ELECTROSTATIC FORCES

INTRODUCTION

In this experiment you will observe three distinct electrostatic phenomena, in increasing order of subtlety:

1. The repulsion between objects with like charges;
2. The attraction between objects with unlike charges;
3. The attraction between a charged object and a neutral object;
4. Quantitative measure of charge using an electrometer.

1. REPULSION BETWEEN OBJECTS WITH LIKE CHARGES

Ordinarily, unlike charges are strongly attracted to one another, and like charges repel one another. However, if two dissimilar materials are rubbed together, it is often the case that free charges will overcome this attraction and will be transferred from one of the materials to the other.[1] If this happens, one of the materials will have a net positive charge, and the other material will have a net negative charge. If we take one of these charged objects and touch (not rub) a third object, the third object may accumulate some of the excess charges. Thus the third object (in this case a tiny ball of pith) should be repelled by the object that donated charge to it in the first place. To test this, carry out the following operations and record and interpret your observations.

1. Suspend a single pith ball by a double thread (so that it swings in only a single direction). Touch it briefly and lightly with your hand to drain off any excess charges.[2]
2. Take the section of PVC (Poly Vinyl Chloride) tubing and lightly run your hand over it, again to drain off any excess charges.
3. Hold the PVC tubing near the pith ball. If you have carefully drained all of the charges, there should be neither attraction nor repulsion between the pith ball and the PVC rod. If there is attraction or repulsion, repeat the neutralization of the rod and the pith ball.
   - Now rub the PVC rod vigorously with silk about 5-10 times, and set the silk aside. Slowly bring the PVC rod toward the pith ball, for now being careful to not touch the ball. You should observe a strong attraction between the charged rod and the neutral pith ball. This mysterious effect will be studied in section 3 below.
4. Now hold the rod *below* the pith ball and slowly raise the PVC rod until it touches the staple protruding from the bottom of the ball. Some charges will leak off the rod onto the pith ball, so that both the rod and the pith ball have similar charges (we can't say yet whether the charges are negative or positive).

[1] The science of charge transfer is known as *triboelectricity*, which comes from the Greek word *tribos* (τριβοζ), *to rub*.
[2] It turns out that your body is a relatively good conductor of electricity. In this case the moving charges are typically ions such as $Na^{(+)}$ and $Cl^{(-)}$.

5. What do you observe when the charged PVC rod is now brought (laterally) toward the charged pith ball?

2. ATTRACTION BETWEEN OBJECTS WITH UNLIKE CHARGES

We would now like to qualitatively investigate the forces between two *unlike* charges. Perform the following operations and record and interpret your observations.

1. You will find a pair of plastic-handled wands at your bench. One is clad with leather, and the other a blue plastic.
2. Charge the pith ball with the PVC rod as in the previous section.
3. Vigorously rub the two wands against each other (taking care not to break them!). This will result in one wand becoming positively charged, and the other negatively charged.
4. Hold the blue plastic wand near the pith ball, taking care to avoid contact. Is the pith ball attracted or repelled?
5. Hold the leather-clad wand near the pith ball, taking care to avoid contact. Is the pith ball attracted or repelled?
6. What can you say about the charge on the pith ball relative to the charge on the plastic, and relative to the charge on the leather?

3. ATTRACTION BETWEEN A CHARGED OBJECT AND A NEUTRAL OBJECT

This effect is at first rather mysterious, but it can be easily understood. If one charges a comb by running it through one's hair, the comb will always *attract* neutral bits of paper; it will never repel them. In general, If a charged object (either positive or negative) is brought near a neutral object (either an insulator or a conductor), the two objects are attracted to one another.

The explanation is as follows. Suppose, for the sake of argument, a positive charged object (say a charged comb) is brought near a neutral *insulator*, such as a bit of paper. The comb will cause the molecules in the insulator to be polarized; that is, the electron charge cloud around each molecule will be slightly shifted away from being centered at the nucleus, and toward the comb. Since the electric field from the comb gets weaker with increasing distance, the attractive force on the electrons (which are slightly nearer to the comb) will be stronger than the repulsive force on the slightly positive far side of each molecule. The net effect is an *attractive* force. By the same argument, you can see that a *negatively* charged comb will also attract a neutral bit of paper.

If a charged comb is brought near a *conductor*, such as a bit of aluminum foil, a fraction of the free electrons in the foil will migrate over significant distances within the material, with the direction depending upon whether the comb is positive or negative. If the comb is positive, the electrons will tend to migrate *toward* the comb. Since the electric field is strongest near the charged object, the electrons will feel a stronger attractive force than the repulsive force that the positively charged molecules remaining on the far side. Again, as with insulators, if the charged comb is negatively charged, the force will still be attractive.

Thus a charged comb, positive *or* negative, will always *attract* a neutral insulating bit of paper, as well as attract a neutral bit of conducting foil. The only difference is that the electrons in an insulator never stray beyond their home atom, whereas the electrons in a conductor can migrate all the way across the material to get closer to the comb.

Using these ideas, repeat experiment #1 (steps 1-4) and interpret the results.

If you have some extra time, see if you can pick up bits of paper with the charged PVC rod. Also, see what happens when you hold the charged rod near a fine stream of water. (A charged comb works just as well).

4. QUANTITATIVE OBSERVATION OF ELECTRIC CHARGE

Not surprisingly, physicists have devised methods for quantitatively measuring electric charge. One method uses a *Faraday Cage*, also known as a *Faraday Ice Pail*. This instrument consists of two nested conducting cylinders, separated by insulating standoffs, as shown in Figure 1. The cylinders may be made from either metal sheet or metal screen; screen is more convenient for visualizing what's happening. If a charge is lowered into the inner cylinder, a potential difference, or voltage, will appear between the two cylinders. (We will explain how this happens in more detail later in the course). This potential difference can be measured with an *electrometer*, which is a very high-quality voltmeter, and can measure a voltage without discharging the conductors. We say that the electrometer has very high *impedance*.

Although the Faraday cage and electrometer can be used to accurately measure the quantity of charge lowered into the cage, for our purposes we will just use the cage for qualitative purposes, including measuring the sign of the charge.

Set up the experiment as follows:

a) Make sure that the electrometer is off when making connections.
b) Connect the electrometer to the Faraday cage as shown in Figure 1. Be sure to connect the positive (red) lead to the inner cylinder.
c) Set the electrometer scale to 100 Volts, and turn the power switch on.
d) Zero the electrometer by temporarily connecting the inner and outer surfaces with a wire.

Note: at any stage in the experiment you may zero the electrometer by performing step (d).

Perform the following operations and record and interpret your observations. In each case, note the sign of the charge on the wand.

a) Gently but briskly rub two dissimilar wands together for 10-15 seconds and set the white (leather) one aside.
b) Lower the blue (plastic) wand into the inner cylinder of the Faraday cage without touching the walls of the cylinder; record the electrometer voltage.
c) Remove the wand from inside the cylinder. What happens?

Now repeat steps a-c above, but using the white wand instead of the blue wand.

PRE-LABORATORY

(Please complete the pre-laboratory question on a separate sheet of paper and turn in to the instructor at the beginning of the lab session).

1. Suppose that a positive charge is brought near a neutral, insulating piece of material. Is the positive charge attracted, repelled, or indifferent to the neutral object? Explain in your own words, using a diagram.

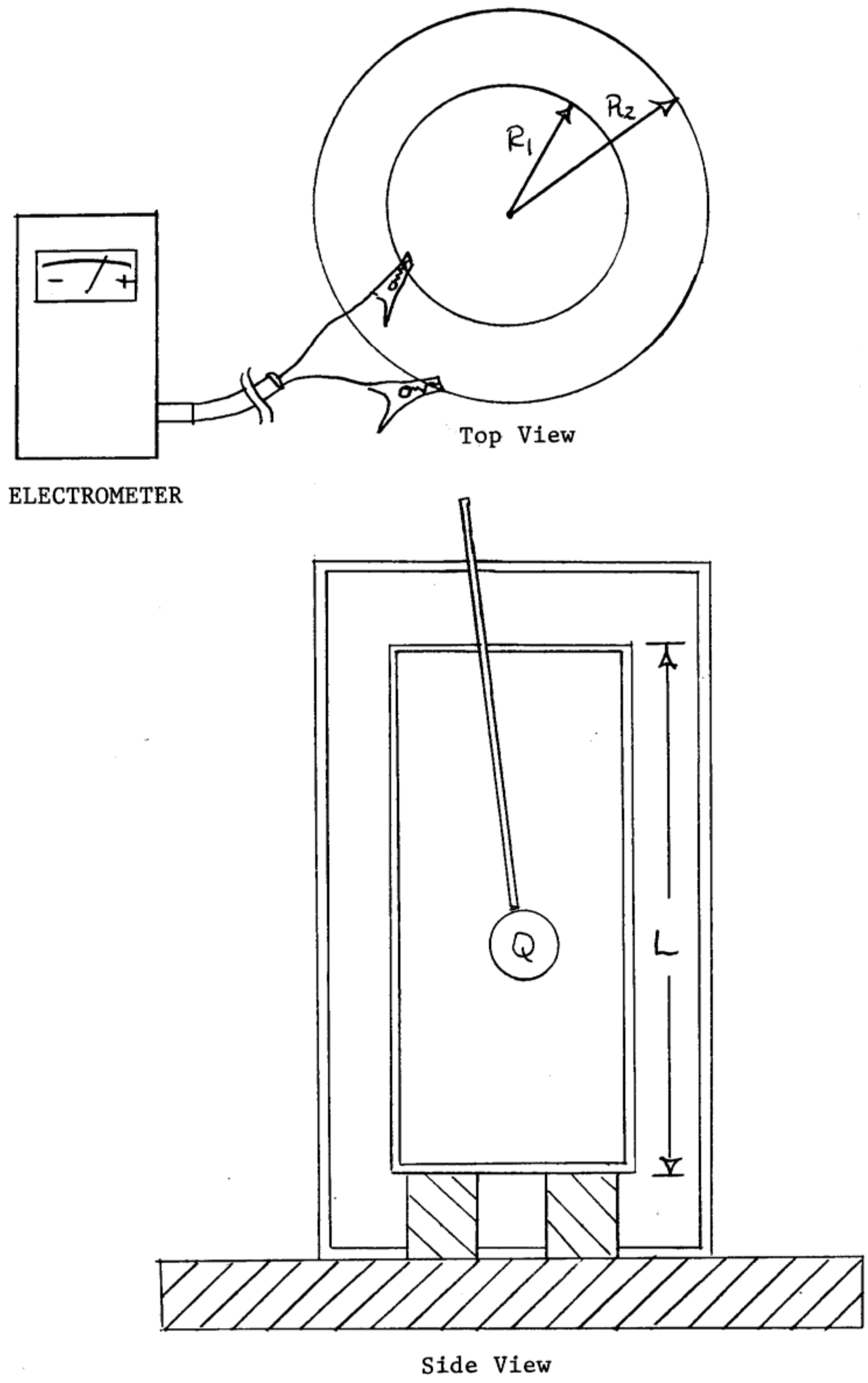

Figure 1 Faraday Cage with Electrometer and Test Charge.