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## CHAPTER THREE

# The Simple Electric Circuit

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In Chapters One and Two you were introduced to some of the basic concepts of electricity. Now you will use those fundamental ideas to begin to understand the electric circuit.

You will need to know some algebra to work through this chapter and many of those that follow. If you need to learn how to solve simple equations (or if you would like a review), turn to Appendix I. The material presented there will teach you all you need to know about the math required in this book.

When you have finished this chapter you will be able to:

- draw schematic diagrams of simple electric circuits, using standard schematic symbols;
- solve simple equations, derived from Ohm's Law, to find voltage, current, and resistance;
- relate power consumption to voltage, current, and resistance, and solve power equations;
- solve problems about the power capacity of electrical devices; and
- relate power to energy and solve energy equations.

### The Electric Circuit

Refer to Figure 3-1 on the following page for frames 1 through 7.

1. An electric circuit includes an energy source, some kind of load to dissipate the energy, and a conductor to provide a pathway for current flow. The energy source could be a battery, as in Figure 3-1, or some other means of producing a voltage. The load that dissipates the energy could be a lamp, as in Figure 3-1, a resistor, or some other device that does useful work, such as an electric toaster, a power drill, or a soldering iron. (Of course, a circuit might include a great many separate devices, or loads.) The conductor, which is usually wire, connects all the loads in the circuit to the voltage source to provide a complete pathway for current flow. No electrical device dissipates energy unless current flows through it. Since wires are not perfect conductors, they heat up (dissipate energy), so they are actually part of the load. For simplicity, how-



ever, we usually think of the connecting wiring as having no resistance, since it would be tedious to assign a very low resistance value to the wires every time we wanted to solve a problem.

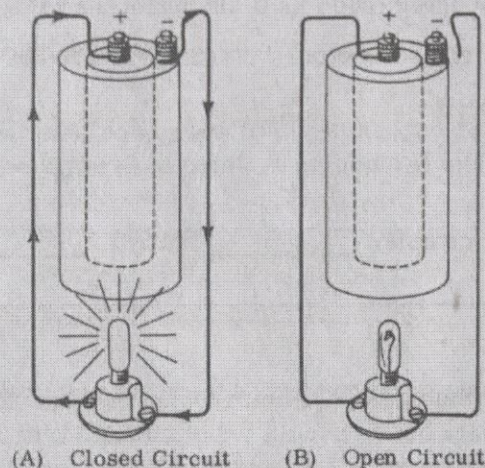


Figure 3-1. (A) Simple electric circuit (closed);  
(B) Simple electric circuit (open).

You can check the circuit in Figure 3-1, View A, to see whether there is a complete pathway for current flow. Start at any point, and go around the circuit only once until you return to your starting point. There is no problem until you try to get from one terminal of the battery to the other. There is current flow inside the battery, but here we have a special case, because we said (in Chapter One) that current flows from negative to positive. This is true outside the battery, in what we call the external circuit, because electrons are negative. Since the negative terminal of the battery repels electrons, the current flow is away from the negative terminal and toward the positive terminal (which attracts electrons). The current flow inside the battery (the internal circuit) results from chemical action, not from the laws of attraction and repulsion, and is from the positive terminal to the negative terminal. This completes the circuit. Once you understand this special case of current flow inside the battery, you need not consider it again. Any consideration of current flow in this book is concerned with current flow in the external circuit.

Figure 3-1 shows a very simple electric circuit that includes only a battery, a light bulb, and the connecting wires. Look at the two drawings and note all the differences you see between drawing (A) and drawing (B).



2. The arrows following the wire, and the "rays" indicating that the bulb is lit, are the artist's way of showing that there is a completed electric circuit in (A) and not in (B). If there is a complete pathway for the flow of electric current, a closed circuit exists. If the pathway is interrupted by a break in the conductor (such as a disconnected wire), the result is an open circuit. Which is the closed circuit, (A) or (B)? \_\_\_\_\_
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- [REDACTED]

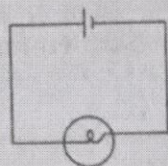
3. Which is the open circuit? \_\_\_\_\_ Why? \_\_\_\_\_
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- [REDACTED]

4. Can you think of any other ways (besides cutting the wire) to cause an open circuit in Figure 3-1? \_\_\_\_\_
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- [REDACTED]

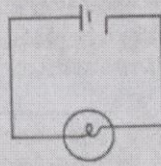
5. The arrows indicate that current flow outside the battery is from negative to positive, but you should know that anyway if you remember the law of attraction and repulsion of charged bodies (Chapter One). Why is the current flow away from the negative terminal? \_\_\_\_\_
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- [REDACTED]

6. Each circuit shown in Figure 3-1 can be represented by a schematic diagram. A schematic diagram (usually shortened to "schematic") is a simplified drawing that represents the electrical, not the physical, situation in a circuit. Circuit elements are indicated by very simple drawings, called schematic symbols, that are standardized throughout the world, with minor variations. The following illustrations are the equivalent schematics for the closed-circuit and open-circuit configurations shown in Figure 3-1.





(A) Closed Circuit



(B) Open Circuit

Now, since there are no arrows to show the direction of current flow, there is only one difference between circuit (A) and circuit (B). What is it?

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7. The drawings in Frame 6 are schematic diagrams representing the electrical situation in a circuit, using standardized symbols. (Conductors are simply lines.) The two schematics in Frame 6 show the symbols in the same positions as the circuit elements they represent in Figure 3-1, but this need not be so. A schematic turned on its side or upside down, or with varying line lengths for the conductors, would still be electrically the same. Compare the schematics with the drawings in Figure 3-1, then draw the symbols for a light bulb (lamp) and a battery in the space below.

light bulb      battery

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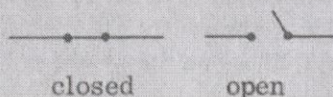
8. By convention, the shorter line in the symbol for a battery represents the negative terminal. It is important to remember this, because it is sometimes necessary to note the direction of current flow, which is from negative to positive, when you examine a schematic. The battery symbol shown in frame 7 has a single cell, so only one short and one long line are used. The number of lines used to represent a battery vary (and they are not necessarily equivalent to the number of cells), but they are always in pairs, with long and short lines alternating. In the circuit shown in frame 6, the current would flow in a clockwise direction; that is, in the direction that a clock's hands move. If the long and short lines of the battery symbol in frame 6 were reversed, the current would flow counterclockwise; that is, in the opposite direction of a clock's hands.

We opened the circuit in Figure 3-1 and in its corresponding schematic (frame 6) by disconnecting a wire from a terminal. Naturally, a switch

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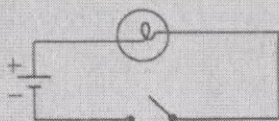


is used for this purpose in most circuits. Here is the schematic symbol for a switch; it may be placed anywhere in the circuit that is convenient.



Draw a schematic for an open circuit that includes a battery, a lamp, and a switch. Connect the battery so the current would flow counterclockwise, and label the battery terminals (+) and (-). Use a separate sheet of paper.

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Here is one possibility. The negative side of the battery is the shorter line. Your battery can have any number of pairs of lines. The other schematic symbols may be shown in any order.

Now that you are familiar with an electric circuit and its equivalent schematic diagram (other symbols will be introduced as you need them), you are ready to examine the relationships of current, voltage, and resistance. The relationships are expressed in Ohm's Law, which is the foundation on which electrical theory is based.

### Ohm's Law

9. A three-cell flashlight casts a brighter beam than a two-cell flashlight using the same size batteries. Flashlights come in different sizes, from the little "penlight" on up. Someone had to decide how much voltage a cell should produce and what kind of bulb should be used, among other things. Flashlight batteries also power toys, clocks, and other devices, so circuits have to be designed to produce the correct amount of current. How does one decide what the relationships of current, voltage, and resistance should be in a circuit? If the voltage source is constant, how much voltage is required to power a device such as a radio or a washing machine? This kind of question is basic in electrical design. To answer such questions, we start with Ohm's Law.

Georg Simon Ohm, a 19th century philosopher, formulated the relationships among voltage, current, and resistance. Ohm's Law states that:

The intensity of the current in amperes in any electric circuit is equal to the difference in potential in volts across the circuit divided by the resistance in ohms of the circuit.

You don't have to memorize the law in words, but you do have to memorize the equation that represents it:

$$I = \frac{E}{R} \quad \text{or} \quad I = \frac{V}{R}$$



Remember that  $I$  represents current expressed in amperes,  $E$  or  $V$  is the difference in potential in volts, and  $R$  represents resistance in ohms. What is the effect on current if resistance is increased?

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\_\_\_\_\_

10. What is another way to decrease current? \_\_\_\_\_
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- \_\_\_\_\_

11. Most of the resistance (sometimes called the load) in a circuit is in the form of components that do specific work, such as a bulb, and certain components, called resistors, whose purpose is to limit current flow. As you have learned, the conductors (wires) themselves have resistance that varies with the size and length of the wire, but it is not practical to limit current flow in this manner. The wire resistance becomes important in advanced electricity, but in this book, you need not consider it. Problems are simplified by ignoring the resistance of the wires. There are no resistors in the simple flashlight, so what component presents most of the resistance? \_\_\_\_\_
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- \_\_\_\_\_

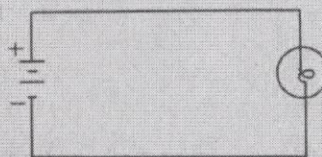


Figure 3-2. Simple electric circuit with a lamp as the load.

Refer to Figure 3-2 for frames 12 through 25.

12. Assume throughout this book that the wiring has no resistance. To use Ohm's Law to solve for current, voltage, or resistance, you have to know two of the values and solve for the third. To find the current flowing in the circuit shown in Figure 3-2, you need to know the values for \_\_\_\_\_ and \_\_\_\_\_.
- 
- \_\_\_\_\_



13. Write the equation for finding the current ( $I$ ) when the voltage ( $E$ ) and resistance ( $R$ ) are known. \_\_\_\_\_  
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14. The lamp in Figure 3-2 is actually a resistor. The resistance of the lamp is  $3\Omega$  and the battery produces 6 v. How much current is flowing in the circuit? \_\_\_\_\_  
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15. The voltage source (battery) produces 10 v. and the resistance of the lamp is  $4\Omega$ . How much current is flowing in the circuit? \_\_\_\_\_  
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16.  $\checkmark = 12 \text{ v.}; R = 4\Omega.$

$I =$  \_\_\_\_\_  
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17.  $\checkmark = 1.5 \text{ v.}; R = 2\Omega.$

$I =$  \_\_\_\_\_  
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18. By now you know that  $I = \frac{E}{R}$ . If you want to solve for E in terms of I and R, you have to manipulate the equation to isolate E. Do so on a separate sheet of paper.
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- \_\_\_\_\_
- \_\_\_\_\_
- \_\_\_\_\_
- \_\_\_\_\_

19. Refer again to Figure 3-2. The current in the circuit is 3 a. and the resistance of the lamp is  $2\Omega$ . How much voltage is produced by the battery?
- \_\_\_\_\_
- 
- \_\_\_\_\_

20. The resistance of the lamp is  $1\Omega$  and the current is 3.73 a. What is the voltage? \_\_\_\_\_
- 
- \_\_\_\_\_

21.  $I = 4$  a.;  $R = 1.5\Omega$ .

$V = E =$  \_\_\_\_\_

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\_\_\_\_\_

22.  $R = 2\Omega$ ;  $I = 0.5$  a.

$V = E =$  \_\_\_\_\_

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\_\_\_\_\_

23.  $E = IR$ . To solve for R, you must manipulate the equation to isolate R. Do so on a separate sheet of paper.
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- \_\_\_\_\_

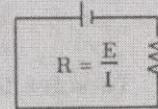
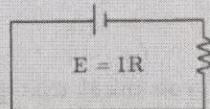
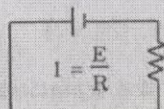


24. Refer again to Figure 3-2. The battery produces 6 v. and the current in the circuit is 2 a. What is the resistance of the lamp? \_\_\_\_\_
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25. A 12-volt battery produces a current in the circuit of 0.5 a. What is the resistance? \_\_\_\_\_
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(Note: The circuit values in these exercises are selected for easy calculation.)

26. You have now used Ohm's Law to solve for all three circuit values: voltage (E), current (I), and resistance (R). It is important to note that resistance (R) is a physical constant. The value of resistance cannot be changed by changing voltage (E) or current (I). Here is an aid to remembering the three basic equations:



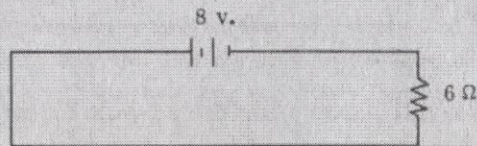


In the preceding circle, cover up the value you wish to solve for, and the rest of the equation is revealed. For example,  $I = \frac{E}{R}$ . Write the equations for E and for R using the memory aid.

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27. A lamp or any other component has resistance. If the purpose of the schematic is to work out relationships among current, voltage, and resistance, the symbol for a resistor may be used instead of that for the actual component. How much current is flowing in this circuit? \_\_\_\_\_



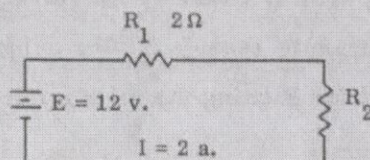
28. Draw the schematic symbol for a resistor. \_\_\_\_\_
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29. The schematic symbol in frame 28 is actually the symbol for a resistance rather than for a resistor only. Any device that consumes power is a resistance. The resistor, which is manufactured to precise specifications and whose function is to limit current, is a resistance, but so is a lamp, an electric iron, or a warming tray. These devices do limit current, and are therefore resistances, but each has a function besides current limiting. When we show the symbol for a resistance in this book, we usually call it a resistor; but remember that the symbol could mean some other kind of resistance.

Of course, the circuit might include more than one resistor. If so, the resistors are usually labeled  $R_1$ ,  $R_2$ , etc., with their respective values. Resistors in series are merely added to get the total resistance. We shall see why this is true later. In the following drawing, what is the value of  $R_2$ ? \_\_\_\_\_

\_\_\_\_\_





30. Without changing the resistors in the circuit, how could you increase the current to 4 a. ? \_\_\_\_\_

### Power

31. Perhaps you have noticed a wheel in your home power-meter that turns when electricity is being used. If the main switch is off, the wheel is at rest, because no power is being consumed. As more lights and appliances draw current, the wheel turns faster. Power, whether electrical or mechanical, pertains to the rate at which work is done, so the power consumption in your home is related to current flow. (You will learn the exact relationship later.) An electric range or dryer consumes more power (and draws more current) in a given length of time than a reading lamp, for example, because more current is required to produce heat than to produce light. (Of course, every device produces some heat.) The ampere is a measure of the rate at which current flows. Power is the \_\_\_\_\_ at which work is done.

32. You might say that an electric range does more work than a reading lamp, but this is true only if the time both appliances are used is the same. If you read a lot and send your clothes to the laundry, your reading lamp could do more work in a year than your dryer. In considering power, we are not concerned with the total amount of work done but the rate at which



it is done. Work is done whenever a force causes motion—even the movement of electrons through a conductor. A dryer uses more current in a given length of time than a reading lamp, so its power consumption is greater. State in your own words what it means to say that a dryer consumes more power than a reading lamp. (Hint: Relate your answer to current flow.) \_\_\_\_\_

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33. If a compressed spring is held in place between two fixed points, a force is exerted on those points, but no work is done. Similarly, if a switch is opened in an electric circuit, a force (difference in potential) exists, but no work is done because no current flows. When the switch is closed, a circuit is completed, current flows, and some kind of work is done; a lamp is lit, perhaps. Only then are we concerned with power. Power is used only in a(n) (open/closed) \_\_\_\_\_ electric circuit.
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34. The basic unit of power, or the rate at which work is done, is the watt. Just as current is measured in amperes, power is measured in \_\_\_\_\_.
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35. Power ( $P$ ) is directly related to the voltage ( $E$ ) across a circuit and the current ( $I$ ) flowing in the circuit. One watt represents the amount of power consumed when the difference in potential of one volt produces a current of one ampere. Power ( $P$ ) is equal to voltage ( $E$ ) multiplied by current ( $I$ ). Write the equation that states this mathematically.  $E = V$
- \_\_\_\_\_
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36. A 10-volt battery is the voltage source for a circuit whose total resistance is  $5\Omega$ . Before you can solve for the power in the circuit, you must first solve for \_\_\_\_\_.
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- \_\_\_\_\_



37. What is the equation for current when voltage and resistance are given?

\_\_\_\_\_

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38. What is the current in the circuit described in Frame 36? \_\_\_\_\_

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39. What is the equation for power (P) when voltage (E) and current (I) are given? \_\_\_\_\_

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40. What is the power in the circuit described in Frame 36? \_\_\_\_\_

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41. In Frame 36, E and R were given. But because you knew only the power equation,  $P = EI$ , you had to solve for I before you could arrive at P. There is, of course, a short cut.

(1)  $P = EI$

(2) Substitute the equivalent of I in terms of E and R. You can do this, since you know that  $I = \frac{E}{R}$ .

(3)  $P = E \left( \frac{E}{R} \right)$

(4)  $P = \frac{E^2}{R}$

If the voltage in a given circuit is 4 v. and the resistance is  $4\Omega$ , what is the power? (Use the equation just developed.) \_\_\_\_\_

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42. The circuit voltage is 2 v. and the resistance is  $12\Omega$ . What is the power?

\_\_\_\_\_  
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43.  $E = 3$ ;  $R = 2$ .

$P =$  \_\_\_\_\_  
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44. You can work the mathematics for power when current and resistance are given, without solving first for voltage.

(1)  $P = EI$

- (2) Substitute the equivalent of  $E$  in terms of  $I$  and  $R$ . Remember that  $E = IR$ .

(3)  $P = IR(I)$

(4)  $P = I^2R$

If the current in a given circuit is 4 a. and the resistance is  $10\Omega$ , what is the power? \_\_\_\_\_  
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45. The circuit current is 0.5 a. and the resistance is  $12\Omega$ . What is the power? \_\_\_\_\_  
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46.  $I = 4 \text{ a.}; R = 2\Omega.$

$P =$  \_\_\_\_\_  
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47. Write the equation for  $P$  when  $E$  and  $I$  are given. \_\_\_\_\_  
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48. Write the equation for  $P$  when  $E$  and  $R$  are given. \_\_\_\_\_  
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49. Write the equation for  $P$  when  $I$  and  $R$  are given. \_\_\_\_\_  
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You probably know that an electric dryer or stove requires a higher voltage than most other appliances in the home. The conversion of electrical energy into heat uses much more current than a radio or electric drill, for example, so some devices require more voltage—and heavier wiring to protect them from damage. Power calculations are quite important in advanced electricity and electronics, but one important application of power theory is discussed in the next section.

If you plan to take a break pretty soon, do it now.

#### Rating of Electrical Devices by Power

50. When you replace a burned-out light bulb, how do you decide which new bulb to select as a replacement? \_\_\_\_\_  
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51. Light bulbs, soldering irons, and motors are a few of the electrical devices that are rated in watts. The wattage rating of a device indicates the rate at which the device converts electrical energy into some other form of energy, such as heat, light, or motion. An electric lamp converts electrical energy into \_\_\_\_\_.
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- \_\_\_\_\_
- \_\_\_\_\_

52. In the kitchen, electrical energy is converted into light or into mechanical energy (in the case of a blender, for example). If you have an electric range, electrical energy is also converted into \_\_\_\_\_.
- 
- \_\_\_\_\_

53. The greater the wattage of an electrical device, the greater the rate at which electrical energy is converted to another form. A 100-watt bulb produces more light than a (50/150) \_\_\_\_\_ -watt bulb.
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- \_\_\_\_\_

54. A soldering iron converts electrical energy into heat. Soldering irons are rated in watts. State in your own words the difference between a 300-watt and a 500-watt soldering iron. \_\_\_\_\_
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- \_\_\_\_\_
- \_\_\_\_\_

55. Since power is related to voltage, current, and resistance, electrical devices produce their rated power only if they are operated at the correct circuit values. In a home electrical circuit, only the (current/voltage/resistance) \_\_\_\_\_ is constant.
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- \_\_\_\_\_

56. Electrical devices are rated for voltage as well as wattage (power). A device will draw the proper amount of current only if the correct voltage is applied. A light bulb, for example, is designed to produce a certain \_\_\_\_\_
- \_\_\_\_\_



amount of light. To do so, it must be operated at a voltage that will result in the right amount of current, and the proper power consumption, to produce that much light. If the applied voltage is too low, the light will be dimmer than is desired. If too much voltage is applied, the light will be brighter, and it will probably burn out, because it draws too much current for its filament to withstand safely. A light bulb is labeled with its wattage, such as 100 w., and also with its proper voltage, which is usually 115 v. (standard house voltage). If a 115-volt lamp is plugged into a 230-volt circuit, what happens to the current? \_\_\_\_\_

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\_\_\_\_\_

57. Let's see how this wattage and voltage rating works. A 100-watt lamp is rated for 110 v. When it is turned on, how much current flows in its circuit? (Hint: Remember the equation,  $P = EI$ .) In this and other problems, you may round off your answer to two decimal places for simplicity.
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- 
- \_\_\_\_\_
- \_\_\_\_\_
- \_\_\_\_\_
- \_\_\_\_\_

58. If the same 100-watt lamp is plugged into a 220-volt circuit, how much current flows? (Hint: Calculate the resistance of the filament from Frame 57.) \_\_\_\_\_
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- \_\_\_\_\_

59. How much power is now consumed by the lamp? (Hint: The lamp is rated at 100 w., but it could consume much more power momentarily before it burns out.  $E = 220$ ;  $I = 1.82$ .) \_\_\_\_\_
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Note that the power did not merely double when the circuit voltage was doubled. The power quadrupled. (The answer was not exactly 400 w. because some values had been rounded off earlier.) That is because not only the voltage but the current doubled. The bulb would probably burn out when \_\_\_\_\_



the lamp is plugged into the 220-volt circuit. Its life would certainly be shortened. If the normal wattage rating of a device is exceeded (by using an incorrect voltage), it will overheat and will probably suffer damage. Now let's see how electrical devices are rated to prevent damage.

### Power Capacity of Electrical Devices

60. The wattage rating of a light bulb indicates its ability to do work. A 100-watt light bulb, for example, is expected to produce a certain amount of light when it is used in its normal circuit. However, the wattage rating of some devices indicates operating limits. A resistor is one such device. It is designed to be used in circuits with widely varying voltages, depending on the desired current. But each resistor has a maximum current limitation for each voltage applied. The product of the voltage drop across a resistor and the current through it (the result when these values are multiplied) must not exceed a certain wattage, since this wattage indicates the maximum safe power consumption. (Remember,  $P = EI$ .) A 10-watt resistor subject to 10 v. has a maximum current limitation of 1 a. because this combination of voltage and current results in a power consumption of 10 w. If the voltage across the resistor is increased, less current is needed to produce the same power, so the maximum current limitation of the resistor will be less. If the voltage across our 10-watt resistor is 20 v., what is the maximum current that can safely flow through the resistor without damage? \_\_\_\_\_
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61. All the resistors in Figure 3-3 are labeled with their wattage rating.

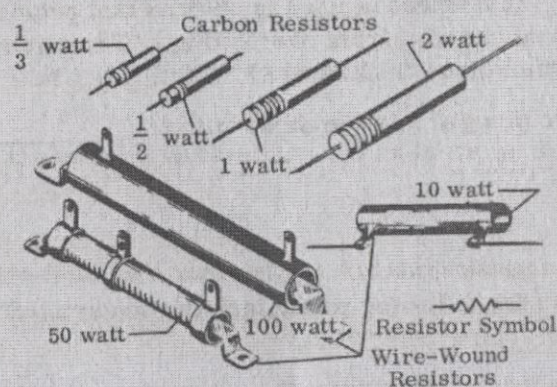


Figure 3-3. Resistors of different wattage ratings.

Small resistors are color-coded for these values; larger resistors are stamped with their resistance in ohms. The two most common types are carbon resistors and wire-wound resistors. Resistors rated at 2 w. and



under are usually carbon resistors. What type of resistors are used for higher wattage ratings? \_\_\_\_\_

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62. From your examination of the carbon resistors in Figure 3-3, what can you say about the relationship of the size of a resistor to its wattage rating? \_\_\_\_\_

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63. Resistors with ratings of 2 watts or less are generally carbon, while wire-wound resistors are usually made in ranges of 2 to 200 watts. (Resistors with higher wattage ratings are of special construction.) Opposite the ratings shown below, indicate the probable construction of a resistor with that rating.

$\frac{1}{2}$  w. \_\_\_\_\_

50 w. \_\_\_\_\_

1 w. \_\_\_\_\_

150 w. \_\_\_\_\_

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64. When current passes through a resistor, electric energy is transformed into heat, which raises the temperature of the resistor. If the temperature becomes too high, the resistor may be damaged. In a wire-wound resistor, the metal wire may melt, opening the circuit and interrupting current flow. This effect is used in devices that protect household (and other) electrical circuits from overloading. From your own experience, what do you think these devices are? (Hint: They will "blow" if too many appliances are plugged into the same outlet.) \_\_\_\_\_

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65. Figure 3-4, on the following page, includes the symbol for a fuse. It is labeled  $F_1$ .

Look at the figure, then draw the schematic symbol for a fuse.

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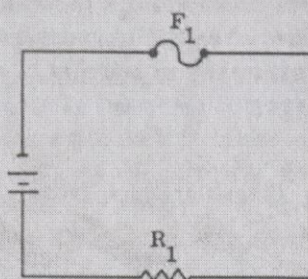


Figure 3-4. Simple circuit that includes a fuse and a resistor.

66. Fuses are actually metal resistors with very low resistance values. They are designed to "blow" when the current exceeds a certain value. A circuit that includes a resistor and a fuse is shown in Figure 3-4. Must the current that flows through the resistor also flow through the fuse? \_\_\_\_\_
- 
- \_\_\_\_\_

67. The fuse ( $F_1$ ) in Figure 3-4 is rated at 0.5 a. and has a resistance of  $1\Omega$ .  $R_1$  has a value of  $29\Omega$ . The applied voltage is 6 v. What is the current in the circuit? \_\_\_\_\_
- 
- \_\_\_\_\_

68. Will the fuse blow? (Yes/No) \_\_\_\_\_, because \_\_\_\_\_
- 
- \_\_\_\_\_

69. If  $R_1$  in Figure 3-4 has a value of  $7\Omega$  and the voltage remains unchanged (6 v.), what is the circuit current? \_\_\_\_\_
- 
- \_\_\_\_\_

70. Will the fuse blow? Explain. \_\_\_\_\_
- 
- \_\_\_\_\_



Yes, because the current now exceeds the rated value of the fuse.  
 (Note: The fuse will blow when the current exceeds 0.5 a. The current is now 0.75, or 50 percent over maximum.)

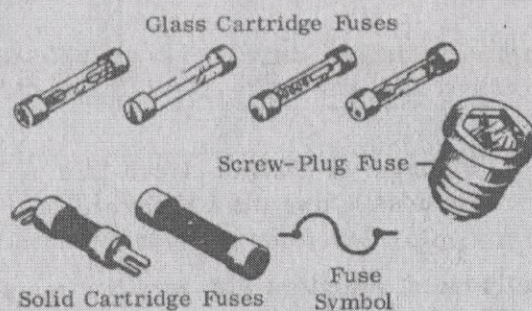


Figure 3-5. Typical fuse types.

Figure 3-5 shows some typical types of fuses. The screw-plug fuse is commonly used for most house circuits, but solid cartridge fuses are used for heavier-duty circuits such as those for the kitchen range and the clothes dryer. Automobile accessory circuits, such as the radio, usually have glass cartridge fuses. Circuit breakers, which are merely reset, are now becoming more and more common. The breaker is "thrown" when the current exceeds the rated value for the circuit breaker.

A subject closely related to power is energy, the subject of the next section.

### Energy

So far in this chapter we have dealt with two basic concepts—current flow and power. Before we move on to still another related concept—energy—it might be a good idea to tie together the material covered so far.

All three values included in Ohm's Law (voltage, current, and resistance) are related to one thing: current. Voltage is the "pressure" that causes current to flow, and resistance is the factor that limits the current flow when voltage of a given value is applied.

Power, too, is related to current, because no work is done (and therefore, no power is consumed) unless there is current flow. All of the power equations involve current. Either current ( $I$ ) is directly included in the equation, or it affects the other values ( $E$  and  $R$ ) in the equation.

Thus, Ohm's Law deals directly with current and the other variables that affect it ( $E$  and  $R$ ), while power is directly related to the current flow in a circuit.



71. Energy is defined as the ability to do work. When the archer draws the bow string, for example, the ability to do work is present, but no work is done until the arrow is released. Then the potential for work (energy) is converted to work actually done (power consumption). Energy is expended when work is done, because it takes energy to maintain a force when that force does work. In electricity, energy (W) is equal to the rate at which work is done, or power (P), multiplied by the length of time (t) the rate is measured. Circle the equation below that expresses this mathematically.

$$W = Pt$$

$$P = \frac{W}{t}$$

72. The symbol for energy, W, comes from "watt." Remember that energy is the rate at which work is done, and "rate" implies a time. Miles per hour and feet per second are both rates. In electricity, W will be in watt-hours if time (t) is in hours. If it is expressed in seconds, W will be in

73. An hour is usually too large a measure for calculations in electricity. The second is much more convenient. Let's return for a moment to our basic power equation,  $P = EI$ . Assume a very simple circuit in which a 1-volt battery causes current flow of 1 a.  $P = \underline{\hspace{1cm}} \times \underline{\hspace{1cm}}$ , or  $\underline{\hspace{1cm}}$  w.

74. Power is consumed in the circuit only while current is flowing. Since 1 a. of current flowed with 1 v. applied to the circuit, the power consumed was 1 w. But how much energy was responsible for that amount of power consumption in one second? Simply apply the energy equation,  $W = Pt$ . The energy, or rate at which work is done, is 1  $\underline{\hspace{1cm}}$  -  $\underline{\hspace{1cm}}$ .



75. Another term for "watt-second" is joule, pronounced "jule." In a given circuit,  $W$  is calculated to be 300 watt-seconds. Another way to express  $W$  in this circuit is 300 \_\_\_\_\_.

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\_\_\_\_\_

76. You are billed for energy used in your house by kilowatt-hours. ("Kilo" is a prefix that means 1,000; thus, one kilowatt is equal to 1,000 watts.) Just for fun, assume your electric bill shows that you used 10 kilowatt-hours and translate this figure into joules. \_\_\_\_\_

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\_\_\_\_\_  
\_\_\_\_\_

77. A 10-volt circuit has a total resistance of  $4\Omega$ , and current flows for 2 seconds.  $P =$  \_\_\_\_\_

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\_\_\_\_\_

78. In the circuit described in Frame 77,  $W =$  \_\_\_\_\_.

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\_\_\_\_\_  
\_\_\_\_\_

79.  $E = 20\text{ v.}$ ;  $I = 4\text{ a.}$ ;  $t = 3\text{ seconds.}$

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

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\_\_\_\_\_  
\_\_\_\_\_

80.  $E = 15\text{ v.}$ ;  $I = 6\text{ a.}$ ;  $t = 2\text{ seconds.}$

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

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\_\_\_\_\_  
\_\_\_\_\_

81.  $I = 6\text{ a.}$ ;  $R = 2\Omega$ ;  $t = 4\text{ seconds.}$

$W =$  \_\_\_\_\_

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82. Figure 3-6 shows the schematic diagram of an unknown device, represented electrically by a single resistor,  $R_2$ , enclosed in a dashed-line box. Device X actually consists of several components, but we are interested only in its total resistance. If you can solve for current, power, and energy, you understand the essential concepts presented in this chapter.

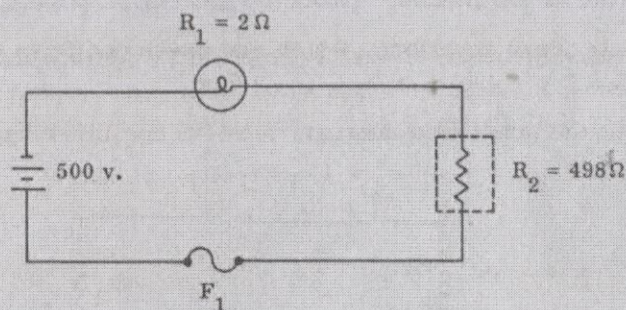


Figure 3-6. Schematic diagram of Device X.

The light,  $R_1$ , indicates when the device is running. A timer in Device X opens the switch 5 seconds after power is applied. When the device shuts off, a button must be pressed to restart it.

Assume for simplicity that the fuse and wiring have no resistance.

1. Total current flow is \_\_\_\_\_.
2. Power consumed during the running time of Device X is \_\_\_\_\_.
3. The energy developed in the circuit is \_\_\_\_\_.

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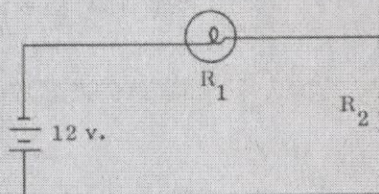
You have learned to apply Ohm's Law to solve for voltage, current, and resistance. You have built on that basic information to solve for power consumption and energy in a simple electric circuit. You have also become aware that electrical devices can be damaged if the power consumption is beyond their capacity. And you have begun to use the schematic symbols and equations that will be your shorthand as we go further into electrical theory. Now proceed to the Self-Test.



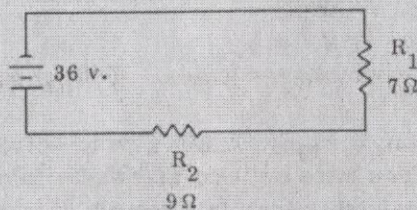
## Self-Test

The following questions will test your understanding of Chapter Three. Write your answers on a separate sheet of paper and check them with the answers provided following the test.

1. Draw a schematic diagram of an electric circuit that includes (a) a battery, (b) a resistor, (c) a lamp, (d) a fuse, and (e) a switch in the open position. Show the battery connected so that current would flow counter-clockwise in the circuit. Label the battery terminals (+) and (-).
2. Complete these equations, which are developed from Ohm's Law.  
(a)  $I = ?$       (b)  $E = ?$       (c)  $R = ?$
3. Refer to the schematic diagram to solve the following problems.



- (a)  $R_1 = 3\ \Omega$ ;  $R_2 = 9\ \Omega$ .  $I = ?$
  - (b)  $R_1 = 5\ \Omega$ ;  $I = 2\text{ a.}$   $R_2 = ?$
  - (c)  $R_1 = 7\ \Omega$ ;  $R_2 = 25\ \Omega$ . To produce a current of  $0.75\text{ a.}$ , remove the 12-volt battery and replace it with a battery of how many volts?
4. Write the power equation for each set of known values listed: (a) Voltage and current are known; (b) Voltage and resistance are known; (c) Current and resistance are known.
  5. Write the equation for energy when power and time are known.
  6. Refer to the schematic diagram to solve the following problems.



- (a)  $P = ?$
  - (b) The current flows for 3 seconds before the circuit is opened.  
 $W = ?$
  - (c) How much energy will be developed in the circuit if a 24-volt battery is substituted for the 36-volt battery and current flows for 3 seconds?
7. How much current is used to illuminate a 100-watt light bulb rated at 115 v.?
  8. A resistor rated at 2 watts is probably wire-wound or carbon?
  9. Name two devices used to protect circuits from overloads.
  10. What is the difference between power and energy in an electric circuit?