# 1. Electrostatic Lab [1]

**Purpose:** To determine the charge and charge distribution on insulators charged by the triboelectric effects and conductors charged by an Electrostatic Voltage Source.

**Equipment:** Faraday Pail setup including ground plane and wire cage, charge sensor, two conducting spheres, high voltage electrostatic voltage source, computer with Lab-Pro, proof plane, nylon charge producer, PVC charge producer, dark green wool fabric, white paper, light green plastic pad, damp white cotton towel, pvc stick, nylon stick, circle paper punch-out, cardboard box.

In this lab you will use a Faraday Pail and charge sensor to measure electric charge on various objects. As measured charges are small we have to make sure to keep all equipment clean and free of body oils. Oil on connectors and wires can act as a conducting path providing a leakage path for the small charges. So we ask you to wash your hands with soap in the bathroom at the start of the lab. Make sure to carefully dry your hands before returning to the lab.

Another effect that can strongly influence the outcome of electrostatic experiments is the effect of the charge on the people conducting the experimenter. Synthetic clothing can be charged on dry days. Because of this the measurement setup is shielded by a grounded metal plane and a grounded wire cage. Furthermore the operator is grounded via a wrist strap. It is best to not walk around when performing the experiments, so that remaining unshielded electric fields do not change during the course of the experiments. As the humidity can have a significant influence on the presence of static charge we want you to record the humidity in the lab at the time of the experiments.

**Fig. 1: Faraday Pail Setup**

The Faraday Pail setup consists of a metal ground plate, a green insulating disk, an aluminum Faraday pail, and a metal wire cage. Place the green plastic disk on the metal ground plate and place the wire cage and the Faraday pail on the green disk as shown in the picture below. Connect the wire cage and the metal ground plate with the black ground wire. Connect the blue ground wrist strap to the wire cage. Connect the ground of the wire sensor (black wire) to the wire cage, and the red wire of the charge sensor to the Faraday pail. The charge sensor is an analog sensor. Connect it to the Vernier LabPro interface and make sure that the interface is connected to the power adapter. Start up the logger Pro software. The software should automatically recognize the sensor and load the appropriate calibration curve. In case that does not happen select EXPERIMENT from the menu bar at the top of the screen and select SETUP SENSORS – SHOW ALL INTERFACES. Look for the Charge Sensor in the Analog Sensor list on the left of the popup window. If it is not there ask the help of your lab TA. The charge sensor has three different ranges which can be set via a switch on the sensor:

1. 100 nC range: This range is labeled with +/- 10 volt
2. 20 nC range: This range is labeled with +/-2 volt
3. 5 nC range: This range is labeled with +/-0.5 volt

The charge sensor also contains a grey button next to the BNC connector of the probe wires. Pushing this button will zero the sensor, i.e. discharge the input capacitor and discharge the capacitor in the sensor's integrator. Note that shorting the inputs of the sensor has a slightly different effect and will not zero the reading of the sensor.

In the first part of this lab you will use the triboelectric effect to charge various materials. When two materials are brought in contact with each other bonds are formed between the atoms of both materials and charge is transferred between them. When those bonds are broken some of the atoms have the tendency to keep the extra electrons while others tend to give the electrons away. If at least one of the materials is an insulator this can lead to electrostatic charge. The effect is greatly enhanced when two material are rubbed together as bonds are made and broken many times. Materials are often listed in a triboelectric series (see table 1 below). When a material high up in the list is rubbed against a material low in the list, the former gets positively charged and the latter negatively charged. The affinity of a material for electrons is often measured in terms of the material work-function. The larger the work-function of the material the stronger it wants to hold on to electrons. You will learn more about this in Modern Physics.

Triboelectric Series

| | |
|---|---|
| Air | +++ |
| Human Skin | |
| Leather | |
| Rabbit's fur | |
| Glass | ++ |
| Human Hair | |
| | |
| | |
| Lead | |
| Silk | |
| Aluminum | |
| | |
| Cotton | No charge |
| Steel | No charge |
| Wood | |
| Amber | |
| Polystyrene | |
| Rubber balloon | |
| Nickel, Copper | |
| Silver | |
| Gold, Platinum | -- |
| Polyester | |

| | |
|---|---|
| Styrofoam | |
| Polyethylene (Scotch Tape) | |
| | |
| | |
| Silicon | |
| Teflon | --- |

In the 2nd part of this lab you will use a high voltage power supply to charge a metal object, a sphere on a stick. This charging method differs in two ways from the triboelectric charging method discussed above:

1. The objects charged with the triboelectric charging methods are electric insulator while metals are electric conductors. In metals some of the outer electrons of the atoms are not bounded to the individual atoms. They can move freely through the metal. Also when additional electrons are added to the object, by charging it, those extra electrons can move freely through the metal object. We call those electrons mobile charge carriers, as they can move around and they transport charge from one point of the object to another point of the object. Electrons in insulators such as for example a PVC tube, behave very different. In PVC the electrons are bounded to the atoms and cannot move around. Even the additional electrons that are placed on the PVC by rubbing it with nylon are bounded to atoms and cannot move freely through the object.
2. Using a power supply to charge an object will allow us to place a certain amount of charge on the object, as the charging is proportional to the output voltage of the power supply. We can modify the latter easily electronically.

## Procedure:

1. Put on the wrist strap and make sure that the charge sensor is switched to the least sensitive range (i.e. =/- 10 volt). You can change the range by the switch on top of the charge sensor. If you change the range, Logger-Pro will detect the change automatically. A CHANGE SENSOR window will pop up: click USE SENSOR SETTING. In the case Logger-Pro not automatically detects the range change, you have to set the range in Logger-Pro manually. To do this select EXPERIMENT – SET UP SENSORS – SHOW ALL INTERFACES. The Lab-Pro window will pop up. The charge sensor should be visible on one of the analog channels on the left. Left click the sensor and select CHARGE SENSOR RANGE. Select the =/- 10 volt range push OK and close the sensor window. Zero the charge sensor by pushing the grey button on the sensor. Take the Nylon rod in the hand with the wrist strap and rub it with the green plastic pad. Insert the Nylon rod in the Faraday pail without touching it. Keep it in the pail for 2 seconds and then pull it out. Observe the sensor readings. Is the charge on the Nylon positive or negative? Why is it not necessary to touch the pail with the charged rod to measure a reading? If it is very dry, the reading of the electrometer should return to zero when you pull the nylon rod out of the pail.

2. Touch with your fingers the ground plane. Zero the charge sensor and repeat the experiment described under (1) but now touch the pail with the nylon rod. When you remove

the charged nylon rod out of the pail, does the reading of the charge sensor return to zero? Explain.

3. Touch with your fingers the ground plane. Zero the charge sensor, Rub the nylon rod with the green plastic pad and insert it in the pail. Do not have it touch the wall of the Faraday pail. While it is in the pail remove the ground wire that connects the ground plate with the wire cage at the side of the wire cage and connect it shortly to the pail. Observe the charge sensor reading while doing so. Reconnect the ground wire to the wire cage. Remove the Nylon stick out of the pail and observe the reading of the charge sensor while doing so. Explain.

4. Touch with your fingers the ground plane. Zero the charge sensor. Rub the nylon rod with the green plastic pad and insert it in the pail. Touch the sides of the pail. Repeat this until the charge sensor shows a reading of more than 15 nC. Now take the grey PVC rod and rub it with the green wool fabric. Touch the walls of the pail and observe the readings of the charge sensor. Repeat this until the reading of the charge sensor is back to zero. Explain.

5. Touch with your fingers the ground plane. Zero the charge sensor. Rub the grey PVC charge producer and the white nylon charge producer across each other. Measure the charge on the grey PVC charge producer and the charge on the white nylon charge producer. Also measure the charge on both charge producers after the rubbing action by sticking them together in the Faraday pail. Do the measurements quickly after each other so that there is not more than 3 seconds between finishing the rubbing treatment and the last measurement. Explain your results.

**Fig. 2: Charge producers**

6. Consider the following materials:
    a. Grey PVC rod
    b. White Nylon rod
    c. Dark green wool fabric
    d. Light green plastic pad
    e. White cotton
    f. Normal paper

Use the Faraday pail and rubbing to rank the 6 materials given above in a triboelectric table. Materials high up in the table should be positive upon rubbing with materials low down in the table. Write down all experiments you did and their results to determine the final ranking.

In the following part of the lab we will use a high voltage power supply to charge objects. The advantage of this approach is that it is possible to put a certain amount of charge on a conducting object. As the high voltage power supply and the charge sensor influence each other place the


**Fig. 3: Voltage terminal, Electrostatic Voltage source, and proof plane**

high voltage power supply on the aisle side of the Faraday pail. Make sure the voltage source is not switched on. Connect the ground of the electrostatic voltage source to the ground plane. Put the voltage terminal (i.e. the aluminum circle with red wire) in the provided stand, away from the Vernier interface, the charge sensor, the keyboard and the computer. Computers and other electronic devices do not like high voltages. Make sure the Electrostatic voltage source is off. Connect the voltage terminal to the 6000 volt output of the electrostatic voltage source. Although the electrostatic voltage source can only provide a very small current, it can still develop a discharge, possible hurting you. So we recommend you to only touch the voltage terminal by the plastic stick and not by the metal disk. Also make sure that the voltage terminal does not directly touch the ground of your setup, the Faraday pail, or the input of your charge sensor. **Touching the Faraday pail with the voltage probe can destroy the charge sensor, so please do not stick the voltage probe in the Faraday pail!** The voltage terminal is used to charge the spheres, and the proof plane, a similar metal disk without wire, is used to measure the charge on the charged object. After you have convinced yourself that the voltage terminal is placed in the stand and not touching your lab-partner, the Vernier interface, the computer, the table, the charge sensor, or the ground plane, switch on the power supply of the electrostatic voltage source.

7. Check the voltage terminal by trying to lift small pieces of paper with it. Try to bounce the provided circular paper punch-outs between the voltage terminal and the table (NOT the ground plane!). Write down what you observe and explain.

8. Temporarily ground the sphere to remove all charge on it. It is best to do this by disconnecting the wire between the ground plane and the wire cage on the side of the wire cage and touch the sphere with the connector. After doing this place the connector back on the wire cage. Put the charge sensor on the most sensitive range. Discharge the charge sensor by pushing the grey button. Remove all charge from the proof plane by dabbing all parts of the proof plane with a damp cotton cloth. Now use the voltage terminal connected to the 6000 volt output of the electrostatic voltage source to charge the sphere. Make sure the other sphere is at least 30 cm away from the sphere you just charged. Put the voltage terminal down and use the proof plane to sample the charge on the sphere. Measure the charge on the proof plane by sticking it in the Faraday pail. Make sure that the proof plane does not touch the walls of the pail. Observe the charge sensor reading before, during, and after you stick the proof plane in the Faraday pail. Repeat this experiment to determine the charge at different locations on the sphere. What do you conclude about the distribution of charge on the sphere?

9. Now place the second sphere (B) next to the first sphere (A). Leave a distance between the two spheres so the proof plane can be used to sample the surface charge of sphere (B) right between the two spheres: One inch should work fine. Now discharge both spheres using the method described under (8). Discharge the charge sensor by pushing the grey button. Remove all charge from the proof plane by dabbing all parts of the proof plane with a damp cotton cloth. Now use the voltage terminal connected to the 6000 volt output of the electrostatic voltage source to charge sphere (A). Make sure not to touch sphere (B) with the voltage terminal. Use the proof plane to sample the charge on the surface of sphere (B) right between the two spheres. Measure the charge on the proof plane by sticking it in the Faraday

pail. Repeat the experiment but now you will measure the charge on the other side of the surface of sphere (B) (the side not facing sphere (A)). Is the charge uniform on the surface of sphere (B)? Explain your results.

10. Now place both spheres at least 20 cm apart. Remove the charge on both spheres using the technique described in (8). Discharge the charge sensor by pressing the grey button on the charge sensor. Remove the charge from the proof plane by using the technique described in (8). Charge sphere (A) by touching it with the voltage terminal connected to the 6000 volt output of the electrostatic voltage source. Measure the charge on the sphere (A) by touching it with the proof plane and inserting the proof plane in the Faraday pail. Record the reading. Now repeat the experiment but before you measure the charge on sphere (A) you touch it with sphere (B). Make sure you do not touch the spheres with your hand or fingers: hold sphere (B) at the base when touching. Place the sphere (B) back at a distance of approximately 20 cm from sphere (A). Now measure the charge on sphere (A). Repeat this last experiment but after placing sphere (B) back at 20 cm, measure the charge on sphere (B). Repeat the whole experiment three times and record the measurements in a table.

| | Initial charge on (A) | Charge on (A) after touching | Charge on (B) after touching |
|---|---|---|---|
| Measurement 1 | | | |
| Measurement 2 | | | |
| Measurement 3 | | | |
| Average | | | |

Explain your results.

11. Now place both spheres as close to each other as possible. Remove the charge on both spheres using the technique described in (8). Discharge the charge sensor by pressing the grey button on the charge sensor. Remove the charge from the proof plane by using the technique described in (8). Charge sphere (A) by touching it with the voltage terminal connected to the 6000 volt. While you charge sphere (A) touch with your finger the top of sphere (B). Remove first your finger from sphere (B) and then the voltage terminal from sphere (A). Place the two spheres at least 20 cm apart from each other and measure first the charge on sphere (B) and then the charge on sphere (A). Record your observations in a table. Make sure to discharge the charge sensor and the proof plane between each measurement. Explain your results. Why are the spheres separate by 20 cm before we measure the charge?

In this lab you have seen two different techniques to charge objects:

A. Rubbing technique: When two different materials are brought in contact with each others, bonds will form between both materials and electrons will be transferred from one material to the other. When separating both objects those transferred electrons will stay in the new host material, giving one material a positive charge and the other material a negative charge. This effect of making and breaking bonds is intensified when rubbing both materials across each other. You have seen several examples of this effect in this lab. The working of the van der

Graaff generator which might have been demonstrated in class is based on this principle. Also the charging of clouds is based on this principle.

B. It is possible to use a high voltage source to charge conducting objects. The positive pole of the voltage source can be considered a vacuum cleaner for electrons. It removes electrons from the object. The higher the voltage, the more electrons are potentially removed from the object. The removed electrons are dumped on the objects connected to the negative pole of the voltage source, in our case the ground plane. Although it is possible to charge objects with a 9 volt battery, the charging results from such battery is too small to be measured with the lab-equipment. For this reason we use an electrostatic high voltage source. Electrostatics is important for the printing business. The toner particles in a photocopier or laser printer are positioned on the paper by electrostatic forces, charging the drum and the toner particles. Also in inkjet printers electrostatic forces play a role. Small charged droplets of ink are shot from the printer head to the paper. Toner particles, drum, and ink droplets are charged by electrostatic voltage sources in the device.

Questions:

1. On a dry windy day we notice that sometimes part of our cloth get charged, and if we touch a keyboard or door knob sparks occur. Explain how your synthetic clothes were charged.
2. In the $2^{nd}$ part of the lab you used a high voltage power supply to charge a metal object. Assume that you place 2 additional electrons on a metal solid sphere by touching the output of the sphere at a specific point B with the voltage terminal of the high voltage power supply. What happens to those electrons? Will they stay together at point B? If not how would they position themselves with respect to each other on the sphere and explain why?
3. Assume you place not two but three additional electrons on the sphere with the procedure described under question 2. Where would they position themselves with respect to each other?
4. Assume that the spheres you used in this lab are made of copper and are not hollow. Copper has approximately 8.3E28 free conduction electrons/m3. Measure the radius of the spheres you used in your lab experiment and calculate the total number of free electrons in such sphere assuming they are solid. Compare this to the number of free electrons you placed on the spheres with the power supply. Are the number of extra electrons you charged the spheres with anywhere close to the number of free electrons present in the spheres.