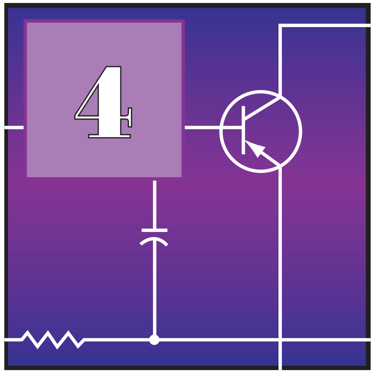

Ohm's Law

Objectives

After studying this chapter, you will be able to answer these questions:

1. What is the relationship between voltage, current, and resistance in a circuit?
2. What is Ohm's law and how can we use it to solve electrical circuit problems?
3. What types of switches are used in electrical circuits?

Important Words and Terms

The following words and terms are key concepts in this chapter. Look for them as you read this chapter.

conductive pathway	load
control	Ohm's law
electrical circuit	voltage source

The Simple Circuit

Electrical circuits are complete pathways through which electric current flows. Three elements are basic to all circuits:

1. ***Voltage source*** (such as a battery or generator). A device that supplies the energy.
2. ***Load*** (such as a resistor, motor, or lamp). A device that uses energy from the voltage source.
3. ***Conductive pathway*** (such as an insulated wire or printed circuit board). A path from voltage source to load and back, which carries electrical current.

Circuits usually contain a fourth element, as well. A ***control*** device such as a switch, fuse/circuit breaker, or relay may be used to stop, start, and/or regulate the flow of electricity.

Figure 4-1 is a schematic diagram of a simple circuit. The symbols show that the circuit has a battery for the voltage source; a load device (resistor), which uses the energy from the voltage source; an "on/off" switch; and connecting wire to conduct the current.

Ohm's Law

One of the basic laws of electrical circuits is Ohm's law. This shows mathematically the relationship between voltage (E),

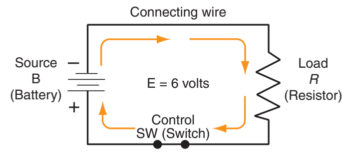

Figure 4-1.
A simple electrical circuit. Note connection of elements that make up circuit.

current (I), and resistance (R). A thorough understanding of the use of Ohm's law will help you to understand how any circuit operates.

If you do not completely understand Chapter 2, perhaps now is a good time to review it once again. You will remember that an electric current was caused to flow in a conductor when a force or voltage was applied to the circuit. Figure 4-1 shows a simple circuit using a battery as a voltage or potential difference source.

R represents the resistance in the circuit and I stands for "intensity" of the current. E or V represents electromotive force.

As the voltage of battery (B) is fixed and the resistance of the circuit is fixed, a definite value of current will flow in the circuit. (Note the direction of current flow as indicated by the arrows.)

If the voltage were increased to twice the value, as in **Figure 4-2,** then the current would also increase to twice its former value. As the voltage increases, the current

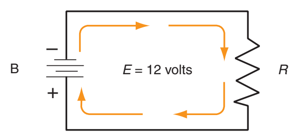

Figure 4-2.
As voltage is increased, the current increases.

increases. As the voltage decreases, the current decreases. A mathematician would say that the current and voltage are in *direct proportion* to each other.

The current flowing in these circuits also depends on the resistance of the circuit. If we increase the resistance to twice its value, the current is cut in half. We may conclude that as the resistance increases, the current decreases. As the resistance decreases, the current increases. Again, mathematically speaking, the current is in *inverse proportion* to the resistance.

Georg Simon Ohm, the German scientist, proved this relationship to be true in his experiments. The law is named in his honor. ***Ohm's law*** is stated as:

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

where,

I = current in amperes
E = voltage in volts
R = resistance in ohms

By simple algebra, the formula may be changed to read:

$$R = \frac{E}{I} \text{ or } E = IR$$

Math Manipulation!

One may readily see that if any two quantities are known in a circuit, the third quantity can be found. Referring to **Figure 4-3**, notice that values have been assigned to E and R.

The current is easily computed by Ohm's law:

$$I = \frac{E}{R} \text{ or } I = \frac{6 \text{ V}}{12\ \Omega} = 0.5 \text{ A}$$

If the voltage were unknown and we knew the current and resistance: $I = 0.5$ A, and $R = 12$ ohms, then:

$$E = I \times R \text{ or } 0.5 \text{ A} \times 12\ \Omega = 6 \text{ V}$$

If the resistance were unknown and the voltage and current were given as: $I = 0.5$ A, $E = 6$ volts, then:

$$R = \frac{E}{I} \text{ or } \frac{6 \text{ V}}{0.5 \text{ A}} = 12\ \Omega$$

If you have difficulty remembering this equation in its three forms, the simple memory device shown in **Figure 4-4** may help.

Place your finger over the unknown quantity and observe what it equals. For example: Put your finger over E, the answer is $I \times R$. Put your finger over I, the answer is:

$$\frac{E}{R}$$

Put your finger over R, the answer is:

$$\frac{E}{I}$$

The purpose of the memory device is to make it easier to remember how to use Ohm's law. The best way to learn Ohm's law is to practice its use.

You must remember that when using Ohm's law, E, I, and R must be in volts, amperes, and ohms, respectively. Study

History Hit!

Georg Simon Ohm (1787–1854)

Ohm was educated at the University of Erlangen and became a professor of physics at Munich in 1849. Ohm developed the law for which he is best known. However, it should be noted that he received little acknowledgment for this achievement for 20 years. He also did much pioneering research on the human ear and how different sounds or frequencies are broken down by the different parts of the inner ear.

Figures 4-5 and **4-6.** Frequently current is given in milliamperes, which is:

$$\frac{1}{1000} \text{ of an ampere or } 0.001 \text{ A}$$

You must convert to amperes before using the equation. Studying the following examples will help you to do this:

1 ampere = 1000 milliamperes
0.5 ampere = 500 mA
0.1 amp = 100 mA
50 mA = 0.05 amp
500 mA = 0.5 amp
10 mA = 0.01 amp
1 mA = 0.001 amp

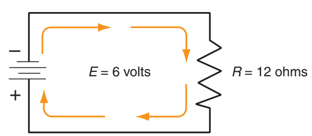

Figure 4-3.
The current equals 0.5 amperes.

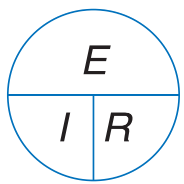

Figure 4-4.
A memory device for Ohm's law.

1 milliampere (mA)	=	1/1,000 (.001) ampere
1 microampere (mA)	=	1/1,000,000 (.000001) ampere

Figure 4-5.
Prefixes used in measuring current.

Math Manipulation!

As you review Figures 4-5 and 4-6, realize that the powers of 10 make it easier to work with very large or very small numbers. These units (milliamperes and microamperes) make it much easier to list very, very small units of current. In the future, we will work with much larger units. It will be important for you to use the powers of 10 in electricity and electronics, so closely review Figures 4-5 and 4-6 as you examine these mathematics principles.

Overload Protection of Circuits

It should be quite clear that a certain kind and size of wire has a specified ability to conduct an electric current. All conductors have some resistance. When a current overcomes this resistance, heat is produced. If a wire is operated within its limitations, this heat is dissipated in the surrounding air and its temperature does not rise excessively. However, if too great a current is forced through the conductor, the temperature will rise to a point where the wire will become hot. If the wire gets hot enough, the insulation that surrounds the conductor may melt off. The wire may even get hot enough to melt itself and be destroyed. If it is near combustible material, such as in the wall of your home, a fire might result.

Overloading a circuit can occur from two causes:

1. An excessive load that draws beyond a safe amount of current.
2. A direct (sometimes called a dead) short circuit.

Circuits and appliances are usually protected by a fuse or circuit breaker. A ***fuse*** is simply a thin strip of metal that melts at a low temperature. Those used in the home are usually designated 15 and 20 amperes. (Carefully examine your fuse box or circuit breaker panel at home.) Note the Safety Suggestions later in this chapter. Typically, circuit breakers have replaced fuses in most home and industrial applications. However, older installations may still contain fuses, or a combination of fuses and circuit breakers.

If a current exceeds the fuse rating, it will melt and open the circuit, preventing damage of equipment and danger of fire. The symbol for a fuse in electrical circuit diagrams is shown in **Figure 4-7.**

Some fuses, of course, are made to carry heavier currents. You will generally find a main power panel in a home rated between 100 and 200 amperes. In fact, as homes utilize more and more electricity, even larger amounts of current are

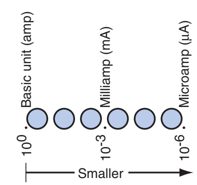

Figure 4-6.
Conversion chart for ampere prefixes.

Figure 4-7.
The symbol for a fuse.

Safety Suggestion!

If you do look into the power panel of your home, be careful! Be sure to touch only the panel door to open it and close it. Fuses or circuit breakers may have been removed. This can expose dangerous and fatal electrical connections! If there are loose wires or metal conductors exposed, do not touch the panel. If you are unsure of the safety of the panel box, leave it alone. You may want to have a qualified electrician examine this possibly dangerous situation.

provided at the main power panel. You will often find in the electrical service panel in your home fuses of the cartridge type, rated for 100 to 200 amperes or more. These main fuses carry the total current used by all of the circuits in your home and give further protection.

In **Figure 4-8,** a simple load in the form of a resistor is connected across a voltage source. If the insulation should become worn or frayed so that wire A could touch wire B, the sparks would fly. This is called a ***short circuit.*** This can happen with lamp and appliance cords.

One improved safety device is called the circuit breaker. You will study these in detail in the unit on magnetism. A ***circuit breaker*** is a magnetic or thermal device that

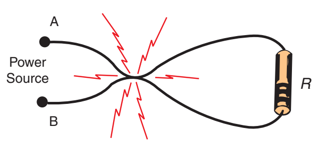

Figure 4-8.
A short circuit, sometimes called a direct or dead short, across the power supply connections A and B will make the sparks fly!

Safety Suggestion!

If you were to examine the cords to lamps and appliances at home, it is possible that you may find a damaged one. Needless to say, these electrical cords are dangerous. You can receive a serious burn from a short circuited lamp cord, as well as the danger of an electric shock. It is best to refer these problems to a qualified repair person and/or electrician.

automatically opens the circuit when an excessive current flows. See **Figure 4-9.** Circuit breakers must be manually reset before the circuit can be used again. Circuit breakers have three positions, *on, off* and *tripped.* The tripped position has stopped current because of an overcurrent condition (a short circuit or a current above its rated value). Needless to say, the cause of the overload should be investigated and removed or repaired before the current is turned on again. Circuit breakers are replacing fuses in most applications in the home and industry. One reason is because they are reusable, the fuse is not. As you examine your home or school electrical service panels, are fuses or circuit breakers used?

Circuits and Switches

There are many varieties of switches used in electrical equipment. The student should be familiar with the common types, **Figure 4-10.**

If only one wire or one side of a line is to be switched, the single-pole, single-throw

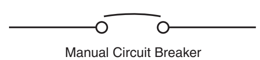

Figure 4-9.
Symbol for a circuit breaker.

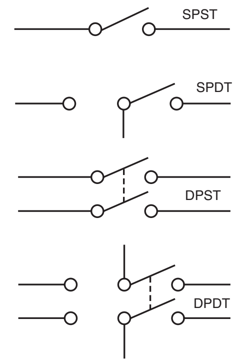

Figure 4-10.
Diagrams of switch types.

(SPST) switch is used. If both sides of the line were to be switched, then a double-pole, single-throw (DPST) switch would be used. Reference to Figure 4-10 will show the circuit diagrams for various switches. If a single line is to switch first to one point and then to another, the SPDT switch can be used. If a double line is to be switched to two other points, then the DPDT switch would be used.

Another type of switch used is the push-button switch. These switches can be of two main types: normally open or normally closed. The normally opened push button (PBNO) is found in **Figure 4-11.** This switch only completes a circuit when pushed. **Figure 4-12** is the opposite of PBNO, the normally closed push button (PBNC). This switch opens the circuit only when pushed or depressed. Otherwise, the circuit is closed. The term "normally" is used to indicate that the push-button switch is at rest (untouched by someone).

Frequently, it is desirable to switch a circuit from two different locations. In this case, a three-way switch is used. Perhaps you

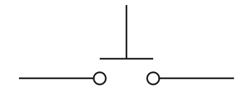

Figure 4-11.
Push button normally open (PBNO).

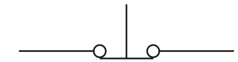

Figure 4-12.
Push button normally closed (PBNC).

have such switches in your home that permit you to turn a light on or off from two places in a room or hallway. The schematic diagram of this circuit is shown in **Figure 4-13.**

The light is on, but it can be turned off by moving either switch 1 or 2. In **Figure 4-14** the light is off, but it can be turned on by either switch 1 or 2. Follow the circuit through the switches in each position.

In *Project 1—Experimenter, Problem 6,* you will gain first-hand experience in connecting three-way switches, so that lights can be controlled from different locations.

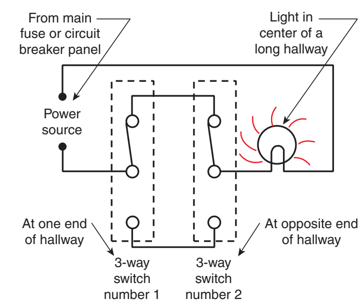

Figure 4-13.
A three-way switch circuit. The light is on.

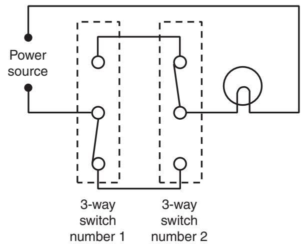

Figure 4-14.
A three-way switch circuit. The light is off.

A common type of switch used in electrical equipment is the multiple-pole rotary switch. In this switch, the rotary contact arm can be connected to one side of an electrical circuit and the contacts can connect to several other circuits. By turning the control knob, any desired circuit configuration can be used. Multiple switching operations can be done by mounting several rotary switches on one control shaft, **Figure 4-15.** Where might a switch like this be used?

Quiz–Chapter 4

Write your answers to these questions on a separate sheet of paper. Do *not* write in this book.

Draw the circuit diagram for each of the following problems and compute the unknown quantities.

1. A circuit has an applied voltage of 100 volts and a resistance of 1000 ohms. What is the current flowing in the circuit?
2. A circuit that contains 100 ohms resistance has a current of two amperes. What is the applied voltage?
3. A circuit that contains 10,000 ohms of resistance has a current of 100 mA. What is the applied voltage?

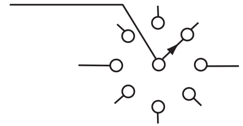

Figure 4-15.
Multiple-pole rotary switch.

4. A circuit has an applied voltage of 200 volts that causes a 50 mA current to flow. What is the circuit resistance?
5. An applied voltage of 50 volts causes a current of 2 amperes to flow. What is the circuit resistance?
6. A voltage of 500 volts is applied to a circuit that contains 100 ohms of resistance. What is the current?
7. If applied voltage is 400 volts and resistance is 20,000 ohms, what is the value of *I*?
8. A meter indicates a current flow in a circuit of 0.5 amp. The circuit resistance is 500 ohms. What is the value of *E*?
9. What applied voltage will cause 500 mA of current to flow through 500 ohms of resistance?
10. What applied voltage will cause 10 mA of current to flow through 1000 ohms of resistance?
11. An electric appliance has a resistance of 22 ohms. How much current will it draw when connected to a 110 volt line?
12. A 110 volt house circuit is limited to 15 amperes by the fuse in the circuit. The following appliances are connected to the circuit. Compute the individual currents for each appliance. What is the total current flowing in the circuit? Will the fuse permit this current to flow?
    Appliance 1 draws 2 amperes.
    Appliance 2 has a resistance of 40 ohms.
    Appliance 3 has a resistance of 20 ohms.

Hands-on experiments are an important part of learning electricity and electronics. Thousands of different circuits can be created on generic circuit boards. Bus wire and jumper wire are often used to make connections.