Young Physicists Program: January 2011

Lab 4: Shocking facts about electrostatics

Laboratory: Static electricity- Charge, con/induction, Coulomb's Law

Introduction

The purpose of this lab is to study the nature of the electrical force, part of what is behind the workings of Electricity, our well known friend. (Hello, Electricity!) We will build the requisite knowledge to understand electrodynamics by investigating fundamental properties of the electric force. What is **electric charge**? What is the fundamental unit of electric charge? What does the **sign** of the electric charge indicate? How is the **electric force** related to charge, and what forces exist between charges of the same or opposite sign? Where do we find "positive" and "negative" charges in nature (and why did I put the two words in quotes)?

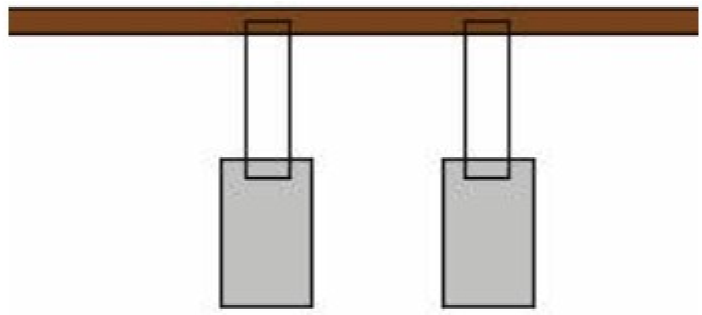
Charge!

1. Press a 10 cm long piece of tape sticky side down on the lab bench, with one end curled over as a non-stick handle. Peel the tape off the table and bring the non-sticky side of the tape toward someone else's strip. What happens as the tapes get closer together?
2. Place two strips of tape on the table sticky side down with a non-stick handle and label them "B" for Bottom. Press another tape (with a non-stick handle) on top of each of the "B" pieces; label these strips "T" for top. Pull each pair of strips off the table. Then pull Top and Bottom strips apart.
   - Describe the interaction between two Bottom strips.
   - Describe the interaction between two Top strips.
   - Describe the interaction between a Top and a Bottom strip.
3. *Discussion*: We say that the tapes are "charged." Based only on the experiments you did in A2, how many types of charge do you have evidence for? Could there be more types of charge? Make a table of the charges you've discovered and how they interact with each other. How might another type of charge interact with these charges, and with itself?

More Charge!

1. If you rub a PVC pipe with a piece of wool, how does the rod interact with the Top and Bottom pieces of tape? How does the wool interact? Rub a glass rod with a piece of silk. How do the glass rod and silk interact with each piece of tape? (You need to rub hard with the silk/glass combination to get a good effect. It works better on clear, dry days)
   - This method of charging an object (charging via friction) is called **triboelectrification**. (DID YOU KNOW THAT: The study of friction is called tribology. NOW YOU KNOW.)

2. Hang two strips of aluminum foil from a wooden rod using transparent tape so that the pieces of foil are close but not touching. Rub a PVC pipe with wool then touch the pipe to each piece of aluminum foil.



    - How do the two pieces of aluminum foil interact with each other? (You may move the pieces of foil by removing them from the wooden rod, touching only the tape NOT the foil.)
    - What happens when you bring Top and Bottom pieces of tape close to the pieces of foil? Make sure you try both Top and Bottom pieces of tape with each piece of foil.
    - This method of charging an object (touching a charged object to another object) is called charging by **conduction**.
3. *Discussion*: Consider the following questions. Can they all be answered based only on your observations so far, or are more experiments required?
    - Can charge be transferred from one object to another? Explain.
    - Is it possible for an object not to have charge? Explain.
    - Is it possible for an object to have more than one type of charge? Explain.
    - How would an object with equal amounts of “Top” charge and “Bottom” charge behave differently from an object with no charge?
    - If an object had equal amounts of “Top” and “Bottom” charges, how would it interact with an object with mostly “Top” charges? How would it interact with an object with mostly “Bottom” charges? Explain your reasoning. How would an object with equal amounts of “Top” and “Bottom” charge interact with another object with equal amounts of “Top” and “Bottom” charge?
    - If an object had no charge, how would it interact if brought near an object with mostly “Bottom” charges? How would it interact with an object with mostly “Top” charges? How would an object with no charge interact with another object with no charge?

Conductors and Insulators

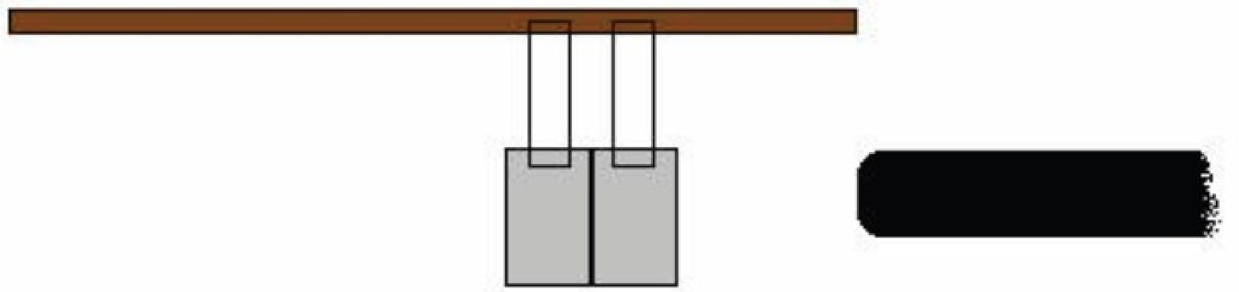
1. Test how the charges move on a PVC pipe using a “Bottom” tape. First rub one end of the pipe. Is the bottom tape attracted or repelled to this end? Now test the other end (that was not rubbed). Is there any charge on this end of the pipe?
2. Repeat the test of step 1, but replace the PVC pipe with an aluminum rod. Hold the rod at one end with your hand, and rub it with wool. Can you detect any charge on the aluminum rod?
3. Now repeat the test with the aluminum rod, but wrap the end of the rod that you hold with a few layers of the wool cloth so you can avoid touching the rod with your skin. Again rub the rod with wool. Under these circumstances can you detect any charge on the rod?
    - We call materials like the pipe INSULATORS as they hold excess charges fixed, and materials like copper, aluminum, silver etc. (usually metals) conductors as they allow

charges to move around. Human beings are also fairly good conductors. Water, especially when there are salts in solution, conducts electricity well. Living cells contain considerable salty water. The earth itself acts like an infinite source of electrons (or sink of electrons).

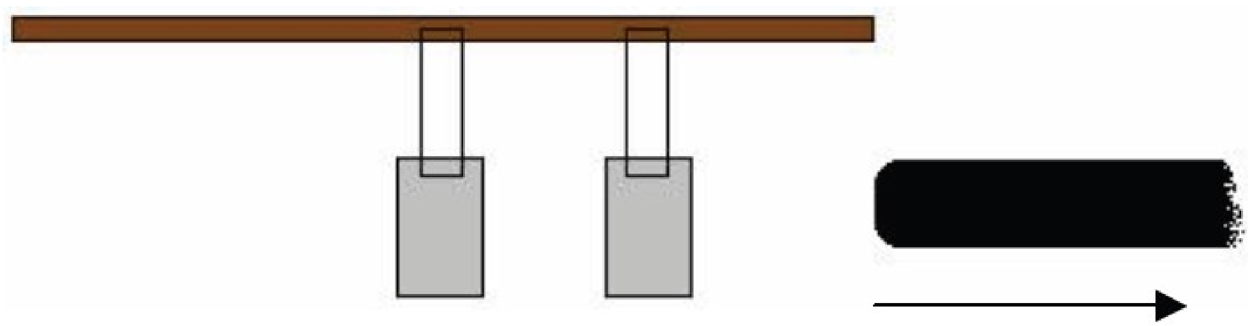
4. Explain what happens to the charges in the experiments in steps 2 and 3.

Induction

1. Cut 2 pieces of aluminum foil in a rectangular shape 4 cm by 4 cm and hang them side by side, touching each other, as in the picture below, from a wooden rod, using a piece of transparent tape.



2. Bring a charged PVC pipe near, but not touching, the edge of the piece of aluminum foil. While the pipe is still near the foil, move the pieces of foil apart by touching the tape only. Then remove the pipe.



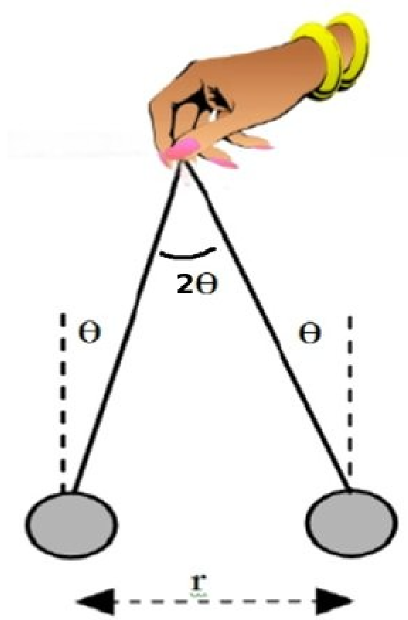
3. Use the Top and Bottom tapes to determine whether there is a net charge on each piece of foil.
4. Repeat steps 1-3 with two strips of aluminum foil that are initially close but NOT TOUCHING.
5. What is the difference between the two situations? In step 4, when you remove the charged pipe were the aluminum strips charged? This method of charging an object (bringing a charged object close to polarize another object) is called **charging by induction.**
6. Obtain an empty soda can, a PVC pipe, and wool. Lay the can on its side on a table. Rub the pipe with wool and hold the rod near, but not touching the can.
   - What happens to the can? Does the soda can contain charge? Does it contain only one type of charge? Does it have more than one type of charge than the other? Could it have equal amounts of “Top” charge and “Bottom” charge? Any other possibilities? Explain.
7. Based on any of your experiments, do you have evidence for the existence of an object

with no charge?

- If so, explain the experiment and your reasoning.
- If not, does this mean that an object with no charge does not exist? Could you do experiments to prove an object with no charge exists? Are there experiments that could be done to prove that an object with no charge does not exist? Explain your reasoning.

Using Coulomb's Law

1. In this exercise we will calculate the force exerted by one charged balloon on another. You will need to inflate two identical balloons to the same size. Start with both of the balloons uncharged. Rub one of the balloons against your clothing, rotating it several times so that you get a fairly even distribution of charges over its surface. (The technical term for the amount of charge on a surface is *surface charge density*. You are trying to achieve a uniform surface charge density on the balloons. Surface charge density is measured in coulombs per square meter. You will use this term later in life). Leave the other balloon uncharged. How is the charge is distributed on the charged balloon? Remember, there are both positive and negative charges present, but there will be slightly more of one type of charge than the other. Use "top" and "bottom" tape strips to determine which type of charge the balloon has in excess.
2. Now charge the second balloon in the same way, and 'refresh' the charge on the first. Suspend both balloons from cotton threads as shown. How can you approximately measure the angles between the threads and vertical? Do you think the balloons have equal charges? How could you observe if their charges are different in sign or in magnitude?



3. Measure the separation distance r and the angle θ for your configuration. Assume that the "center" of the charge distribution for each balloon is the center of the balloon. Using the equations below, calculate the electrostatic force (in Newtons) on each balloon and the charge (in coulombs) on each balloon.
   - Force (in Newtons) = $m*9.81*\tan(\theta)$ where m is the mass of the balloon in kilograms
   - Charge on balloon (in microCoulombs) = $0.11*r*\sqrt{F}$ where r is given in centimeters and F is in Newtons.
4. Put your charge value on the class white board for comparison with other groups in the lab. Are the values similar? What might limit the amount of charge you can store on a balloon?

Demos

Leyden Jar (demo 1)

- Charge up by hand (use a silk rod, fur cloth, etc.). See if there is discharge by pulling hooked end out of plastic cup and bring to capacitor "plates" of the Leyden jar together.
- Charge up with Van de Graff generator. Do this by firmly attaching (*firmly*, else you risk getting shocked) the ground wire from the base terminal of the VDG generator. Bring the jar close to the VDG dome. Don't hold it too close for too long, or your jar/capacitor will discharge (through the plastic, but be careful). Once you have it appropriately charged, use a discharging device, like a coat hanger with an insulating handle, to touch the positively charge hook. Bring the other end of the discharging device close to the bottom/ outer jar SLOWLY until it discharges (should be a VERY large spark, so be careful). Talk about storing charge, what discharging means, and the electrostatics of this whole process.
- Perform trick suggested online:
  - http://vip.vast.org/NEWSLETT/SPRING97/HOME.HTM
  - (Volunteers who run this demo MUST read this before completing it)
- Where does charge reside in the capacitor? When is it ok to touch something charged? What does it mean to be "grounded"? Why do we use conductors to run to ground (bring up the example of hitting a metal rod, which is connected to your house's antenna (in the old days) into the ground)? What role does the insulating cup play in the Leyden jar?
- Why is the Leyden jar useful? It used to be a primitive battery/capacitor. How does this show the students this is a capacitor?

Van de Graff Generator (demo 2)

- How does a VDG generator work? Why is it less effective on humid days?
- What happens when a student touches the dome at the top, if they walk from far away? What happens if they touch it again after having touched it? What if they first put one hand on, then two? When is it "safe" to touch the generator?
- What happens when we form a chain of people, linking hands, from the VDG generator? Who gets shocked when a new person joins the chain- the last person, the new person, the first person, all, etc. ...?
- How does the discharge rod work?
- Use pie plates and packing peanuts to demonstrate how electric charge works on both insulators and conductors.
- What does it mean to be grounded?

Chalk dust photocopier (demo 3)

- From the lab we have learned that we can deposit charge using scotch tape. Here we will use this to demonstrate how photocopiers work, using plastic transparencies (which are insulating). The idea is simple, and students can make their own designs, which should be fun. Note to do this on an insulating surface. Put tape on the transparencies in the desired design and peel them off. Now shake a rag full of chalkdust (need to make this beforehand) near/over the transparencies. Put the transparencies up against a dark surface to see your design. Voilà!

Dirod generator (demo 4)

- A more instructive way of seeing how a VDG works. Students usually enjoy playing with the shock emitted when the two charged ball/rods come close together after being charged. Discuss which ball/rod has which charge, and why this process works. Do your own this if you wish. What happens when one “discharges” the balls by touch both together with a conductor (e.g. a coat hangar, but with an insulating handle for you to use). Will the venturesome student be shocked if they touch one of the balls/rods after you “equalize/discharge” them?

Electrostatic shielding/Faraday cage (demo 4)

- Use the graphite-coated ping-pong balls (“pith” balls) and observe their behavior when put near a VDG generator (unshielded). Now observe what occurs when they are put in the Faraday cage. You can also charge up the cage (with the VDG generator), then discharge it to produce a large spark, and show that still nothing happens to the pith balls.

- Repeat this with the electroscope (to show the “strength” of the electric field).

- Cute, but doesn't always work (but should, since cell phone wavelengths are much longer than spacing of Faraday cage grid): call someone's cell phone (perhaps on speaker phone for effect) outside the cage. Then put a phone inside the cage and attempt to call it.