Lab 1 – ELECTROSTATICS

OBJECTIVES

• To understand the difference between conducting and insulating materials.

• To observe the effects of charge polarization in conductors and insulators

• To understand and demonstrate two ways to charge an object: conduction and induction

• To determine the polarity of charge on a charged object based on macroscopic observations

OVERVIEW


Electrostatics\(^1\) is the study of charges which are not in motion and the interactions between them. Most of the phenomena we observe in the study of electrostatics arise from ionization. Although atoms are electrically neutral, their outermost electrons are sometimes easily removed; when an atom gains or loses electrons, the resulting imbalance of charge is referred to as ionization. Positive ions are atoms which have lost electrons, while negative ions are atoms which have gained electrons. A material with easily detached electrons (which can then move through the material somewhat freely) is referred to as a conductor. Conversely, a material with strongly attached electrons is called an insulator. Objects can be charged by making contact with another charged object, a phenomena known as charging by conduction.

When objects are charged without coming into contact with a charge source, the process is known as charging by induction; this process primarily works with conductors. One method of charging involves moving a charged object to the vicinity of two uncharged conductors in contact with each other, as shown in Figure 1. An induced charge flows to one conductor, leaving the other conductor oppositely charged. When separated the conductors have equal, but opposite, charges. As always, it is important to remember for these experiments that charge is conserved and that like charges repel while opposite charges attract.

\(^1\) Adapted from Dr. Richard Lindgren, Charlene Wyrick, Karyn Traphagen, and Lynn Lucarto. The Shocking Truth: Lessons in Electrostatics. 2000.
INTRODUCTION TO THE APPARATUS

The electroscope is an instrument that detects the presence of charge on an object, either through actual contact (conduction) or through induction. When the electroscope itself is charged, its two conductive components (which vary from electroscope to electroscope) will acquire like charge and deflect from the vertical position of gravitational equilibrium. Thus a rod is proven to possess a charge when contact between the rod and the electroscope transfers charge to the previously neutral electroscope. A charged object brought in the vicinity of the charged electroscope will change the angle of deflection, indicating the presence of charge via induction (or induced polarization). This process is explained in greater detail in the experiments.

Figure 1: Charging by Induction

Figure 2: UVa Electroscope
The UVa electroscopes have been designed with the following considerations:

- The base of the electroscope is constructed out of acrylic, an insulator, to minimize charge leakage to the table (or to the object on which the base sits).

- The tube is made of copper, a conductor, and is suspended slightly above its center of gravity so that it will quickly reach stable equilibrium when no charge is present.

- The support structure is made of brass, another conductor. The rounded edges of the support minimize charge leakage into the atmosphere. [Sharp points on conductors tend to leak charge away easily.] If a charged rod is brought into contact with the upper lip of the support structure, charge will distribute across the brass and the copper, causing the tube to deflect from the brass structure.

The following hints will optimize your use of the electroscope:

- Insulators (e.g. Teflon and acrylic) do not transfer charge easily to other objects, so draw or scrape the rod across the brass lip in order to transfer charge to the electroscope.

- Oils and salt transferred from your hand to the rod may adversely affect experimental results. Only handle the unmarked end of the Teflon rod and charge the marked end so as to minimize these effects. [A useful mnemonic is to think of the marked end as “red hot”.]

- Occasionally you will have to touch the marked end to “bleed off” the charge. To do this, grab the rod a couple of times along its length with a clean hand (rubbing may actually charge, not discharge, the rod). You may need to periodically clean the rod with alcohol.

- When using the electroscope to detect the presence of charge, it may be necessary to bring a charged rod near the tube in a back-and-forth rhythmic motion to cause visible movement of the tube.

- Humidity increases the charge leakage into the atmosphere. Ideally, humidity should be below 50%. Winter is thus the best time in Virginia for static electricity demonstrations, but we use air conditioners and dehumidifiers to help improve the situation.

**THE TRIBOELECTRIC SERIES**

Materials possess various tendencies to acquire or to lose electrons; the ordering of these tendencies is referred to as the triboelectric series. When you use a silk cloth to charge a Teflon rod, you are engaging in a process known as triboelectric charging. Teflon’s electrical nature dictates that it will acquire a negative net charge, as it has a tendency to take electrons from the silk. Glass, on the other hand, has a tendency to acquire a positive net charge from silk. The list below
orders a number of common materials by their electrical nature\textsuperscript{2}. Note that human hands have a strong tendency to gain positive charge. We will use Teflon and silk.

<table>
<thead>
<tr>
<th>Material</th>
<th>Tendency to gain charge</th>
</tr>
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<tbody>
<tr>
<td>Human hands</td>
<td>POSITIVE charge</td>
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<tr>
<td>Asbestos</td>
<td></td>
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<tr>
<td>Rabbit Fur</td>
<td></td>
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<tr>
<td>Glass, Mica</td>
<td></td>
</tr>
<tr>
<td>Human Hair</td>
<td></td>
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<tr>
<td>Nylon, Wool</td>
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<tr>
<td>Lead</td>
<td></td>
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<tr>
<td>Silk</td>
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<td>Aluminum</td>
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<tr>
<td>Paper</td>
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<td>Cotton</td>
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<td>Steel</td>
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<td>Wood</td>
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<tr>
<td>Amber</td>
<td></td>
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<tr>
<td>Hard Rubber</td>
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<tr>
<td>Mylar</td>
<td></td>
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<tr>
<td>Nickel, Copper</td>
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<tr>
<td>Silver, Brass</td>
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<tr>
<td>Gold, Platinum</td>
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<tr>
<td>Polyester, Celluloid</td>
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<tr>
<td>Saran Wrap</td>
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<td>Polyurethane</td>
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<td>Polyethylene</td>
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<tr>
<td>Polypropylene</td>
<td></td>
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<tr>
<td>Vinyl, Silicon</td>
<td></td>
</tr>
<tr>
<td>Teflon</td>
<td>NEGATIVE charge</td>
</tr>
<tr>
<td>Silicon Rubber</td>
<td></td>
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</tbody>
</table>

Figure 3

**Question 1:** If you rub a glass rod with silk, what is the polarity of the charge on each object? What about Teflon and silk? Gold and lead? Use the Triboelectric series above.

- Glass and silk: Glass _________ Silk _________
- Teflon and silk: Teflon _________ Silk _________
- Gold and lead: Gold _________ Lead _________

\textsuperscript{2} This Triboelectric series was adapted from Allen, Ryne C., Desco Industries Inc. (DII), December 2000. Downloaded from http://www.esdjournal.com/techpapr/ryne/ryntribo.doc, July 31, 2002.
INVESTIGATION 1: CONDUCTORS AND INSULATORS

The purpose of the experiment is to observe the electrical properties associated with an insulator and a conductor. Recall that, as stated in the Overview, electrons can move freely through conductors, while they are not free to move within insulators.

The following equipment is needed for this investigation:

- Spinner
- Silk cloth
- Brass rod
- Acrylic rod
- Electroscope
- Teflon rods (2)
- Wooden rod

Activity 1-1: Teflon

In the following activity, you will observe the interaction between two negatively charged Teflon rods, one held in your hand and one placed on a spinner. You will charge only one end of each Teflon rod.

The “spinner” consists of a metal pin attached to a plastic acrylic base and a second piece of plastic which rotates on the metal pin. It thus rotates very freely. The rod is positioned on this second piece of plastic.

Prediction 1-1: Consider Figure 4. Predict what will happen if you position the charged end of the Teflon rod [in your hand] alongside and parallel to the charged end of the Teflon rod on the spinner without letting them touch? What about along the uncharged end of the Teflon rod on the spinner? Do not yet try it.
**Question 1-1:** How is it that we can charge one end of the Teflon rod and leave the other end uncharged? Is this true for all materials?

1. Charge one end of the first Teflon rod by striking or rubbing it on the silk and place this Teflon rod on the spinner. Now charge one end of the second Teflon rod.

2. Use the spinner and the Teflon rods to test your predictions: After charging both rods, hold one Teflon rod in your hand parallel to the Teflon rod on the spinner as shown in Figure 4 in order to ensure the greatest possible interaction between the two. If nothing happens, you may need to recharge the Teflon rods.

**The Charging Process:**
When you strike the silk with the Teflon rod, a charge transfer occurs between the two materials. As Teflon attracts negative charge, the Teflon rod attracts the loose electrons from the silk’s surface and becomes negatively charged. Because charge is conserved, the silk is left positively charged. Transfer of electrons is responsible for charging; atoms do not transfer protons.

**Question 1-2:** What were your results? In particular, was there any interaction with the uncharged end of the rod on the spinner (you need to hold the rods very close together to see)? Discuss.
Activity 1-2: Movement of Charge in Metals

1. Use the charged Teflon rod to charge the electroscope by rubbing the top of the brass support with the end of the Teflon rod that is charged. You may need to charge the rod and rub the support a few times until the tube deflects a little.

2. Recharge the Teflon rod and add more charge to the electroscope.

Question 1-3: What did you observe? Discuss your observations in terms of metal’s conducting properties and the charge distribution.

How the Electroscope Works: Metals contain some electrons which are not tightly bound to the atoms and are free to move about through the conductor. When you charge the electroscope, excess charge distributes itself across the conducting parts of the electroscope (the brass support and the metal tube). This distribution occurs as a result of the force of repulsion between like charges, which attempt to move as far away from each other as possible. After the charges reach static equilibrium, the tube should be deflected at a constant angle.
Activity 1-3: Using Conductors to Discharge the Electroscope
When you provide the electrons in a charged object a route of escape through contact with an uncharged conducting object, electrons will flow from the charged object to the uncharged conducting object until electrical balance is achieved.

When you bring the metal parts of the charged electroscope into contact with a conducting element, you provide a pathway for the charges to flow in to (or out of) the electroscope so as to balance the forces between the charges, leaving it electrically neutral. This is called “grounding” or “discharging”.

Touching a charged object with an insulator will not completely discharge it. Some charges may transfer near the region of contact, but, as charges are not free to move about in an insulator, most of the charge imbalance will remain.

Prediction 1-2: Predict what would happen if you touched the top of the charged electroscope with your finger? What does this indicate about the conducting properties of the human body?

1. Observe as you touch the top of the brass support with your finger and record the results:

Question 1-4: Were your observations consistent with your prediction? Discuss.

Prediction 1-3: What would happen if you touched the top of the charged electroscope with a brass rod held in your hand? An acrylic rod? Justify your prediction on the basis of the properties of conductors and insulators.
2. Charge the electroscope. Touch the **charged** electroscope with the (uncharged) brass rod. Re-charge the electroscope (if necessary) and touch it with the (uncharged) acrylic rod. Observe and record the results.

**Question 1-5:** Explain your observations in terms of each rod’s conducting properties.

**Prediction 1-4:** Is wood a conductor or an insulator? What could you do to see?

3. Re-charge the electroscope (if necessary). Touch the **charged** electroscope with the wooden rod and observe and record the results.

**Question 1-6:** Is wood a conductor or an insulator? Explain in light of your observations.
INVESTIGATION 2: CHARGE POLARIZATION

An object is said to be neutral if it contains the same number of positive and negative charges. A neutral object can, however, produce some of the same phenomena as a charged object as a result of a process known as polarization. We already know that opposite charges attract. If we recall that charges are somewhat free to move within an object, we should not be surprised that a positively charged object will induce a charge alignment in a neutral object so that the object’s electrons are as near to the positively charged object as possible. As a result, the neutral object will appear to react to an electric force as though it were charged. When you charge by induction, you are exploiting polarization.

Recall that in a conductor, electrons are free to move. Polarization in a conductor, then, is a result of a movement of electrons to one side of an object. Electrons are not free to move (at least not very far) in an insulator. This does not mean, however, that an insulator does not experience polarization. Polarization in an insulator is a result of an alignment of the charge within each individual atom or molecule.

A negative charge in the vicinity of an atom, for example, will repel the atom’s electron cloud and attract the positive nucleus. This results in a rearrangement of the charges of the atom (Figure 6). The closer the atom is to the charged object, the more it will be “stretched”. Polarization does not create a permanent charge; it is instead a temporary effect caused by the proximity of a charged object. The polarized object acquires no net charge.
Prediction 2-1: What charges will the left and right sides of the insulating rod tend to have in Figure 7? Using Figure 6 as a guide, indicate on Figure 7 how the charges are distributed. Discuss.

Activity 2-1: Charge Polarization in an Insulator

1. Place the acrylic rod on the spinner.

Prediction 2-2: Predict what will happen if you bring a charged Teflon rod near the uncharged acrylic rod? Will it matter which end of the acrylic rod you place the charged rod near? Will it matter which side of the acrylic rod you choose?
2. Test your predictions and record your observations:

**Question 2-1:** Discuss the agreement between your prediction and your observations.

**Activity 2-2: Charge Polarization in a Conductor**

1. Use the charged Teflon rod to charge the electroscope.

2. Recharge the Teflon rod and bring the charged side (not the end, as the simplistic 2-D rendering shown in Figure 8 might imply) of the rod slowly near the lower end of the tube. At first you should notice repulsion between the tube and the charged Teflon rod; as the rod slowly approaches the tube, it should then begin to attract.

**Question 2-2:** In terms of polarization, what causes the attraction of the tube to the Teflon rod? Why does the tube initially repel and then attract? Discuss.

1. Charge the electroscope using the Teflon rod and silk.

2. Bring the charged Teflon rod near the bottom of the brass support (on the side opposite from the tube, see Figure 8 (below), but not touching. You should observe an increased deflection angle between the tube and the brass support.
**Question 2-3:** In terms of polarization, what causes this increased deflection?

![Figure 8](image)

**Question 2-4:** What charge sign do the elements of the electroscope have? Indicate in the diagram above the sign of any charged element of the electroscope. Discuss.

**INVESTIGATION 3: CHARGING BY INDUCTION**

When you charge the electroscope by touching the negatively charged rod to the top of the brass support, you are charging via conduction, which requires contact. The electroscope acquires the same charge as the charged rod; the negatively charged rod (which has taken electrons from the silk) distributes electrons on the electroscope. Charging via conduction necessitates that the charged object physically touch the object to be charged, and both objects will have the same sign of charge.

Charging via **induction** occurs without contact between the charged object and the object to be charged. The charged object
which we will refer to as an inducer) is brought near the neutral object, inducing polarization. Suppose the inducer has a negative charge. If you place your finger on the polarized object, your finger will drain electrons from the object, thus creating a net positive charge (Figure 9). When your finger and then the inducer are both removed, this net positive charge remains. The newly charged object is thus of the opposite polarity as the initially charged inducer.

Figure 9

You do not need any new equipment for this investigation.

**Activity 3-1: Charging by Induction**

1. Ground the electroscope to neutralize it. You can do this by touching the top of the brass support with your finger, thereby providing a pathway for the charge to the ground.

2. Have one partner hold his/her finger to the top of the brass support.

3. While the finger is on the brass support, have another partner bring the side (not the tip, as the figure seems to indicate) of the charged Teflon rod to the base (on the side away from the tube, as shown) of the brass support (without touching it) until you see a deflection of the tube.

4. Remove the finger from the support, and then remove the Teflon rod.
5. Record your observations:

**Question 3-1:** What is the sign of the charge on the electroscope? Explain what has happened.

**Question 3-2:** How can you verify the sign of charge on the electroscope? Describe. Now try it, and discuss your results.