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So far, you have studied topics in physics dealing with kinematics, dynamics, waves, and light. This LIFEPAC® is the first to deal with electrophysics, the relation of the electrical nature of matter to physical systems. Static electricity deals with the physical laws of the interaction of steady electric fields with charges and conductors. These steady fields produce forces on objects and currents in conductors, for example. Our present electronic age is based upon a knowledge of static electricity.

In this LIFEPAC you will study the laws that the Lord has provided in nature that permit such wonders as lightning and the aurora borealis, or northern lights. These electrical phenomena have been provided by the Master Designer. From outer space to the depths of the sea, the laws of electrical charge are at work. These areas also are under the Master Designer’s control. Isaiah 30:30 speaks of lightning as “... the lighting down of his arm...”

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 charges.
2. Explain why some materials are good conductors.
3. Solve problems involving Coulomb’s law.
4. Tell two ways that charges are transferred.
5. Sketch the configuration of electric fields.
6. Relate electric potential to fields and to energy.
7. Solve problems involving electric field strength.

Survey the LIFEPAC. Ask yourself some questions about this study. Write your questions here.
I. ELECTRIC CHARGES

Gravity, magnetism, and electricity are the three forces in the universe that act without need of an intervening medium. Gravity acts across billions of kilometers of high-vacuum space to hold galaxies together. Magnetism is the weakest of the three; nevertheless, it is a significant characteristic of our planet. Electricity, both static and current, plays an integral part in all developed societies.

SECTION OBJECTIVES

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

1. Trace the conceptual development of electric charges.
2. Explain why some materials are good conductors.
3. Solve problems involving Coulomb’s law.
4. Tell two ways that charges are transferred.

VOCABULARY

conductor insulator
Coulomb’s law lightning

Note: All vocabulary words in this LIFEPAC appear in boldface print the first time they are used. If you are unsure of the meaning when you are reading, study the definitions given.

THE NATURE OF CHARGES

The effect produced by rubbing two nonconducting substances together was known to the Greeks. In more recent times, investigations that would be classified as scientific experiments were performed in England and the United States. A quantitative definition of electrostatic forces has been formulated.

Conceptual development. The early ideas of charge were the result of experiments carried out by William Gilbert (1540-1603), personal physician of England’s Queen Elizabeth I. He noted that electric charges were produced by “rubbing a galosh against a fur coat.” He also discovered that electric charges could be produced by rubbing a glass wand with a silk handkerchief. William Gilbert made the early discoveries that served as a foundation for our understanding of electrical charges. The ultimate result of these discoveries is our electronic age.

Gilbert did some simple experiments that showed the nature of electrical charges. He suspended two light spheres on threads and brought charged objects near the spheres. He rubbed a rubber wand with a piece of fur and touched the wand to the spheres. He noticed that the spheres repelled each other.

When Gilbert touched (grounded) the spheres with his hand, they returned to their normal positions.

He then rubbed the wand with the fur again, but this time he touched the fur against the spheres. They again became charged and repelled each other.
He tried one other experiment, this time touching one sphere with the wand and the other with the fur. The result was that the spheres now attracted each other.

Gilbert concluded that the two charges must be different, and thus that charges occur in two varieties.

Gilbert performed experiments using a glass wand and a silk handkerchief and found that the effects were repeated even though the rubber wand and fur were not used. The properties of electrical charge were thus not limited to the use of the rubber and fur. Gilbert found that a glass wand produced a charge opposite to that produced by the rubber wand.

In the late eighteenth century, the American scientist and statesman, Benjamin Franklin, gave names to the electrical charges studied by Gilbert. Franklin called the charge from the fur and the glass rod, positive; and the charge on the rubber wand, negative. This designation is still in use today. All electrically charged bodies are either negative or positive. The early experiments, however, did not indicate the nature of an electrical charge.

You may have experienced this same process after walking across a rug and getting a shock when you touched the doorknob. The same electrical charge may build up in a clothes dryer. Some fabrics are able to separate the electrical charge into positive and negative portions. The friction of two objects rubbing against each other causes the separation of electricity into the positive and negative parts. Some objects are insulators and do not distribute or communicate a charge to any other part of their bodies.

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**Answer these questions.**

1.1 Why do charges build up on clothing in an electric dryer?

1.2 Why do some types of fabric build up more charge than others?

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**Choose the correct answer.**

1.3 Charged spheres repel each other when ____.
   a. they are charged    
   b. they are charged oppositely    
   c. they both received the same type of charge  

1.4 Charged spheres attract each other when ____.
   a. they are charged by the same object    
   b. they are touched after grounding    
   c. the air is dry    
   d. they are oppositely charged
Complete these sentences.
1.5 Electrical charges were named by ________________.
1.6 Electrical charges are of ________________ types.
1.7 Gilbert found that a glass wand and rubber wand produce ________________ charges.
1.8 An object may be charged either a. ________________ or b. ________________.

The electron. What the early experimenters did not realize was that the basic unit of electrical charge is the tiny electron. No one has seen an electron, but we know it has the simplest form of electrical charge. Atoms consist of a positively charged nucleus and negatively charged electrons encircling the nucleus. The charges are in balance. The electrons are found in outer shells surrounding the nucleus.

Conductors have many “free” electrons in their atoms, electrons that can easily be moved away from their normal orbits. If an object has an excess of free electrons, the body is charged negatively. If electrons are removed from the atoms of a conducting material, the balance in each atom is upset. Electrons missing from the outer rings will leave the atom with a net positive charge.

If a conducting material (metal) has electrons drawn from its atoms, the charges on the nucleus of each atom are no longer balanced by the outer-orbit electrons. To make the metal positively charged requires the removal of electrons. The positive charge is thus the result of a lack of electrons in the outer shells of the atoms.

A body becomes negatively charged when electrons are added to the material. These free electrons can be transferred by contact. If the outer shells of the atoms all have enough electrons to give a proper balance, additional electrons are considered surplus; the conductor now has a negative charge. The negative charge is the result of a surplus of electrons in the material.
**Answer true or false.**

1.9  ____  The unit of electrical charge is the proton.
1.10  ____  An atom’s nucleus has a positive charge.
1.11  ____  The electrons and protons in an atom are always in balance.
1.12  ____  The nucleus of an atom is much heavier than an electron.
1.13  ____  Good conductors have many free electrons.

**Complete these sentences.**

1.14  Neutral atoms may be made positive in charge by ________________.
1.15  A conducting material must have many ________________ to qualify as a conductor.
1.16  Electrons in a conductor are removed from ________________ of the atoms.

**Choose the correct answer.**

1.17  Free electrons may be transferred between bodies by ____.
   a. heat loss  c. action at a distance
   b. contact
1.18  Negative charge in a conductor is a result of ____.
   a. lack of electrons  c. neutralization by the atom’s nucleus
   b. surplus of electrons

---

**Coulomb’s law.** The early experiments with static charges showed how like charges repel and unlike charges attract. Experiments showed that when unlike charges were close to each other (but not touching), a large force was required to separate them. The closer they were moved together, the stronger the charges would attract. Similar results are observed for a light bulb or a heat source: In each case the effect is stronger near the source.

The early experiments also showed that as two like-charged bodies were moved apart, the repelling force diminished. The “influence” of each charge on the other is reduced when the distance between them increases.

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**Try this investigation of static electricity.**

**These supplies are needed:**

- glass wand
- Bakelite (or hard rubber) wand
- silk cloth
- wool cloth (or cat’s fur)
- stand
- pith ball
- silk thread

**Follow these directions and answer the questions.** Put a check in the box when each step is completed.

- 1. Suspend the pith ball from the stand by means of the silk thread.
- 2. Rub the Bakelite wand with the piece of wool. Touch the wand to the suspended pith ball.
- 3. Recharge the Bakelite wand by again rubbing it with the wool. Bring the wand near the pith ball.
4. Discharge the pith ball by touching it.
5. Rub the glass wand vigorously with the silk cloth. (Positive charges are generally harder to generate than are negative charges.) Touch the charged glass wand to the pith ball.
6. Recharge the glass wand and bring it near the pith ball.

What happened to the pith ball?

What do you conclude about the force between two positively charged objects?

7. Discharge the pith ball by touching it.
8. Charge the pith ball negatively as in Step 2 (Bakelite wand and wool cloth). Bring a positively charged object (glass wand rubbed by silk) near the charged pith ball.

What happened to the pith ball?

What do you conclude about the force between two unlike-charged objects?

**Lightning** is formed when the clouds become positively charged, with respect to the earth, strongly enough to cause the air to “break down.” In this breakdown an electrical discharge occurs; that is, electrons move from the earth to the cloud. Lightning is the oldest evidence of electrical charge in nature.

The Scriptures often do not refer to nature as we do. Instead they refer to the things God has set in place. The book of Job (Job 38:25) refers to the lightning as a work of God. The letter to the Colossians (Colossians 1:16) refers to Christ as the Creator. It also states (Colossians 1:17), “… and by
Complete these sentences.

1.25 When two similar charges are moved closer together, the force of repulsion ____________.

1.26 In general, forces between objects will ____________ as the objects are separated.

1.27 Coulomb’s law states the relationship between a. ____________, their b. ____________, and the c. ____________ between them.

1.28 Coulomb’s law predicts attraction between two ____________ charges.

1.29 The attraction will vary ____________ with the Separation between the charges.

Apply Coulomb’s law.

1.30 Given: $Q_1 = +20 \ \mu C = 20 \times 10^{-6} \ C$ \hspace{1cm} $K = 9 \times 10^9 \ \text{N} \cdot \text{m}^2/\text{C}^2$

$Q_2 = +30 \ \mu C = 30 \times 10^{-6} \ C$ \hspace{1cm} $r = 3 \ \text{m}$

Determine: $F$
Given: \[ Q_1 = +10 \, \mu C = 10 \times 10^{-6} \quad K = 9 \times 10^9 \, \text{N} \cdot \text{m}^2/\text{C}^2 \]
\[ Q_2 = -15 \, \mu C = -15 \times 10^{-6} \quad r = 6 \, \text{m} \]

Determine: \( F \)

Choose the correct answer.

1.32 Like-charged bodies, when brought closer together, will ______.
   a. repel less strongly  
   b. repel more strongly  
   c. be neutralized  
   d. attract more strongly

1.33 “Influence” between bodies is reduced as the bodies are ______.
   a. brought closer  
   b. increased in charge  
   c. moved farther apart  
   d. held stationary

1.34 The law of repulsion by Coulomb agrees with ______.
   a. the findings of Gilbert  
   b. Newton’s laws of motion  
   c. increased in charge  
   d. the direct-square law

1.35 Coulomb’s law applies to ______.
   a. like charges and unlike charges  
   b. charge motion  
   c. gravitational fields  
   d. moving objects

Complete these activities.

1.36 Write Colossians 1:16.

1.37 The words in Colossians 1:17 “…and by him all things consist,” can be translated

1.38 Explain what Colossians 1:16 tells us about Christ and Creation.

THE TRANSFER OF CHARGES

The normal state of objects is a balance of negative and positive charges. Objects that have an excess or deficiency of electrons will attempt to regain their balance. Charges will flow either by direct contact or through a conductor.

By contact. The glass wand of Gilbert’s experiments was an insulator. An insulator is a material that does not have free electrons; that is, it does not freely allow electrons to move through it. When rubbed with silk, the glass wand
becomes positively charged. Electrons have been removed from its surface. When the charged glass wand is used to touch a conducting object, charge is transferred to that object. Actually, the positive wand will draw electrons from the object it touches and thus leave the body charged due to this contact. Drawing electrons from the object will make the object positive. The glass wand appears to pass a positive charge to the object. In reality it removes negative charges (electrons) from the object.

An insulated sphere becomes charged when it is touched by a charged glass wand. The sphere, in turn, can be used to charge an electroscope by simply touching the electroscope’s terminal. The electroscope will indicate a charge by the separation of its leaves. The greater the charge, the more the leaves separate. Thus the electroscope is a measuring device. It can be calibrated to measure electrical charge.

By conductor. We may transfer the electrical charge from the glass wand to the electroscope by means of a conductor such as a wire. The wire will permit a flow of electrons from the wand to the electroscope terminal. The wire will thus provide the means for moving electrical charge from one point to another. This transfer will happen at speeds approaching that of light.

Liquids, such as saltwater, will also conduct electrical charge. Seawater will not conduct as well as copper wire, but it can permit fairly large amounts of charge to be transferred. Specific liquids, such as that in a storage battery, will conduct electrical charge at very high rates. That is, very large quantities of charge are conducted rapidly in a storage battery, over long periods of time.

Choose the correct answer.

1.39 Insulators have _______.
   a. many electrons   c. few free electrons
   b. many free electrons   d. few electrons

1.40 Objects become positively charged by _______.
   a. adding electrons   c. losing protons
   b. losing electrons   d. adding protons

Answer true or false.

1.41 _______ Insulators conduct charge.
1.42 _______ Electroscopes indicate the presence of charge.
1.43 _______ Electroscopes cannot measure the amount of charge.

Complete these sentences.

1.44 Electrical charge may be rapidly moved from one body to another by means of _______.
1.45 A transfer of charge is actually a gross movement of _____________.
1.46 Seawater is a _______________ of electrical charge.

Score ______________________
Adult check

Initial          Date
Review the material in this section in preparation for the Self Test. This Self Test will check your mastery of this particular section. The items missed on this Self Test will indicate specific areas where restudy is needed for mastery.

**SELF TEST 1**

**Choose the correct answer** (each answer, 2 points).

1.01 The earliest ideas of charge were the result of experiments by _______.
   a. Benjamin Franklin
d. Isaac Newton
   b. William Gilbert
   c. Charles Coulomb

1.02 A rubber wand rubbed with fur will become _______.
   a. charged negatively
c. uncharged
   b. charged positively

1.03 Common units of electrical force are _______.
   a. coulombs
c. meters
   b. newtons

1.04 A positive charge means _______.
   a. surplus of electrons
d. gained protons
   b. lack of electrons
   c. excess atoms

1.05 Lightning is formed when clouds _______.
   a. are charged with respect to earth
c. disintegrate
   b. attract the earth

1.06 The Scriptures refer to lightning as a _______.
   a. natural event
c. strange fire
   b. work of God
d. source of light

1.07 Charges exist in _______.
   a. the sea
c. outer space
   b. the air
d. a, b, and c

1.08 An insulator is a material that _______.
   a. conducts electrons
c. has essentially no free electrons
   b. repels electrons

1.09 Charges may be transferred by _______.
   a. induction
c. reduction
   b. conduction

1.10 A storage battery will conduct _______.
   a. small quantities of charge
c. only when heated
   b. large quantities of charge

**Complete these sentences** (each answer, 3 points).

1.011 An instrument to measure charge is called an _________________.

1.012 A battery provides a steady flow of ________________ to the load connected its terminals.

1.013 In 1787 Coulomb discovered a relationship between a. _________________, their separation, and the b. _________________ the two charges.

1.014 Coulomb’s law indicated that like charges a. _________________ and unlike charges b. _________________.

1.015 Coulomb’s law also indicates that the force between charges _________________ as their separation is decreased.
Define (each answer, 3 points).
1.016 force ____________________________
1.017 negative charge ______________________
1.018 positive charge ______________________
1.019 conductor __________________________
1.020 insulator __________________________

Complete this item (this answer, 5 points).
1.021 Explain why the flow of electrical charge from a battery differs from discharging a glass wand.

Score ______________________
Adult check ____________________
Initial          Date