Electrostatic Charging

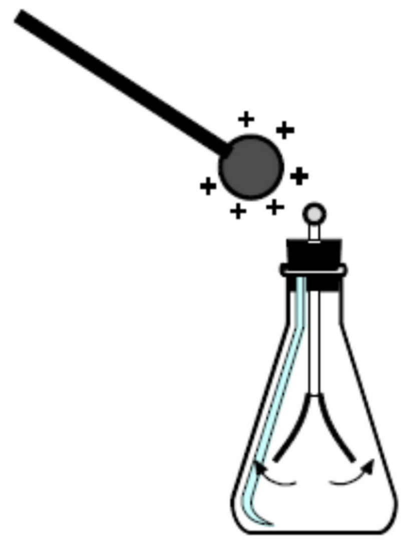
Equipment list

Qty	Items	Parts Numbers
1	Charge Sensor	CI-6555
1	Charge Producers and Proof Planes	ES-9057A
1	Faraday Ice Pail	ES-9024A

Introduction

The purpose of this activity is to investigate the nature of charging an object by contact as compared to charging an object by induction. You will also determine the polarity of two charge 'producers' and measure the amount of charge on each.

Background



Electric charge is one of the fundamental properties of matter, and in an isolated system it is always conserved. Electrostatics is the study of electric charges and their characteristics. For example, like charges tend to repel and unlike charges attract. An object is electrically neutral most of the time; that is, it has a balance of positive and negative electric charges. The positive charges (+) come from the proton, while the negative charges (-) are a result from the electrons. Rubbing different materials together, contact with a charged object, and charging by induction are the three ways to create an imbalance of electric charge – sometimes called static electricity. Static electricity is a charge and the unit of charge is the coulomb with its SI symbol, *q*. Because electric charge is "quantized", any positive or negative charge, q, that can be detected can be written as $\boldsymbol{q = ne}$ where $n = \pm1, \pm2, \pm3, \ldots$ in which e, the **elementary charge**, has the value of 1.602×10^{-19}C. Frequently in experiments, milliCoulombs (mC), microCoulombs (µC), nanoCoulombs (nC) and even picoCoulombs (pC) are used. **Electrical conductors,** like copper, silver or aluminum, are materials in which a tiny fraction of their electrons are not bound to atoms and freely move around the material. For **electrical nonconductors, also called insulators**, all of their electrons are bound to atoms, which means they do not move freely around the material. Both are equally likely to acquire electrostatic charge.

As mentioned above, opposite charges always attract and like charges tend to repel. At an elemental level, like charges always repel (electrons repel electrons, protons repel protons), but for macroscopic objects, non-symmetric charge distribution can result in an overall attraction between two objects that carry the same type of overall charge (positive or negative). Non-symmetrical charge distribution always results in an attraction between a charged object and an electrically neutral (overall) object. Looking at the three types of charging mentioned earlier, we can look at how the charges are distributed in each case:

1. ***Charging by rubbing***: when two initially neutral non-conducting objects are rubbed together, one of them will generally bind electrons more strongly than the other and take electrons from the other. The law of conservation of charge requires that the total amount of electrons be conserved. That is, electrons only move from one object to another, but no new electrons are created, nor do they disappear. Overall, the two objects when considered together still have zero net charge.

2. *Charging by contact*: when a charged object is touched to a neutral (or less charged) object, repulsive forces between the like charges result in some of the charge transferring to the less charged object so the like charges will be further apart. This effect is much larger for conducting objects.

3. *Charging by induction*: the protons and electrons inside any object respond to electric forces of attraction or repulsion. When an object is placed near a charged object, the charged object will exert opposite forces on the protons and the electrons inside the other object, forcing them to move apart from each other. One side of the object will become more positive than it was initially. The other side will become more negative, as electrons migrate internally. This condition is called **polarization**, a word that refers to the object having “poles,” or opposite sides with different electrical states, even though the object as a whole may still be neutral. If a conductor is touched to the polarized object, some of the charge will transfer to the conductor. If the conductor is then removed, the object now carries a net charge different from its initial charge.

Historically, Michael Faraday used a metal ice pail as a conducting object to study how charges distributed themselves when a charged object was brought inside the pail. The ‘ice pail’ had a lid with a small opening through which he lowered a positively-charged metal ball into the pail without touching it to the pail. Negative charges in the pail moved to the inner surface of the pail leaving positive charges on the outside.

If the charged ball touches the inside of the ice pail, electrons would flow into the ball exactly neutralizing the ball. This would leave the pail with a net positive charge residing on the outer surface of the pail.

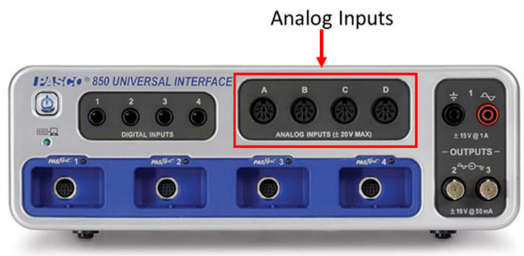
To experimentally investigate electrostatics, some charge-detecting or measuring device is needed. A common instrument for this purpose is the electroscope, a device with two thin gold leaves vertically suspended from a common point. When a charged object is brought near the electroscope, the gold leaves separate, roughly indicating the magnitude of the charge.

Although there are many different versions of the electroscope, all such instruments depend upon the repulsion of like charges to produce an output or reading. Unfortunately, such devices are relatively insensitive (large amounts of charge are needed to make the gold leaves separate), and the device does not have a quantitative reading.

The Charge Sensor is an ‘electronic electroscope’. In addition to providing a quantitative measurement, the Charge Sensor is more sensitive and indicates polarity directly. Assuming there are no residual charges and no charge leakage in the experiment, this instrument should provide accurate results.

Setup

1. Connect the Charge Sensor to the 850 Interface to any Analog Input available as shown below.



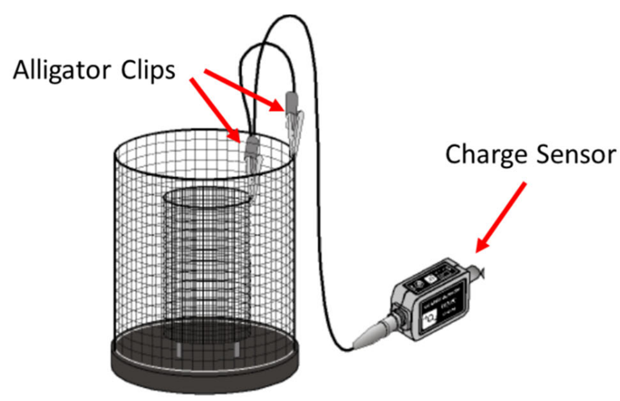
2. Start *PASCO Capstone* in the computer, and set the “Gain Select Switch” on the Charge Sensor to 5X.

3. Set up hardware by going to the left side menu and selecting Hardware Setup. Make sure the 850 Interface is selected and add the Charge Sensor by clicking on the Add Sensor/Instrument button. Make sure Charge Sensor is added to the proper Analog Input in the diagram.

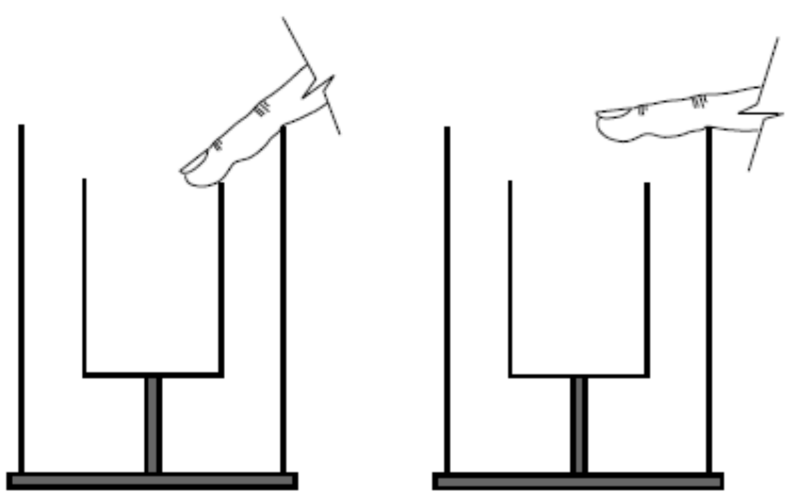
4. Set the sample rate to 10 Hz in *PASCO Capstone* at the lower bottom menu.

5. Drag a graph and meter displays from the Displays menu located at the right side. Set the “y” and “x” axes by left clicking on <Select Measurements> button and select Charge (µC) for the y-axis and Time (s) for the x-axis.

6. Connect the alligator clips of the sensor’s cable assembly to the inner (**longer wire inside – red band**) and outer baskets (**shorter wire outside – black band**) of the Faraday Ice Pail as shown in the diagram below.



Preparing to Record Data



Before starting any experiment using the ‘Faraday Ice Pail’, the pail must be momentarily grounded. To ground the pail, touch the inner pail and the shield at the same time with the finger of one hand as shown in the image to the left.

NOTE: You may need to redo the grounding and/or zeroing of the Ice Pail during the experiment. It is very easy to transfer charge to the ice pail by touching it or even getting too close to it with a charged object. It may even acquire a charge sitting on the table for a while. To see how sensitive the system is, stick a finger down the axis of the inner cylinder (without touching the cylinder.) Now rub your fingers through your hair, or on your shirt, or shuffle your shoes on the floor and try sticking your finger back into the Ice Pail. See any difference? What happens if you touch the Ice Pail? What's the moral about where you put your hands during the experiment? **Redo the grounding of the Ice Pail immediately before each procedure**.

<u>Procedure</u>

Part 1: Determine the Polarity of the Charge Producers

7. Ground the 'Ice Pail' and press the 'ZERO' button on the Charge Sensor to discharge the sensor. Press Record in *Capstone*. Then insert, without touching the walls, the white charge producer into the inner pail then stop recording. Record their values for Question 1. Save the graph. Then repeat process for the dark charge producer, and then repeat process for both charge producers at the same time.
8. Briskly rub the black and white Charge Producers together several times.
9. Click 'Record' in *Capstone* to start recording data.
    a. Without touching the 'Ice Pail', lower the white Charge Producer as close to the bottom of the 'Ice Pail' as possible without touching the walls. Watch the Meter and Graph displays.
    b. Remove the white Charge Producer and then lower the black Charge Producer into the 'Ice Pail'. Watch the results. Remove the black Charge Producer. After a few moments, stop recording data and save the graph.

Part 2: Measure the Charge on the White Charge Producer.

10. Ground the 'Ice Pail' and press the 'ZERO' button on the Charge Sensor to discharge the sensor.
11. Briskly rub the black and white surfaces of the Charge Producers together several times.
12. Start recording data. Record the zero value on line 1.
    a. Lower the white Charge Producer into the bottom of the 'Ice Pail'. Record this value on line 2.
    b. Quickly rub the surface of the white Charge Producer against the inner pail Watch the Meter and Graph displays. Record this value on line 3.
    c. Remove the white Charge Producer from the inner pail. Record this value on line 4.
13. After a few moments, stop recording data and save graph.

Measure the Charge on the Dark Charge Producer

14. Ground the 'Ice Pail' and press the 'ZERO' button on the Charge Sensor to discharge the sensor.
15. Briskly rub the black and white surfaces of the Charge Producers together several times.
16. Start recording data. Record the zero value on line 1.
    a. Lower the black Charge Producer into the bottom of the 'Ice Pail'. Record this value on line 2.

b. Quickly rub the surface of the black Charge Producer against the inner pail Watch the Meter and Graph displays. Record this value on line 3.

c. Remove the Charge Producer from the inner pail. Record this value on line 4.

17. After a few moments, stop recording data and save graph.

Part 3: Charge the ‘Ice Pail’ by Induction

18. Ground the ‘Ice Pail’ and press the ‘ZERO’ button on the Charge Sensor to discharge the sensor.
19. Briskly rub the black and white surfaces of the Charge Producers together several times.
20. Start recording data. Record the zero value on line 1.

a. Without touching the ‘Ice Pail’ with the Charge Producer, lower the white Charge Producer into the bottom of the ‘Ice Pail’. Record this value on line 2.

b. While the white Charge Producer is still inside the inner pail, use the finger of one hand to momentarily ground the ‘Ice Pail’. Watch the results, the charge should go to approximately zero. Record this value on line 3.

c. After you ground the ‘Ice Pail’, remove your hand and then remove the white Charge Producer.

21. After a few moments, record this value on line 4 and stop recording data. Save graph.
22. Ground the ‘Ice Pail’ and zero the sensor and repeat the procedure using the black Charge Producer and save graph.

Analysis of Electrostatic Charging Lab

Name____ **Group#**________

Course/Section_______________________________________

Instructor____

Graphs:
Indicate on the graphs each step of the experiment (i.e. charge producers 'far' away from experiment; charge producer inducing current, pail grounded, charge producer in contact with pail, etc.). You can annotate directly on the graph by using the large red A: on the graph display, or physically write on the graphs once printed out. (20 points for the graphs)

Line	State	White Disk Contact (μC)	Dark Disk Contact (μC)	White Disk Induced (μC)	Dark Disk Induced (μC)
1	**Zero**				
2	**Initial**				
3	**Transfer**				
4	**Disk Out**				

Questions

1. From Part 1, what charge and polarity (what sign) are the two Charge Producers? Where did the electrons go (or come from)? (6 points)

2. (Part 1) After the rubbing process, what is the overall net charge of the two wands? (6 points)

3. (Part 1) What evidence is there that the rubbing gave each wand an electrical charge? (6 points)

4. (Part 2) After charging by contact, what was the charge of the white charge producer and the basket? Was it the same polarity? (6 points)

5. (Part 2) After charging by contact, what was the charge of the dark charge producer and the basket? Was it the same polarity? (6 points)

6. (Part 3) After charging by induction, what was the charge of the white charge producer and the basket? Was it the same polarity? (6 points)

7. (Part 3) After charging by induction, what was the charge of the dark charge producer and the basket? Was it the same polarity? (6 points)

8. How does the process of charging by contact differ from the process of charging by induction? (6 points)

9. How many electrons are inside of the pail if the pail has a charge of 50 μC? (6 points)

10. Assuming you have 6.24×10^{14} electrons and the surface area of the pail is 0.2 m2, what is the charge density (C/m2)? (6 points)

11. The Faraday Ice Pail used during the experiment has two wire mesh cylinders. Briefly explain what their functions were for the experiment. Think about the leads from the charge sensor and which color (black or red) was connected to which cylinder. (5 points)

12. State at least <u>two</u> possible reasons for errors in the experiment (*do not include rounding errors, calculation errors, human errors or equipment malfunction*). (5 points)

13. Did the results of the experiment make sense? Why or why not? You <u>MUST</u> reference each of the graphs for charging by contact & induction (4 in total) for full credit. (10 points)