# Chapter 1

# From Electrons to Electronics

### In This Chapter

- Understanding the role of electrons, conductors, and voltage
- Looking at how electricity is generated
- Exploring some electronic components
- Connecting components together in circuits
- Introducing a few tools of the electronics trade
- Breaking it all down into units
- Understanding Ohm's Law



When you plug in the coffee maker in the morning, you're using electricity. When you flip on the TV to watch a rerun of *Sex in the City*, you're using electricity again (for better or worse).

You use electricity and electronics devices all the time, and you've finally worked up enough curiosity to want to tinker with electronic gadgets yourself. That's great. But before you can jump into playing with wires and batteries, it helps to understand what puts the *elec* in electricity and electronics.

In this chapter, you discover all about how electrons make electricity and how harnessing that electricity is the basis of electronics. You also get an introduction to some of the tools and parts that you can play with in the electronics projects in Chapters 14 and 15.

## Just What Is Electricity?

Like most things in life, electricity is more complex than you may think. A lot of conditions have to come together to make that little spark when you touch a doorknob or provide the power to run a supercomputer. To understand how electricity works, it helps to break it down into its parts.

## First, you take an electron

Electrons are one of the building blocks of nature. Electrons are buddies with another of nature's building blocks, protons. Electrons and protons are very small and are contained in . . . well, everything. A speck of dust contains millions and millions of electrons and protons, so you can imagine how many there are in your average sumo wrestler.

*Electrons* and *protons* have equal and opposite electric charges, with electrons having the negative charge and protons the positive. Opposite charges are attracted to each other. You can visualize a similar type of attraction by putting the ends of two magnets together. If the ends of the magnets are opposite poles, the magnets cozy right up to each other and stick together. If the ends of the magnets are the same pole, the magnets will move apart like two politicians in a heated debate. In a similar way, because electrons and protons have opposite charges, they are attracted to each other just as you can see opposite magnetic poles attracting. The attraction between electrons and protons acts like glue on a microscopic scale, holding matter together.

Although protons stay reasonably static, electrons are adventurous little fellows who don't like to just sit around at home. They can, and often do, move from one object to another. Walk across a carpet on a dry day and touch a doorknob; electrons traveling between your finger and the doorknob cause the spark that you feel and sometimes see. Lightning is another example of electrons traveling between two things — in this case, between a cloud and the ground. These examples both show electricity in an unharnessed state.

## Moving electrons around through conductors

What do electrons use to travel from one place to another? The answer to that question gives you the next piece of the electricity puzzle. Although you may use your old Chevy to get around, electrons use something called a conductor. *Electricity* is simply the movement of electrons through a conductor.

A lot of materials can act as conductors, but some are much better at it than others. Electrons can move more easily through metal than through plastic. In plastic, even though all the electrons are moving around their proton buddies, they pretty much stay in their own backyard. But in metal, the electrons are free to move all over the place. Free electrons in metal act like marbles thrown on an ice-skating rink. The electrons glide through the metal like the marbles slide across the ice. Plastic, an insulator, is more like sand. Marbles don't go much of anywhere if you throw them into a sandbox, and neither do electrons in an insulator.

So which materials are good conductors and which are good insulators? Most folks use copper and aluminum as conductors. In fact, electronics projects often use copper wire conductors. Plastic and glass are commonly used insulators.

*Resistance* is the measurement of the ability of electrons to move through a material. A copper wire with a large diameter has lower resistance to the flow of electrons than a copper wire with a small diameter. You need to understand resistance because almost every electronics project you do involves a resistor. Resistors have controlled amounts of resistance, which allows you to control the flow of electrons in a circuit.

## Voltage, the driving force

The previous sections in this chapter explain how electrons move and that they move more freely in a conductor. But some kind of force has to pull the electrons from one place to another. This attractive force between positive and negative charges is an electromotive force called *voltage*. Negative electrons move toward a positive voltage by way of a conductor.

Remember Ben Franklin's adventure flying a kite in a storm? The spark he produced that night gave him an understanding of how an electric current moves. In Ben's case, electrons traveled down the wet string, which acted as a conductor. (This was at least in part because the string was wet. Try this same stunt with dry string and it doesn't work nearly as well). The voltage difference between the negatively charged clouds and the ground pulled the electrons down the wet string.


Don't try Franklin's experiment yourself! By flying a kite in a storm, you're basically playing with lightning — which can effectively turn you into toast.

### What happened to protons?

You may have noticed that we stopped talking about protons. Although you should understand the positive and negative charges in protons and electrons, we're focusing on electrons because they're more mobile than protons. In most cases, it is electrons, and their negative charges, that move through conductors and generate electricity. But in special cases, such as batteries, positive charges also move through conductors.

To explain this process, you also have to get into things called ions, atoms, electrochemical reactions, and maybe even the concept of holes as used in semiconductor physics. Because you don't need to understand these concepts to complete the projects shown in this book (or most hobbyist level projects), we'll leave the more complex physics to Einstein and keep our focus on electrons.

### Conventional current versus real current

Early experimenters believed that electric current was the flow of positive charges. So they described electric current as the flow of a positive charge from positive to negative voltage. Much later, experimenters discovered electrons and determined that the flow of electrons in wires goes from negative to positive voltage. The original convention is still with us today, — so the standard is to depict the direction of electric current in diagrams with an arrow that points opposite to the direction that electrons actually flow. *Conventional current* is the flow of a positive charge from positive to negative voltage and is just the reverse of real current.

## An important combo: Electrons, conductors, and voltage

Say that you have a wire (a conductor), and you attach one of its ends to the positive terminal of a battery and the other end of the wire to the negative terminal of the battery. Electrons then flow through the wire from the negative to the positive terminal. This flow of electrons is referred to as an *electric current*. When you combine electrons, a conductor, and voltage you create an electric current in a form that you can use.

To help you picture how conductors and voltage affect the flow of electric current in a wire, think of how water pressure and pipe diameter affect the flow of water through a pipe. Here's how this analogy works:

- Increasing water pressure causes more water to flow through the pipe. This is analogous to increasing voltage, which causes more electrons to flow, producing greater electric current.
- Using a larger diameter pipe allows more water to flow through the pipe for a given amount of pressure. This is analogous to using wire with a larger diameter, which allows more electrons to flow for a given voltage, producing greater electric current.

# Where Do You Get Electricity?

*Electricity* is created when voltage pulls an electric current through a conductor. But when you sit down and run a wire between a switch and a light, just where do you get the juice (the electricity) to power that light?

There are many different sources of electricity — everything from the old walking-across-a-carpet-and-touching-a-doorknob kind to solar power. But to make your life simple, this book takes a look at the three sources that you're likely to use for electronics projects: batteries, your wall outlet, and solar cells.

## They just keep on going: Batteries

A battery uses a process called electrochemical reaction to produce a positive voltage at one terminal and a negative voltage at the other terminal. The battery creates these charges by placing two different metals in a certain type of chemical. Because this isn't a chemistry book, we don't get into the guts of a battery here — but trust us, this is essentially what goes on.

Batteries have two terminals (a *terminal* is just a fancy word for a piece of metal to which you can hook up wires). You often use batteries to supply electricity to devices that are portable, such as a flashlight. In a flashlight, the bulb has two wires running to the battery, one to each terminal. What happens next? Something like this:

- Voltage pulls electrons through the wire from the negative terminal of the battery to the positive terminal.
- The electrons moving through the wire pass through the wire filament in the light bulb, causing the bulb to light up.

Because the electrons move in only one direction, from the negative terminal through the wires to the positive terminal, the electric current generated by a battery is called *direct current,* or DC. This is in contrast to alternating current (AC) which is discussed in the following section, "Garden-Variety Electrical Outlets."

REMEMBER

The wires on a battery must connect to both terminals. This setup allows electrons to flow from one terminal of the battery, through the bulb, and all the way to the other terminal. If the electrons can't complete this kind of loop between negative and positive, electrons don't flow.

## Garden-variety electrical outlets

When you plug a light into an electrical outlet in your wall, you're using electricity that originated at a generating plant. That plant may be located at a dam or come from another power source, such as nuclear power. Or it may be fired by coal or natural gas. Because of the way electricity is generated at a power plant, the direction in which the electrons flow changes 120 times a second, making a complete turnaround 60 times a second. This change in electron flow is called *alternating current,* or AC.

When the change in electron flow makes a complete loop, it's called a *cycle*. The number of cycles per second in alternating current is measured in *Hertz,* abbreviated Hz. The example of a cycle in the previous paragraph is based on the fact that the United States uses a 60 Hertz standard frequency; some other countries use 50 Hertz as a standard, which means that the electrons change direction 100 times a second.

Electricity generated at a dam uses water to turn a coil of wire inside a huge magnet. One of the properties of magnets and wires is that when you move a wire near a magnet, a flow of electrons is induced in the wire. First, the magnet causes the electrons to flow in one direction, and then, when the wire loop rotates 180 degrees, the magnet pulls the electrons in the other direction. This rotation creates alternating current.

Just plugging a cord into a wall outlet sounds easy enough, but you need direct current for most projects, rather than alternating current. If you use wall outlets to supply electricity for your project, you have to convert the electricity from AC to DC. You can do this conversion with something called a power supply. For an example of a power supply, think of the charger that you use for your cell phone; this little device essentially converts AC power into DC power that the battery uses to charge itself back up. You can find out more about power supplies in Chapter 3.

REMEMBER

Safety, safety, safety. It's an important issue for you to consider when deciding whether to use the AC electricity that you get from wall outlets. Using the electricity from a battery is like petting a house cat. Using the electricity from wall outlets is more like cozying up to a hungry lion. With a cute tabby, you may get your hand scratched; with the king of the jungle, you may be eaten alive. If you think that you need to use electricity from a wall outlet for a project, make sure that you know what you're doing first. See Chapter 2 for specific advice about safety.

## Which came first, voltage or current?

Batteries produce a voltage that drives an electric current. Generators at dams drive a current that produces a voltage. Which comes first?

This is like asking yourself the well-known question about the chicken and egg. Voltage, currents, and conductors all work together. If there is a voltage applied across a conductor, electric current flows. If you have an electric current flowing through a conductor, there will be voltage across the conductor. Bottom line: Don't worry about which comes first.

### A simple choice: AC or DC

What difference does it make to you if you use alternating or direct current? A lot of difference!

AC costs less to generate and send over transmission lines than DC. That's why you use AC for many household electricity needs, such as powering light bulbs and heaters.

However, DC is simpler to use for the projects discussed in this book (and many other electronics applications). It's just plain harder to control AC current because you don't know which way it's headed at any point in time. It's the difference between controlling traffic on a two-way, six-lane highway, and controlling traffic on a one-lane, one-way street. So, most of the circuits you read about in this book use direct current.

## Solar cells

Solar cells are a form of semiconductor. Like batteries, solar cells have wires attached to two terminals. Shining light on a solar cell causes an electric current to flow. (This reaction to light is a property of semiconductors and is discussed in the sidebar "Getting fancy with semiconductors," later in this chapter.) The current is then conducted through wires to devices, such as a calculator or a garden light beside the pathway to your front door.

Using a calculator containing a solar cell, you can demonstrate that the calculator depends on the light shining on the solar cell for its power. Turn the calculator on and punch some numbers into the screen (choose a nice big number, like your income tax). Now, use your thumb to cover the solar cell. (The solar cell is probably near the top of the calculator in a rectangular area with a clear plastic cover.) After you've covered up the solar cell for a moment, the numbers fade away. Take your thumb off the solar cell, and the numbers reappear. Things powered by solar cells need light to work.

# Where Do Electrical Components Fit In?

Electrical *components* are parts you use in electronics projects. Simple enough, right? You use some electrical components to control the flow of electricity, such as a dimmer switch that adjusts the brightness of a light. Electricity simply powers other electrical components, such as speakers blasting out sound. Still other electronic components, called *sensors,* detect something (such as light or heat) and then generate a current to do something in response, such as set off an alarm.

In this section, you meet some basic electrical components. Chapters 4 and 5 provide much more detail about components.

## Controlling electricity

Electrical components, or parts, can control electricity. For example, a switch connects a light bulb to electric current. To disconnect the light bulb and make it go dark, the switch simply makes a break in the circuit.

Some other parts that control electricity are resistors, capacitors, diodes, and transistors. You can find more information on these parts in Chapter 4.

## Controlling electricity even better (ICs)

*Integrated circuits,* or ICs, are components that contain a whole bunch of miniature components (such as resistors, transistors, or diodes, which you hear about in Chapter 4) in one device that may not be much bigger than an individual component. Because each IC contains many components, one little IC can do the same job as several individual parts.

### Getting fancy with semiconductors

Transistors, diodes, LEDs, integrated circuits, and many other electronic devices use a semiconductor instead of a conductor. A *semiconductor* is a material, such as silicon, that has some of the properties of both conductors and insulators.

Silicon is pretty cool stuff. In fact, they've named a whole valley in California after it. In its pure state, silicon conducts an electric current poorly. But if you add contaminates, such as boron or phosphorus, to the silicon, it conducts. When you add phosphorus, silicon becomes an "n"-type semiconductor. When you add boron, silicon becomes a "p"-type semiconductor. An *"n"-type semiconductor* has more electrons than a pure semiconductor and a *"p"-type semiconductor* has fewer electrons than a pure semiconductor.

When the regions containing boron and phosphorus are next to each other in silicon, you have a *"pn" junction.* Current flows in only one direction across a "pn" junction. *Diodes,* components that can convert AC to DC by limiting the flow of current to one direction, are an example of a component that contains a "pn" junction.

A "pn" junction generates an electric current when exposed to light; this property is used when building solar cells. On the other hand, when you run an electric current through a "pn" junction, it emits light, as light-emitting diodes (LEDs) do.

Transistors use junctions in which three adjacent areas have contaminants added. For example, one region with phosphorus, one with boron, and another with phosphorus result in an "npn" junction. In a transistor, you apply a current to the middle of the three regions (the base), allowing a current to flow.

Most electronics projects you work on use components such as transistors, diodes, and integrated circuits, and these are made with semiconductors. It's semiconductors that have made possible much tinier electronic gadgets (like handheld computers and palm-sized radios).

An audio amplifier is one example of an IC. You can use audio amps to increase the power of an audio signal. For example, if you have a microphone, its small output signal is fed through an audio amplifier to make a strong enough signal to power a speaker.

Another type of IC used in electronics projects is a *microcontroller,* a type of integrated circuit that you can actually program to control cool gadgets like robots. We discuss microcontrollers in more detail in Chapter 13.

## Sensing with sensors

Certain electrical components generate a current when you expose them to light or sound. You can use the current generated, together with a few of the components listed in the previous sections that control electricity, to turn on or off electronic devices, such as light bulbs or speakers.

Motion detectors, light sensors, microphones, and temperature sensors all generate an electrical signal in response to a stimulus (motion, light, sound, or temperature, respectively). These signals can then be used to turn other things on or off. A high signal level might turn something on and a low signal level turn something off. For example, when a salesperson walks up to your house, a motion detector can turn on a light (or better yet, sound a general alarm).

These signals take different forms, depending on the component supplying them. For example, a microphone supplies an AC signal, and a temperature sensor supplies a DC signal.

Figure 1-1 shows diagrams of a few signals that you run into often when working with electronics. These signals include

- **+ 5 Volt DC signal:** A high input.
- **0 volt DC signal:** A low input.
- **0 to 5 volt DC square wave:** The output of an *oscillator* (a device that cycles between high and low voltage); if you use this signal as input to a light bulb, it causes the light to blink on and off.
- **- 5 volt to + 5 volt AC sine wave:** A signal, such as from a microphone, that generates alternating current that a device, such as an amplifier, uses as input. A microphone generates the waveform in Figure 1-1 when it receives the sound produced by a tuning fork. Notice in Figure 1-1 that the transitions from +5 volts to -5 volts are gradual for the sine wave and more abrupt in the square wave.

You can find out more about various types of sensors in Chapter 5.

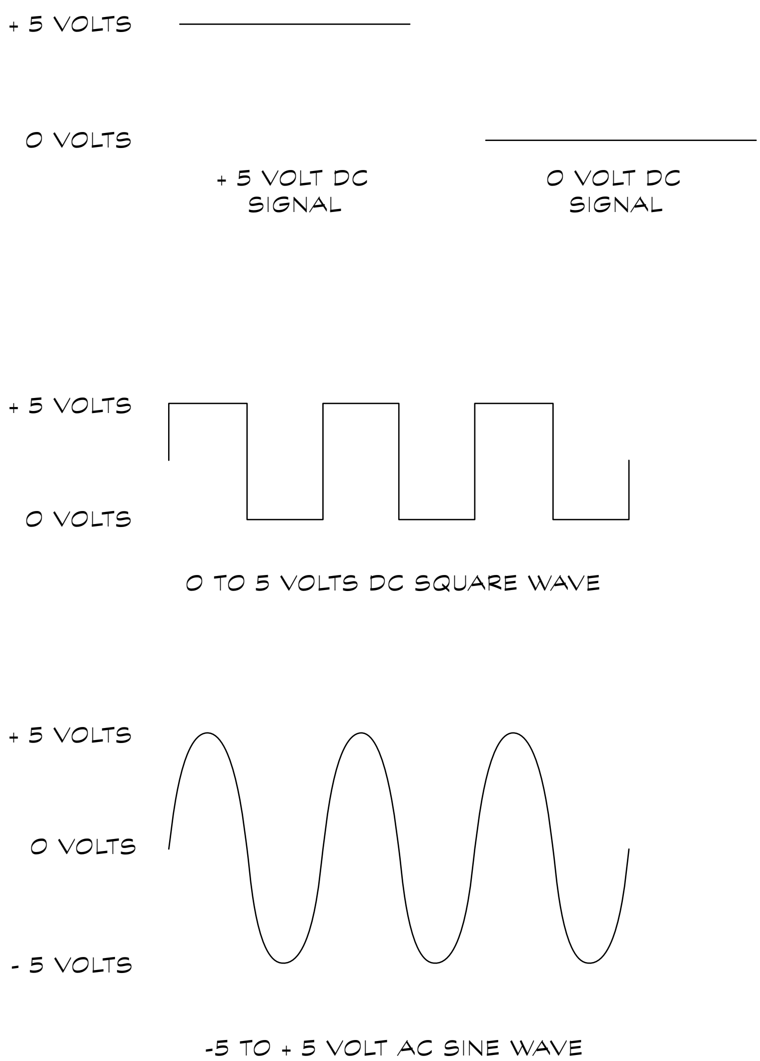



**Figure 1-1:** Just a few examples of input signals.

## Powering up

Electricity can power electrical components to produce light, heat, sound, motion, and more. For example, an electric current supplied to a DC motor causes the shaft of the motor to rotate, along with anything you've attached to that shaft.

You can power speakers, light bulbs, LEDs, and motors with electricity. If you want to read more about these types of components, check out Chapters 4 and 5.

# How Electricity Becomes Electronics

When you need to use electricity to make something work, such as a boom box, you've entered the world of electronic gadgets. No doubt you're eager to start making your own electronic gadgets. We cover the basics of how electronics and gadgets interact in the following sections.

## Creating a simple circuit

Take a battery, a resistor, an LED, and some wires, put them together, and you have a simple electronic circuit. That's all an electronic *circuit* is — wires connecting components so that a current can flow through the components and back to the source.

Figure 1-2 shows a simple circuit. You place the parts in this circuit (also called components) on something called a breadboard and connect those parts with wires. If you've ever played with Mr. Potato Head, you understand the principle of a breadboard. You stick things in the potato (ears, a hat, eyes, and so on) to form a potato person. In the same way, a *breadboard* has slots for you to insert electronic components to build a sample circuit. If you're really happy with what you've created, you can then use that design to get a printed circuit board made. (See Chapter 11 for more information on building circuits on breadboards.)

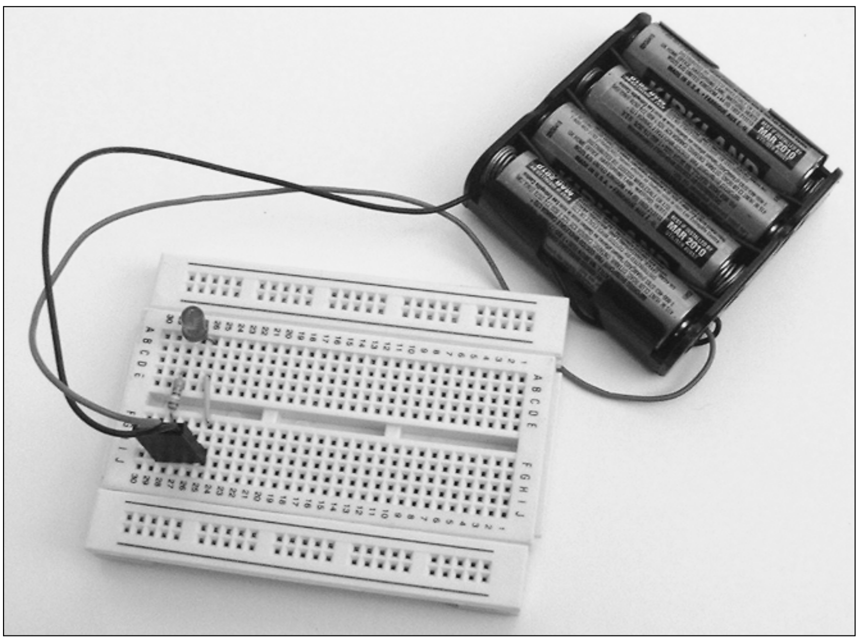


**Figure 1-2:** A collection of parts is assembled into a circuit.

Figure 1-2 shows wires connected to both terminals of the battery in the circuit. This connection allows the current to flow from the battery, through the LED and other components, and back to the battery to complete the circuit. You can also complete the circuit by connecting parts of the circuit to the metal chassis of a gadget, such as the metal housing of a stereo. We call this connection a *ground* because it is used as the reference for all voltages in the circuit. Ground may or may not be connected to the actual earth, but it is always the reference from which you measure all other voltages. We discuss grounding in detail in Chapter 6.

You can represent a circuit as a schematic. A *schematic* is just a drawing showing how components are connected together by wires. Check out the schematic for the circuit in Figure 1-2 in Figure 1-3. You can go to Chapter 6 for more on schematics.

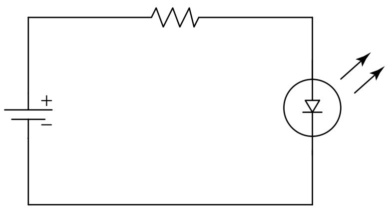



**Figure 1-3:** Can you decipher this schematic of the circuit shown in Figure 1-2?

## Deciding what to build

If you're itching to build a simple circuit to try out your skills, you can find several circuits in Chapter 14. For example, you can create a breadboard circuit that sounds an alarm when someone turns on a light in your room. Building these projects is a fun way to get familiar with how to put together a circuit. (But don't jump right into projects if you're a beginner — not until you've read through a few chapters in this book, especially Chapter 2 about safety.)

After you put together some of the breadboard projects in Chapter 11 and build up your basic skills, you can move on to the projects in Chapter 15, such as constructing a small robot. These projects take more time, but they can result in some truly neat gadgets.

TIP

After you've developed your skills building some of the projects in this book, you can go farther. One place to get additional ideas is on the Internet. Two sites we recommend are `discovercircuits.com/` and `www.electronics-lab.com`.

# Along the Way You Get to Play with Tools

One of the best things about building electronics projects is that you get to tinker with tools and parts and see what you can make from them. You use some tools to put the circuits together and some tools to check out how the circuits you build are working.

## Tools to build things

You're probably glad to hear that you don't need that many tools to get started. You just need a wire cutter, needle-noise pliers, a wire stripper, and a few screwdrivers to get started with the projects covered in Chapter 14.

If you design a circuit that you want to make more permanent, you need to get a soldering pencil (also called a soldering iron) to attach the elements of a circuit together. We cover choosing a soldering pencil in Chapter 8.

REMEMBER

As you work with projects, no doubt other miscellaneous tools pop up that you may want to get your hands on. You can use a magnet to retrieve screws and other tiny things that you inevitably drop in hard-to-reach places, for example. Check out Chapter 3 for details on outfitting your workbench.

## Tools to measure things

When building or troubleshooting a circuit, you need to make measurements to check that parts are working the way they should and that you designed and built the circuit correctly. Tools that you can use to measure things include a multimeter, an oscilloscope, and a logic probe. Chapters 9 and 10 cover the use of these tools.

We'll take a moment to briefly tell you what you can use a multimeter for because it's the measuring tool that you buy first and possibly the only one that you ever need.

Say you build a circuit, and you've just turned it on. What if the circuit doesn't work? With a multimeter, you can find out which part of the circuit is causing the problem. You can measure voltage, resistance, and current at different points on the circuit. For example, if there are 5 volts at one location on the circuit and further along at another location your voltage suddenly drops to 0 volts for no logical reason you can make a good guess that your problem lies between those two locations. You can then check (after the power is disconnected, please!) for loose wires or damaged parts between those two locations.

WARNING

Before troubleshooting a circuit for problems, read Chapter 2 on safety. You can very easily hurt yourself or your electronic gadget if you're not careful.

# The Wonderful World of Units

To understand the results of your multimeter measurements, you need to understand electrical units. In the following sections, we run through the basics with you.

## Measuring things in units

*Units* simply tell you how much of something you have. For example, when you buy apples, you measure how much they weigh in pounds (lbs). Similarly, a multimeter measures resistance in ohms, voltage in volts, and current in amperes (amps for short).

Table 1-1 shows common units and abbreviations used in electronics.

**Table 1-1 Units Used in Electronics**

| *Term* | *Abbreviation* | *Unit* | *Unit Symbol* | *Component* |
|---|---|---|---|---|
| **Resistance** | R | ohm | Ω | Resistor |
| **Capacitance** | C | farad | F | Capacitor |
| **Inductance** | L | Henry | H | Inductor |
| **Voltage** | E or V | volt | V | |
| **Current** | I | amp | A | |
| **Power** | P | watt | W | |
| **Frequency** | f | hertz | Hz | |

## Getting to bigger or smaller units

If you're measuring apples, you may have a tiny wedge of an apple (a fraction of an apple) or a few pounds of apples, right? Electronics has much larger ranges of units. You can have a single circuit using millions of ohms or another one with a very small current (maybe a thousandth of an amp). Talking about these very, very big numbers and very, very tiny numbers requires some special terminology.

Electronics uses things called prefixes and scientific notation to indicate small or large numbers. Table 1-2 shows common prefixes and scientific notations used in electronics.

**Table 1-2 Prefixes used in Electronics**

| *Number* | *Name* | *Scientific Notation* | *Prefix* | *Abbreviation* |
|---|---|---|---|---|
| 1,000,000,000 | 1 billion | $10^9$ | giga | G |
| 1,000,000 | 1 million | $10^6$ | mega | M |
| 1,000 | 1 thousand | $10^3$ | kilo | k |
| 100 | 1 hundred | $10^2$ | | |
| 10 | ten | $10^1$ | | |
| 1 | one | $10^0$ | | |
| 0.1 | tenth | $10^{-1}$ | | |
| 0.01 | hundredth | $10^{-2}$ | | |
| 0.001 | 1 thousandth | $10^{-3}$ | milli | m |
| 0.000001 | 1 millionth | $10^{-6}$ | micro | µ |
| 0.000000001 | 1 billionth | $10^{-9}$ | nano | n |
| 0.000000000001 | 1 trillionth | $10^{-12}$ | pico | p |

So how does this $10^{-6}$ or $10^6$ stuff work? *Scientific notation* is basically a shorthand method of telling how many zeros to add to a number using our decimal system, which is based upon powers of 10. For example, the superscript '6' in $10^6$ means place the decimal point six places to the right. $10^{-6}$ means move the decimal point six places to the left. So, with 1 x $10^6$, you move the decimal point 6 places to the right of the 1, which gives you 1,000,000 or 1 million. With 1 x $10^{-6}$, you move the decimal point 6 places to the left, giving you 0.000001 or 1 millionth. With 3.21 x $10^4$, you move the decimal point 4 places to the right, for a result of 32,100.

## Prefixes + units = ?

The previous section shows you the abbreviations for prefixes and units. This section tells you how to combine them. Combining these two results in very compact notation. For example, you can write 5 milliamps as 5 mA or 3 megahertz as 3 MHz.

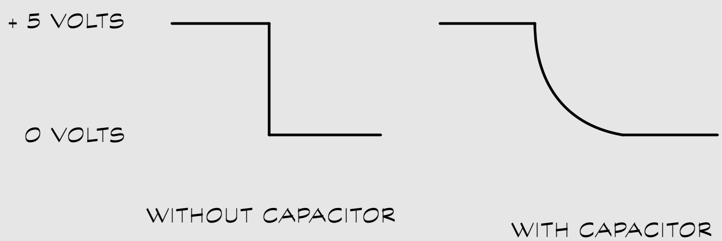
Just as you usually use a pound or so of apples to bake your average pie or several tons of steel to build a suburban office park, in electronics, some things just naturally come in small measurements and others in large measurements. That means that you typically see certain combinations of prefixes and units over and over. Here are some common combinations of notations for prefixes and units:

- **Current:** pA, nA, mA, µA, A
- **Inductance:** nH, mH, µH, H
- **Capacitance:** pF, nF, mF, F
- **Voltage:** mV, V, kV
- **Resistance:** Ω, kΩ, MΩ
- **Frequency:** Hz, kHz, MHz, GHz

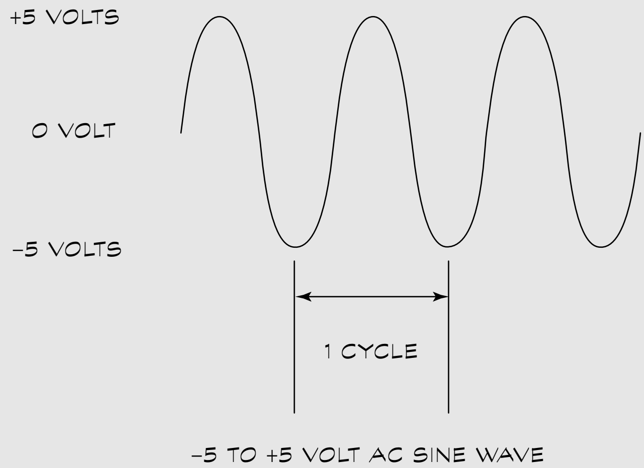
## Exploring some new terms

Although we discussed resistance, voltage, and current earlier in this chapter, some other terms in this section may be new to you.

*Capacitance* is the ability to store a charge in an electric field. This stored charge has the effect of making decreases or increases of voltage more gradual. You can use components called *capacitors* to provide this property in many circuits. This figure shows the signal that occurs when you decrease voltage from +5 volts to 0 volts, both with and without a capacitor.




*Frequency* is a measurement of how often an AC signal repeats. For example, voltage from a wall outlet undergoes one complete cycle 60 times a second. The following figure shows a sine wave. In this figure, the signal completes one cycle when the current goes from -5 to +5 volts then back down to -5 volts. If a signal repeats this cycle 60 times a second, it has a frequency of 60 hertz.




*Inductance* is the ability to store energy in a magnetic field; this stored energy resists changes in current just as the stored charge in a capacitor resists changes in voltage. Components called *inductors* are used to provide this property in circuits.

*Power* is the measure of the amount of work that electric current does while running through an electrical component. For example, when voltage is applied to a light bulb and current is driven through the filament of the bulb, work is done in heating the filament. In this example, you can calculate power by multiplying the voltage applied to the light bulb by the amount of current running through the filament.

Using the information in Tables 1-1 and 1-2, you can translate these notations. Here are some examples:

- **mA:** milliamp or 1 thousandth of a amp
- **µV**: microvolt or 1 millionth of a volt
- **nF:** nanofarad or 1 billionth of a farad
- **kV:** kilovolts or 1 thousand volts
- **MΩ:** megohms or 1 million ohms
- **GHz:** gigahertz or 1 billion hertz

The abbreviations for prefixes representing numbers greater than 1, such as *M* for *mega,* use capital letters. Abbreviations for prefixes representing numbers less than 1, such as *m* for *milli,* use lowercase. The exception to this rule (there's always one) is *k* for *kilo,* which is lowercase even though it stands for 1,000.

The use of capital K is a special case reserved for kilohms; when you see a capital K next to a number such as 3.3k, this translates as 3.3 kilohms.

You have to translate any measurement expressed with a prefix to base units to do any calculation, as you can see in the following sections.

# Understanding Ohm's Law

Say that you're wiring a circuit. You know the amount of current that the component can withstand without blowing up and how much voltage the power source applies. So you have to come up with an amount of resistance that keeps the current below the blowing-up level.

In the early 1800s, George Ohm published an equation called Ohm's Law that allows you to make this calculation. *Ohm's Law* states that the voltage equals current multiplied by resistance, or in standard mathematical notation

$$V = I \times R$$

## Taking Ohm's Law farther

Remember your high school algebra? Remember how if you know two things (such as *x* and *y*) in an equation of three variables, you can calculate that third thing? Ohm's Law works that way; you can rearrange its elements so that if you know any two of the three values in the equation, you can calculate the third. So, here's how you calculate current: current equals voltage divided by resistance, or

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

You can also rearrange Ohm's Law so that you can calculate resistance if you know voltage and current. So, resistance equals voltage divided by current, or

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

So far, so good. Now, take a specific example using a circuit with a 12-volt battery and a light bulb (basically, a big flashlight). Before installing the battery, you measure the resistance of the circuit with a multimeter and find that it's 9 ohms. Here's the formula to calculate the current:

$$I = \frac{V}{R} = \frac{12 \text{ volts}}{9 \text{ ohms}} = 1.3 \text{ amps}$$

What if you find that your light is too bright? A lower current reduces the brightness of the light, so just add a resistor to lower the current. Originally, we had 9 ohms; adding a 5-ohm resistor to the circuit makes the total resistance 14 ohms. In this case, the formula for current is

$$I = \frac{V}{R} = \frac{12\ \text{volts}}{14\ \text{ohms}} = 0.9\ \text{amps}$$

## Dealing with numbers both big and small

Say that you have a circuit with a buzzer that has resistance of 2 kilohms and a 12-volt battery. You don't use 2 kilohms in the calculation. To calculate the current, you have to state the resistance in the basic units, without using the "kilo" prefix; in this example that means that you have to use 2,000 ohms for the calculation, like this:

$$I = \frac{V}{R} = \frac{12\ \text{volts}}{2,000\ \text{ohms}} = 0.006\ \text{amps}$$

You now have the calculated current stated as a fraction of amps. After you finish the calculation, you can use a prefix to restate the current more succinctly as 6 milliamps or 6 mA.

REMEMBER

Bottom line: You have to translate any measurement expressed with a prefix to base units to do a calculation.

## The power of Ohm's Law

Ohm (never one to sit around twiddling his thumbs) also expressed that power is related to voltage and current using this equation:

$P = V \times I$; or power = voltage x current

You can use this equation to calculate the power consumed by the buzzer in the previous section:

$P = 12$ volts x 0.006 amps = 0.072 watts which is 72 milliwatts (or 72 mW)

What if you don't know the voltage? You can use another trick from algebra. (And you thought Mrs. Whatsit wasted your time in Algebra 101 all those years ago!) Because $V = I \times R$, you can substitute $I \times R$ into this equation, giving you

$P = I^2 \times R$; or power = current squared x resistance

You can also use algebra to rearrange the equation for power to show how you can calculate resistance, voltage, and current if you know power and any one of these parameters.

TIP

Do you really hate algebra? Did Mrs. Whatsit fail you those many years ago? You're probably happy to hear that online calculators can make these calculations much easier. Try searching on `www.google.com` using the keyword phrase "Ohm's Law Calculator" to find them. Also, check out Chapter 18. It provides ten of the most commonly used electronics calculations.