CHAPTER TWO
Understanding Voltage, Current, and Resistance

Throughout most of this book, you will be working with electric circuits. Later in the book, you will learn in detail just what an electric circuit is. For now, you only need to know that it is a complete path for current flow from a battery, or some other source of voltage, through one or more conductors back to the voltage source.

While you will have to understand various circuit factors from time to time, you will almost constantly manipulate values assigned to the three basic circuit factors: voltage, current, and resistance. These three variables are interrelated, so first you must know what they are and how each affects the total electric circuit.

You will also have to know something about magnetism, since alternating-current theory is based on this phenomenon. Magnetism will be discussed in Chapter Six.

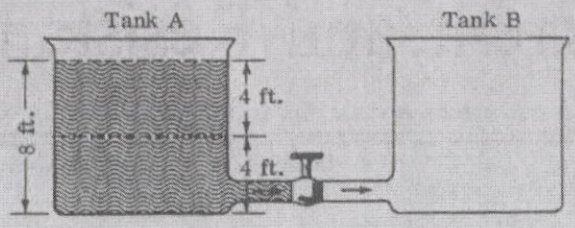
When you have finished this chapter, you will be able to:

- relate electromotive force (voltage) to the flow of electric current;
- describe the difference between direct current and alternating current;
- describe the function of resistance in limiting current flow and the factors that affect resistance;
- write and use the symbols representing voltage, current, and resistance;
- describe some general methods of producing voltage; and,
- distinguish between wet-cell and dry-cell batteries and describe their components.

Difference in Potential

1. Just as water pressure causes water to flow in pipes, an electrical "pressure," called a difference in potential, causes current to flow in a conductor. Since a difference in potential causes current flow, you need to understand what this is before you can grasp the concept of current

flow. In the drawing below, part of the water in Tank A will flow into Tank B when the valve is opened. Draw a line across Tanks A and B to indicate where you think the water level will be after the water has stopped flowing.



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2. Why do you think part of the water flowed into Tank B when the valve was opened? _____

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3. The "water tank" analogy is useful in understanding one of the basic concepts in electricity: difference in potential. The force that causes free electrons to move in a conductor as electric current is known as the difference in potential. It is also called electromotive force (emf); but you are probably familiar with the most common term, voltage. All three of these terms are interchangeable. In dealing with electricity we naturally need some units of measurement. The unit of measurement of voltage is very common and similar to the word "voltage." What do you think that unit of measurement is? _____

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4. When a difference of potential exists between two charged bodies that are connected by a conductor, electrons will flow along the conductor. This flow is from the negatively charged body to the positively charged body. Why is this so? _____

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5. The water stops flowing between two tanks when the pressure on the two tanks is equal. The force with which the water flows, however, is not constant. When do you think that force is greatest? _____

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6. The force with which the water flows between the tanks is directly proportional to the pressure differential. Similarly, current flow through an electric circuit is directly proportional to the difference in potential (or voltage) across the circuit. What happens to current flow when the difference in potential is increased? _____

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7. If voltage is increased, current is _____. If voltage is decreased, current is _____.

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8. What is the effect on current flow if the voltage is doubled? _____

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9. "Voltage" is also called _____ or _____.

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10. The abbreviation for "electromotive force" is _____.

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11. Tell in your own words what is meant by the statement, "Current is directly proportional to voltage." _____

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Electric Current

12. The drift or flow of electrons through a conductor is called electric current or electron flow. Some conventional textbooks make a distinction between current flow and electron flow. Everyone concedes that electron flow is from a negative to a positive terminal, since electrons are negative, and like charges repel. However, some authorities think of current flow as from positive to negative. Since the concepts of "positive" and "negative" are constantly encountered in the theory of electricity, it is important to avoid any confusion about the direction of current flow. In this book, we will make no distinction between current flow and electron flow. The terms current flow and electron flow are interchangeable; therefore, the direction of current flow is from _____ to _____.

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13. Electric current is generally classified into two general types: direct current (dc) and alternating current (ac). Direct current does not change its direction of flow. Alternating current periodically reverses direction. These two types of current will be discussed thoroughly later in the book. The common battery is a source of direct current. Does the current flow from a battery change direction? _____

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14. The current that lights your house changes direction many times per second. What type of current is it? _____

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15. What is direct current? _____

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16. What is alternating current? _____

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17. The greater the voltage, the greater the current flow. Current is measured in amperes (often called "amps" for short). One ampere may be defined as the flow of 6.28×10^{18} electrons per second past a fixed point in a conductor (but you don't have to know that). Since both quantity and time are involved, the ampere indicates a rate of current flow. Your house fuses (or circuit breakers) are rated in amperes; that is, the rate of current flow that will blow the fuse or trip the circuit breaker. A fuse will blow when too many _____ of current flow in its circuit.

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18. The ampere is a measurement of the rate of current flow. The unit that measures the quantity of electrons is the coulomb, which is defined as one ampere of current flowing for one second. If we want to measure the quantity of electrons, rather than the rate of current flow, what unit would we use? _____

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19. Thus, electromotive force (the "pressure" that causes electrons to move) is measured in _____. The rate of flow of electric current is measured in _____. The quantity of electrons is measured in _____.

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20. Each of these units has a standard symbol that is used in circuit drawings and equations. The symbol for voltage is the first letter of the phrase, "electromotive force," E or V. Symbol for the quantity of electricity, which is measured in coulombs, is Q. The rate of current flow, which is measured in amperes and is very important in the study of electricity, is represented by the symbol I. Write the symbols corresponding to the units of measurement listed below.

ampere _____

coulomb _____

volt _____

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21. For each of the following symbols, name the unit represented and tell what the unit measures.

Q _____

V=E _____

I _____

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Resistance

22. In Chapter One you learned about good conductors and poor conductors (insulators). You learned that free electrons, or electric current, could move easily through a good conductor, such as copper, but that an insulator, such as glass, was an obstacle to current flow. Every material—even copper or silver—offers some resistance, or opposition, to the flow of electric current through it. If the material offers high resistance to current flow, it is termed an insulator. If its resistance to current flow is low, it is called a conductor. The amount of current that flows in a given circuit depends on two factors: voltage and resistance (represented by the symbol R). Thus the amount of current that flows in a circuit can be changed by changing either _____ or _____.

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23. The unit of resistance is the ohm, named for the man who developed Ohm's Law, which you will study in Chapter Three. Resistance, as the word implies, is the ability of a material to impede the flow of electrons. (If you later study advanced electricity, you will encounter another concept of electricity, conductance, which is the opposite of resistance, but you do not need this concept to understand the material in this book.)

Current is measured in amperes, and voltage is measured in volts.

Resistance is measured in _____.

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24. The abbreviation for "volts" is "v." "Amperes" is abbreviated "a." But the small letter "o" looks too much like "a," and "ohm" would be awkward and tiresome to indicate values of resistance. Thus the Greek letter omega (Ω) is used as an abbreviation for "ohms." "Ten amperes" is abbreviated "10 a." Write the abbreviation for "10 ohms" below.

_____

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25. Give the abbreviations for the following units of measurement.

amperes _____

volts _____

ohms _____

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26. The wires that carry current in an electric circuit are usually made of copper, because it is both a good conductor and relatively inexpensive. But the size of the wires is a factor, too. Just as water flows more easily (at a given pressure) in a large pipe than in a small one, electric current flows more easily (at a given voltage) in a large (greater diameter) wire than in a small one. In an electric circuit, at a given voltage, the larger the diameter of the wires, the (higher/lower) _____ will be the current flow.

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27. If voltage is held constant, current flow depends on the resistance of the wires (and other devices) in the circuit. A larger diameter wire offers less resistance to current flow than a smaller diameter wire, but one other factor affects the total resistance to current flow: the length of the wires. Since the material of the wires offers resistance to current flow, increasing the amount of material (for a given diameter) increases total resistance. Increasing the length of the wires in an electric circuit has what effect on resistance? _____ _____ This in turn has what effect on the amount of current flowing in the circuit? _____ _____

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28. It would not be practical to change the rate of current flow by changing the size or length of the wires. Electrical circuits require varying amounts of current flow for different uses. For that reason, parts are manufactured that present precise amounts of opposition or resistance to current flow. These devices are called, not very surprisingly, resistors. The amount of resistance is measured in ohms. (Although you don't need to know it at this point, one ohm is the resistance in a circuit that permits a steady current of one ampere—one coulomb per second—to flow when a steady emf of one volt is applied to the circuit.) If you want to increase the current flow in a circuit, one way is to take out a resistor and replace it with one rated at (more/fewer) _____ ohms.

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29. Without changing the wiring or values of resistors, how could you increase current flow? _____

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30. How does increasing the diameter of the wires affect resistance?

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31. Increasing the length of the wires in a circuit has what effect on resistance? _____

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32. Increasing the voltage applied to a circuit has what effect on current flow? _____

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33. Without changing the wiring, resistors, or other devices in a circuit, how could you decrease current flow? _____

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34. Later you will use the symbols E, I, and R in equations to solve problems involving electric circuits, so it is important that you remember them. The symbol for voltage is _____; for current, _____; and for resistance, _____.

V is also used for voltage.

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Primary Methods of Producing a Voltage

35. There are many ways to produce electromotive force, or voltage. On the following page, match the six most common methods in the first column with their appropriate descriptions in the second column.

_____ 1.	FRICTION	(a) Voltage produced by heating the junction where two unlike metals are joined.
_____ 2.	PRESSURE	(b) Voltage produced in a conductor that is moved in a magnetic field.
_____ 3.	HEAT	(c) Voltage produced by squeezing certain crystals (piezoelectricity).
_____ 4.	LIGHT	(d) Voltage produced by the use of certain photosensitive substances.
_____ 5.	CHEMISTRY	(e) Voltage produced in a battery cell.
_____ 6.	MAGNETISM	(f) Voltage produced by rubbing two materials together.

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36. In understanding the fundamentals of electricity, you will be most concerned with chemistry and magnetism as means to produce voltage. Friction has little practical application, although we discussed it earlier in studying static electricity. Heat, light, and pressure do have useful applications, but we do not need to consider them in the early stages of study. Chemistry and magnetism, on the other hand, are the principal sources of voltage. Anyone who drives a car is familiar with one of these voltage sources, because if it is dead or missing, the car can't be started. This voltage source, which uses chemistry as its basis, is the

_____.

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37. But the battery alone cannot keep the automobile running. A generator, or alternator, supplies the voltage necessary for running the engine and keeping the battery charged. This device operates by moving a conductor in a magnetic field. Thus, an understanding of both chemical action and magnetism is necessary to understand practical electricity. A generator produces alternating current and uses the principles of magnetism. A battery employs which of the six methods of producing voltage?

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Batteries

38. Batteries are widely used as sources of direct-current electrical energy in automobiles, boats, aircraft, portable electric and electronic equipment, and lighting equipment. A battery consists of a number of cells assembled in a common container and connected together to function as a source of electrical power. The ordinary flashlight battery is not actually a battery but a cell, according to this definition, because two or more "batteries" (which are actually cells) operate together to provide the power. Which parts of a flashlight make up the true battery? _____

_____

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39. The cell is the device that transforms chemical energy into electrical energy. It consists of a positive electrode (carbon), a negative electrode (zinc), a chemical solution, and a glass container. The chemical solution is the electrolyte.

Aside from the container in which they are assembled, the basic parts of a simple cell are: two _____, and a chemical solution called the _____.

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40. The basic device that transforms chemical energy into electrical energy is the _____.

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41. A _____ consists of two or more cells assembled in a common container to produce electricity.

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42. What is the relationship between a cell and a battery? _____

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43. The cells of a battery are like "mini-batteries." The battery has internal electrical connections between the cells, and then the battery provides power to some external circuit. Each cell provides part of the power to the entire circuit. The electric current that flows in a circuit "powered" by a cell consists of free electrons that leave the (negative/positive) _____ electrode and return to the cell through the (negative/positive) _____ electrode. (Hint: Like charges repel.)

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44. The simple cell consists of two electrodes suspended in a chemical solution called an <u>electrolyte</u>. (The electrodes are usually strips, rods, or sheets of two different materials. The most common materials are carbon and zinc, but you don't need to know that for this book.) The battery works because of the interaction between the chemical solution and the two dissimilar materials. Thus, you might say that chemical energy results from the interaction of the two different materials, called _____, and the chemical solution, called the _____.

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45. Batteries are classified as either <u>wet-cell</u> or <u>dry-cell</u> batteries. The difference lies in the form of the electrolyte. The wet cell has a liquid electrolyte, but the dry cell is not completely dry; its electrolyte is actually a damp paste. (If it were completely dry, there would be almost no chemical action.) A common example of the wet-cell battery is the storage battery in an automobile. An example of the dry-cell battery is the common flashlight. The major difference between a wet-cell battery and a dry-cell battery is in the form of the _____.

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46. What general type of battery has cells whose electrodes are suspended in a liquid electrolyte? _____ Which type has an electrolyte that is a wet paste? _____

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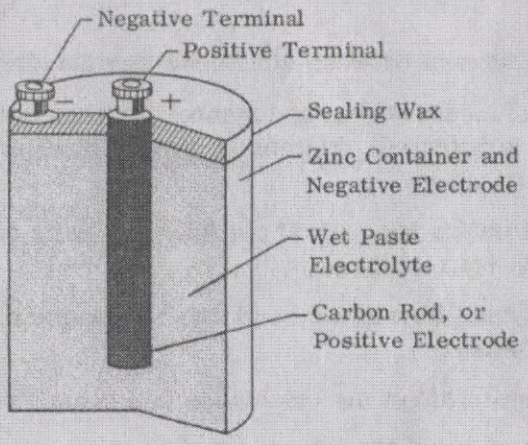
47. For most applications, a dry cell is more convenient as the basic unit of a battery. Shown here is a cutaway view of a typical dry cell.



Which part of the cell is the negative electrode? _____

Which part is the positive electrode? _____

Which electrode is buried in the electrolytic paste? _____

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You are now able to relate electromotive force (difference in potential) to the flow of electric current and to describe how resistance limits current flow. You have become familiar with the symbols representing voltage, current, and resistance. You have learned some general methods of producing voltage as well as the types and composition of one such method: batteries. Now complete the Self-Test.

Self-Test

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

1. One battery terminal is negative and the other is positive. What force of "pressure" causes current to flow in the circuit connecting the terminals?
2. Why is current flow in a battery-powered circuit from the negative terminal to the positive terminal?
3. What is the effect on the rate of current flow if the voltage is reduced by 50 percent?
4. What is the difference between direct current and alternating current?
5. Give the unit of measurement and symbol for each of the following: (a) difference in potential; (b) rate of current flow; (c) quantity of electricity; (d) resistance.
6. Give the abbreviation for each of the following units of measurement: (a) ampere; (b) volt; (c) ohm.
7. The rate of current flow in a circuit can be changed by changing what other two variables?
8. What three factors affect the resistance in a circuit?
9. Give two ways of increasing the resistance of the circuit wiring.
10. What are the two most widely used methods of producing a voltage?
11. What method of producing a voltage is used in batteries?
12. What is the relationship between a cell and a battery?
13. Current flows away from what electrode of a cell?
14. What are the two basic components that cause a cell to produce electricity?
15. What is the major difference between a wet cell and a dry cell?
16. What is the form of the electrolyte of a dry cell?