Lab 6
Electrostatic Charge and Faraday's Ice Pail

Learning Goals

- to investigate the nature of charging an object by contact as compared to charging an object by
- induction
- to determine the polarity of two charge 'producers'
- to measure the amount of charge on a charge producer.
- to investigate the distribution of charge on conducting objects of different geometries

Apparatus:

Qty	Instrument	Instrumental Error	Instrumental Resolution
1	PASCO Interface (for one sensor)	± 0.1%	± 0.005 volt
1	GLX with Charge Sensor (microcoulombs)	± 1%	± 0.005 volt
3	Plastic Charge Producers and Proof Planes		
1	Faraday Ice Pail		
1	Pair of parallel plates		
1	Hollow Conductive sphere		
1	Electrostatics Voltage Source		

Theory:

Electrical Charge

All matter is composed of atoms, and those atoms contain subatomic particles, namely *neutrons, protons* and *electrons*. These particles can be described in terms of the *charge* they carry. Charge is a fundamental quantity (like mass) that is responsible for *electric forces* between particles. Charge is to electric forces like mass is to gravitational forces.

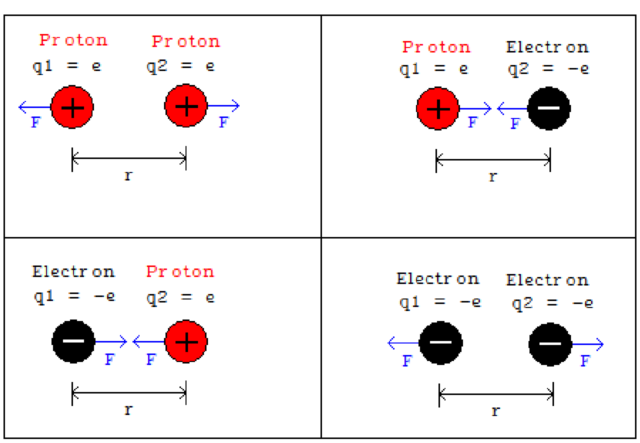
Protons and electrons are the ultimate sources of charge. **P**rotons are said to have a ***positive*** (+) charge, electrons are said to have a *negative* (-) charge, and **n**eutrons are said to be ***neutral*** (no charge). The fundamental unit of charge is called the *Coulomb* [C]. Protons and electrons, while having different types of charge, both have the same magnitude of charge ≡ **e** = 1.602×10^{-19} C.

The relationship defining the electric force between charged particles is called ***Coulomb's Law***:

$$\mathbf{F_e = Kq_1q_2 / r^2} \qquad [1]$$

where

$\mathbf{K}$ ≡ "electrostatic constant" = 9×10^{9} [Nm^2/C^2]
$\mathbf{q_1}$ ≡ "charge on particle 1"
$\mathbf{q_2}$ ≡ "charge on particle 2"
$\mathbf{r}$ ≡ "distance between particles"



This equation tells us that *like charges repel* and *unlike charges attract*. For instance, electrons (negative charge) are <u>attracted</u> to protons (positive charge). Electrons repel other electrons, and protons repel other protons (see diagram below).

Many atoms in matter have an equal number of protons as they do electrons. When we add all the charges together (electrons, protons, and neutrons), these atoms are called electrically neutral, because there is no *net charge* on the object since the total positive charges and total negative charges are in balance. However, if an electron is removed, the atom becomes an *ion*, meaning the total net charge of the whole atom becomes positive (since there are now more protons than electrons). This also applies to macroscopic objects. By "charging" an object, you are creating a <u>net</u> charge on that object. You are unbalancing the number of positive and negative charges that object contains. By "discharging" an object, you are restoring the balance of positive and negative charges, thereby making the object electrically neutral once again (net charge = 0).

<u>Conductors and Insulators</u>

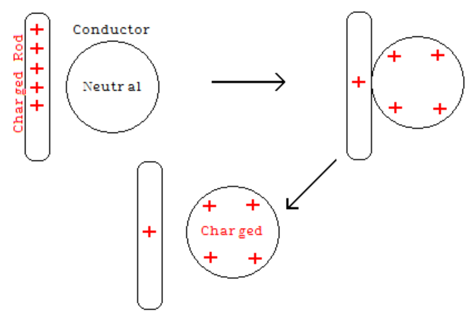
There are three main categories of objects which carry charge: *conductors*, *semiconductors*, and *insulators*. This lab will only focus on conductors and insulators.

Conductors are materials that allow charged particles, like electrons, to flow through them easily. Metals such as copper, silver and aluminum are some examples. When a conductor has a net charge, the excess charges feel the Coulombic forces of equation [1] from the other charges, and they spread out evenly over the surface of conductor.

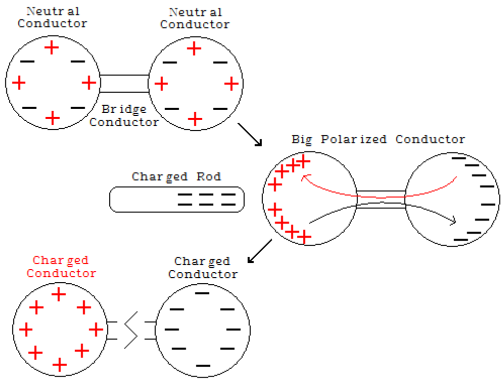
Insulators are materials through which charges have a difficult time flowing. Plastic, rubber, and wood are insulators. In fact, net charges on an insulator do not spread out evenly, but generally stay in one locale.

<u>Charging by Contact</u>

If a charged object comes in contact with a neutral conductor, many of the excess charges will transfer to the surface of the conductor. When the initially charged object is removed it leaves behind some of its excess charge.The conductor is now considered charged. The diagram below shows a positively charged rod charging a neutral conductor (in this case, only the <u>excess</u> charges are labeled in the diagram). This process is charging through contact.

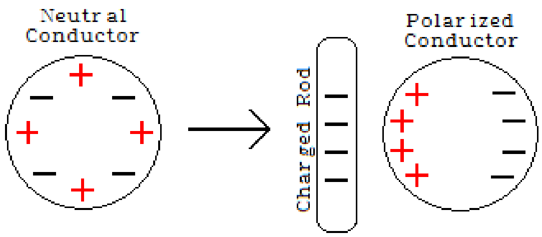


<u>Charging Through Induction</u>



A conductor can also be charged through induction. Consider two conductors joined together so that they can share their charges as if they were one large conductor (see diagram below). If a charged object is brought close the surface of the conductor, the charges will rearrange and the conductor will be come polarized as before. If the conductors are detached while they are polarized, and the charged rod removed, both separate conductors will now be charged. However, this charge was NOT produced through contact with a charged object, but was *induced* through polarization.

<u>Polarization</u>



When a charged object is brought within close proximity of a neutral conductor, the surface charges of that conductor will shift and rearrange due to the Coulombic forces. This rearrangement is called *polarization*, which turns a neutral object into an *electric dipole* (with positive and negative electric poles).

Notice in the diagram to the left how the conductor stays neutral, but becomes polarized by the negatively charged rod. This is because the charges are free to move and rearrange themselves on the conductor's surface in response to the charged rod

<u>Electroscope</u>

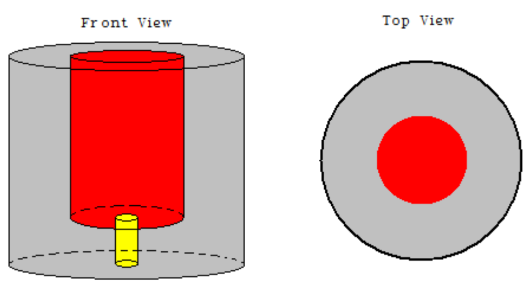
To experimentally investigate electrostatics, some charge-detecting or measuring device is needed. A common instrument for this purpose is the electroscope, a device with two thin gold leaves vertically suspended from a common point. When a charged object is brought near the electroscope, the gold leaves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

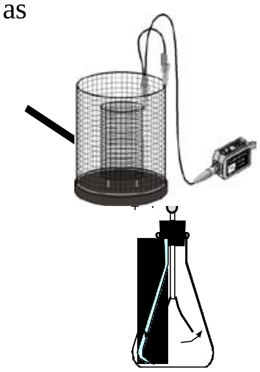
Although there are many different versions of the electroscope, all such instruments depend upon the repulsion of like charges to produce an output or reading. Unfortunately, such devices are relatively insensitive (large amounts of charge are needed to make the gold leaves separate), and the device 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.

<u>Faraday's Ice Pail</u>

This lab will use a conductor configuration known as Faraday's Ice Pail. This setup involves a metal can placed inside of a larger metal can, with an insulator placed between them (see diagram). Think of the cans as two neutral conductors.



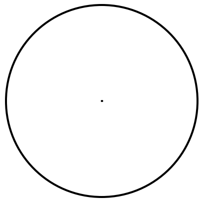


If the inner can has any excess charges on its outside surface and the outer can is connected to a "ground" wire, the *voltage difference* between the outer and inner can be measured with a voltmeter to represent the net charge on the inner can. This lab involves lowering a charged rod into the inner can and measuring the polarized charge, or charging the inner can and measuring contact charge or induced charge. When inducing the charge on the inner can, the "bridge conductor" can be replicated by using your finger. This is done by touching both inner and outer can simultaneously with the same finger, allowing inner and outer cans to share charges. This is called *grounding* the inner can. When measuring the voltage, the charge detector will automatically convert the voltage reading (in [Volts]) to a charge reading (in [Coulombs]).

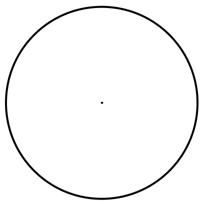
The white and blue charging rods are both insulators that can be charged by rubbing them together. After rubbing, one rod will be positively charged, the other will be negatively charged. You will discover which rod has which charge during the experiment. The magnitude and sign of the charge on these rods can also be measured using Faraday's Ice Pail.

Prelab:

#1 Draw on the surface of the plastic sphere below an equal number of both positive and negative charges.



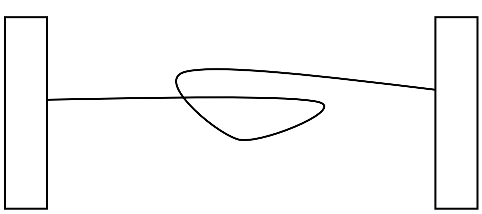
#2 Draw on the surface of the plastic sphere below an unequal number of positive and negative charges to indicate the sphere is negatively charged.



#3 Draw on the surfaces of the plastic spheres below an unequal number of positive and negative charges to indicate the sphere on the left is negatively charged and the sphere on the right is positively charged. Indicate with arrows that the spheres are attracting each other.

#3 Draw on the surfaces of the plastic sticks below an unequal number of positive and negative charges to indicate the sticks were rubbed together, then separated-- resulting in the left being negatively charged and the right being positively charged.

#4 Draw on the surfaces of the plastic sticks below the situation described in #3 **after** a wire was connected between the two sticks.



Part I Electrostatic Charging

Procedure:

1. Set up the PASCO Interface and the computer and start *DataStudio*. Connect the Charge Sensor to the interface. Open the *DataStudio* file: **64 Charging.ds** The file opens with a Graph display of voltage from the Charge Sensor and a Meter display. The sample rate is set at 10 Hz.
2. Connect the alligator clips of the sensor's cable assembly to the inner (using two cable alligator) and outer (using single cable alligator) baskets of the Faraday Ice Pail.

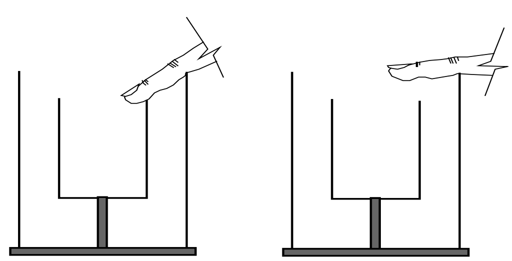
3. **Before starting any experiment using the 'Faraday Ice Pail', the pail must be momentarily grounded. To ground the pail, touch the inner pail and the shield at the same time with the finger of one hand or simultaneously touch inner and outer pails with a connecting wire.**

4. Determine the Polarity of the Charge Producers
   A. Ground the 'Ice Pail' and press the 'ZERO' button on the Charge Sensor to discharge the sensor. Click 'Start' in *DataStudio* to start recording data.
   B. Briskly rub the blue and white surfaces of the Charge Producers together several times.
   Without touching the 'Ice Pail', lower the white Charge Producer into the 'Ice Pail'. Watch the Meter and Graph displays.

   C. Remove the white Charge Producer and then lower the blue Charge Producer into the 'Ice Pail'. Watch the results.
   D. Record observations in notebook using the questions in the Data below

5. Measure the Charge on the White Charge Producer.
   E. Ground the 'Ice Pail' and press the 'ZERO' button on the Charge Sensor to discharge the sensor. Start recording data.
   F. Briskly rub the blue and white surfaces of the charge Producers together several times.
   Lower the white Charge Producer into the 'Ice Pail'. Rub the surface of the white Charge Producer against the inner pail and then remove the Charge Producer. Watch the Meter and Graph displays.
   G. Record observations in notebook using Questions in the Data below

6. Measure the Charge on the Blue Charge Producer
   H. Ground the 'Ice Pail' and press the 'ZERO' button on the Charge Sensor to discharge the sensor. Start recording data.
   I. Briskly rub the blue and white surfaces of the Charge Producers together several times.
   Lower the blue Charge Producer into the 'Ice Pail'. Rub the surface of the blue Charge Producer against the inner pail and then remove the Charge Producer. Watch the Meter and Graph displays.
   J. Record observations in notebook using Questions in the Data below



7. Charge the 'Ice Pail' by Induction
   K. Ground the 'Ice Pail' and press the 'ZERO' button on the Charge Sensor to discharge the sensor. Start recording data.
   L. Briskly rub the blue and white surfaces of the Charge Producers together several times.

Without touching the 'Ice Pail' with the Charge Producer, lower the white Charge Producer into the 'Ice Pail'. While the Charge Producer is still inside the inner pail, use the finger of one hand to momentarily ground the 'Ice Pail'. Watch the results.

M.. After grounding the 'Ice Pail', remove the hand and then remove the Charge Producer.
N. Record observations in notebook using Questions in the Data below
O. Ground the 'Ice Pail' and zero the sensor and repeat the procedure using the blue Charge Producer.
N. Record observations in notebook using Questions in the Data below

Data: Answer the following questions using the observation recorded above (**record in notebook**):

1. When two charge producers with different surface materials are rubbed together to create a charge imbalance, how will the electric charge on one of the producers compare to the electric charge on the other? Ans.: .

2. What polarity is the white Charge Producer? What polarity is the blue Charge Producer? Ans.: _______________________.

3. What happens to the charge on the 'Ice Pail' when you rub the inner pail with the white Charge Producer and then remove the Charge Producer? Ans.: _______________________.

4. What happens to the charge on the 'Ice Pail' when you rub the inner pail with the blue Charge Producer and then remove the Charge Producer? Ans.: _______________________.

5. What happens to the charge on the 'Ice Pail' when the white Charge Producer is lowered into the inner pail without touching the inner pail? Ans.: _______________________.

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6. What happens to the charge on the 'Ice Pail' when the 'Ice Pail' is momentarily grounded while the Charge Producer is still inside the inner pail? Ans.: _______________________.

7. What happens to the charge on the 'Ice Pail' after the Charge Producer is removed from the inner pail? Ans.: _______________________.

8. What steps and in what sequence are used to charge the ice pail by conduction? Ans.: ____.

9. What steps and in what sequence are used to charge the ice pail by induction? Ans.: ____.

10. How does the result of charging by contact differ from the result of charging by induction? Ans.: _______________________.

Part II Electrostatic Charge Distribution

Learning Goals:

to investigate electric charge distribution on conductive specimens: a hollow sphere and parallel plates.

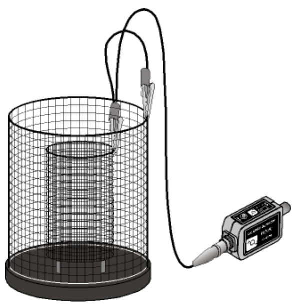
to use a charge sensor, proof plane, Faraday 'Ice Pail', and the *DataStudio* software to record the magnitude and plot the distribution of charge on the sphere and parallel conducting plates.

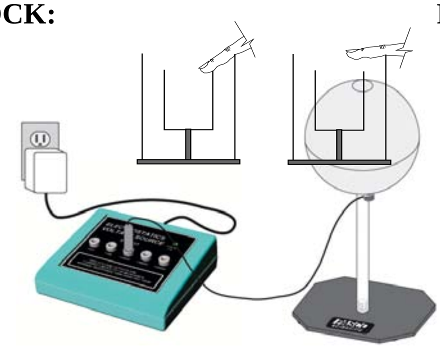
Background

Like electric charges repel and unlike charges attract. The distribution of electric charge on the surface of an object illustrates this principle. If electric charge is transferred to an object that is electrically neutral, the transferred charge will tend to distribute itself evenly over the surface of the object *IF* the surface is conductive and allows the charges to move freely. The transferred electric charges repel each other and move as far from each other as possible. However, if the surface is non-conductive, the charges cannot move as freely and won't distribute evenly. The arrangement of charges in a non-conductive surface tends to attract or 'hold' the transferred charges to that part of the object where they were transferred.

Procedure:
1. Set up the PASCO Interface and the computer and start *DataStudio*. Connect the Charge Sensor to the interface. Set the GAIN switch to '5'.
2. Open the *DataStudio* file: **65 Distribution.ds** The file opens with a Table display of 'Location on Specimen' and 'Charge'. It also has a graph display and a meter display. The sample rate is set at 10 Hz.
3. Connect the alligator clips of the sensor's cable assembly to the inner (using two cable alligator) and outer (using single cable alligator) baskets of the Faraday Ice Pail. Connect the Electrostatic Voltage Source to a conductive specimen. Attach the 'spade plug' end of the cable to the sphere and put the banana plug end into the +1000 V jack on the voltage source.

AVOID DANGEROUS ELECTRICAL SHOCK: FOLLOW





DIRECTIONS

4. Plug a second cable into the 'COM' jack on the voltage source, but don't connect it to anything. 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 or simultaneously touch inner and outer pails with a connecting wire.
5. <u>Measure the Charge at Several Locations on the Hollow Conductive Sphere</u>
(NOTE: Have one person handle the apparatus and a second person handle the computer)

   A. Ground the 'Ice Pail' and press the 'ZERO' button on the Charge Sensor to discharge the sensor.
   B. Click 'Start' in *DataStudio* to start recording data.
   C. Touch the top of the Conductive Sphere with the Proof Plane. Without touching the 'Ice Pail', lower the Proof Plane into the 'Ice Pail' about halfway down. Watch the Table display. Record the charge for position 1 in the Data Table.
   D. Remove the Proof Plane and ground it by touching it to the end of the cable that is connected to 'COM' on the voltage source. Ground the ice pail and press 'ZERO' on the Charge Sensor.
   E. Touch one side of the conductive sphere with the Proof Plane and then lower the Proof Plane into the 'Ice Pail'. Record the charge for position 2 in the Data table.
   F. Ground the Proof Plane, ground the ice pail and 'ZERO' the Charge Sensor again. Touch the opposite side of the conductive sphere and again and record the charge on the Proof Plane in the Data table.
   G. Repeat the process for other places on the outside and inside of the conductive sphere to complete the study.
   H. Click 'Stop' to end data recording.

6. Repeat Procedure 5. using two parallel plate conductors.
7. Repeat procedure 5. using two parallel plate conductors that are much closer together.

Data (record in notebook)

11. For the outside of the conductive sphere

Position Description				

Charge and sign				

12. For the inside of the conductive sphere

Position Description				
Charge and sign				

13. Sketch the charge distribution on the inside and outside of the conductive sphere according to location. Was the charge distribution on it uniform or not? ___________.

14. For the outside of the parallel plates

Position Description				
Charge and sign				

15. For the inside of the parallel plates

Position Description				
Charge and sign				

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16. Sketch the charge distribution on the inside and outside of the parallel plates according to location. Was the charge distribution on it uniform or not? ___________.

17. For the outside of the close parallel plates

Position Description				
Charge and sign				

18. For the inside of the close parallel plates

Position Description				
Charge and sign				

19. Sketch the charge distribution on the inside and outside of the close parallel plates according to location. Was the charge distribution on it uniform or not? ___________.

21. How does a conductor become charged when connected to a source of charge such as the Electrostatic Voltage Source?
.

22. How does the charge distribution determine the magnitude and direction of the electric field in the vicinity of the charged conductor? ____.