

Lab 01B Electrostatics Revised for SP2020

Note: your writeup for this lab is largely in the form of several paragraphs describing what you are testing, how you are testing it and what your results are. Thus this lab is more qualitative than many other labs that you have previously done. You also will complete the worksheet for this lab and include it as part of your report.

The law of charges and Coulomb's law

In Lab01A, you verified an important aspect of Coulomb's law:

$$\vec{F}_{2,1} = k \frac{q_1 q_2}{r_{1,2}^2} \hat{r}_{1,2} ,$$

namely that the force between two charges varies as

$$\frac{1}{(\text{separation})^2} .$$

You did this by measuring the electrostatic force between two charges for different separations between the charges. If we take the logarithm of Coulomb's law, then we find:

$$\ln(F) = \ln(kq_1q_2) - 2 \ln(r_{1,2})$$

so that a plot of $\ln(F)$ vs $\ln(r_{12})$ would give a straight line with a slope of -2.

We did this part of Lab01A early in order to obtain favorable humidity conditions. This lab is a continuation of that lab which will perform a qualitative investigation of the validity of the law of charges which states simply like charges repel and unlike charges attract.

I hope that you come away from labs 01A and 01B with a better feeling for the nature of electrical charges. You will need to know before hand that charge comes in units of Coulombs (C) and the smallest unit of charge is the charge on an electron or a proton which is of magnitude $1.60 \times 10^{-19} \text{C}$.

The law of charges

You are provided with an electroscope which I have made for you. The electroscope is simple enough to make that you might consider making them for yourself. It consists of two pieces of aluminum foil which are free to swing attached to a copper wire all enclosed in a plastic cup for protection. You will also need for this lab glass and rubber rods and wool, cat's fur and acetate and an electrophosphorus. In general, static charges are created by rubbing two materials together: rubbing the rubber rod on cat's fur will produce **a negative charge on the rubber rod (by definition)** while rubbing the glass rod on acetate will produce what we define to be a positive charge. It is amazing that this definition of negative charge still persists even in our modern era. Note though that the hanging ball may provide a more sensitive indicator in this method of measurement but do not change the string length!

Experiment 0 is to transfer the definition of negative charge from rubber rods and cats fur to straws and wool. Essentially what is required is to verify that the same charge that forms on a rubber rod when a rubber rod is rubbed with cats fur is the same as when a straw is rubbed with wool. After this, when the lab calls for a rubber rod, use the straw and when the lab calls for cats fur, use wool. **In fact, I do now have enough rubber rods for this lab so you may feel free to continue to use rubber rods.**

Experiment 1 (Two types of charges)

Completely discharge your electroscope by touching the electroscope ball at the top with your finger.

Rub your rubber rod with cat's fur about 20 times.

Touch the rubber rod to the electroscope ball.

You will observe that the leaves separate.

Rub the glass rod on the acetate about 20 times.

Touch the glass rod to the electroscope.

You will observe that the leaves are now separated by less distance.

An important note: don't hold the cat's fur very long since you will make it have a higher humidity than is desirable.

The results of Experiment 1 should now leave you with little doubt that there are two types of charges. The sign of each of these charges is only a result of convention. Charges aren't born with little + and - signs on them.

A bit later in this lab, you will learn to charge by induction. The method you used above is called "charging by contact." Then you can use the system from last week's lab to very clearly show also that two types of charges must exist. The argument for two types of charges is this: a system that is electrically neutral and is then positively or negatively charged, even if it is due to an excess or deficit of electrons must have had the other sign of charge to produce electrical neutrality.

Now devise an experimental method to test for the sign of rubber on acetate and glass on wool. Perform your experiment and report the signs of the charges on the rods that result.

Experiment 2: (Like charges repel each other)

It is possible to now do a quick experiment that ought to convince you about some elementary behavior of charges, namely that like charges repel. It stands to reason that if you rub a balloon with cat's fur the result will be that the balloon will contain a negative charge.

However you will want to devise an experiment to test this. Before you proceed further, I want you to write a short paragraph that describes an experiment (that you design) to test the sign of the charge deposited on a balloon when rubbed with cats fur. (This will be part of your final report).

I have inflated two balloons and tied them to the end of a thread which is about 1 m long. Support the string in the middle above your head in some way so that the two balloons are hanging downward but are free to move around. Rub each of the balloons with cat's fur so that at least the sign of charge is the same on both balloons. Do the balloons attract or repel each other?

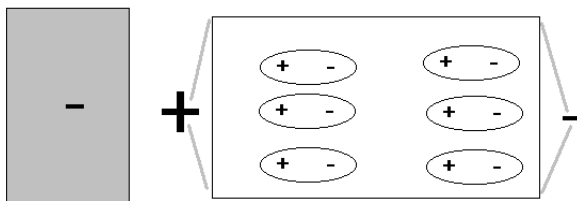
You could, if you wished, knowing the mass of the balloons and by knowing the length of the string from the pivot point determine the magnitude of the force.

Now, we are pretty sure that the charge on the balloons is negative. If you think of how to confirm this quickly, you may think that the easiest way is to charge the rubber rod and then bring it close to the balloons. If the balloon were attracted to the rod, it would seem to be positive, right? Try this and see what happens.

For a reason which is less obvious, this technique will not necessarily give you the result that you expect. Here is the way to confirm the sign on the balloons: rub the electroscope ball over the charged balloons until the leaves separate. Be careful to make sure that the leaves remain separated when you remove the electroscope away from the balloon. Then with the charged rubber rod, touch the electroscope ball. If the leaves separate more, then the charge on the balloons is the same as on the rubber rod. What is the sign of the charge on the balloons from your observations?

The "reason which is less obvious" is now something to look at. With your balloons hanging in the air, walk in a circle around them. You will see that one of the balloons seems to follow you, always pointing towards you. I call this device, therefore, a people locator. The balloon is inducing a charge in your body (which is mostly water) and since opposite charges are attracted to each other, the balloon is attracted to your body. This is also easily demonstrated with a third balloon.

Find a third inflated balloon and rub it with cats fur. Place it against the wall. If luck (in the form of correct humidity) is with us, you will see that the balloon sticks to the wall. The reason both of these phenomena happen is because of polarization. Look at the picture below.



A negative charged object such as a balloon when brought close to a polar object such as a wall will tend to reorient the molecules inside the wall providing an attractive force.

Probably the molecules which are being reoriented are water molecules since they are highly polar. This is also a demonstration of the second part of the law of charges which is that unlike charges attract. Thus, we have the **law of charges** stated as:

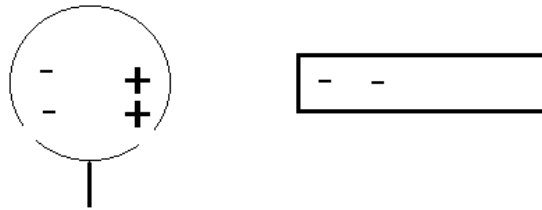
Unlike charges will be attracted towards each other and like charges will be repelled from each other.

You should regard this law as one of the fundamental laws governing electricity and magnetism and you must stick this inside your mind for use whenever you are working with electrostatics problems.

Experiment 3: Charging by induction

The type of charging which you have just done is called charging by contact. The charges actually flow to or from the body directly when charged by contact. We can charge bodies in another way, however.

We can charge the electroscopes positively by inducing a charge on them. Inside a metal conductor, the electrons are free to move about (the physical term for a conductor is equipotential surface). If a negatively charged rubber rod is brought close to the ball of the electroscopes {Note: replace the word ball with ball if you are using an older electroscopes}, but not in contact with the ball. You will observe a migration of the charges to the ball of the electroscopes as shown below.



If you momentarily touch your finger to the negatively charged side of the electroscopes ball, you will remove the negative charge located there. Upon removal of the rubber rod (after removing your finger from the electroscopes), you will find that the electroscopes has a net positive charge. Go through the steps required to place a positive charge on the electroscopes (in this manner) until you are sure you understand the process. You should use your glass rod in order to confirm that the charge placed on the electroscopes through this technique is indeed positive.

Now that you know how to charge your electroscopes positively by induction, you also should know what you need to do to charge your electroscopes negatively by induction. Do this and confirm that you have indeed placed a negative charge on the electroscopes. Describe your technique for charging by induction to produce a positive charge and a negative charge in a paragraph which is also part of your lab report.

Charging with **electrophorus**

You will find additional information about this at the Exploratorium:

http://isaac.exploratorium.edu/~pauld/summer_institute/summer_day14electrostatic/Electrophorus.html

A pie pan and a Styrofoam block can be used to charge effectively even in conditions of higher humidity. The idea is this: rub wool on the block a few times. Place the pie pan onto the top of the plate. Touch the pie pan (a spark will jump). Then remove your finger and separate the pie pan from the block. Note that pie plates can be used but they work less perfectly here.

Your assignment here is to use your electroscopes to determine the charge on the pie pan (positive or negative). You will need to devise the steps need to justify this judgment and in a few sentences write the technique you used to prove this sign which will also be part of your report.

The electrostatic chime (demonstration)

A really neat electrostatic engine is the electrostatic chime. This is a demonstration that you may see in the lab today. Charge one plate with your electrophorus and the small ball will bounce back and forth as charge is transferred between the plates. Explain (in your words) how this works.

Measurement of Charge

Your quantitative measurement for today's lab is a measurement of charge with a separate link.