AP Physics-B **Electric Charge and Electric Force**

Introduction:

For many centuries it has been known that electric charges can accumulate on objects. Most likely you've experienced the effect of accumulated charges when your clothes stick together after they are taken from a dryer. Accumulated charges can discharge. You might have experienced that discharge of accumulated charges when you got shocked after walking across a rug. Lightning is an impressive display of the discharge of accumulated charges.

The nucleus of an atom contains protons (positively charged) and neutrons (no charge). About the nucleus is a "cloud" of electrons (negatively charged). Each electron has a negative charge equal in magnitude to the charge of a proton. The magnitude of the charge is the same on all electrons and protons. The charge on one electron or proton is called the elementary unit of charge. An atom contains the same number of electrons as protons. Thus, the atom is electrically neutral. Electric charges appear when this balance is disturbed.

The proton is firmly "locked" in the nucleus of the atom. It cannot be dislodged easily. The electron is the mobile particle of the atom. Thus, all electric phenomena are due to the movements of electrons.

A neutral object has the same number of electrons as protons. When a neutral object gains electrons, it gains a net negative charge. When a neutral object loses electrons, it has a net positive charge. When an object is given a negative or positive charge and the charge stays on the object for a short time, we say the object has a *static charge*. Static: meaning "at rest."

Electric charges interact with other electric charges. The interaction produces an electric or coulomb force on each of the charges. Like (similar) electric charges exert repulsive forces on each other. And unlike (opposite) electric charges exert attractive forces on each other. A charged object will attempt to share its charge with any object with which it comes in contact. If the second object is considerably larger, the charged object loses much of its charge. If the charged object is touched to the earth, the object will share its charge with the earth effectively losing all charge; we call this grounding.

The coulomb is the SI unit of electric charge. One coulomb is the charge found on 6.25×10^{18} electrons or protons. The charge on a single electron or proton is 1.6×10^{-19} coulombs. Coulomb's law states that the force between two charged objects varies directly with the product of their charges and the inversely with the square of the distance between the charges.

$$F_E = k \frac{q_1 q_2}{r^2} \qquad \text{where } k = 9.0 \times 10^9 \text{ N-m}^2/C^2$$

A charged object brought near a neutral object will induce a charge on the neutral object and attract it. Charges exert forces at a distance. A charged object can produce a force on a second charged object through a distance. The electric field concept is used to describe the behavior of a charged object near another charged object. The electric field is not, in itself, an explanation of forces.

Performance Objectives: Upon completion of the readings and activities of this unit and when asked to respond either orally or on a written test, the student will:

- Describe the structure of the atom. State the elementary unit of charge on the proton and electron.
- Describe the means by which objects are charged either positively or negatively by contact or induction.
- Explain the behavior of the electroscope under several different situations.
- Explain grounding.
- Describe the characteristics of good conductors and good insulators.
- Define the coulomb - state the charge on the electron and proton in coulombs.
- State Coulomb's law including a clear statement of the inverse nature of the law, clearly indicate an understanding that Coulomb's law is limited to point charges, use the law to solve problems.
- Recognize the vector nature of the electric or coulomb forces exerted on charged particles. Solve problems involving point charges in electrostatic equilibrium.
- Describe the electric field model; diagram the field between like and unlike charges.

- Recognize the vector nature of the electric field, state the direction of the electric field, state the equation used to calculate the magnitude of the electric field. Solve problems using the equation.
- Explain why the field between parallel plates would be uniform.
- Describe and explain the properties of a conductor in electrostatic equilibrium.
- Describe and explain Faraday's ice-pail experiment, Millikan's oil-drop experiment, the Van de Graaff generator, and the oscilloscope.
- Know and use the law of conservation of charge.

Textbook Reference: Wilson, Buffa, Lou: Chapter 15 - 17
Merrill: Chapter 20
PSSC: Chapter 11
Sears College Physics: Chapter 24, 25: Section 1-3, 6
Serway College Physics: Chapter 15
University Physics: Chapter 24, 25: Section 1-3, 6

"We call that fire of the black thundercloud, electricity. But what is it? Whence comes it?"
–Thomas Carlyle (1795-1881)

Problems and Questions:

1.) At automobile toll-collecting stations a thin metal wire sticks up from the road and makes contact with cars before they reach the toll collector. What is the purpose of this wire?

2.) Why are the tires for trucks carrying gasoline and other flammable fluids manufactured to conduct electricity?

3.) Would it be necessary for a charged body to actually touch the ball of the electroscope for the leaves to diverge? Explain.

4.) Strictly speaking, when an object acquires a positive charge, what happens to its mass? If it acquires a negative charge?

5.) How can you charge an object negatively with only the help of a positively charged object?

6.) Which of the two would be safer: a house with no lightning rod - or - a house with a lightning rod not connected to the ground? Explain.

7.) Why is a good conductor of electricity also a good conductor of heat?

8.) If you rub an inflated balloon against your hair and place it against the wall, it will stick. Explain.

9.) How are electrically neutral atoms and molecules able to electrically attract each other?

10.) Five pith balls are tested against each other, Ball A attracts B and repels C. Ball D has no effect on E. A charged rubber balloon attracts both A and E. Are all the pith balls charged? What charges are on the pith balls?

11.) Describe the process of putting a negative charge on an electroscope by induction. Use diagrams as necessary and explain the motion of the electrons in the electroscope in terms of attractive and repulsive forces between the charges.

12.) A positive charge of 6.0 μC is 0.03m from a second positive charge of 3.0 μC. Calculate the magnitude of the force exerted on each charge. *180 N*

13.) What is the magnitude of the force that a positive charge of 1.5 μC exerts on a negative charge of 6×10^{-6} C which is 5.0 cm away? What is the direction of that force? *32.4 N toward the positive charge*

14.) The most common isotope of hydrogen contains a proton and an electron separated by about 5.0×10^{-11} m. Determine the magnitude of the electric force of attraction between the two particles. *9.2×10^{-8} N*

15.) The mass of a proton is 1.67×10^{-27} kg and the mass of an electron is 9.11×10^{-31} kg. a.) Use Newton's Law of Universal Gravitation to calculate the gravitational force of attraction between the electron and the proton in the hydrogen atom. b.) Compare this solution to the solution in Problem 14. How many orders of magnitude greater is the electric force between the two particles than the gravitational force between the two? *4.1×10^{-47} N* *40*

16.) Point charges of 2.0 nC are situated at each of three corners of a square whose side is 0.20 m. What would be the magnitude and direction of the resultant force on a point charge of -1.0×10^{-9} C if it were placed a.) at the center of the square? b.) at the vacant corner of the square?
9.0×10^{-7} N *8.6×10^{-7} N toward the center of the square*