Experiment 1 - Electrostatics

PHYS 231: Fundamentals of Physics: Electricity and Magnetism

**Most of this material was developed by Dr. Marianne Breinig. It was modified with additional information by Dr. Christine Cheney for this class.*

> Note: Humidity or moisture in the air can make the air more conductive so that charge does not build up as easily on surfaces. You may notice that you get shocked more easily in the winter when the air is drier than in the summer. You should still be able to do the tape experiment. If you have trouble rubbing items together from the lists, think about rubbing a balloon on your hair when you were little and what the result was!

Charges are the basic unit of study for electricity. Protons that are in the nuclei of atoms are positively charged, and electrons that orbit the nuclei are negatively charged. Electrons and protons have an equal and opposite charge. One electron has a charge of -1.602×10^{-19} coulombs, or -1.602×10^{-19} C, and one proton has a charge of $+1.602 \times 10^{-19}$ C. Just like the Earth exerts a force on the moon and vice versa, charges exert forces on other charges that are separated in space. However, gravitational forces are attractive in nature whereas electrical forces, or Coulomb forces, can be attractive or repulsive. Like charges repel and opposite charges attract. The amount of force between two charges is given by Coulomb's Law:

$$F = \frac{1}{4\pi\epsilon_0}\frac{q_1 q_2}{r^2}$$

where ϵ_0 is a constant called the permittivity of free space, q_1 and q_2 are the charges and r is the distance between the two charges. The direction of the force on one charge is either toward (attractive) or away (repulsive) from the other charge. The electric force is a vector quantity, just like other forces that you have learned about, since it has magnitude and direction.

If you have an excess of negative charge on a conductive (metal) sphere where the electrons can easily move through the material, the extra electrons repulse each other and want to get as far away from each other as possible. Thus, they go to the surface of the sphere so that they are the most spread apart. When charge builds up in the sky, the like charges want to get away from each other. Air is usually an insulator and the charges cannot escape fully from each other. When the charge builds up enough, the air can break down (the insulating capacity no longer holds) such that the charge can discharge through the air to the surface of the Earth (or between clouds). The charge will look for the path of least resistance to discharge. That is why you do not want to be high on a mountain or under a tree. If your hair stands up outside, you want to get away from that area because you can more easily be struck by lightning.

Static electricity is an imbalance of charge on or within the surface of a material. Static charge buildup can result in potentially dangerous electrical shocks, which can cause fires, explosions and severe damage to sensitive electronic components. Static charge buildup can be obtained by rubbing materials together (or friction between two surfaces). This is called triboelectrification. Two entities that were originally uncharged become charged when they are separated after coming in contact. One entity becomes positively charged by losing electrons while the other becomes negatively charged by gaining electrons.

As the pressure and the speed of contact and separation increase, the amount of the static charge buildup increases. Rapidly moving materials can quickly develop charges, which produce a potential of more than 25,000 volts.

In this lab, you will separate electric charges. You will consult the triboelectric sequence to find out which object acquires a positive, and which object acquires a negative charge. You will then investigate the interaction between the charged objects.

Equipment needed:

- Sticky tape
- Rods and rags

> Open a Microsoft Word document to keep a log of your experimental procedures, results and discussions. This log will become your lab report. After each step write down what you have observed. Address the points highlighted in blue. Answer all questions in blue in your log.

Experiment 1

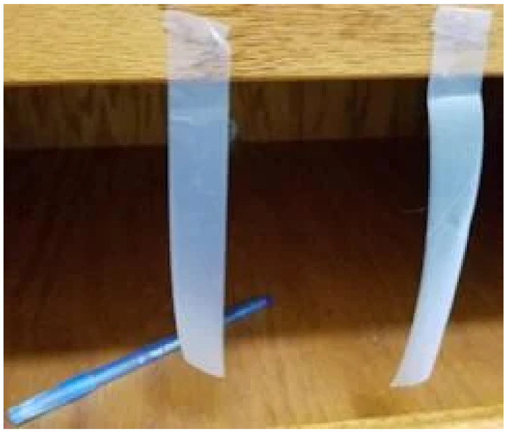
a. Obtain a piece of sticky tape, about 15-20 cm in length. For ease in handling, make "handles" by folding each end of tape to form portions that are not sticky. Press the tape firmly onto a smooth, unpainted surface, for example, onto a textbook or onto the table. Then quickly peel the tape off the surface and hang it from a support.

> Describe the behavior of the tape as you bring objects, such as a finger or a pen, toward it.

b. Make another piece of tape as described above. Bring the second tape toward the first tape with the non-sticky sides facing each other. Describe your observations. It is important, that during this experiment you keep your hands and other objects away from the tapes.

> Explain why this precaution is necessary. Describe how the distance between the tapes affects the interaction between them?

c. Press two pieces of tape onto the surface and write a B (for bottom) on them. Then press another tape on top of each B tape and label it T (for top). Pull each pair of tapes off the surface as a unit. After they are off the surface, separate the T and B tapes. Hang one of the T tapes and one of the B tapes from a support.



Describe the interaction between the following pairs of tape when they are brought near one another.

- Two T tapes
- Two B tapes
- One T and one B tape

d. Among your belongings find a rag and a rod-like object. The rag and the rod should be made from materials near the opposite ends of the triboelectric sequence. Consult the table of triboelectric materials below.

The items on top are less attractive to electrons and become positively charged when rubbed against items below, while the items on the bottom are more attractive to electrons and become negatively charged when rubbed against items above.

- Human Skin (usually too moist though) (very positive)
- Rabbit Fur
- Glass
- Human Hair
- Nylon
- Wool
- Fur
- Lead
- Silk
- Aluminum
- Paper
- Cotton
- Steel (neutral)
- Wood
- Lucite
- Amber
- Hard Rubber
- Nickel, Copper
- Brass, Silver
- Gold, Platinum

- Polyester
- Styrene (Styrofoam)
- Saran Wrap
- Polyurethane
- Polyethylene (like scotch tape)
- Polypropylene
- Vinyl (PVC)
- Silicon
- Teflon (very negative)

Choose a rod and a rag, for example, for the ”rag” choose your hair and for the rod choose a vinyl pen. Try different objects. Rub the rod vigorously with the rag and then hold the rod near newly-made T and B tapes hanging from a support. Compare the interactions of the rod with the tapes to the previously observed interactions between the tapes.

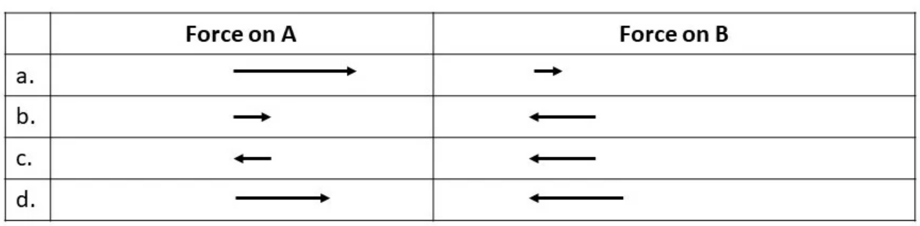
> Describe any similarities or differences.

e. The rod and the tapes interact, because they are electrically charged.

> Answer the following questions based on the observations you have made thus far.
> - How many different types of charge do there appear to be? Explain.
> - Which tape, T or B, has a positive charge? Explain.
> - How do two objects that are positively charged interact? Explain how you can tell.

Activity 1

f. In the figure below, A and B represent objects with -1 and +2 unit of charge, respectively.



> Choose the pair of force vectors that correctly compare the electric force on A (caused by B) with the electric force on B (caused by A). Why did you choose this pair?

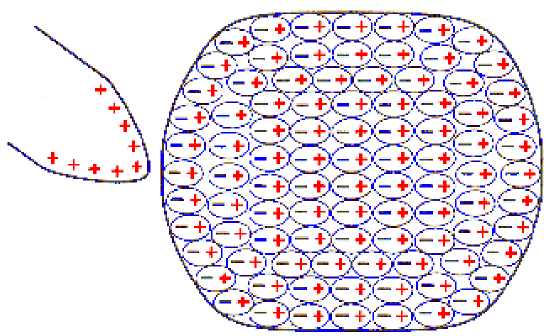
Go to https://phet.colorado.edu/sims/html/coulombs-law/latest/coulombs-law_en.html and choose the atomic scale. Vary the distances and types of charges that interact and observe the force vectors that are depicted.

g. The figure below shows two tapes.

What kind of charge could be on tape 1 and tape 2? Do the two tapes have to hold the same amount of charge?

Activity 2: Polarization

Charged objects exert forces on each other. But even objects that have no net charge can be acted on by electrical forces. Consider the case of a neutral insulator placed close to a positively charged rod, as shown in the figure below.



The electrons in the insulating material are bound to their atomic nuclei. They are not free to move throughout the material. However, the electric field produced by the positive charges on the rod attracts the electrons and repels the nuclei. The electrons are therefore no longer symmetrically distributed around their nuclei, but are pulled over to the side closer to the rod. The net effect is that the entire negative charge is displaced by a small amount with respect to the positive charge in the material. This results in an effective surface charge density, which is negative on the side close to the rod and positive on the side farther away from the rod. This is the phenomenon of electrical **polarization** The field of the rod decreases with distance, so the attractive force on the negative surface charge is stronger than the repulsive force on the positive surface charge. The material is attracted towards the rod due to its polarization.

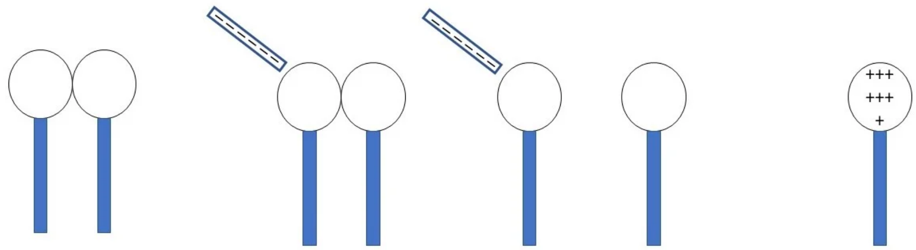
If, instead of an insulator, we have a conductor, then an excess of free electrons gathers on the side close to the rod, and the side farthest away from the rod is depleted of free electrons and therefore has a net positive surface charge. Again the material is attracted towards the rod.

h. Go to https://phet.colorado.edu/sims/html/balloons-and-static-electricity/latest/balloons-and-static-electricity_en.html. Check the box that says "Show all charges." Rub the balloon on the sweater and observe the charge distribution. Then take the balloon and place it on the wall.

> How are the charges in the wall distributed? Are they polarized? Draw a picture of what you observe. Now remove the wall. What happens?

Activity 3: Charging by Induction

i. Imagine the following situation. Two metal balls are touching each other. A charged rod is brought near the left one. While the rod is near, the right ball is taken away. Finally the rod is taken away. At the end of this procedure, the left-hand metal ball has a positive charge.



> Describe what you think is happening. Why is the left ball positively charged at the end of the procedure?

References

[1] https://labs.phys.utk.edu/mbreinig/phys222core/Labs/Studio%20Session%201.html

[2] http://crodriguez.s3-website-us-east-1.amazonaws.com/fiznotes/ch20/notes20_1.html

[3] https://phet.colorado.edu/sims/html/coulombs-law/latest/coulombs-law_en.html

[4] https://phet.colorado.edu/sims/html/balloons-and-static-electricity/latest/balloons-and-static-electricity_en.html