ELECTROSTATICS
PHYS 296

Your name__________________ **Lab section____________________**

PRE-LAB QUIZZES

1. What do we investigate in Lab II?

2. Describe the principle of conservation of electric charge.

3. State three different methods to charge an object.

4. Give a detailed description of the correct and safe procedure to use a high voltage power supply to charge the graphite-coated ping-pong ball.

5. Use the equation in Part II to find the capacitance of a hollow conducting sphere (the graphite-coated ping-pong ball) of diameter *3.75* cm. Show the derivation.

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Name_________________________ Lab section______________________

Lab partner's name(s)____

Objective

Lab II is designed for students to learn how to use a charge sensor and to understand electric charge, conservation of electric charge, and different methods to charge objects.

Background

The phenomena associated with electric charge have been known for millennia. For example, ancient Greeks recorded that amber, after rubbing against wool, could attract straw. In the 17th century, scientists demonstrated that many other materials could also attain attractive or repulsive force through rubbing against wool or silk. In 1730, Grey discovered that this property could be acquired and then transferred from one object to another object by connecting a conducting wire between them. Grey called this phenomenon electricity.

In 1747, Benjamin Franklin proposed two types of electric charges: positive and negative. Based on this concept, Franklin explained how charge was transferred from one material to another and developed the principle of conservation of electrical charges. A conserved physical quantity can be neither created nor destroyed – it can only transfer from one object to another. The Principle of charge conservation means that the net electric charge in the universe or an isolated system remains constant. By now, you should have learned that protons and electrons respectively carry positive and negative charges. Electric charges produce electric field (which we will study later) and can thus be manifested by this produced electric field.

PART I PRODUCING NET CHARGE

In Part I, we investigate three methods for charging an object.

a) CHARGING BY FRICTION

As mentioned earlier, electrical charge can be produced by rubbing two objects (of different materials) against each other, such as glass with silk, amber with wool, etc. During rubbing, some charges (usually as electrons, the outmost constituent in atoms/molecules) are stripped away from one object by motion and are transferred to the other object because of the close contact between the two objects. Therefore, after rubbing two objects acquire net charges of the opposite signs. In this lab, charge is measured using the setup as shown in Figure 1. A charge sensor is connected to a pair of two metal cans (forming two concentric conducting cylinders) by a coaxial cable. Through the BNC connector on the surface of the big can, the inner connection of the coaxial cable is connected to the surface of the small can and the outer connection (the ground) is connected to the big can.

When you place a charged object with charge of q into the small can (but do not touch the can), (by induction) a net charge of –q will distribute on the inner surface of the small can and a net charge of +q will distribute on the outer surface of the small can. Meanwhile, (again by induction) a net charge of –q will distribute on the inner surface of the big can and a net charge of +q will be transferred through the outer surface of the big can to the charge sensor. The charge sensor functions like a charge-to-voltage converter. Thus, such a charge meter, consisting of the two cans and the charge sensor, can measure electrical charge as small as 1 nano-coulomb (10^{-9} C).

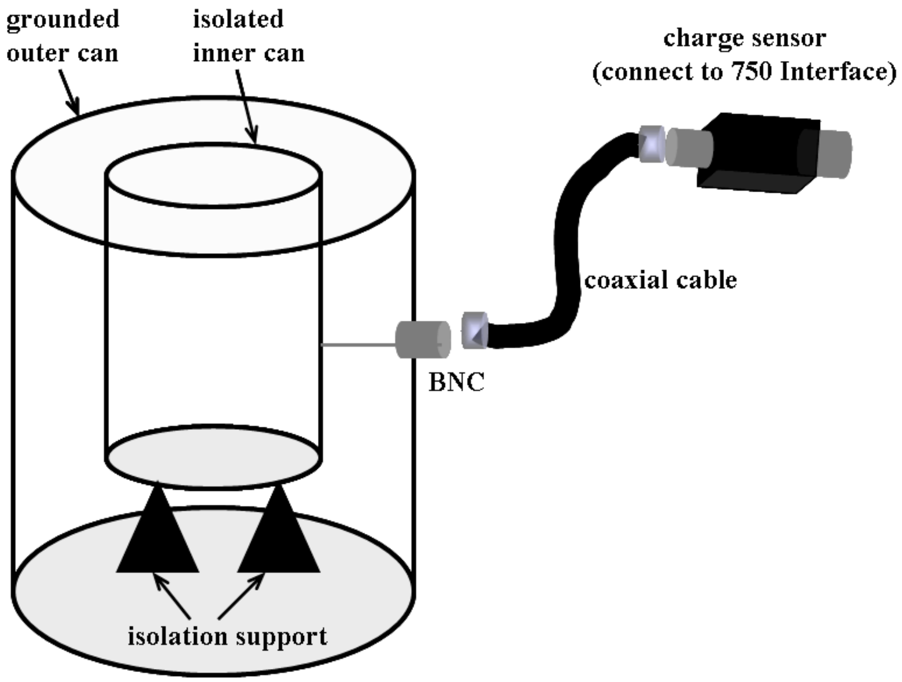

Figure 1. The setup to measure electrical charge.

PROCEDURES

2. Set up the charge meter as shown Figure 1. The charge sensor is connected directly to one of the analog inputs on ***750 interface***, for instance, input Channel A. Use the "GAIN" switch on the charge sensor to set the gain to 1X, 5X, or 20X. This Gain is real. Thus, the measured charge value must be divided by the corresponding gain. When "ZERO" button on the charge sensor is pressed, the input capacitor of the charge sensor is discharged and the reading of charge sensor becomes zero. Therefore, to make correct measurement "ZERO" button should be pressed only when the charge is zero on the connected object. This procedure should be repeatedly used in this lab. Note: charge is measured in μC. To convert the unit of charge to coulomb, multiply by 10^{-6}.

3. Open ***Data Studio***. use DataStudio to establish connection to conform with the connection you just set up on ***750 interface***. Click on input Channel A to open "Add Sensor" window. Scroll down the menu bar and click on "the charge sensor". Click on "OK" to select. A "Charge Sensor" icon is now displayed below input Channel A. Click on this icon to open "Charge Sensor" Window which is displayed below "Experiment Setup" window. In "Charge Sensor" Window, you can set Gain and Sample Rate. Set the sample rate at 10 Hz. Appropriately set sensitivity to X1, X10, or X100. For example, set sensitivity to X1 to measure large charge (after gain setting) while set sensitivity to X100 to measure small charge (after gain setting). Note: you however do not divide the measured charge value by the sensitivity.

4. For display, select “Digits” from the display window and set it to measure “charge”. A digit-meter window will pop up and will be use to read the charge. You will need to increase “precision” of the digital meter to read out small charge values.

5. Click on the “Start” button at the top of the ***Data Studio*** window to start taking data. There may be some residual charge or the zero point may be set incorrectly for the charge sensor. To discharge the cans, place your fingers across both cans. Because the big can is connected to the ground, any charge on the small and big cans will leak to the ground through your fingers and to the big can. If you do this while recording data, you will see the charge reading reaches a steady number. It indicates that charge is removed from both cans. Now, you can press the “ZERO” button on the charge sensor. Before taking any data, you must perform this procedure.

6. Take the provided black plastic rod and rub it against the wool cloth for many vigorous strokes. Then insert the wool cloth inside the small can, getting the wool cloth entirely inside the can while making sure it does not touch the can. If it touches the can, it will transfer charge to the can and you must go back to step 4 and zero the charge sensor again. After finishing the measurement with the wool cloth, insert the plastic rod into the small can after rubbing and follow the same procedure to measure its net charge. You do not need to stop recording data while switching to measure different objects. You need to stop recording and restart only if you accidentally transfer charge to the cans. If the net charge is too large, set Gain to “5X” and measure again. If the net charge is too small, set Gain to “20X” and measure again. You may need to accordingly change sensitivity.

7. Several problems may occur. For instance, charge may leak from the charged objects. Charge leaking may be faster for some charged objects. Perform experiment to find out which object leaks faster and devise a way to minimize this problem. When you are satisfied with the measurement, record the data in Table 1.

8. Repeat the experiment using the provided glass rod and silk cloth.

TABLE 1

OBJECT	CHARGE
PLASTIC ROD	
WOOL CLOTH	
GLASS ROD	
SILK CLOTH	

QUESTIONS

1. What should the combined charge of the plastic rod and the wool cloth be?

2. What is the sum of the measured charges of the glass rod and the silk cloth? Does the result support the principle of charge conservation? Explain your result.

3. Calculate how many electrons are transferred to the wool cloth using the data in Table 1. Show your calculation. (Recall the charge of an electron is $-e = -1.60 \times 10^{-19}$ C)

4. Can weather affect the experiment? If so, how?

b) CHARGING BY CONTACT

An uncharged object may acquire charge by contact with a charged object.

PROCEDURES

1. Discharge the charge sensor as you did in experiment (a). Now, hold the graphite-coated ping-pong ball by the insulation handle. Because of the graphitic coating, the surface of the ball is conducting.

2. Have a lab partner charge the glass rod by rubbing against the silk cloth. Take the charged silk cloth and bring it in contact with the pin-pong ball for several seconds. To ascertain the transferred charge is induced solely by contact, you should minimize relative motion between the cloth and the ball. Now measure the charge on each object by inserting them inside the small can. Practice several times until you become comfortable with the procedure.

3. Discharge the ball and the cloth by touching them to the large metal can. But make sure not to rub them against the can because it may produce charge. Measure the charge on both objects and ascertain that they are discharged appropriately.

4. Now, charge the silk cloth by rubbing it against the glass rod. Measure the charge on the silk cloth with the charge sensor and record the data in Table 2. Next, transfer charge from the silk

cloth to the graphite-coated ball by contact. Then, measure the charge on the ball and the charge on the silk cloth after contact. Record the data in Table 2.

TABLE 2

OBJECT	CHARGE
CLOTH before contact	
BALL after contact	
CLOTH after contact	

QUESTIONS

1. What is the expected sum of the charges on the ball and on the cloth AFTER contact? Explain why.

c) CHARGING BY INDUCTION

Figure 2 illustrates the induction method to charge a graphite-coated ball. When the initially neutral ball is brought near (but not in contact with) the positively charged rod, negative charge moves towards the side of the ball closer to the rod. If a grounded object (your finger) is placed on the ball, negative charge (electrons) will move from the ground onto the ball to balance the positive charge. When the hand is removed (while the charged rod is still near the ball), the ball remains negatively charged. Now, when you move the rod away from the ball the charge on the ball will distribute uniformly over the surface.

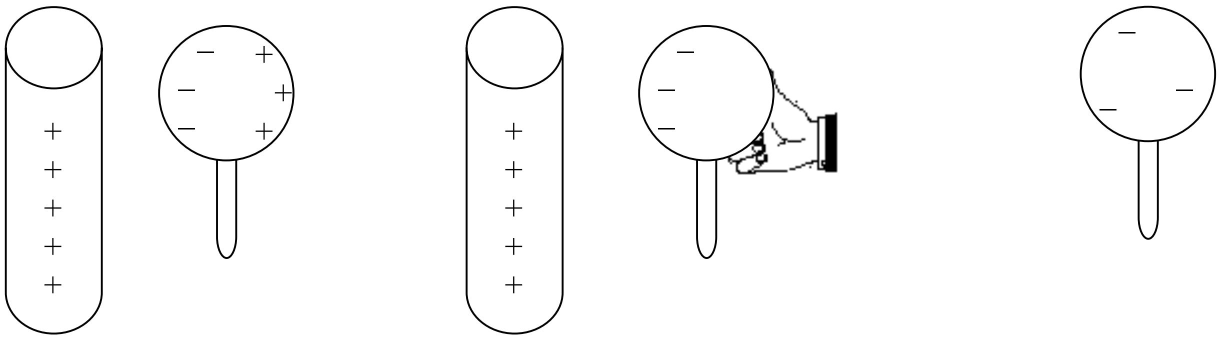

Figure 2. The setup to measure electric charge from induction.

PROCEDURES

1. The experiment will use the provided plastic rod and wool cloth. The advantage is that the plastic rod holds charge longer than the glass rod. Charge the plastic rod by rubbing it against the wool cloth. Measure the acquired charge.

2. Take the graphite-coated ball and hold the tip of the rod near, *but not in contact with*, the ball. Ask the lab partner gently touch the opposite side of the ball while the rod is still near the ball. As explained earlier, this will allow a net charge to be produced on the ball. Now, remove the finger from the ball. Then, remove the rod away from the ball. Quickly measure the charges on the ball and on the rod. Depending on the weather, charge may leak through the air.

3. Practice until you become comfortable with the above procedures. After discharging the charge meter, the graphite-coated ball, and the rod, you are ready to take data. Record the data in Table 3.

TABLE 3

OBJECT	CHARGE
Rod (before induction)	
Ball	
Rod (after induction)	

QUESTIONS

1. Does the rod lose charge during this experiment? Explain.

2. For this experiment, why do you put the tip of the rod near the ball instead of the other positions of the rod?

3. Suppose you have a negatively charged rod and an equally negatively charged ball. You bring the tip of the rod close to but not in contact with the ball, and then connect the ball to the ground. When you remove the ground, measure both the rod and the ball. Assuming no loss through charge leak, what would be the polarity of the net charge on each object?

PART II. CHARGING BY CONTACTING HIGH-VOLTAGE OBJECT

In this experiment, we study how to charge the graphite-coated ping-pong ball (diameter 3.75 cm) by contacting it with a charging probe connected to a high voltage power source. **Be Aware Of the Danger of High Voltage!** Make sure the charging probe does not touch any part of your body or any other objects. (One terminal of the power supply should be grounded.) Turn off the power supply immediately after you finish charging the ball.

The charge on the ball, Q, is a function of the applied voltage (V) described by

$$Q = CV,$$

where C is the capacitance of the ball. The capacitance of a hollow conducting sphere of radius R, in unit of Farad, is given by

$$C = 4\pi\varepsilon_o R$$

with the constant $\varepsilon_o = 8.85 \times 10^{-12}$ F/m. In this experiment, you will measure the increase of the induced charge on the graphite-coated ping-pong ball as a function of the applied voltage.

PROCEDURES

1. Connect the provided red probe to the right plug of the provided power supply. Then connect the ground wire (black) to the left plug. The ground wire should be fixed with the metal screw on the right side of the frame of the power supply. **When the red probe is in high voltage, it can shock you if you touch the metal tip!!!**
2. To charge the ball, hold the red probe and ask the lab partner turn on the power supply and adjust the dial to the targeted voltage. Now, take the probe and touch the graphite ball with its tip for a few seconds. The ball is now charged to the voltage of the power supply. After (not before) removing the probe from the ball, turn off the power supply for safety.
3. Measure the charge using the charge meter. Practice until you become comfortable with this experiment. Use the "GAIN" switch on the charge sensor to set the gain to 5X. Then, discharge the ball and the charge meter. You are ready to take date.
4. Measure the induced charge on the ball with the voltage increased from 0.5 to 5.5 kV with increment of 0.5 kV. Record the data in Table 4. Note, when you increase the voltage to apply to the graphite ball, you do not need to discharge the ball between measurements.
5. Create a graph using the data in Table 4. Print it out and attach it to the lab report. In the graph, plot charge versus voltage and fit the curve using the equation Q=CV. Using the measured curve of charge versus voltage, find the capacitance of the ball. Use Excel for plotting and fitting the data. In the graph, you should properly label the axes with proper units, show the equation and indicate the capacitance with the proper unit, give proper title for the graph.

TABLE 4

APPLIED VOLTAGE	MEASURED CHARGE
0.5 kV	
1.0 kV	
1.5 kV	
2.0 kV	
2.5 kV	
3.0 kV	
3.5 kV	
4.0 kV	
4.5 kV	
5.0 kV	
5.5 kV	

Calculations

1. Write down the fitted equation using Excel and the measured capacitance with the proper unit.

2. Use the formula for the capacitance of a hollow conducting sphere and measure the radius of the graphite ball to calculate the expected capacitance. Show the calculation.

3. Find the percentage discrepancy between the expected capacitance and the measured capacitance. Show the calculation. Discuss the factors which may cause the discrepancy.