle in its nucleus and one electron circling around the outside. An oxygen atom has eight positive particles in the nucleus and eight electrons around the outside. When two hydrogen atoms combine with one oxygen atom, we have water. *For more information on atomic structure see Understanding Basic Electronics – Chapter 9.*

Electricity and Magnetism:

Have you ever played with magnets? What happens when you push two North poles together? What happens when you put a North and Sough pole together? We find that similar (like) poles *repel* each other and opposite (unlike) poles *attract* each other.

Charged particles in the atom behave very similar to the two magnets. Like charges repel each other and unlike charges attract each other. The nucleus of the atom has a positive charge and the electron has a negative charge. This attraction causes the electron to circle around the nucleus and not go flying off into space.

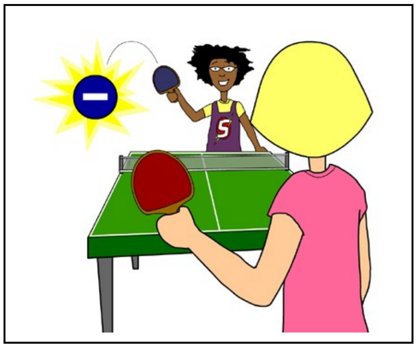


To demonstrate this effect, we can use a device called an electroscope. This simple device illustrates the effect of electric charge on an object. The metal rod and gold leaves are inside a glass jar, mainly to protect the delicate gold foil. When the two leaves of gold foil are electrically neutral, they hang straight down, as shown.

When we bring a negatively charged object close to the metal ball on top of the jar. Some electrons move away from the ball and unto the gold foil. When the two gold leaves have extra electrons, they push away from each other. This force causes the leaves to stand out to the side as shown on the left in the diagram. When we remove the negatively charged rod from the area around the metal rod, the electrons flow back to a positively charged ion until the atoms are again *neutra*l. *For more information on the laws of charges see Understanding Basic Electronics, Chapter 9.*

Ions:

It is important for you to remember that when an atom has an equal balance of negative and positive charges, we say the atom is *neutral*. If the atom has more positive than negative charges it is called a *positive ion*. If the atom has more negative than positive charges it is called a *negative ion.*

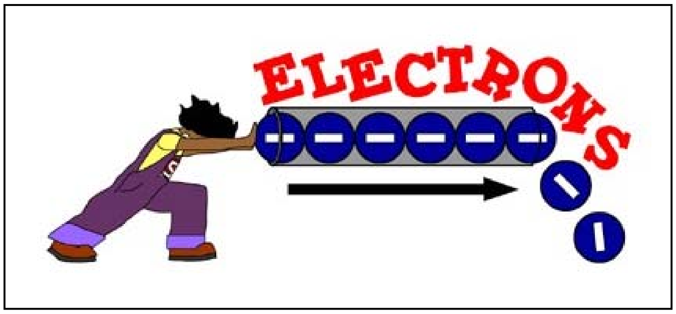


The Flow of Electrons:

Now that we understand the law of charges and we know what ions are, its time to move on to the next step: How electrons flow.

We know that electrons are circling around the nucleus of the atom constantly. In some materials it's easy to dislodge one of these electrons from their orbit around the atom. When an atom loses an electron, it upsets the stability and electrical balance of the atom. With one particle of negative charge gone, the atom has an excess of positive charges. The free electron has a negative charge. We call the atom that lost the electron a positive *ion* because of its net positive charge. If there are billions of similar ions in one place, the charge becomes large enough to cause a noticeable effect.

With this collection of negative particles (electrons), there is a natural tendency that they want to join with atoms that lack the number of electrons needed to make them neutral or have no charge. If this collection of electrons is brought into contact with a material that will allow the electrons to pass through from one side or end to the other, the electrons will try flow toward a positive charge (ions with too few electrons). The material that allows electrons to freely pass through is called a conductor. Most metals are good conductors because the outer electrons in outer orbits or shells are not held very tightly to their parent atom and are free to move from one atom to an adjacent atom. Think of these outer electrons in a metal as forming a sea of electrons. If an electron is stuffed into one end of the conductor, it eventually pushes an electron out of the other end of the conductor, kind of like a row of dominoes bumping into each other as the first one falls. The electron that flows out of the conductor is not the same one that was pushed into the conductor. This illustration might help better explain how electrons flow through a conductor. The electrons are moving from left to right in this diagram. We call this flow of electrons *electricity*. So, electricity is nothing more than the flow of electrons.

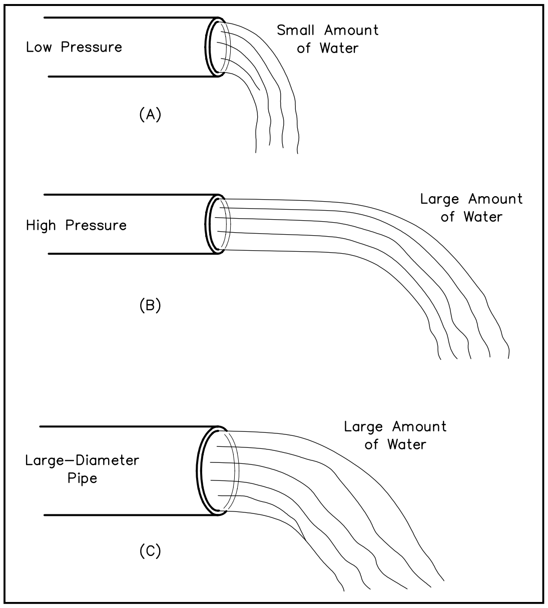


So What Makes It Work?

To help us understand how electricity flows in a wire, we can relate it to something you are already familiar with. Most people are familiar with what happens when you open a faucet and water comes out. We can use this to make a useful comparison between water flow and electron flow (electricity). Throughout this unit we use examples of water flowing in a pipe to help explain electronics.

Do you know how your town's water system works? Chances are, there is a large supply of water stored somewhere above the town in a reservoir or water tank. The system then uses gravity to pull the water down from the tank or reservoir. The water travels through a system of pipes to your house. Because the force of gravity is pulling down on the water in the tank, it puts pressure on the water in the pipes. This makes the water flow out the faucets in your house with some force.

We said we can compare electrons flowing through wire to water flowing through a pipe. We need some force to make water flow through a pipe. What force exerts pressure to make electrons flow through wire?



Voltage

The amount of pressure that it takes to push water to you house depends on the path the water has to take. If the water has to travel over hills along the way, more pressure will be needed that if the water simply has to flow down off a mountain. The pressure it takes to make electrons flow in an electrical circuit also depends on the path that the electrons must follow. This pressure that forces the electrons through the circuit is known as Electromotive Force or, simply, **EMF.**

EMF is similar to water pressure. More pressure moves more water. Similarly, more EMF moves more electrons. We measure EMF in a unit called the volt (V), so we usually refer to the EMF as a *voltage.* We measure voltage with a device called a *voltmeter.* Some voltage comparisons are:

• D-cell battery	1.5 V
• Car Battery	12 V
• Wall Outlet	120V

Because there are two types of electric charges (positive and negative), there are also two polarities associated with a voltage. A voltage source always has two terminals, or poles: the positive terminal and the negative terminal. The negative terminal repels electrons (because electrons have a negative charge) and the positive terminal attracts electrons. If we connect a piece of wire between the two terminals of a voltage source, electrons will flow through the wire. Remember! The flow of electricity is the flow of electrons. We call the flow of electrons *current. For more information on voltage, see Understanding Basic Electronics – Chapter 7.*

Current

We often use the term *current* to describe the flow of water in a stream or river. We also call the flow of electrons a current, an *electric current*. Each electron is extremely small. It takes quintillions and quintillions of electrons to make your toaster make toast. (A quintillion is a one with 18 zeros after it – 1,000,000,000,000,000,000.) Remember how to use the power of 10? We could also write this as 1 X 10^{18} power.

When water flows from your home faucet, you don't try to count every drop. The numbers would be too large. To measure water flow, you count larger quantities such as gallons and describe the flow in terms of gallons per minute. Similarly, we can't deal with large numbers of individual electrons, so we measure current in units called *amperes* of electric current. To measure the flow of current we use a device called an *ammeter.*

So how much is one ampere? To have one ampere of current, it would take 6,240,000,000,000,000,000 (or 6.24 X 10^{18}) electrons moving past one spot in one second. (Don't worry! You won't have to remember this number.) So when you express a circuit's current in amperes, remember that it is a measure of the number of electrons flowing through the circuit. A circuit with a current of 2 amperes has twice as many electrons flowing out of the supply as a circuit with a current of 1 ampere.

We write "2A" for two amperes or "100mA (milliamps) for 0.1 amperes. You can use all the metric prefixes with the ampere. Most of the time you will see currents expressed in amps, milliamps and sometimes even microamps. *For more information on current, see Understanding Basic Electronics – Chapter 8.*

Conductors

A conductor is a material that electricity will flow through easily. As we pointed out earlier, some atoms have a firm grasp on their electrons and other atoms don't. Materials that only have a weak hold on their electrons will pass current (electrons) easily. We call these materials *conductors.*

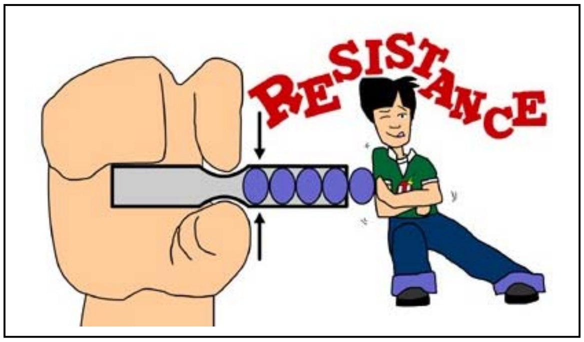
Silver is an excellent conductor. The loosely attached electrons in silver atoms need very little voltage (pressure) to produce an electric current. Copper is much less expensive than silver and conducts almost as well. We use copper to make wire needed in houses, and in radio and other electronic devices. *For more information on conductors, see Understanding Basic Electronics – Chapter 10.*

Insulators

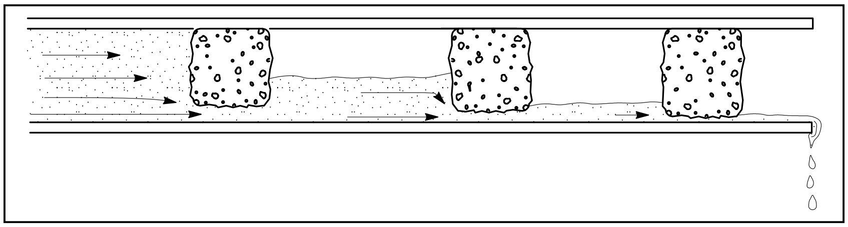
An *insulator* is a material that keeps a very firm grip on their electrons. These materials do not conduct electricity very well. Materials such as glass, rubber, plastic and ceramic make good insulators. **Important!** *Water from a faucet is not a good insulator.* It is a conductor because of the minerals dissolved in it. You should always keep water away from electrical devices. Pure distilled water, however, is a good insulator because the minerals have been removed.

The electric power company supplies 120 V to your home. The voltage is available at the outlets to operate your electric and electronic devices in your home. Have you ever stopped to think why the electrons don't spill out from the outlets onto the floor? Air is an excellent insulator. The air around the outlet will not allow the electrons to pass. When the force of millions of volts builds up, however, there's enough pressure to send a bolt of electrons through the air – we call this lightning. *For more information on insulators, see Understanding Basic Electronics – Chapter 10.*

Resistance



There is another electrical property we need to discuss before we move on, *resistance*. Resistance can be described as the opposition to current flow. That means, resistance tries to slow down the flow of electrons. Remember the water flowing through the pipe? If we place a sponge in the pipe, the amount of water flowing through the pipe will decrease. The sponge "resists" the flow of water. The same thing happens in an electrical circuit when we place a "resistor" in an electrical circuit. The resistor acts like the sponge and resists the flow of current. The result is less current flow in the circuit. Resistors limit, or control the amount of current that flows through a circuit. The unit of measurement for resistance is called the “Ohm,” and has a funny looking symbol “Ω.” *For more information on resistance, see Understanding Basic Electronics – pages 10-5, 10-6.*



Review

Now lets take some time to review what we have just covered:
There are three basic properties in an electrical circuit:

- Voltage (we’ll call it electrical pressure), unit of measurement – Volt (V)
- Current (the flow of electrons), unit of measurement – Ampere (A)
- Resistance (opposition to current flow), unit of measurement – Ohm (Ω)
- Electricity flowing through a circuit can be compared to water flowing through a pipe.
- The more water pressure in a pipe, the more water flows through the pipe; the more electrical pressure (voltage) in a circuit, the more current flows through the circuit.
- The more resistance in a pipe, the less water flows, the more resistance (Ω) in a circuit, the less current flows.

Now lets look at what we can do with this information.

Ohm’s Law

The relationship between voltage, current and resistance is predictable. We call this relationship Ohm’s Law and it is one of the foundations of electrical theory.

As mentioned above, the ohm is the unit used to measure resistance. The abbreviation (symbol) for ohm is “Ω,” the Greek capital letter omega. This unit is named for George Simon Ohm, a German physics teacher and mathematician. We also use metric prefixes with ohm, when appropriate. So you will often see resistors specified as having 47 kΩ and 1.2 MΩ. A device called an “*ohmmeter*” is used to measure resistance.

We also spoke about the units of measurement for voltage (volts) and current (amps). Let’s see how it all works together.

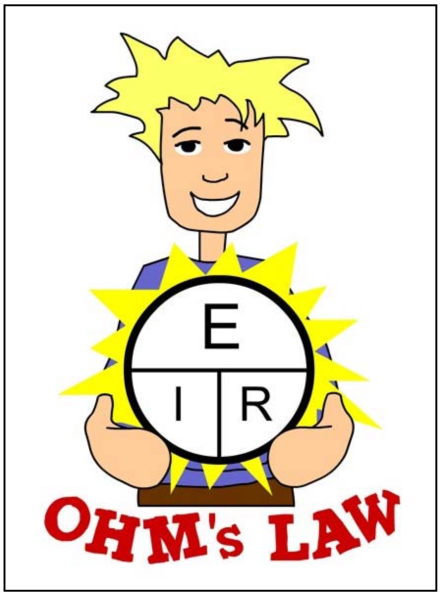
The amount of water flowing through a pipe increases as we increase the pressure and decreases as we increase the resistance. If we replace “pressure” with “voltage,” this same statement describes current through an electric circuit:

Current = Voltage / Resistance **Equation 3.1**

This equation tells us the current through a circuit equals the voltage applied to the circuit divided by the circuit resistance.

If the voltage stays constant but more current flows in the circuit, we know there must be less resistance. The relationship between current and voltage is a measure of the resistance.

Resistance = Voltage / Current **Equation 3.2**



We can state this equation in works as: The circuit resistance is equal to the voltage applied to the circuit divided by the current through the circuit. This equation shows that if we apply a voltage of 1 volt to a circuit, and measure a current of 1 ampere through that circuit, then the circuit has a resistance of 1 ohm.

Finely, we can determine the voltage if we know how much current is flowing and the resistance in the circuit:

Voltage = Current X Resistance **Equation 3.3**

The voltage applied to a circuit is equal to the current through the circuit times the circuit resistance. Scientist are always looking for shorthand ways of writing these relationships. They use symbols to replace the words:

E – represents voltage (remember EMF?)
I – represents current (from the French word intensit'e)
R – represents resistance

We can now express Ohm's Law in a couple of letters:

E = I * R (volts = amperes x ohms) **Equation 3.4**

And

I = E / R (amperes = volts ÷ ohms) **Equation 3.5**

And

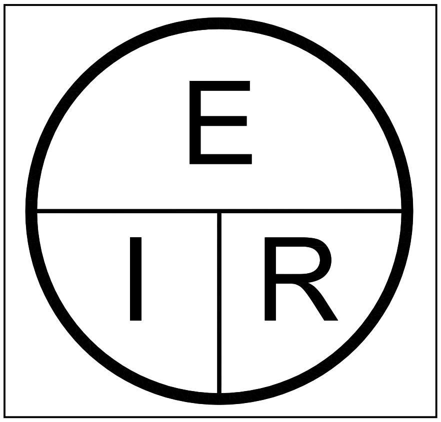
R = E / I (ohms = volts ÷ amperes) **Equation 3.6**

If you know two of the numbers, you can calculate the third.

This diagram to may help you set up and solve Ohm's Law problems. Simply cover the symbol of the quantity you do not know. If the remaining two are side-by-side, you must multiply them. If one symbol is about the other, then you must divide the number on top by the one on the bottom.

If you know current and resistance in a circuit, Ohm's Law will give you the voltage (Equation 3.4). For example what is the voltage applied to the circuit if two amperes of current flows through 50 ohms of resistance? From the Equation 3.4, we see that we must multiply 2 amperes times 50 ohms to get the answer, 100 volts. The EMF in this circuit is 100 volts:

E = IR **Equation 3.7**
E = 2 amperes x 50 ohms
E = 100 volts



Suppose you know voltage and resistance – 200 volts in the circuit to push electrons against 100 ohms of resistance. Equation 3.5 will give you the answer:

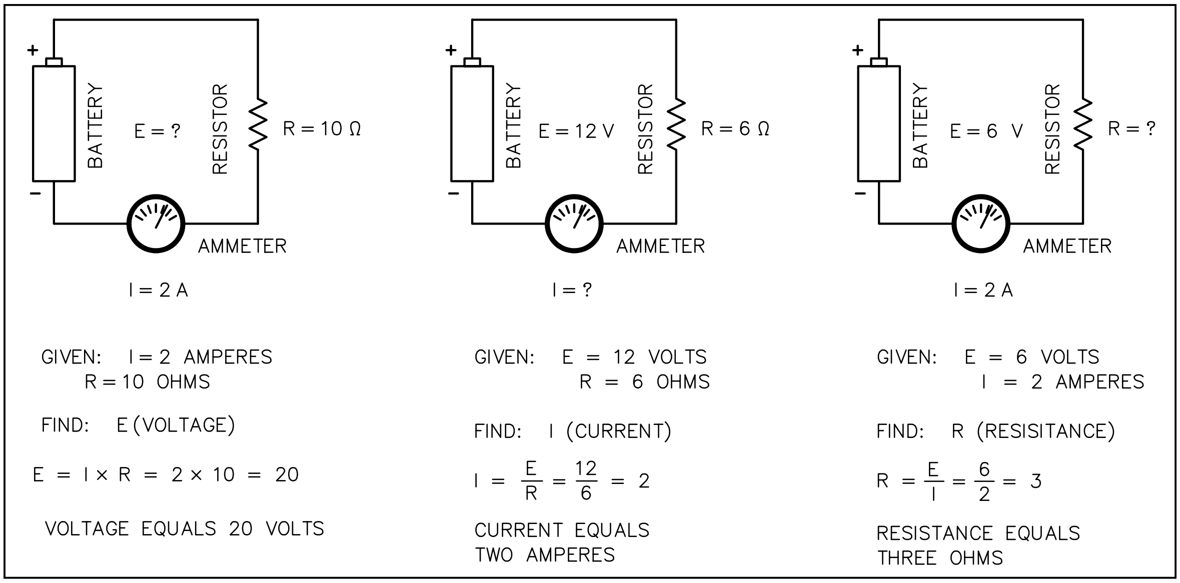
I = E / R **Equation 3.8**
I = 200 volts / 100 ohms
I = 2 amperes

If you know voltage and current in a circuit, you can calculate resistance. Suppose a current of 3 amperes flows through a resistor connected to 90 volts.

R = E / I
R = 90 volts / 3 amperes
R = 30 ohms

Ohm's Law is one electrical principle you will use when working with almost any electronic circuit!

For more detailed information on Ohm's Law, go to Understanding Basic Electronics, Chapter 12 (See Activity Sheet 3.4 for some practice)



GIVEN: I = 2 AMPERES
R = 10 OHMS

FIND: E (VOLTAGE)

$E = I \times R = 2 \times 10 = 20$

VOLTAGE EQUALS 20 VOLTS

GIVEN: E = 12 VOLTS
R = 6 OHMS

FIND: I (CURRENT)

$I = \frac{E}{R} = \frac{12}{6} = 2$

CURRENT EQUALS
TWO AMPERES

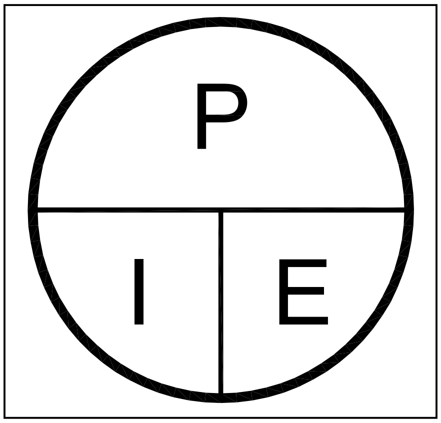
GIVEN: E = 6 VOLTS
I = 2 AMPERES

FIND: R (RESISITANCE)

$R = \frac{E}{I} = \frac{6}{2} = 3$

RESISTANCE EQUALS
THREE OHMS

Power



What is *electrical energy*, and how do we measure it? Energy can be defined as the ability to do work. In the metric system the unit for work is the *joule*. Energy is a measure of how much work something can do. It takes one joule of energy to do one joule of work. While the joule measures the amount of work being done, there is a special term that measures the rate at which work is being done. This term is *Power*. If something uses energy at the rate of 1 joule per second, the power is 1 *watt* (abbreviated W). This basic power unit is named in honor of James Watt, a scientist and inventor. A watt is a small unit of power, so we use the *kilowatt* (1000 W or 1 kW) to measure large amounts of power.

By now you are probably wondering how we measure energy and power in a practical way. To simplify it, we can define the watt in terms of current and voltage. We simply multiply the current through a circuit times the voltage drop across the circuit to get the power in the circuit. Since we can measure current and voltage easily, this gives us a good, practical way to measure power.

We can write an equation to calculate power.

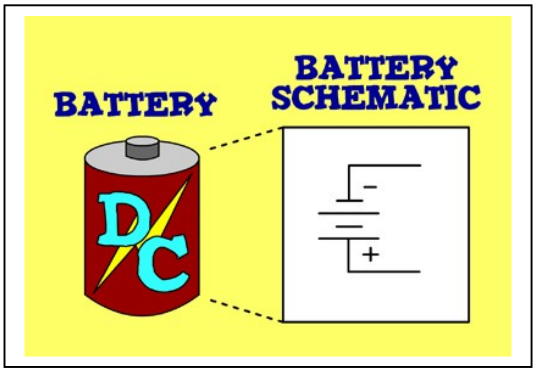
$P = I E$ **Equation 3.9**

Where

P = power in watts
I = current in amperes
E = voltage in volts

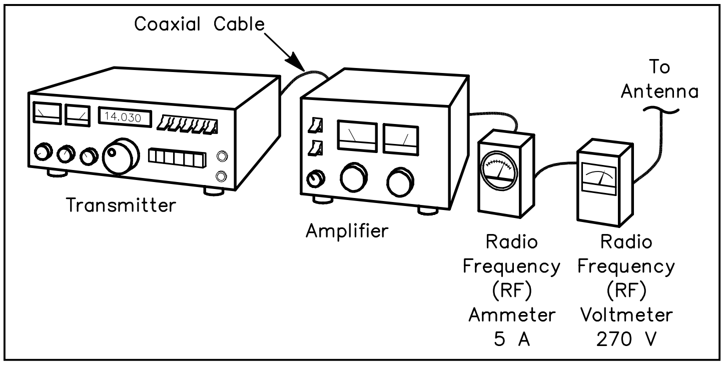
This may be the easiest electronics equation to remember. Just look at the letters. Don't they spell out your favorite kinds of dessert? Once you've made the association, you will always remember the equation to calculate power.

How much power does the battery in this circuit provide if the battery voltage is 15V, and the circuit current is 25mA? Since Equation 3.9 calls for current in amps, we'll have to convert the 25 mA to 0.025 A. Then using Equation 3.9, we have:



$P = I E$

$P = 0.025\text{A} \times 15\ \text{V} = 0.375\text{W}$



Here is another problem. A radio transmitter and amplifier is tuned to 14.030 in the amateur 20 meter band. A meter in the feed line to the antenna measures the radio frequency current from the transmitter. The current in the feed line is 5 amps. A voltmeter measures the amplifier output as 270 V. What is the power output from this transmitter and amplifier combination?

P = I E
P = 5 A x 270 V = 1350 W

You can also express this in kilowatts. The amplifier is feeding 1.35 kW to the antenna in this amateur station.

If you know power and either current or voltage in a circuit, the power equation will help you calculate the third quantity. You can solve Equation 3.9 for current and voltage in much the same way we solve Ohm's Law for current or resistance.

I = P / E **Equation 3.10**

E = P / I **Equation 3.11**

Let's use a simple flashlight circuit as an example. Our flashlight uses a 6-V battery and a bulb rated at 2 W. How much current will this bulb draw from the battery? From the Power Circle, we write Equation 3.10.

I = P / E
I = 2W / 6V = 0.33 A

You could use a similar procedure to find the circuit voltage if you know power and current.

All you need to remember, is the power rating of an appliance describes the rate that it uses electric energy.

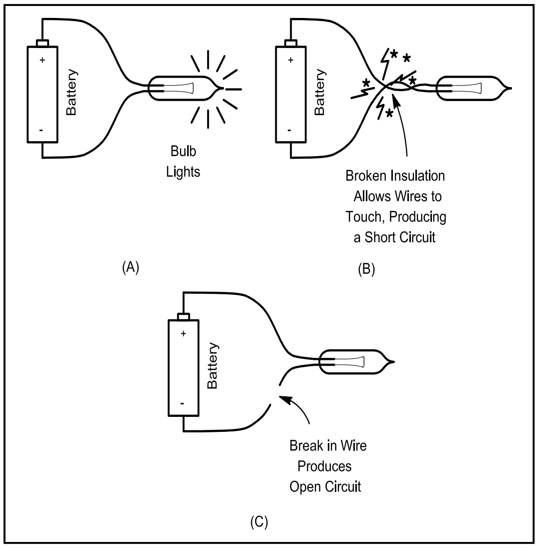
For more on Power Calculations go to Understanding Basic Electronics, Chapter 14, pages 14-5 and 14-6.

Section 3.3
ELECTRICAL CIRCUITS

As you begin to work with electronics you will find that even very complicated equipment can be broken down to simple circuits. We will first look at the three states of a simple circuit.

Closed Circuit

A *closed, or complete circuit* has an uninterrupted path for the current to flow. This allows the circuit to work as it was intended. Part A in the picture shows a properly operating completed (closed) circuit.



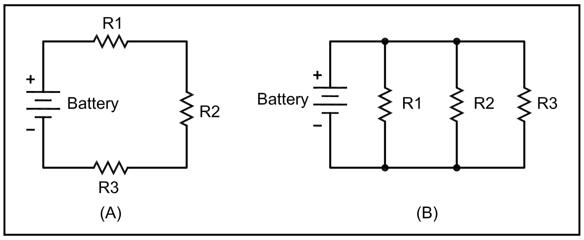
Short Circuit

A *short circuit* happens when the current flowing through the components (parts) doesn't follow the path we expect it to as in part B of the picture. Instead, the current finds another path – a shorter one – between the terminals of the power source. There is less opposition to the flow of electrons, so there is high current.

Open Circuit

The opposite of a short circuit is an *open circuit*. In an open circuit the current is interrupted, just as it is when you turn a light switch off. There is no current through an open circuit. An open circuit can be bad if it's the result of a broken wire as in part C of the picture.

Series Circuit



There are two other types of circuits we need to know about. The first is called a *series circuit*. A series circuit is a simple circuit that has only one path for current to flow. This picture shows two simple series circuits. Look at part A of the picture. This is a diagram of a series circuit. The name comes from the way the components in the circuit are arranged. If you follow an electron flowing out of the negative (-) side of the battery the resistors (R1, R2, R3) and then to the positive (+) side of the battery. The electrons (electricity) have to flow through each of the components (parts) of the circuit because there is only one path for the current to flow.

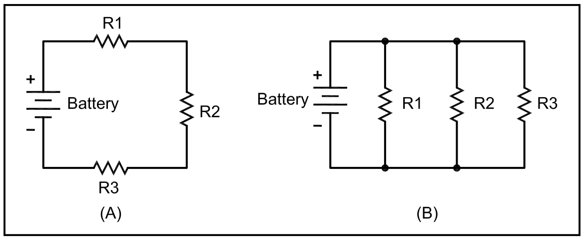
Remember the water pipe? What would happen to the current through the pipe if we placed another sponge in it? You're right! Each added sponge would further reduce the flow of water. The total resistance in a series circuit is the sum of all the resistances in the circuit. That means if you add up the value of all the resistors in a series circuit, you will get the total resistance. Why? The electricity (current) has to flow through each of the resistors, so all you have to do is add their values up. Easy!

So let's plug in some numbers and see how we can use Ohm's Law to determine how much electricity is flowing in the circuit in Figure 3.17B. If the battery produces 12 volts of electrical pressure, and each resistor is one ohm, then we can use the equation:

Total Resistance is: $R_1 + R_2 + R_3 = 1 \text{ ohm} + 1 \text{ ohm} + 1 \text{ ohm} = 3 \text{ ohms}$

$I = E / R$ or $I = 12 \text{ volts} / 3 \text{ ohms} = 4$ amperes of current. Simple!

Parallel Circuits

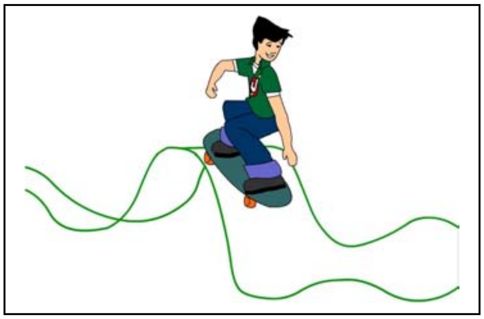


The last type of circuit we will work with is called a *parallel circuit*. A parallel circuit has more than one path for current to flow. Here is the same picture again. Compare part B to part A, do you see a difference? In part B the resistors are arranged next to each other or parallel. Now the electrons flowing through the circuit have three paths to follow and some flow through each resistor to return to the positive pole of the battery. Let's look at the water pipe example again. If there are three pipes connected together, the water has three different paths to follow. More water can flow through three parallel pipes of the same size than through a single pipe. So, there is less resistance and more water will flow. In the electrical circuit in part B, when the electrons approach the junction (connection) of the wires, they have a choice to go through R_1, R_2, or R_3. The three paths represent less resistance than one path so, as with the water in the pipes, more current flows.

As with series circuits, Ohm's Law can be used to determine the total amount of current, voltage or resistance in a parallel circuit as well. Once the total resistance is determined the process is the same as it is for a series circuit.

For more information on circuits see, "Understanding Basic Electronics," pages 11-1 to 11-4.

Two Types of Current



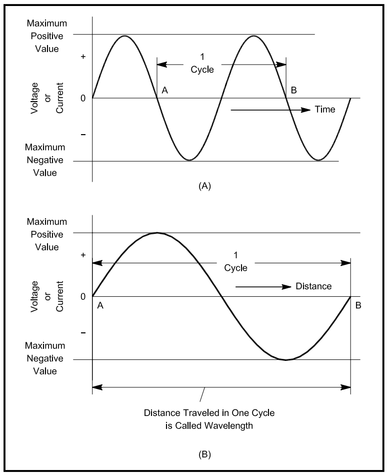
We said that current flow is the movement of electrons through a conductor. There are actually two types of current, *direct current* and *alternating current*. Up to this point in our discussion, we have been speaking of direct current. The definition of direct current (dc) is; current that flows in one direction. Current delivered from a battery is an example of direct current. The current (electrons) flows from the negative side of the battery, through the circuit and returns to the positive side of the battery. Current flows directly from negative to positive. The circuit shown in Figure 3.22 is a dc circuit. It uses a battery to supply the voltage (electrical pressure) to the circuit. A car is a good example of something that uses “dc.” The lights, radio/CD player and horn, all use “dc” electricity to operate.

Where do we get “dc” electricity? As we have mentioned, a battery produces direct current. There are other devices that also produce dc. Solar cells, wind generators, portable generators, and many power supplies that operate electronic equipment produce dc.

There is a second kind of electricity called *alternating current*, or “ac.” In ac, the terminals of the voltage source (battery) change from positive to negative to positive again. Because the poles change and electrons always flow from negative to positive, ac flows first in one direction, then the other. The current *alternates* in direction. We call one complete round trip a cycle. *Frequency* is a measure of the number of times the alternating current flows back and forth in one second (cycle). We measure frequency in hertz (abbreviated Hz). One cycle per second is 1 Hz. 150 cycles per second is 150 Hz. One thousand cycles per second is one kilohertz (1kHz). One million cycles per second is one megahertz (MHz). If a radio wave makes 3,725,000 cycles in one second, this means it has a frequency of 3,725,000 Hz, 3725 kilohertz (kHz), or 3.725 megahertz (MHz).

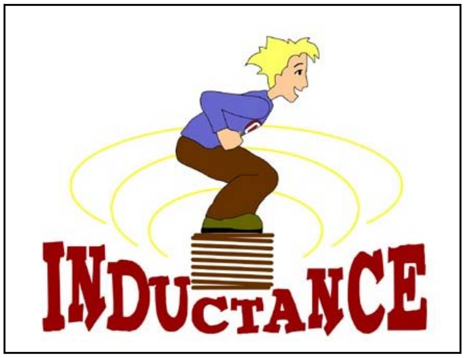
Remember, batteries provide direct current. To make an alternating current from a battery it would be necessary to switch the battery terminals back and forth each time you wanted the current to change direction. Not very practical.

The power company has a more practical way to create ac. They use a large machine called an *alternator* to produce power at their generating station. The ac supplied to your home goes through 60 complete cycles each second. Therefore, the electricity from the power company has a frequency of 60 Hz.



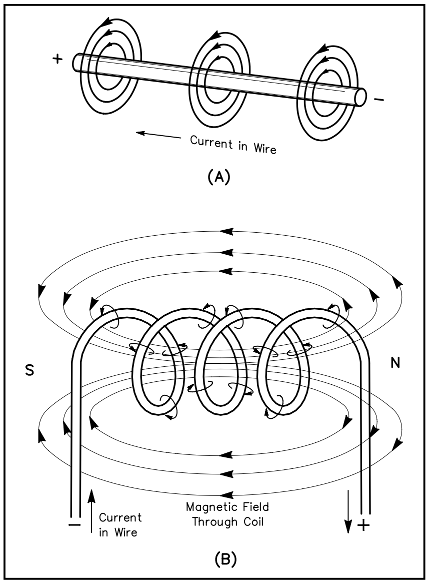
What does ac electricity look like? This 60-hertz ac electricity builds slowly to a peak current or voltage in one direction, then decreases to zero and reverses to build to a peak in the opposite direction. If you plot these changes on a graph, you get a gentle up-and-down curve. We call this curve a *sine wave*. Figure 3.20A shows two cycles of a sine-wave ac signal.

Alternating current can do things direct current can’t. Alternating current can be increased or decreased by using a device called a transformer. This allows the power company to transmit electrical power over long distances through power lines. *More information on ac electricity can be found in Understanding Basic Electricity, Chapter 16.*



INDUCTANCE

Here is where you can have some fun working with electricity. Remember, we said current flow is the movement of electrons through a conductor? Scientists have found that when these electrons move through a wire (conductor) they cause a *magnetic field* to build up around that wire. This magnetic field represents the invisible magnetic force, such as the attraction and repulsion between magnets. Like an invisible tube, the magnetic filed is positioned in *concentric circles* around the wire (conductor). The magnetic filed starts as soon as the current starts to flow, and collapses back on to the conductor when the current stops. The magnetic field increases in strength when the current increases and decreases in strength as the current decreases. (See *Understanding Basic Electronics*, Chapter 19, page 19-1) The force produced around a straight piece of wire by this magnetic field is usually very small. When the same wire is formed into a coil, the force is increased. In coils, the magnetic field around each turn also affects the other turns. Together, the combined forces produce one large magnetic field. Such a device is called an *inductor*. Much of the energy in the magnetic field concentrates in the material in the center of the coil (the core). Most practical inductors are made up of a length of wire wound on an iron core.

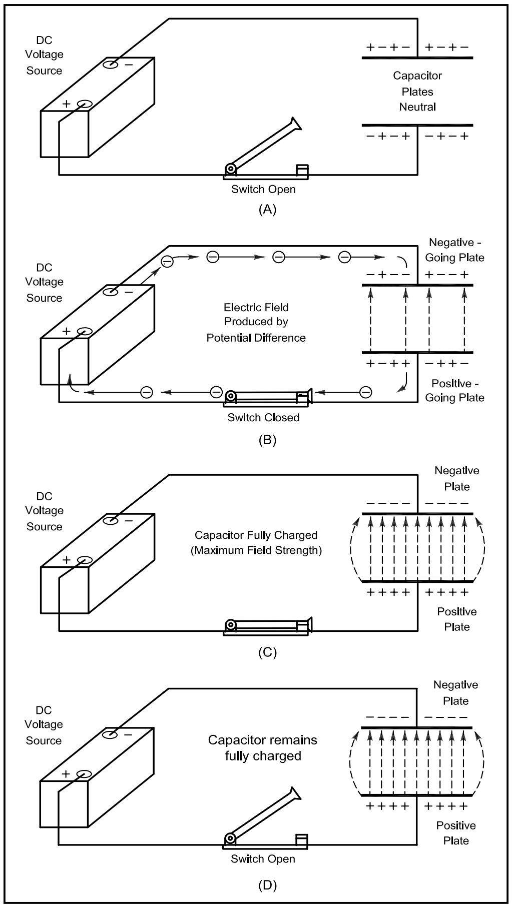


The basic unit of inductance is the henry (abbreviated H), named after the American physicist Joseph Henry. The henry is often too large for practical use in measurement. We use millihenry (10^{-13}) abbreviated mH, or microhenry (10^{-6}) abbreviated µH.

If we connect the ends of the wire forming an inductor to the positive and negative sides of a battery, we form what is called an *electromagnet*. You will be creating your own electromagnet with activity sheet 3.3.

CAPACITANCE

The last of the electrical components we will be discussing is called a *capacitor*. Capacitors come in many different sizes and shapes but they all have the same basic function, to store energy. A capacitor consists of two conductive plates separated by an insulating material. Like two aluminum pie plates with a sheet of wax paper between them. Simple!



How does it work? If you connect a wire to each plate and then connect the wires to a battery, one to the positive side of a battery and the other to the negative side of the battery, things begin to happen. What happens? The electrons flow out of the negative side of the battery onto the plate of the capacitor. Wait a minute! How can that happen? There is no connection to the positive side of the battery. This looks like an open circuit to me! You're right, it is an open circuit. But! Because the two plates are close together, separated by only a sheet of wax paper, called the *dielectric*, there is an attraction between the negative and positive plates in the capacitor. The electrons flow out of the negative side of the battery and are attracted to the positive plate but are not allowed to pass through the wax paper. These electrons build up on the plate giving it a negative charge. The electrons on the opposite plate are attracted to the positive side of the battery, leaving that plate with a positive charge. As shown in Figure 3.23, the plates become charged (stored energy), and if disconnected from the battery, stay charged. (*See Understanding Basic Electronics, Chapter 17*)

How does it work? If we connect a load to a charged capacitor, it will discharge through the load, releasing the stored energy. The basic property of a capacitor (called capacitance) is the ability to store a charge in an electric field.

If we connect an ac signal to a capacitor, the plates will charge during one part of the ac cycle. After the signal reaches the peak voltage, however, the charge will start ot flow back into the circuit in the opposite direction until the capacitor is charged with the opposite polarity during the second half of the ac cycle. This process of charging in one direction and then the other will continue as long as the ac signal is applied.

A capacitor will block direct current (dc) because as soon as the capacitor charges to the applied voltage level, no more current can flow. A capacitor will pass alternating current (ac) with little or not opposition.

The basic unit of capacitance is the *farad* (abbreviated F), named for Michael Faraday. The farad is usually too large a unit for practical measurements. For convenience, we use microfarads (10^{-6}), abbreviated µF, or picofarads (10^{-12}) abbreviated pF.