NAME ______________________ LAB PARTNERS ______________________

Station Number ______________________ ______________________

Electric Charge and Electrostatics *Experiment* 5

INTRODUCTION

Positive and negative electric charges make up neutral atoms. The atoms within our own bodies are held together by electric forces whose behavior is similar to that of gravitational forces, only much stronger. Most objects in their natural state are electrically neutral; *i.e.*, they contain equal amounts of positive and negative charge. For conducting materials, any excess charge placed on the object distributes itself to make the electric field inside the object zero. For insulators (glass, plastic, *etc.*), charge does not move easily. When some materials are rubbed together, charge is transferred from one to the other, and one object obtains a net positive charge, whereas the other object is negatively charged. In this experiment, you will study charging by contact, charging by induction, and conservation of charge. The concepts of electric force, electric fields, and electric potential will also be introduced.

THEORY

When two charges, q_1 and q_2, are separated by a distance r_{12}, q_1 exerts a force $\mathbf{F}_{12}$ on q_2. The magnitude of $\mathbf{F}_{12}$ is given by

$$F_{12} = \left(\frac{1}{4\pi\varepsilon_o}\right)\left(\frac{q_1 q_2}{r_{12}^2}\right), \tag{1}$$

where ε_o is a constant whose value is 8.854×10^{-12} $C^2/(N\ m^2)$. The force is repulsive if the two charges have the same sign and attractive if the charges have opposite signs. Another convenient way of discussing the force between charges is to consider that one charge q_2 produces an electric field $\mathbf{E}_2$whose magnitude is given by

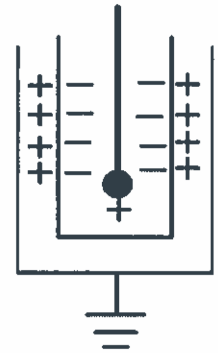
$$E_2 = \left(\frac{1}{4\pi\varepsilon_o}\right)\left(\frac{q_2}{r_{12}^2}\right). \tag{2}$$

The relationship between the magnitudes of the force and the electric field is given by

$$F_{12} = q_1 E_2. \tag{3}$$

Defining the electric field in this way makes it possible to calculate the total electric field from several charges by adding vectorially the electric field produced by each charge. The force on another charge is then given by Eq. (3). Because the electric field is a vector, using the super-position principle requires the use of vector addition.

Sometimes it is more convenient to use the concept of electric potential. For a point charge, the electric potential is given by $V = \left(\frac{1}{4\pi\varepsilon_o}\right)\left(\frac{q}{r}\right)$.



In this experiment, the proportionality between charge and potential difference is used to measure the relative charges carried by different objects using an electrometer and a Faraday ice pail. An electrometer is a voltmeter with an extremely large resistance, usually about 10^{14} ohms. With such a large resistance, very little current will exist when it is connected across a potential difference. A Faraday ice pail is a metal cup or cage with a second cage surrounding it to provide a grounding shield. For practical purposes, a ground is an infinite source or sink for charge. Negative charge flows to or from the ground to make the potential of the object connected to ground be zero. When an object carrying a positive charge or a negative charge is placed inside the ice pail, the outside part of the cage will have the same charge induced on it, and the potential difference measured between the inside cage and ground is proportional to the charge on the object inside the ice pail. The diagram shows a positive object inside the ice pail with the induced negative charge on the inside of the cage and the corresponding positive charge on the outside of the cage. The potential difference between the inner cage and the ground (outer cage) is measured by the electrometer and is proportional to the charge on the object inside the Faraday ice pail.

EXPERIMENT NO. 5

1. In this part, you use a battery and the electrometer to establish sign conventions for your measurements. You will also realize that the electrometer acts as an ordinary voltmeter. The electrometer should be set on the 10-volt scale.

   During all measurements in the experiment, everyone close to the Faraday ice pail needs to remain as still as possible.

   Put the negative terminal of the battery in contact with the outer mesh of the pail. Disconnect the red alligator clip from the inside mesh of the pail and touch the positive terminal of the battery with it. Record the electrometer reading.

   Electrometer reading = ____________

   Reverse the battery so its positive terminal is in contact with the outer mesh and the negative terminal is connected to the red alligator clip. Record the electrometer reading.

   Electrometer reading = ____________

2. Three wands are included in the apparatus. The wands with the dark and white faces are the charge producers, and the aluminum-faced wand is the proof plane, *i.e.*, a device used to

sample the charge on an object. Before any measurements can be performed with the ice pail, the ice pail must be grounded to the shield, and the electrometer must be zeroed. Do this by touching your finger across the inner and outer cages while pushing the zero button on the electrometer. **YOU MUST DO THIS BEFORE EVERY MEASUREMENT, OR RESIDUAL CHARGE WILL NEGATE THE MEASUREMENT. WHOEVER MAKES THE MEASUREMENT SHOULD BE TOUCHING THE SHIELD AT THE TIME OF THE MEASUREMENT.** Rub the dark and white faces of the wands together gently for 10 to 15 seconds. Insert the dark section of the wand nearly to the bottom of the ice pail, being careful not to touch the ice pail. Record the reading of the electrometer with the wand inside the pail.

Electrometer reading = ______________

The sign of the charge carried by the dark-faced wand is ______________

Remove the wand and record the electrometer reading after the wand is removed.

Electrometer reading = ______________

Discharge the charge-producing wands by touching each to the shield of the ice pail. Sometimes discharging the dark-faced wand can be somewhat of a challenge. You may need to touch the shield several times and even blow gently on it so that the moisture in your breath helps discharge it. Rub the charge-producing wands together, and insert the white-faced wand into the ice pail, again being careful not to touch the ice pail. Record the reading of the electrometer.

Electrometer reading = ______________

The sign of the charge carried by the white-faced wand is ______________

Remove the wand and record the electrometer reading after the wand is removed.

Electrometer reading = ______________

State your conclusions concerning the charge on each wand.

3. Discharge the wands and the ice pail, and zero the electrometer. Rub the charge-producing wands together. Insert both wands into the ice pail, being careful not to touch the ice pail with either wand. Record the electrometer reading.

Electrometer reading = ______________

What do you conclude about the total charge on the wands?

4. Discharge the wands and the ice pail, and zero the electrometer. Rub the two wands together, insert the dark-faced wand into the ice pail, and touch the ice pail. Remove the wand from the ice pail and record the electrometer reading.

Electrometer reading = _______________

Discharge the wands and the ice pail, and zero the electrometer. Rub the two wands together, insert the white-faced wand into the ice pail, and touch the ice pail. Remove the wand from the ice pail and record the electrometer reading.

Electrometer reading = _______________

What is the difference between the results you obtained here and those you obtained in Part 2? Explain why there is a difference.

5. Discharge the wands, the proof plane, and the ice pail, and zero the electrometer. Rub the two wands together and touch the dark-faced wand to one of the spheres. Touch the proof plane to one side of the sphere and insert it into the ice pail without touching it. Record the electrometer reading.

Electrometer reading = _______________

Discharge the proof plane, touch it to the other side of the sphere, and insert it into the ice pail. Record the electrometer reading.

Electrometer reading = _______________

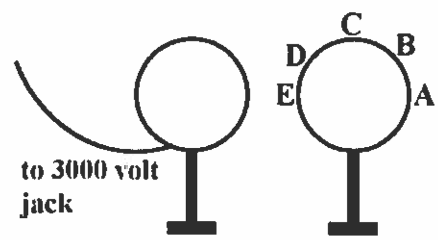
Discharge the proof plane, touch it to the top of the sphere, and insert it into the ice pail. Record the electrometer reading.

Electrometer reading = _______________

From this information, is the charge approximately uniformly distributed on the sphere?

6. Discharge the wands, the proof plane, the sphere, and the ice pail, and zero the electrometer. **BE SURE THE POWER SUPPLY IS OFF.** Connect one of the spheres to the 3000-volt jack of the power supply and **turn the power supply on**. Discharge the second sphere and leave it about 50 cm from the first sphere. Use the proof plane to check for any charge on the sphere not connected to the power supply by touching the sphere in several places and inserting the proof plane into the ice pail. Remember to discharge the proof plane after inserting it into the ice pail. Is there any charge on the sphere not connected to the power supply? Justify your answer.

7. Now move the sphere not connected to the power supply to within about 1 cm of the one connected to the power supply, but do not let them touch. Use the proof plane to sample the charge on the side of the sphere farthest from the charged sphere (point A). Refer to the diagram for the locations for points A, B, C, D, and E. Insert the proof plane into the ice pail and record the electrometer reading.



Electrometer reading A = ______________

Discharge the proof plane and the electrometer. Repeat the measurement for points B, C, D, and E. Record the electrometer reading for each point in the space below.

Electrometer reading B = ______________

Electrometer reading C = ______________

Electrometer reading D = ______________

Be careful not to touch the sphere connected to the power supply.

Electrometer reading E = ______________

Make a sketch showing how the charge is distributed on the uncharged sphere. Explain why the charge is distributed as it is.

Turn off the power supply and the electrometer.

QUESTIONS

1. The relationship between the charge Q, potential V, and radius R for a sphere is given by $V = \left(\frac{1}{4\pi\varepsilon_o}\right)\left(\frac{Q}{R}\right)$. $(1/4\pi\varepsilon_0)$ is approximately 9×10^9 (N m^2)/C^2. How much charge is on a sphere with $R = 5.00$ cm when $V = -1000$ volts? For unit considerations, recall that one volt is one joule/coulomb and that a newton meter is a joule. How many electrons is this? Recall that the charge on one electron is -1.602×10^{-19} C.

2. A dark-faced wand is moved to within 1.00 cm of a 5.00-cm radius metallic sphere that is insulated from ground. The sphere is grounded while the wand is close to it. The ground wire is then disconnected, and the wand is then moved away from the sphere. Does the sphere contain positive charge, negative charge, or no charge? Explain the process. This process is called charging by induction.