

Name \_\_\_\_\_ Date \_\_\_\_\_ Partners \_\_\_\_\_

# 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

Source: Fishbane, Paul M., Stephen Gasiorowicz, and Stephen T. Thornton. *Physics for Scientists and Engineers, 3<sup>rd</sup> Edition*. Prentice-Hall, Inc. Upper Saddle River, NJ. 2005. pp. 609-617

Electrostatics<sup>1</sup> 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.

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<sup>1</sup> Adapted from Dr. Richard Lindgren, Charlene Wyrick, Karyn Traphagen, and Lynn Lucarto. *The Shocking Truth: Lessons in Electrostatics*. 2000.

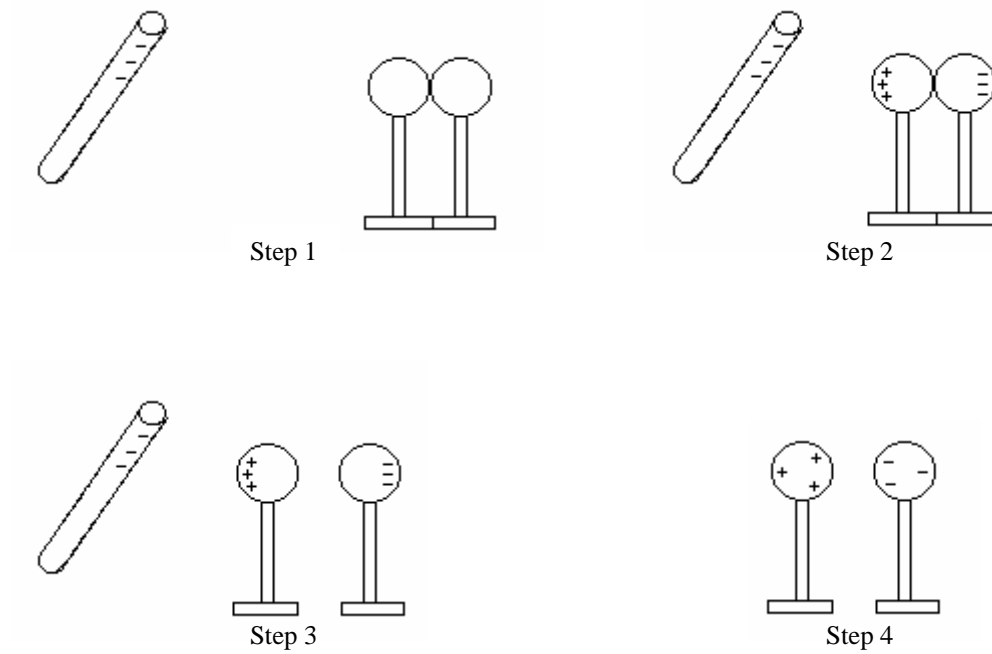
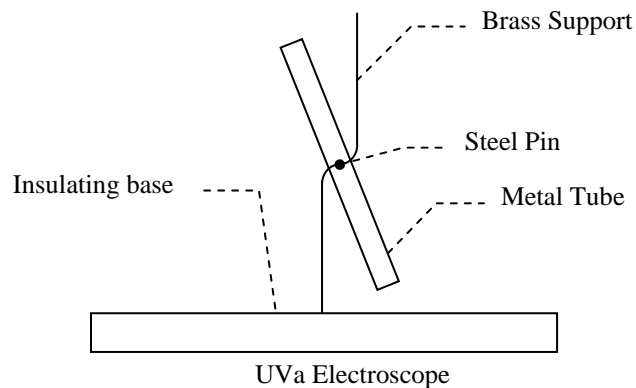


Figure 1: Charging by Induction

## 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.



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 metal 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, a 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 aluminum, 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 transferred from your hand to the rod may adversely affect experimental results; you may need to clean the rod with alcohol to ensure that it is as clean as possible.
- Handle only the unmarked end of the Teflon rod and charge the marked end to minimize the effects of hand oils.
- 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 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 lose electrons; the ordering of these tendencies is referred to as the triboelectric series. When you use the silk to charge the 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<sup>2</sup>. Note that human hands have a strong tendency to gain positive charge. We will use Teflon and silk.



Figure 2\*\*

<sup>2</sup> 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.

\*\* **WARNING:** One should use the triboelectric series such as the one illustrated above with caution. The ability of a material to acquire or lose electrons is related to several physical factors, including the material's conductivity and surface finish as well as the microscopic surface area contact between the two charging elements. Also, many materials are not pure, and impurities in the material may change its electrical nature. We have found tables with acrylic being positive and negative. The acrylic rods we have are more positive than negative. But one should not be surprised if acrylic, for example, gains negative instead of positive charge.

**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	_____

**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; they are not free to move within insulators.

The following equipment is needed for this investigation:

- Spinner
- Silk
- Brass 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.



Figure 3

**Question 1-1:** Why is it possible to charge only one end of the Teflon rod (as opposed to charging the entire rod)? Is this true for all materials?

**Prediction 1-1:** Predict what will happen if you hold the **charged** end of the free Teflon rod in your hand and place it along the **charged** end of the Teflon rod on the spinner without touching

(Figure 3)? What about along the **uncharged** end of the Teflon rod on the spinner? **Do not try it yet.**

1. Charge one end of the first Teflon rod by striking 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 3 in order to ensure the greatest possible interaction between the two. If nothing happens, you may need to recharge the Teflon rods. **MAKE SURE THAT YOU CHARGE THE SAME END OF THE TEFLON RODS THAT YOU CHARGED BEFORE.** Otherwise, it will be necessary for you to discharge the rods to produce accurate results. You can discharge the rods by rubbing the charged end with your hand to allow excess negative charge to flow away.

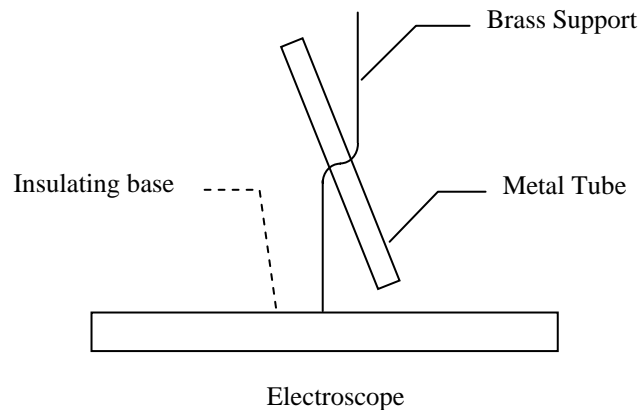
**The Charging Process:**

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? Was there any interaction with the *uncharged* end of the rod on the spinner? If so, discuss. (You need to hold the rods very close together in this case.)

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### Activity 1-2: Movement of Charge in Metals



**How the Electroscope Works:** Metals contain some electrons which are not tightly bound to atoms and which are able to move through the conductor. When you charge the electroscope, excess charge distributes itself evenly 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 charge reaches static equilibrium, the tube should be deflected at a constant angle.

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 bring it slowly near the lower end of the tube. At first you should notice repulsion between the tube and the charged Teflon rod; however, as the rod slowly approaches the tube, it should then begin to attract.

**Question 1-3:** Explain your two observations above in terms of metal's conducting properties and the charge distribution. What happens to the charge distribution in the electroscope when the negatively charged Teflon rod is nearby?

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**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 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. Touch the top of the brass support with your finger, observe, and record the results.

**Question 1-4:** Were your observations consistent with your prediction? If not, explain.

**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. Touch the **charged** electroscope with the brass rod. Re-charge the electroscope and touch it with the 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. 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 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 molecule (Figure 4). A positive charge in the vicinity of an atom, for example, will attract the atom's electron cloud and thus shift the cloud toward the positive charge. This results in a reorientation of the charges of the atom. In a neutral object, atoms closest to the charged object will experience the greatest amount of stretching. 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.

**Question 2-1:** What charge will the left and right sides of the insulating rod tend to have in Figure 4?

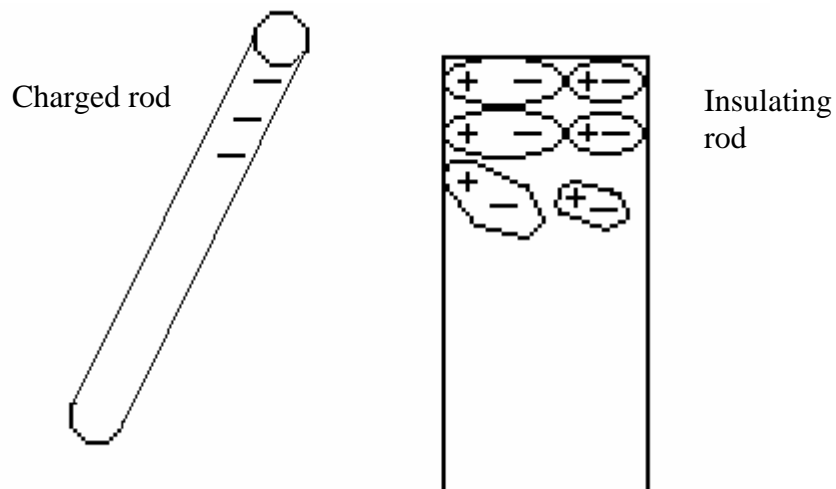


Figure 4

In addition to the equipment used previously, you will need for this investigation:

- Acrylic (insulating) rod

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**Activity 2-1: Charge Polarization in an Insulator**

1. Place the acrylic rod on the spinner.

**Prediction 2-1:** Predict what will happen if you bring a charged Teflon rod near the 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 using a charged Teflon rod.

**Question 2-2:** Was your prediction correct? If not, explain.

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

In Activity 1-2 you charged the electroscope with the charged Teflon rod until the tube deflected just a little. Then you used the charged Teflon rod to come near the lower end of the tube, but didn't touch it. At first, when you approached 5-10 cm away, the tube repelled. As you came closer, the tube was attracted. If you don't recall this experiment, you may want to repeat it now.

**Question 2-3:** In terms of polarization, what causes the attraction of the tube to the Teflon rod?

**Question 2-4:** Why does the tube initially repel and then attract?

1. Charge the Teflon rod using the silk.
2. Bring the charged Teflon rod near the bottom of the brass support (on the side opposite from the tube, see Figure 5), but not touching. You should observe an increased deflection angle between the tube and the brass support.

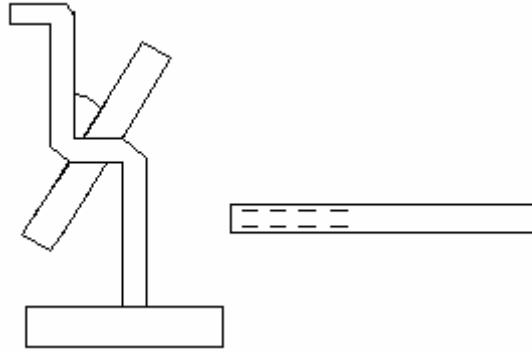
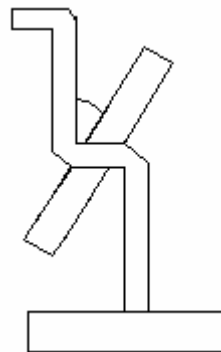


Figure 5

**Question 2-5:** In terms of polarization, what causes this increased deflection?

**Question 2-6:** What charge sign do the elements of the electroscope have? Indicate in the diagram below the sign of any charged element of the electroscope.



**INVESTIGATION 3: CHARGING BY CONDUCTION AND 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 touches 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 6). 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.

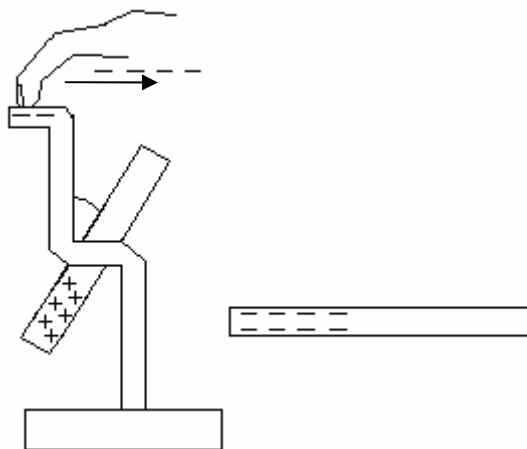


Figure 6

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 your partner hold his/her finger to the top of the brass support.

3. While the finger is on the brass support, bring the charged Teflon rod to the base of the brass support without touching it until you see a deflection of the tube.
4. Have your partner remove his/her finger, **then** remove the Teflon rod.
5. Observe the deflection angle of the tube.

**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 explain your results.