Part I
Electricity and Magnetism

E-1: Electrostatics

PART I. THE ELECTROSCOPE

OBJECTIVE: To use an electroscope to study electrostatic phenomena.

APPARATUS:

A wooden box containing: aluminum-leaf electroscope, insulated hollow sphere proofball, hard rubber rod, rabbit fur, lucite rod, silk cloth.

INTRODUCTION:

In this lab you will use a deceptively simple device, an electroscope, to study the nature of charge. The electroscope's primary working parts are two connected conducting foil leaves. Charge appears in two forms, positive and negative, and like charges repel. At this point the only meaningful distinction between a conductor and an insulator is that a conductor allows charge to flow (in analogy to water in a pipe) whereas insulators do not. Thus as charge is placed on (or near) the conducting electroscope knob at top, the like charge in the electroscope assembly will redistribute so as to move as far away from charge on the rod and electroscope as physically possible. Since the hanging foil leaves of the electroscope are extremely lightweight the repulsive force between the like charges on each leaf is sufficient to force the leaves apart; the greater the charge the greater the angular displacement. In the schematic below we demonstrate the physical response.

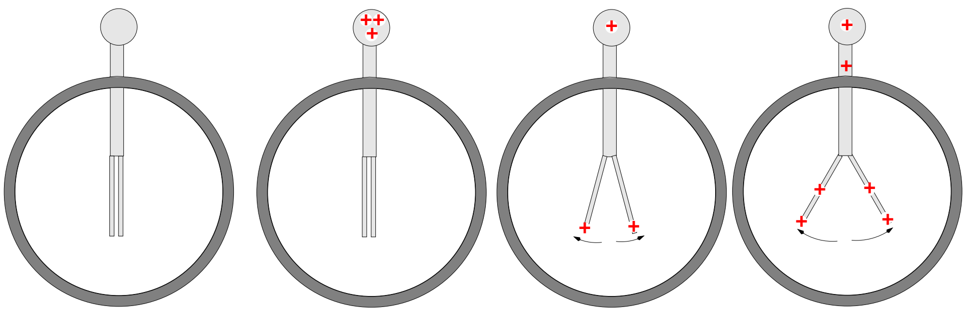


Figure 1: *Qualitative* schematic of electroscope response.

Preliminary Question: Will the charge in the electroscope assembly redistribute itself if a charged object is brought close to (but does not touch) the conducting knob? If so, will the net charge on the knob be of the same or opposite sign? What will be the sign of the charge on the foil leaves be?

Suggestions and precautions

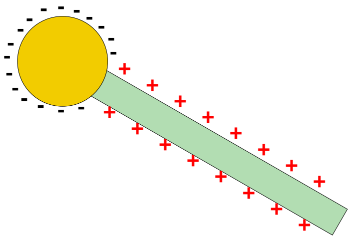
1. In humid air insulators may adsorb enough moisture that charges leak off rapidly. If so, dry all insulators with a heat gun.

2. In very dry or cold weather the humidity is so low that clothing, table tops, etc. become good insulators. Their large surface charges may influence nearby unshielded instruments. If so, ask your instructor for help; e.g. use grounded foil to shield against them. Also remove any clinging loose bits of fiber (e.g. silk or rabbit fur) that may disturb results.

3. The fragile leaves of the electroscope may tear if charged too heavily. **Do not disassemble electroscope** to attempt repair: see your instructor.

4. To remove charges on the glass windows of the electroscope, lightly rub your hands over the windows while grounding your body.

5. Charges on the insulating handle of a proofball can cause serious measuring errors. Test the handle by grasping the ball with one hand (while the other hand touches the electroscope ground), and then bring parts of the insulating handle close to the electroscope knob. If the leaves move, the handle is charged.

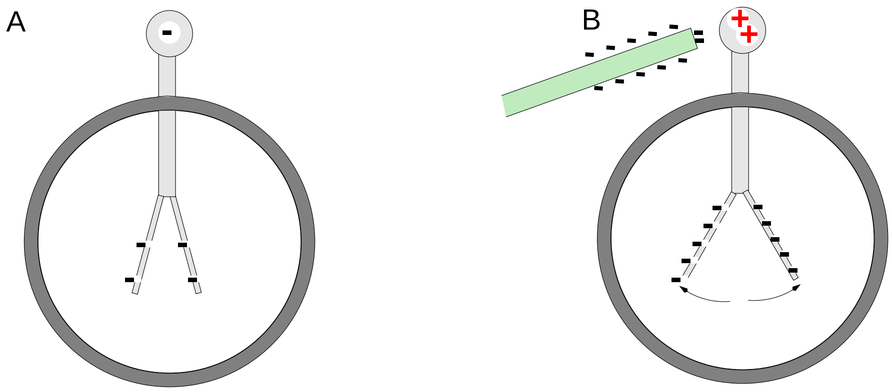


   To discharge it, hold the handle in a source of ionized air. The charged insulator will attract ions of the opposite sign until it is neutral. An open flame is a simple source of both positive and negative ions. The heated air convects these ions upward so **hold the insulator at least 10 cm above open flame to avoid heat damage to the insulator**. Avoid unnecessary handling of insulators because handling may impair their insulating capability. (Perspiration is a salt solution which is a conductor.)

6. Ground the electroscope *case* to a grounding jack near the electrical outlet. Leave it grounded throughout the experiment.

EXPERIMENTS:

1. Charge a rubber rod negatively (-) by rubbing with fur, and transfer some of the charge to the electroscope leaves by touching the rod to the electroscope knob. See diagram A. Note what happens when a (-) charged rod approaches the knob (diagram B). Without grounding the electroscope, also observe and diagram what happens when a lucite rod rubbed with silk approaches the knob.



2. **Charging by induction** (First discharge the electroscope by touching the knob and case simultaneously.) To **charge by induction** make the leaves diverge by bringing up a (-) charged rod: keeping the rod fixed, **ground the knob** to the case,

break the ground and then **remove the rod**. Explain with diagrams each step of the process. Show by diagrams what happens when a (-) charge is brought near the knob; a positive (+) charge. Explain each step briefly.

3. In the following give the proofball a charge of known sign by contact with a charged lucite or rubber rod. **Use diagrams to explain and record results**.

   a. Connect the hollow conductor to electroscope knob by fine wire. Discharge them. Charge proofball by touching[1] it to a charged rubber or lucite rod, then introduce the proofball into the hollow conductor but without contacting the conductor. (If your proofball won't hold charge, you can try cleaning or heating the handle, or putting the lucite rod into the hollow conductor directly.) Ground the hollow conductor by touching it. Note behavior of electroscope. Break the ground and remove proofball. Test the sign of charge on the electroscope.

   b. Repeat part a, but now ground the hollow conductor by touching it **only on the inside** with your finger or a short conductor. Explain.

PART II. Use of ELECTROMETER (a sensitive voltmeter)

OBJECTIVE:

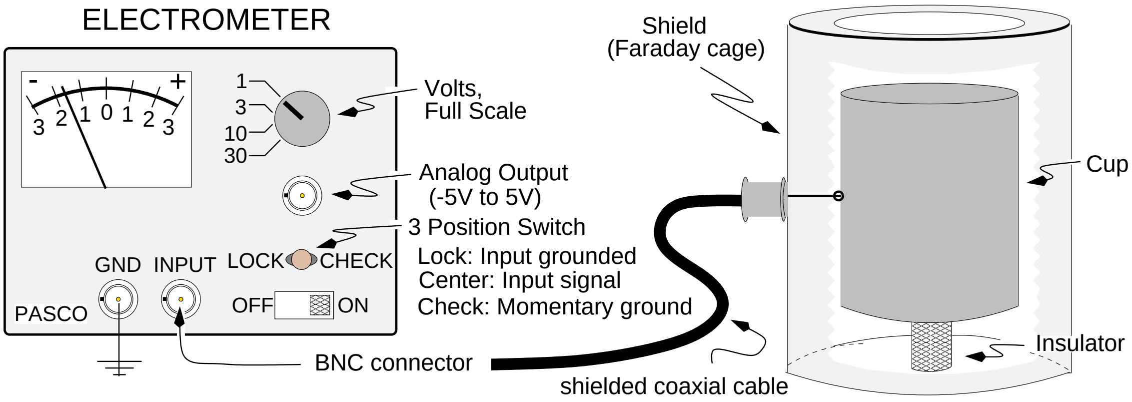
To measure potential (voltage) differences (i.e. the work/charge to move a small test charge between two conductors) and thus, in an indirect fashion, charges.

Preliminary Questions:

1. Does the electroscope allow you to discern the absolute sign of a charge?
2. If you are given a spherical conductor where does the excess charge reside?

APPARATUS:

PASCO electrometer & power supply; two hollow conducting spheres, one open hollow sphere; two charge producing paddles (white & blue), one aluminum paddle; proofball; insulated cup and shield: **do not carry the cup and shield by the top cover** (it may separate causing the cup to drop and become damaged); heat gun; alcohol lamp.



[1]Avoid rubbing which may result in charge separation of opposite sign (depending on the proofball metal and type of insulator: "triboelectric series", see exp #6 of Part II).

INTRODUCTION:

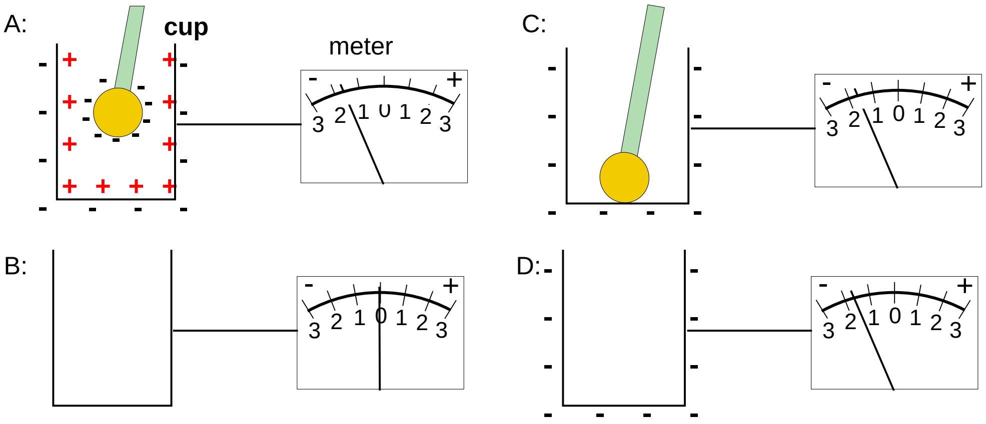
The electrometer reads the difference of potential (in volts) between the center terminal of the input and the grounded shield. (Normally electrometers perform floating measurements, i.e., both the positive and negative side of the measurement is allowed to be any voltage. For convenience our electrometer has been modified to force the negative side to be ground.) What makes the electrometer special is that the electrometer's input resistance is so high, $\sim 10^{14}\ \Omega$, that negligible current flows and hence discharging effects are negligible. Typical handheld voltmeters have resistances five to six orders of magnitude *smaller.* (For the circuit "layout," see your instructor.) From the several voltage ranges, choose one that gives a large but less than full scale deflection. Accuracy is about $\pm$ 3% of full scale. Connect the insulated cup and shield to the electrometer as shown in the sketch. The electrometer measures the potential difference between the cup and grounded shield. *This potential is proportional to the quantity of charge on the cup if the surrounding aluminum can furnishes a perfect shield from external charged objects.*

PRECAUTIONS: These are needed for reliable measurements:

1. Large static charges (common in dry weather) if applied to electrometer input may damage the sensitive input **f**ield **e**ffect **t**ransistor ("FET"). Minimize this possibility by *keeping the electrometer input grounded via the SHORT switch during the initial hook up and when you are done with the experiment.* Also use a banana plug lead to connect the GND terminal of the electrometer to the ground jack near an electrical outlet. In otherwords:
   Keep the Input switch in the "Short before making connections" position whenever there is nothing connected to the input or while you are making a connection. (In older models, this switch may be labled "lock." It is the left position in either case.) After the connection is made, you put the switch in the Input position. If you need to get rid of charge that may have been collected, you can move the switch to either of the short positions, the "momentary" positionusually being more convenient.
2. If your clothing or hair has a net charge, the electrometer reading may change if you move around. Hence, during a given measurement, change position as little as possible and ground yourself (e.g. touch the grounded shield all the time during a measurement or connect a bare wire from your body to ground. Note that grounding yourself is usually a *bad* idea when working with electronics, because of the danger of electrocution. Be careful not to touch any voltage sources while you are grounded.)
3. To remove all charge from the cup, switch the electrometer momentarily to the CHECK position. (This connects the electrometer terminals to each other so that any charge flows from/to ground). If the meter does not read zero, notify your instructor. adjust to zero
4. Always discharge paddles and cup before starting an experiment. To test if an object is charged, put it into the cup and see whether the electrometer deflects. Conductors discharge easily by touching them to a grounded conductor. To discharge an insulator, you must create sufficient ions in the surrounding air. The insulator will then attract ions of the opposite charge until all charge is neutralized. An open flame is a simple source of ionized air; the ions in the flame convect upward with the hot gas. **To avoid damage to the insulator, keep it at least 10 cm above the flame**!

SUGGESTED EXPERIMENTS:

1. Rub the blue and white paddles together and determine which paddle has a net positive charge and which has a net negative charge. Explain the following experiments with diagrams showing charge distributions, e.g. appropriate sample diagrams for this experiment are:



2. Discharge both the blue and the white paddles. Gently rub the white and the blue surfaces of the paddles together. Then:

   a) Hold one of them near the bottom of the cup, but don't let it touch.
   b) Take the paddle out.
   c) Put it back in, touching the cup this time.
   d) Remove the paddle.

   Record the electrometer reading after each step. Explain the results. Was there any charge left on the paddle at the end?

3. **Charging by induction:** Momentarily ground the cup. Charge one of the paddles, then:

   a) Place paddle in cup without **touching**.
   b) Again momentarily ground the cup.
   c) Remove the paddle.

   Note the reading after each step. Explain what happened at each step.

4. Start with both paddles discharged. Then rub them together. Measure the charge on each. Explain. Compare the amount of charge produced by rubbing two paddles of the **same** kind (borrow one from another group), or by rubbing a metal paddle on a metal paddle, etc. (Surface "dirt" on one paddle may mean you are rubbing dissimilar paddles. Sometimes cleaning the paddles with alcohol makes a big difference.)

5. Discharge the cup and the blue and white paddles. What happens if you place the paddles inside the cup (without touching the cup) and,

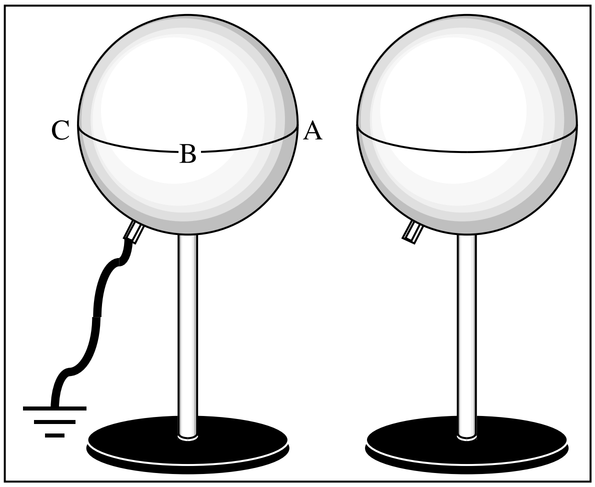
   a) you charge them by rubbing while they both are inside the cup?
   b) Take out one paddle?

c) Put it back in?
d) Take out the other?
e) Take them both out?
Observe electrometer reading after each step. Explain.

6. QUESTION: Do only insulators acquire charge by rubbing? Rub the aluminum paddle on the white (or blue) paddle. Determine sign of effect. Arrange the white, blue and aluminum paddles in a series such that the rubbed one with a positive charge is always higher ("triboelectric" series). Tribology is the study of friction.

   NOTE: In the remaining parts you may measure charge and still avoid spurious effects from charges on the insulating handles if you will touch the charged proofball (or paddle) to the bottom of the cup and then remove it from the cup before reading the electrometer. But remember to discharge the cup (by momentarily grounding) before taking the next reading! However, if the potential of the insulating handle is too large (e.g. way off the least sensitive scale), one can still get spurious effects from leakages.

7. Instead of frictional charging, use the DC power supply. The "ground" binding post is internally connected to earth ground. Adjust the voltage to $\cong$ 500V. Charge the hollow sphere to 500V (use a copper wire to connect the sphere to the power supply). **The switch must be in the correct position or no voltage results even though the meter may read**! Discharge the proofball and test that it (and handle!) have zero charge; then touch it to the outside of the hollow sphere and measure its charge. Do the same experiment but touch inside the sphere. What do you conclude?



8. Connect the power supply to an isolated solid metal sphere (shown in the next figure). Measure the relative charge density σ at various points of the sphere (such as A, B and C). Charge density σ is $\Delta Q/\Delta A$ where ΔQ is the charge on a small element ΔA of the surface. Since it is not practical to remove a piece of the surface, we place the aluminum paddle **flat** against the surface and measure the charge on the paddle after it is removed. This measurement gives a number only approximately

proportional to the charge density (why?) but does give a good idea of the relative charge distribution.

OPTIONAL: Repeat step 8 but with paddle perpendicular to the surface instead of flat. Can you explain the differences?

9. Discharge the second solid sphere when it is far from the charged sphere. Then move it within a few centimeters of the charged sphere. Explore the charge distribution on both spheres with the paddle. Observe carefully the polarity of charge on different parts of the second sphere.

10. Does a grounded conductor necessarily have no net charge? Momentarily ground the second sphere when it is near the first one, then move it away and see whether it is charged. What is the polarity? Explain.

11. How much deflection does one get if one applies 1000V to the aluminum leaf electroscope? Compare the sensitivity to that of the electrometer (but do **not** connect 1000V to the electrometer or to anything connected to the electrometer e.g. the cup.)

12. Set the electrometer switch in the LOCK position.