Electrostatics

Revision 4.0b

Objective:
This experiment allows you to investigate the production of static charge, charging by: induction and contact, the measurement of charge, grounding techniques and the decay of charged objects.

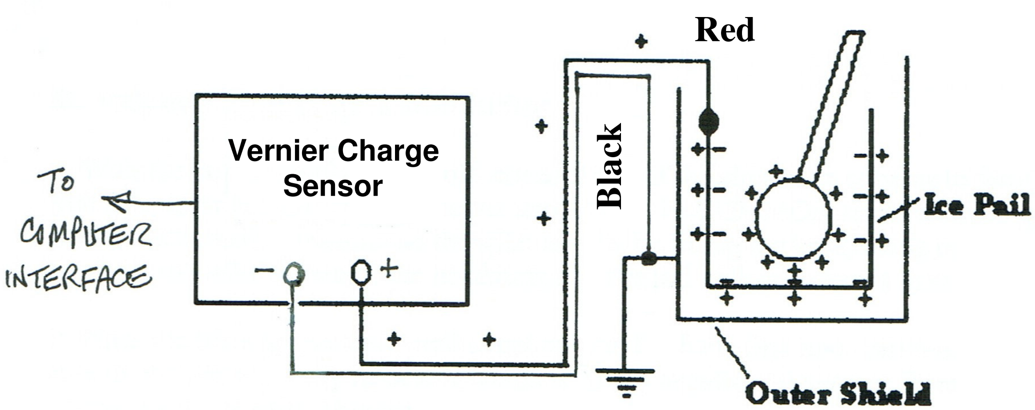


Figure #1 shows the effect of inserting a net positive charge into the cylinder

Apparatus:

Computer with Lab Pro interface	Rubber rod & Plexiglass rod & piece of fur
Faraday ice pail apparatus	Glass & piece of silk
Vernier Charge Sensor	Long white plastic rod
Aluminum foil (2 pieces) 12" x 18"; 12" x 3"	Connecting leads

Introduction:
When a positively charged object such as a glass rod is placed near a conductor, electric fields inside the conductor exert forces on the free charge carriers in the conductor (electrons in metallic conductors), which cause them to move. Some of those negative charges redistribute themselves near the glass rod leaving the parts of the conductor furthest from the glass rod positively charged. This process occurs rapidly, and is completed when there is no longer any electric field inside the conductor. The surface of the conductor ends up with regions where there is an excess of one type of charge over the other. This charge distribution is called an *induced charge distribution.* The process of separating positive from negative charges on a conductor by the presence of a charged object is called *electrostatic induction.*

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. Suppose our "ice pail" has a lid with a small opening through which we lower a positively charged metal ball into the pail ***without touching it to the*** *pail.* When we do this, negative charges in the pail move to the inner surface of the pail, because they are attracted to the positive charges on the metal ball, leaving positive charges on the outside of the pail. If at this point we touch our hand to the outside of this inner pail, those positive charges on the outside of the pail will be neutralized be pulling in electrons through our hand. If we then remove our hand from the outside of the pail, and then remove the positively charged metal ball from the inside of the pail, the outside of the pail will be left with a net negative charge. This is called <u>charging by induction</u>.

In contrast, if we put the positively charged ball inside the uncharged pail and touch the inside of the ice pail with the positively charged ball, electrons from the metal pail flow into the ball, exactly neutralizing the positive charge on the ball. This leaves the pail with a net positive charge residing on the outer surface of the pail. This is called <u>charging by contact</u>.

Finally, when a positively charged ball approaches the ice pail from outside of the outer pail, electrons in the pail will redistribute themselves on the outside surface of the pail and will exactly cancel the electric field inside the pail. This is called <u>electrostatic shielding</u>.

Charge Sensor:

The Charge Sensor can be used to measure the size and sign of the charge on an object, the units displayed on the computer are nano-Coulombs.

The Charge Sensor circuit consists of a very high-impedance voltmeter that is measuring the voltage across an internal 10-nanofarad capacitor. The external leads are connected to these internal capacitor plates. A large internal 1 MΩ resistor is placed in series with this capacitor to limit the current flow.

External objects connected to these leads form an external capacitor in parallel with the internal capacitor. As long as the external capacitance is small compared to the internal capacitance, the charge can be calculated using the relationship $Q = C\Delta V$, where C is the capacitance of the internal capacitor.

"For example, the range -0.5 V to +0.5 V on the Vernier Charge Sensor corresponds to a range in charge of -5 nC to +5 nC. Two metal plates 50 cm on a side placed 5 cm apart in air have a capacitance of about 44 pF, giving only a 0.4% change in the total capacitance and a corresponding small error in determining the charge."

"The same size plates separated by a 0.5-mm plastic sheet with a dielectric constant of 5 have about 22-nF capacitance, roughly twice the internal capacitance, meaning that the sensor could not be used to measure charge with that arrangement, at least not without reinterpreting the charge scale."

Source: “Electrostatics with Computer-Interfaced Charge Sensors”, by Robert A. Morse, St. Albans School, Washington, DC. THE PHYSICS TEACHER, Vol. 44, November 2006, p. 498.

Figure #2. The Vernier Charge Sensor.

The Faraday Ice Pail used in this experiment has a capacitance of less than 0.10 nF so the approximation is valid in our case.

Since charges exert forces on one another there is the possibility of work being done. The volt concept is related to potential energy much like that found in gravitational theory. This semester you will study the potential energy of charge distributions and the "potential" at a point in space. These are used in much the same way as gravitational potentials were used.

The Charge Sensor is so sensitive that charges that build up on you may affect it strongly and result in inaccurate measurements. It is advisable to touch a grounded piece of metal (cold water pipe or something connected to an outlet ground) frequently. Avoid wearing long sleeve sweaters (not really a problem in Austin) when making measurements if possible. Later we will discuss the use of a ground strap to control this problem.

Experimental Set Up Procedures:

Assembling The Faraday Ice Pail

Assemble your Faraday Ice Pail by first placing a small piece of insulating material in the bottom of the outer can. Insert the smaller can into the larger can and push it down so that it touches the insulating material at the bottom of the outer can. Three more pieces of insulating material should be placed between the sides of the inner and outer cans so that the two cans do not touch each other.

For the purpose of discharging (grounding) the inner and outer cans, during the course of this experiment, attach a short connector to the inner can with an alligator clip. The wire should hang over the top of the outer can but not actually come into contact with anything until we wish to ground the inner can. To ground the inner can, just connect this free end of the connector to the outer can’s ground connection.

The system ground will be the metal electrical conduit under the lab table. Use a wire with an alligator type connector to connect the outer can to a metal conduit screw.

Zeroing the Charge Sensor (Only after following the Set Up Procedure below)
Set the Charge Sensor on the ±10 volt scale. With the red and black leads shorted together Zero the Charge Sensor by pressing the Zero Button and holding it for several seconds. The charge readout on the computer screen should read ±0.10 nC. You should always push the zero button to discharge the electrometer before making a measurement, unless instructed otherwise.

Set Up Procedure
1. Turn on the computer.
2. Attach the Lab Pro Interface to the computer. Connect the LabPro power supply.
3. Attach the Charge Sensor to the Lab Pro Interface.
4. Select the ±10 volt scale on the Charge Sensor. Short the red and black leads of the Charge Sensor.
5. Start up the Logger Pro application. The correct data tables and chart will automatically be selected and displayed.
6. With the leads of the Charge Sensor shorted together "Zero" the Charge Sensor, as described above. The charge should read less than 1.0 nC
7. With the Faraday Ice Pail fully assembled, as described above, short the inner can to the outer can.
8. Now connect the Charge Sensor to the Faraday Ice Pail. The red lead goes to the inner can and the black lead goes to the outer can.
9. "Zero" the Charge Sensor again.
10. Disconnect the short between the inner and outer cans.
11. The Faraday Ice Pail is now ready for use.

Experimental Procedures:
Charge "Creation" by Friction
Refer to the Triboelectric Series data in Appendix 1.
1. Glass & silk ➔ measure charge using the Faraday Ice Pail.
2. Rubber & fur ➔ measure charge using the Faraday Ice Pail.

   Try each object several times to determine the range of charges produced by each technique. Describe your observations below.

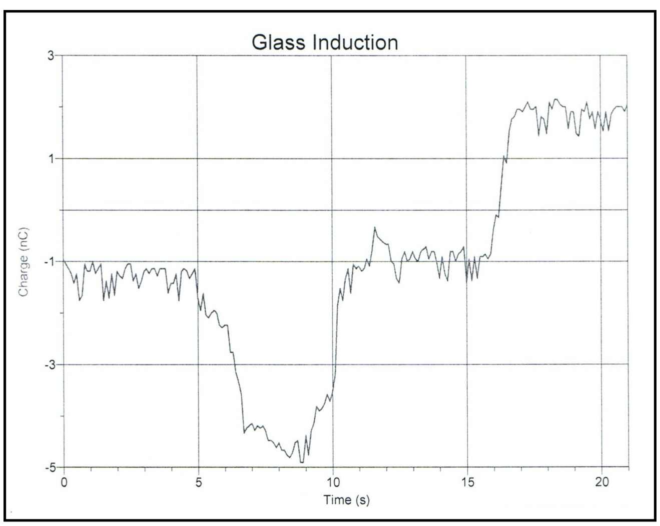
Glass or Plexiglass:	**Rubber:**

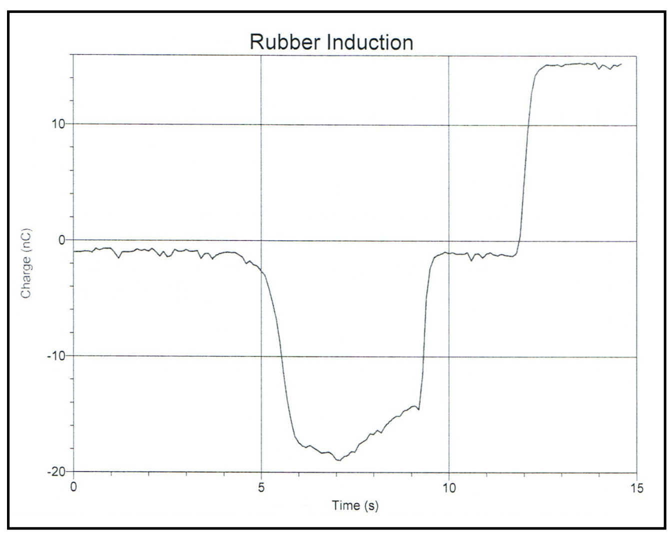
Tips:
1. Only rub about 1/3 of the length of each rod. This will keep the charge localized in one portion of the rod and improve the repeatability of the measurements.
2. Dip the rod into the inner can as far as possible without touching the inner can.
3. The value of the charge should reach a maximum value and stay there if the rod is held motionless in the inner can.

Charging by Induction
Describe your observations in terms of the movement of the ELECTRONS.

1. Charge Glass rod; a. Meas. Charge; ☐ b. Ground inner can; c. Unground can; d. Remove glass rod; e. Meas. charge. ☐ f. Print Chart.	Describe your observations in detail.
2. Charge Rubber rod; a. Meas. Charge; ☐ b. Ground inner can; c. Unground can; d. Remove rubber rod; e. Meas. charge ☐ f. Print Chart.	Describe your observations in detail.

Plexiglass was used instead of glass in the chart below on the left.



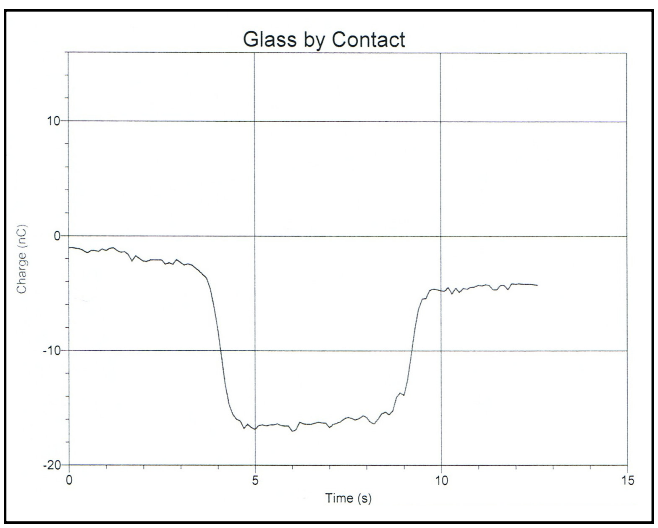


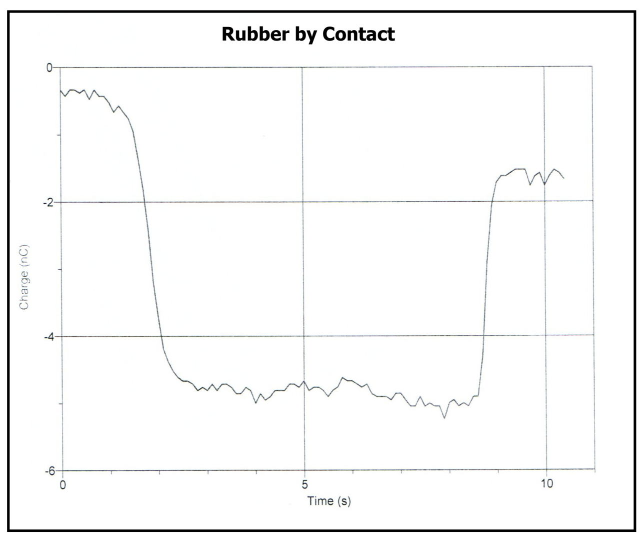
Charging by Contact

Describe your observations in terms of the movement of the ELECTRONS.

1. Charge Glass rod; a. Meas. charge; [ ] b. Rub rod on inner surface of inner can; c. Remove rod; d. Meas. charge. [ ] e. Print Chart.	Describe your observations in detail.
2. Charge Rubber rod; a. Meas. charge; [ ] b. Rub rod on inner surface of inner can; c. Remove rod; d. Meas. charge. [ ] e. Print Chart.	Describe your observations in detail.

Plexiglass was used instead of glass in the chart below on the left.





Outside Effects

1. Wave hands over and around the Faraday Ice Pail.	Describe your observations in detail.
2. Charge long plastic rod and partially insert into inner can. Wave it in the vicinity of the ice pail and the Charge Sensor	Describe your observations in detail.
3. Construct a ground strap	See below
4. Construct and install an Aluminum ground plane	See below
5. Using the ground strap and the aluminum ground plane does the large plastic rod still have an effect?	Describe your observations in detail.

The Ground Strap
Material:

- 12” x 3” strip of Aluminum foil;
- 18” - 24” connectors (Alligator type clips).

Fold the Aluminum strip into thirds along the long dimension. Wrap the resulting 12” x 1” strip tightly around your wrist, folding over the excess material. Connect the wire between this fold and the ground connection. Warning: Commercial grounding straps incorporate a 1MΩ resistor for added safety when working around power supplies. We aren’t using any power supplies so we omitted the resistor.

The Ground Plane
Material:

- 12” x 18” piece of Aluminum foil.
- 18” - 24” connectors (Alligator type clips).

Place the Faraday Ice Pail in the center of the Aluminum ground plane. Fold the corner of the plane, nearest the ground connection, twice to form a small aluminum tab perpendicular to the plane of the aluminum sheet. Connect this tab to ground. Connect the outer can of the Faraday Ice Pail to the same tab. At the opposite corner of the ground plane fold the aluminum over the Charge Sensor to shield it from stray charge effects.

Charge Decay
Use the ground strap and keep the ground plane in place and connected to ground. Click on the Clock icon in the tool bar and set the data collection time to 300 seconds. You will be repeatedly dipping the charged rods into the inner can, being careful not to let the rods actually touch either of the cans.

1. Discharge the inner can of the Faraday Ice Pail and zero the Charge Sensor.
2. Charged Glass rod - dip cycle: 5 sec in followed by 10 sec out - repeat for 5 minutes.
3. Print chart
4. Charged Rubber rod - dip cycle: 5 sec in followed by 10 sec out - repeat for 5 minutes.
5. Print Chart
6. Using the chart data, estimate the half-life of the charge on **each** of the rods.

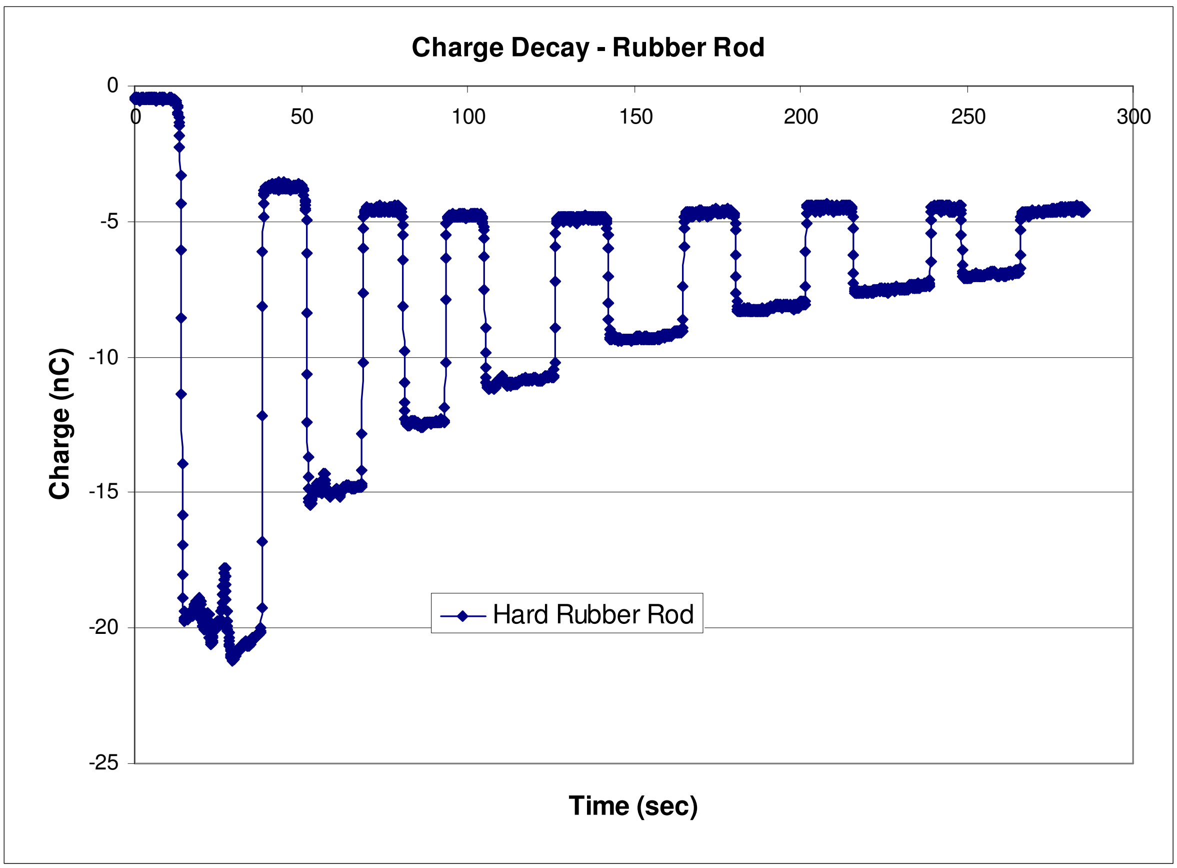


Figure #3. An Excel display of the charge on a rubber rod as a function of time. The data was measured by a Vernier CRG BGA Charge Sensor and was collected via Logger Pro software. Note: The Charge Sensor was not zeroed between the measurement cycles during the acquisition of the above data.

Appendix 1 - Triboelectric series

More Positive
* Human Hands (if very dry)
* Leather
* Rabbit Fur
* Glass
* Human Hair
* Nylon
* Wool
* Fur
* Lead
* Silk
* Aluminum
* Paper
* Cotton
* Steel (neutral)
* Wood
* Amber
* Hard Rubber
* Nickel, Copper
* Brass, Silver
* Gold, Platinum
* Polyester
* Styrene (Styrofoam)
* Saran Wrap
* Polyurethane
* Polyethylene (scotch tape)
* Polypropylene Vinyl (PVC)
* Silicon
* Teflon

More Negative