LIFEPAC®

SCIENCE

STUDENT BOOK

12th Grade | Unit 7

Alpha Omega
PUBLICATIONS

SCIENCE 1207
ELECTRIC CURRENTS

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Alpha Omega PUBLICATIONS

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Electric Currents

Introduction

Science LIFEPAC® 1206 dealt with the nature of static electricity and was the first LIFEPAC in electrophysics, the relation of the electrical nature of matter to physical systems. This LIFEPAC will deal with the laws of current flow, the electrical conductivity and resistance that regulate current flow, and basic electrical circuits. These topics will be a natural step from the LIFEPAC on static electricity and will follow the historical development in the knowledge of both electricity and electric circuits. Our present electronic age is built upon these principles. Since we know of no exceptions to these rules, we consider them as electrical laws. The same laws apply both to outer space and to the northern lights. Electric currents flow all the way from the sun to the earth, and the same laws apply that are given in this LIFEPAC.

Electric currents are part of the invisible creation, since we cannot see currents flow. They obey well defined laws, however; and we shall study these invisible laws that the Creator built into the universe and thus better understand the order and beauty He has built into this system.

Objectives

Read these objectives. The objectives tell you what you will be able to do when you have successfully completed this LIFEPAC. When you have finished this LIFEPAC, you should be able to:

1. Trace the conceptual development of electric current.
2. Define electromotive force and list two sources.
3. Cite parallels between fluid flow and charge flow.
4. Develop a mathematical expression for resistance of a conductor.
5. Apply Ohm's law to series and parallel circuits.
6. Solve problems involving electrical power.

Survey the LIFEPAC. Ask yourself some questions about this study and write your questions here.

1. CURRENT

The early ideas of electricity were the results of the experiments conducted by William Gilbert. He concluded that two basic types of electric charges exist. Later, Benjamin Franklin named the two types of charges, *positive* and *negative*, according to the way in which they were generated.

The force law that charges obey is called Coulomb's law. It is given in the following form:

$$F = K\frac{Q_1Q_2}{r^2}$$

K is a constant that depends on the system of units, Q_1, and Q_2 are charges on objects, and r is the separation between the charged objects. Coulomb's law predicts that unlike charges attract with a force F that varies inversely as the square of the distance between the charged bodies.

Although individual and static charges behave according to Coulomb's law, charges in motion are described somewhat differently. Electric currents behave analogously to fluid flow; in fact, electricity was considered a fluid. Work must be done on fluid to give it the potential energy to do work; and the characteristics of the channel, or **conduit**, will affect the work done.

Section Objectives

Review these objectives. When you have completed this section, you should be able to:

1. Trace the conceptual development of electric current.
2. Define electromotive force and list two sources.
3. Cite parallels between fluid flow and charge flow.

Vocabulary

Study these words to enhance your learning success in this section.

analogy	**conductance**	**conduit**
potential	**potential drop**	

Note: *All vocabulary words in this LIFEPAC appear in* **boldface** *print the first time they are used. If you are not sure of the meaning when you are reading, study the definitions given.*

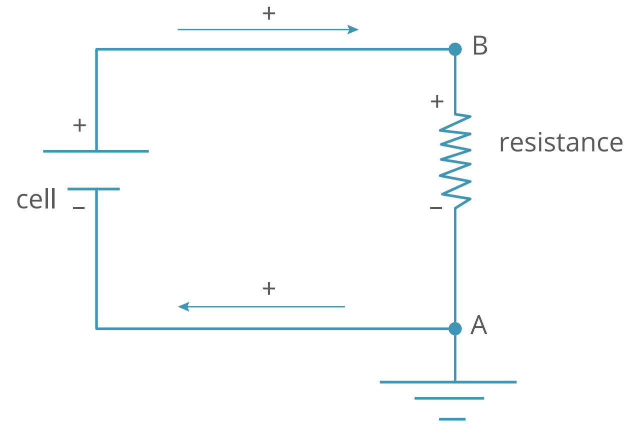
CONCEPTS

The preceding LIFEPAC (Science 1206) covered early experiments on the nature of static charges. When charges are caused to flow in a conductor (for instance, a wire), this flow is called an *electric current*. The flow of an individual charge between two charged objects is very rapid and is difficult to study. What was lacking in the early days was a source of steady current.

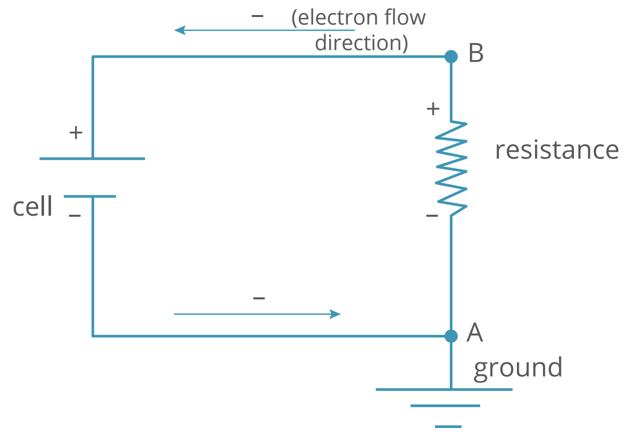
Positive charge flow. Steady currents became possible when the Italian physicist, Alessandro Volta (1745–1827), invented the electric (voltaic) cell. The voltaic cell made possible the production of steady currents and, thereby, a means for producing steady voltages in an electrical circuit. The current was first considered to be a flow of positive charges. The charge flow had to be "downhill" from the terminal of high potential to the terminal of low potential. The current was considered to flow as Figure 1 illustrates. Positive charges flowed out of the cell and flowed "down" to the return terminal of the battery, which was negative. The result was an expenditure of energy across the resistance. Again, the positive side of the resistance was where the positive charges entered. If point A was grounded, point B was "hot," or "above ground." The logic of this flow seemed reasonable at the time. Many electricians today still use these concepts.

Electron flow. Since in a metallic conductor the true charge motion is a movement of electrons in the conductor (LIFEPAC 1206), the more accurate picture is presented in Figure 2. When Point A is again grounded, Point B is still the "hot" point, and the voltage is still positive in respect to ground. Point A is more negative than Point B. The external result is the same as Figure 1.

Thus, the assumption of a positive charge flow was useful at the time because it gave proper voltage polarity, and it satisfied our intuition. Because all of the equations for electricity were developed using the positive charge flow model, we will continue to use this concept for all our conventional electrical studies.



| Figure 1



| Figure 2

Complete these sentences.

1.1 The inventor of the electric cell was ________________________ .

1.2 The electric cell made possible ________________________ currents.

1.3 In a voltaic cell electrons flow from the a. ________________________ to the b. ________________________ terminal.

1.4 The negative terminal of an electric cell is negative because it possesses a surplus of ____________________ .

Research and report.

1.5 The men listed below contributed to the development of electrical theory. Write a report integrating their contributions in a historical perspective. The report should be about 1,500 words, double-spaced. You will be graded 60 percent for content and 40 percent for grammar.

Charles Coulomb Alessandro Volta André Ampère Georg Ohm

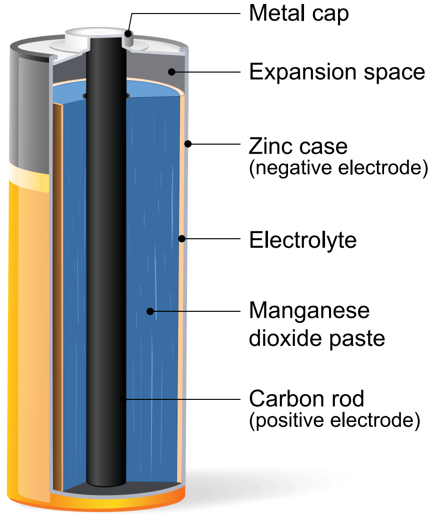
CHECK ______________ ______________
Teacher Date

ELECTROMOTIVE FORCE

Analogy with fluid flow requires a device to raise the fluid to a level from which it can fall to do work. In nature the sun raises water by evaporation; the most common man-made device to raise water is a pump.

In current electricity, a device is required to "lift" a charge to a potential from which they can "fall" to do work. The "lift" in potential is called the electromotive force (emf). Two common examples of such an electron pump, called source of *emf*, are storage batteries and generators.

Storage batteries. A battery is a chemically operated device for storing very large numbers of electrons on one battery terminal (electrode) by stripping an adjacent electrode of its supply. Because of this lack of balance, one (electrode) is negative and one is positive, with the result being a voltage (or *potential difference*, or **potential**) between terminals. The electron-rich electrode is considered negative. The electrode with an electron shortage is considered positive.



| Diagram of a dry cell battery

Requirements for a battery are an electrolyte and two dissimilar conducting materials. When the two electrodes are immersed in the electrolyte, a battery is formed. The cell formed will convert chemical energy into electrical energy.

An example of a simple storage battery is a container of ionic liquid with two metal plates. The liquid (electrolyte) is sulfuric acid, and the two plates are made of copper and zinc. The zinc atoms are converted into charged ions in the acid. When this conversion occurs, two electrons are left on the electrode for every ion that leaves, giving the zinc electrode excess electrons.

The electrolyte stays neutral in charge by taking hydrogen ions from the electrolyte and converting them to neutral hydrogen at the copper electrode. The net result is a chemical process that constantly deposits electrons on the zinc electrode and removes the same number of electrons from the copper electrode. This sequence of events happens billions or trillions of times a second, with the result that the battery provides a steady flow of electrical charge to the resistance connected across its terminals. When a light bulb is placed across the battery terminals, electrical charge will flow from one terminal to the other through the bulb. The same amount of charge per second delivered to the bulb must be returned to the other battery terminal.

Generators. Whereas a battery converts chemical energy to electrical energy, a generator converts mechanical energy to electrical energy. A generator operates on the principle that an electric current is induced in a wire that is moving through a magnetic field. This principle is developed in detail in Science LIFEPAC 1208.

Answer *true* **or** *false***.**

1.6 ____________ Batteries convert chemical energy into electrical energy.

1.7 ____________ The negative battery terminal is electron-enriched.

1.8 ____________ The battery electrolyte is positively charged.

1.9 ____________ Batteries can supply a steady flow of electrons.

1.10 ____________ A generator converts chemical energy to electrical energy.

Complete this activity.

1.11 Describe the principle upon which a generator operates. ____

____

____

____

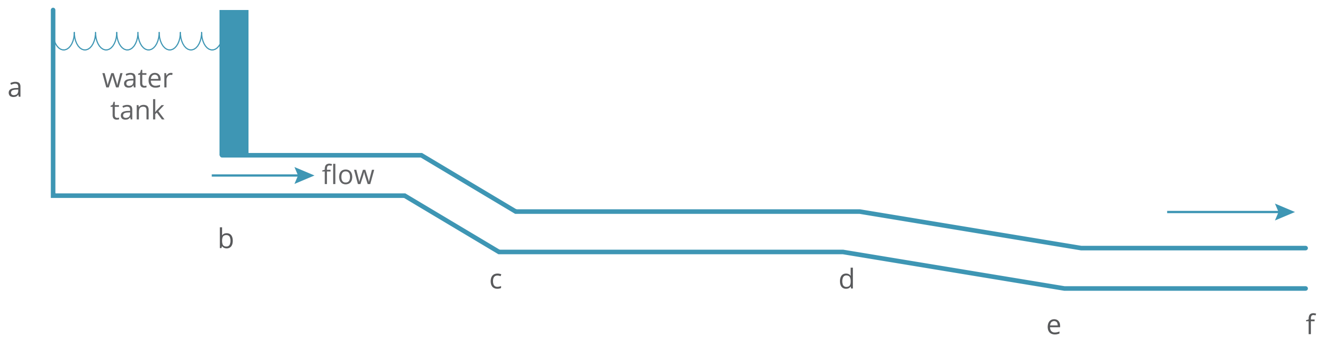
FLUID FLOW

Having never seen a flow of electrical charges, the early experimenters thought of the movement of electrical charges as a flow of a fluid, such as water. Water in a stream flows downhill; a stream must have a drop in height from one end to the other, or the water will not flow. The potential decreases from a higher level to a lower level.

Conduit. The flow of water is illustrated in Figure 3. Water flows from a tank at Point b and goes over a small waterfall at Point c. The gradual drop from Point d to Point e results in more flow of water. If the drop is increased from Point d to Point e, the water will flow faster in that part of the channel. If Point f in the channel is lifted up so that it is at the same height as Point a, all water flow will stop. A physical drop in the channel is necessary to permit water flow.

If the flow is stopped at Point e, then all flow in the channel will stop. Flow at Point b in the channel is not permitted unless flow at Point d is also permitted. The amount of water leaving the tank per minute at Point b must equal the amount of water leaving Point f per minute. The current at Point b must be equal to the current at Point f. If the tank is filled with more water, the flow all along the channel must increase, because the water has increased in potential. More water in the tank raises the water level at Point a forcing more flow.

If the channel had a dam inserted at Point d, the water would rise up to Point a in level at Point d and



| Figure 3

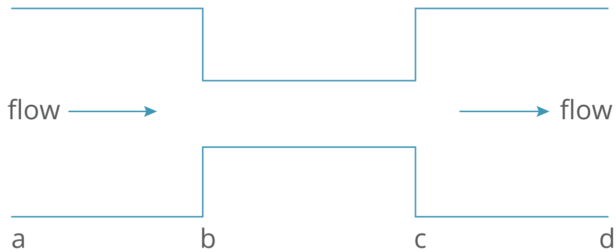
flow would stop. This description is another way of saying that the "water seeks its own level."

The water flow was conducted downstream by the water channel. We refer today to water **conduits** as the means of conducting water from one part of a city to another. If a large flow is to be conducted, a large conduit is required. The cross-sectional areas of the conduit must be large enough to permit sufficient water flow. Too small an area (or pipe size) will clearly restrict the flow. If the pipe size (diameter) is too small, the height of the tank in Figure 3 becomes excessive; that is, the "drop" required would be too high to obtain adequate flow or current in the pipe. Thus, we must consider not only whether the drop in the flow is sufficient but also whether each pipe, or channel, can conduct the flow without excessive loss. If the pipe is not conductive enough, the drop required will be too large. A small pipe will have too much internal friction and will limit the flow of water.

Impediments. (Restrictions to flow) Water flow in a pipe will be restricted also if the pipe contains some obstruction or constriction. This impediment will be equivalent to having a small diameter pipe inserted into a length of large diameter pipe. The result will be that flow will be reduced.

In Figure 4, the total flow of water will be reduced by the constriction between Points b and c. The resistance to flow will be proportional to the cross-sectional area at each point in the line. Thus, if the pipe cross-sectional area at Point a is twice that at Point b, the water at Point a will conduct with twice the ease.

Another factor must be included: the length of the constricted pipe. A long length of pipe between Points b and c will further reduce the ability of the pipe to conduct fluid. Thus, the conductive nature



| Figure 4

of the pipe, called **conductance**, will be directly proportional to its cross-sectional area and inversely proportional to its length.

A formula for this conductance can be written:

$$G = \sigma \frac{A}{L}$$

σ = conductivity constant, a proportionality factor

A = cross-sectional area of the pipe

L = length of the pipe

G = conductance of the pipe

Restrictions to the flow of water in the pipe could be either abrupt or gradual and still have the same overall effect. An abrupt restriction of short length could have the same effect as a long but less abrupt restriction. If the ratio of A to L is the same, the pipe conductance would be the same. Direct analogies may be drawn from this flow of water to the flow of electrical current. The water-pipe analogy will help in visualizing the flow of electrical current; such analogies are necessary since electrical current flow is invisible.

Choose the correct answer.

1.12 To permit a large water flow, the pipe must have _______ .

a. enough strength
b. a large cross-sectional area
c. enough length to conduct the flow
d. a sufficient drop

1.13 Small pipes restrict water flow because of _______ .

a. excessive curvature
b. internal friction
c. insufficient drop

Answer *true* or *false*.

1.14 _____________ Water flow will be reduced in a pipe if the pipe is constricted.

1.15 _____________ The conductance of a pipe is directly proportional to its length.

1.16 _____________ The larger the constriction, the greater will be the reduction in conductance.

1.17 _____________ The conductance of a pipe will be increased if its cross-sectional area is reduced.

1.18 _____________ Flow of electrical current in a wire is analogous to the flow of water in a pipe.

Complete these activities.

1.19 Calculate the conductance of a conduit whose cross-sectional area is cm^2 and whose length is 9 cm if its conductivity is 0.7 unit-cm^{-1}.

1.20 Find the conductivity of a conduit with a cross-sectional area of 0.5 cm^2 and a length of 15 cm if its conductance *G* is 0.05 units.

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