Electrostatics: The law of charges and Coulomb's law

Revised Spring 2007

In this lab, you will verify the law of charges and also you will verify two aspects of Coulomb's law. I hope that you come away from this lab 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 $1.60x10^{-19}$C.

Part I: The law of charges

You are provided with an electroscope (which has gold-plated leaves inside), glass and rubber rods and wool, cat's fur and acetate. In general, static charges are created by rubbing two materials together: rubbing the rubber rod on cat's fur will produce what we define to be a negative charge on the rubber rod while rubbing the glass rod on acetate will produce what we define to be a positive charge. It is relatively easy now to verify that there are two different types of charge in the following way:

Experiment 1

(Two types of charges)

(1) Completely discharge your electroscope by touching the ball at the top.
(2) Rub your rubber rod with cat's fur about 20 times.
(3) Touch the rubber rod to the electroscope ball.
You will observe that the leaves separate.
(4) Rub the glass rod on the acetate about 20 times.
(5) Touch the glass rod to the ball of 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.

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 negative charges repel each other)

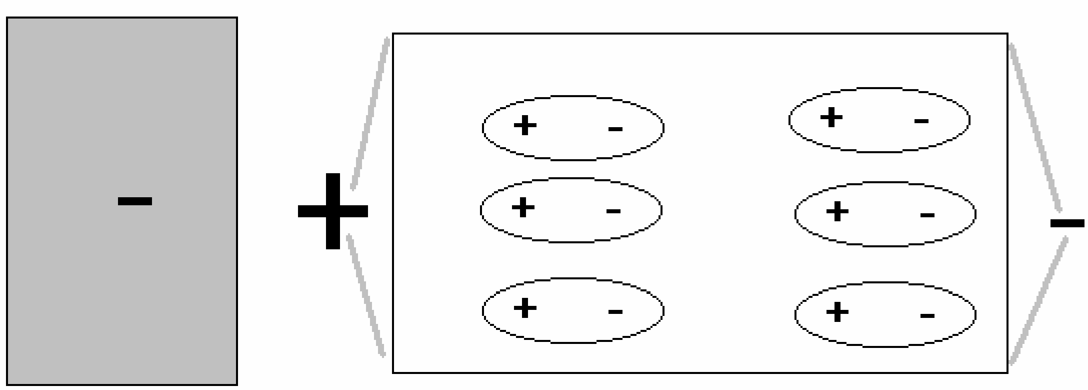
It is possible to now do a quick experiment that ought to convince you about some elementary behavior of charges, namely that like charges repel. It stands to reason that if you rub a balloon with cat's fur the result will be that the balloon will contain a negative charge.

Take two balloons and inflate them and then tie the two balloons to each 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 the charge is the same on both balloons. You will notice that the balloons 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 repulsive force. For now, however, I merely want you to see that like charges repel each other.

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 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 bring the charged rubber rod close to 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 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. Inflate your third balloon and then 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.



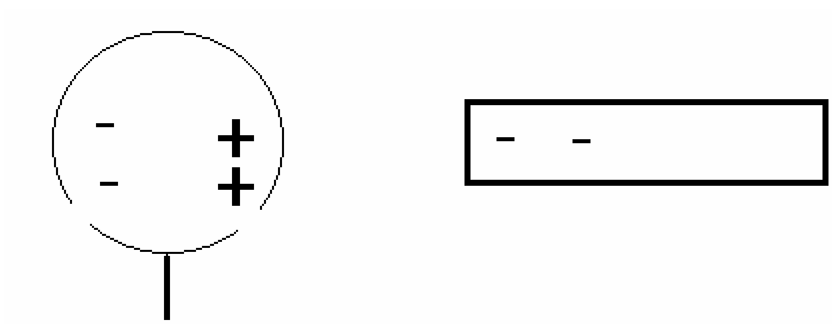
A negative charged object such as a balloon when brought close to a polar object such as a wall will tend to reorient the molecules inside the wall providing an attractive force. Most likely, the molecules which are being reoriented are water molecules since they are highly polar. This is also a demonstration 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.
Let's do some further experiments with the electroscopes.

Experiment 3: Charging by induction

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 electroscope (but not in contact with the ball) you will see a migration of the charges to the ball of the electroscope as shown below.



If you momentarily touch your finger to the negatively charged side of the electroscope, you will remove the negative charge located there. Upon removal of the rubber rod (after removing your finger from the electroscope), you will find that the electroscope has a net positive charge. Go through the steps required to place a positive charge on the electroscope (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 electroscope through this technique is indeed positive.

Now that you know how to charge your electroscope positively by induction, you also should know what you need to do to charge your electroscope negatively by induction. Do this and confirm that you have indeed placed a negative charge on the electroscope.

Charging with **electrophorus**

You will find additional information about this at the Exploratorium:

http://www.exploratorium.edu/snacks/charge_carry.html

A pie pan and a Styrofoam plate can be used to charge effectively even in conditions of higher humidity. The idea is this: rub wool onto the plate for about 1 minute. 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 plate. Your assignment here is to use your electroscope to determine the charge on the pie pan (positive or negative). You will need to devise the steps need to justify this judgment and discuss them in your writeup.

A really neat electrostatic engine is the electrostatic chime. This is a demonstration that you may use in the lab today. Charge it with your electrophorus and the small ball will bounce back and forth as charge is transferred between the plates.

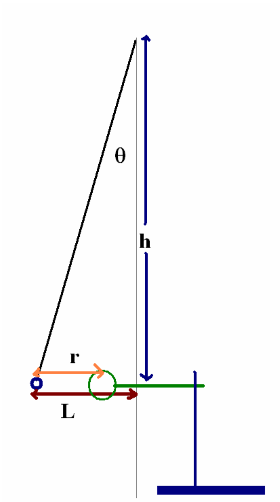
Experiment 4: Experimental verification of the inverse square law

Without vectors, **Coulomb's law** state that the force of attraction or repulsion between charges is given by

$$F = \frac{kq_1q_2}{r^2}$$

where k is Coulomb's constant (k=8.99 x $10^9 Nm^2/C^2$, q_1 is the charge 1, q_2 is charge 2 and r is the distance of separation between the two charges. Incidentally, Coulomb's constant is often written $k=1/(4\pi\varepsilon_0)$ where ε_0 is the permittivity of free space and has the value 8.854187817 x 10^{-12} $C^2/(Nm^2)$. We can know the value of ε_0 to so many decimal places in part by measurements involving the speed of light.

I have constructed an apparatus which will help you to verify Coulomb's law. This consists of a thread connected to the ceiling and two aluminum coated balls. The analysis of this setup is as follows:



The angle θ is measured by measurement of h and L:

$$\tan(\theta) = \frac{L}{h}.$$

The separation r is measured by the distance that the stand moves from the non-charged vertical position (you need to subtract ½ of the diameter of the large ball from this difference).

The electrostatic force on the small ball is given by:

$$F_c = k\frac{q^2}{r^2}$$

where I have assumed both spheres carry the same charge. The gravitational restoring force on the small ball is given by:

$$F_g = mg\sin(\theta)$$

In equilibrium, these two forces are equal in magnitude. This then gives us the result:

$$k\frac{q^2}{r^2} = mg\sin(\theta) \approx mg\tan(\theta) = mg\frac{L}{h}$$

We can thus find the displacement L as a function of r to be given by:

$$L = k\frac{hq^2}{mgr^2} = \left[\frac{khq^2}{mg}\right]\frac{1}{r^2}$$

This can be verified by obtaining the two measurements of r and L. Let

$$\text{slope} \equiv \left[\frac{khq^2}{mg}\right]; x \equiv \frac{1}{r^2}; y \equiv L$$

Then, a plot of y vs. x should produce a straight line, provided that the charge does not leak off the charged bodies. In actuality, some charge will leak off. You should take multiple measurements after charging your system (you should try to get at least 5). Then, a plot of x vs. y should show a linear relationship which will verify the $1/r^2$ dependence of Coulomb's law. This experiment could be taken further ... knowing Coulomb's constant, m and h, you can also obtain the charge on the spheres. This is not required for today's lab, however. I am including a table for you to record your measurements. You will not fit this data today with the solver, instead I am using the excel built-in linear fit here.

You need to get zero readings for your setup. To do this, lower the small ball until it almost touches the table. Record the reading from the metal ruler (this is L0). Then, move the large ball up to the string until the edge just touches the string (still hanging at L0). The wooden ruler provides you with the measurement R0. Now move the large ball back some and raise the small ball until it is positioned about in the center of the larger ball.

Charge your large ball. You will probably want to insure that the small ball and the large ball touch once in order to transfer charge. Now without taking too much time, make at least 5 measurements of L and R by sliding the larger ball towards the smaller ball. The spreadsheet will provide you with the corrections for the diameter of the large ball and the zero settings. You need to do these measurements fairly rapidly since the charge will decrease on the balls with time.

Dball: Diameter of ping pong ball [mm]: ____________________

L0: Initial position where small ball hangs vertically [cm]:______________________

R0: Initial position where big ball touches string hanging at L0 [cm]: ______________

Measurement	L [cm]	R [cm]
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		

After you enter your data into the worksheet you will want to look at the R^2 value from the excel fit. According to the definition, a value close to 1 indicates a reliable fit.

A note on the spreadsheets: I am trying to follow a cell color scheme in which required entries are indicated by green cells, calculated quantities are orange and defined quantities are blue. Also, although the spreadsheets are designed to assist you in the labs, you are responsible for understanding the calculations required for measurements and to include spreadsheets properly formatted in you lab reports.