

Electric Charge and Capacitance

Name: _____

Lab Partner: _____

Section #: _____ Instructor: _____

Activities**Qualitative Observation Of Electric Charge Effects (Activities #1 to #5)**

- #1 Charging by friction, and the Braun electroscope
- #2 Conductors and insulators
- #3 The electrophorus
- #4 Qualitative observation of electrical forces
- #5 Qualitative observation of electric current using a neon lamp

Quantitative Measurements of Electrical Effects (Activities #6 to #10)

- #6 A calibrated coulombmeter for measuring electric charge
- #7 The calibration of a Braun electroscope for use as a (high voltage) voltmeter
- #8 The charge carried by an isolated sphere at a known potential
- #9 Faraday's "ice pail" demonstrations
- #10 The conservation of charge in various processes

Some Reminders: As with all records of laboratory work, you are expected to:

1. use pen (except perhaps when making graphs);
2. preserve your original data records.

In today's lab, you will be asked several times to predict what is likely to happen in various situations. You should respond by saying what you believe will happen. Do not simply state what you read somewhere, or what someone told you! You will not be penalized for your beliefs.

Qualitative Observation Of Electric Charge Effects (Activities #1 to #5)

Activity 1 Charging by friction, and the Braun electroscopes

1. Some preparations:

- a. **Convenient electrical connection to the earth!** We say an object is “grounded” if it is connected electrically to the earth. Several “banana jacks” connected to ground are available; ordinary lab wires can be plugged directly into these “jacks”. All of these jacks are connected to the “third” wire, i.e., the grounded wire of the 3-wire AC electrical supply available at the table.

Use whichever of the following “grounded” jacks that is convenient:

- i. The black jack on a special plug that plugs directly into a common 3-wire AC electrical outlet;
- ii. The black jack on the power supply unit for the coulombmeter;
- iii. The black jack on the front of the coulombmeter.

figure
special plug
(black)

Several exposed metallic surfaces are also connected to ground. These include:

- iv. the large outer cylinder on top of the coulombmeter.

(Note: Items ii, iii, and iv above assume that the coulombmeter power supply is plugged in).

- b. **Each student should wear a conductive wrist strap**, which in turn should be connected to “ground”. The strap will carry excess charge from your body to the earth. Without this strap, a significant excess charge may accumulate on your body; while this is not hazardous, it may lead to erratic results for some of your observations today.

figure
Wrist strap

Are you now wearing a wrist strap that is connected to “ground”? _____

2. Charging by friction, and detecting the presence of charge with the Braun electroscopes:

- a. Inspect the construction of the electroscopes. Then use a wire to connect the base of the electroscopes to “ground”. Is this done? _____

electroscopes

(This connection prevents the build-up of charge on the outer ring of the electroscopes; erratic results could result from such charge.)

- b. Discharge the electroscopes by momentarily touching the disk (at the top) with your hand. The movable vane of the electroscopes should now be at (or near) a vertical orientation. Is it? _____
- c. Using alcohol and tissue, clean and dry the solid gray rod (PVC, 11.75” x 5/8” diameter).

- d. Charge the gray rod! While holding the dry rod in one hand, rub it vigorously with tissue. You should hear faint “cracking” sounds, and perhaps feel it getting warm.
- e. Hold the charged rod about a foot above the electroscope, and then lower it toward the disk of the electroscope, touching the disk with the rod if you like.

Does the vane rotate away from the vertical position as the **gray** rod approaches the disk? _____

Does it start to rotate even before the **gray** rod touches the disk? _____

(Repeat steps b to e as necessary, until you have confidence in your observations and answers.)

- f. Repeat these activities, using now the **solid clear rod** (acrylic, 11.75” x 5/8” diameter). (Discharge the electroscope, clean and charge the rod, and bring it near the disk, etc. - steps b, c, d, and e above.)

Does the vane rotate away from the vertical position as the **clear** rod approaches the disk? _____

Does it start to rotate even before the **clear** rod touches the disk? _____

Questions

Q1. When you rubbed the **gray PVC plastic rod** with tissue, it gained a net **negative** charge.

When you rubbed the **clear acrylic plastic rod** with tissue, it gained a net **positive** charge.

Did the behavior of the electroscope depend noticeably on the sign of the charge of the rod? _____ Explain this result if you can.

Activity 2 Conductors and insulators

1. Metals: Do they appear to be conductors or insulators?

- a. **Place a net charge on the electroscope.** To do this, charge the gray rod, and then drag the length of the rod several times across the flat portion of the electroscope disk. Repeat this until the electroscope vane remains deflected even when the charged rod is removed from the vicinity of the electroscope.

Is the electroscope now charged? _____

How can you tell? _____

- b. Holding an aluminum rod (12" x 3/8" diameter) in your hand, **touch the rod momentarily to the disk at the top of the "charged" electroscope.**

Describe what happened. _____

- c. Repeat steps a and b if necessary until you have confidence in your observations and statements above.

Your conclusions: Does the aluminum rod appear to be a conductor of electric charge, or an insulator? _____ Justify your conclusion:

- d. An **ordinary lab wire** consists of a core of copper strands with an outer covering of plastic. Each end of the copper core is connected to metal plugs.

Repeat the process above (steps a, b, and c), using now an **ordinary lab wire** instead of the aluminum rod. With one hand, hold the bare metal plug at one end of the wire. Then with your other hand holding the plastic cover of the wire, bring the other bare metal plug into contact with the disk of the charged electroscope.

Repeat these steps until you have confidence in your observations.

Does the length of lab wire act as a conductor of electric charge, or as an insulator? _____ Justify your conclusion:

2. Plastics: Do they appear to be conductors or an insulators?

- a. **Again, place a net charge on the electroscope** (as you did in part 1-a above).
- b. Holding any available plastic rod in your hand, **touch the rod momentarily to the disk at the top of the "charged" electroscope, and then remove it.**

Did the electroscope discharge (as it did when you touched the electroscope with the aluminum rod)? _____

Repeat these steps until you have confidence in your observations.

Your conclusions: Does the plastic rod appear to be a conductor of electric charge, or an insulator? _____ Justify your conclusion:

Question

In part 1-a above, you were directed to use a charged rod to charge the electroscope as follows, "drag the length of the rod several times across the flat portion of the electroscope disk".

Q1. Why can't one simply just touch the disk with the rod? Why should one want to "drag the length of the rod several times across thedisk"?

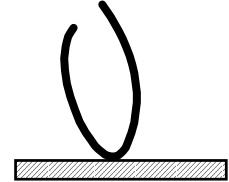
Comments

Materials are not purely insulators or conductors. Different materials have values of electrical conductivity (or resistivity) that are distributed over a range covering many orders of magnitude. When we say a material is an insulator, we mean that the electric current through it is likely to be negligible for typical applications.

3. The plastic insulation on an ordinary lab wire: Is it perfectly insulating?

a. **Place a net charge on the electroscope.**

b. Hold the two metallic plugs of a short lab wire (say 12" long) tightly in one fist. Then with the other hand, press the plastic insulation (only!) near the middle of the wire against the disk atop the charged electroscope.



pressing the insulation of a lab wire against the disk of a charged electroscope

Does the electroscope discharge (perhaps slowly but noticeably) through the plastic insulation? _____

Estimate roughly the observed discharge rate (e.g., 30° in 10 s): _____

Comments

Typically a noticeable amount of charge flows from the electroscope through the plastic insulation. This flow of charge, or **current**, is of the order of 10^{-9} Amperes (1 nA, or 1 nanoampere).

4. Teflon insulation: Is current leakage through Teflon noticeable?

a. Locate a length of wire insulated with (red) Teflon. (There should be one at your table; it is red, and should have a label near one end.)

b. Using the Teflon wire, repeat steps a.) and b.) in section 3 above.

Does the electroscope discharge (slowly but noticeably) through the Teflon covering? _____

Does the Teflon appear to a better insulator than that of the PVC plastic used on ordinary lab wires? _____

Comments

Because Teflon is an excellent electrical insulator, it is used for key components of the apparatus for this experiment. The white insulating material directly below the disk of the electroscope is Teflon, as is the white handle of the electrophorus which you will use shortly.

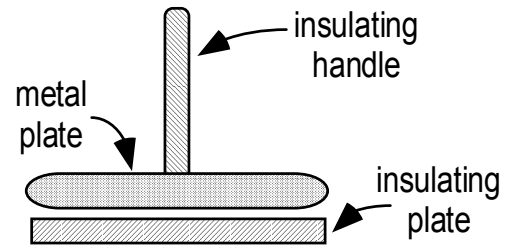
Activity 3 The electrophorus

The electrophorus is a device for producing sizable amounts of static electric charge with relative ease.

1. Inspect the parts of the electrophorus.

It consists of:

- a. a (plastic) insulating plate;
- b. a circular metal plate with an insulating handle.



Note that there are two insulating plates available; we recommend that the gray (PVC) plate be used initially. The other clear (acrylic) plate can be set aside for now.

2. Preparation of the electrophorus:

(Step #1) Charge the (dry) top surface of the gray plate; to do this, rub it vigorously with tissue. You should hear “cracking” sounds. (If you hear nothing, the plate may need cleaning. Use tissue and alcohol as necessary.)

Is the large gray plastic plate of the electrophorus now charged? _____

As you will see, the plate will retain its charge over many cycles of use! It will need recharging only occasionally!

3. The cyclic operation of the electrophorus: In normal use, the metal plate acquires a significant net electric charge; this is the desired result. As you will see, this charge can be acquired repeatedly and rapidly.

Produce now a useful charge on the metal plate of the electrophorus. To do this:

(Step #2) Place the metal plate on top of the (charged) plastic plate;

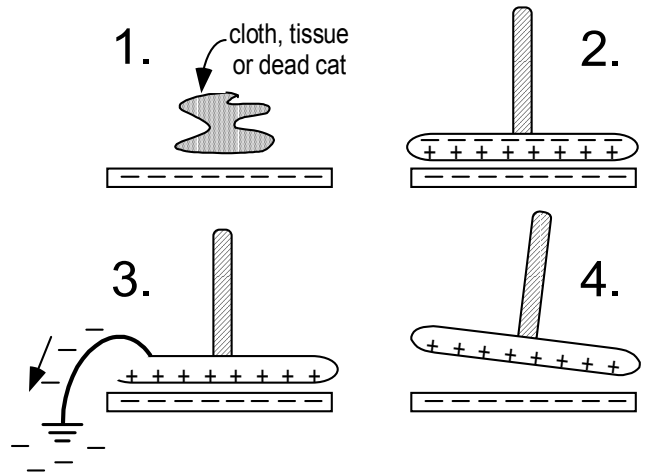
(Step #3) Momentarily “ground” the metal plate, that is, provide a conducting path between the metal plate and the earth. You can do this:

- i. by touching the metal plate with your hand (you are wearing a wrist strap, so your body is connected electrically to the earth), or
- ii. by making (with a wire) a momentary connection between the metal plate and some object that is connected to ground, such as the outer ring of the electroscope.

Have you (momentarily) “grounded” the metal plate? _____

(Note that the connection to ground should not be permanent! The plate should be connected briefly to ground, and then the connection removed!)

Is the connection from the plate to ground now broken? (It should be!) _____



(Step #4) Now lift the metal plate by means of its insulated handle. The metal plate should now be charged!

(Step #5) Test for the presence of (net) charge on the metal plate. Use the electroscope as necessary.

Does the electroscope indicate the presence of a significant charge on the metal plate? _____

You can also test for charge on the plate by discharging the plate to some exposed surface of a human body (yours, or better yet, that of your lab partner).

4. Repeat the **cyclic** process above (steps #2 to #5 above, but **not** step #1) as often as you like, using the electroscope or someone's body as a "charge detector".

Does the electrophorus work well, over many cycles of use, without the necessity of recharging its plastic plate? _____

Questions

- Q1. Explain how the electrophorus operates. In particular, since the plastic plate only occasionally needs to be recharged, where the heck is the charge accumulated on the metal plate coming from???

Prediction

If the lower plastic plate carries a net positive charge, predict the sign of the charge acquired by the metal plate? _____

If the lower plastic plate carries a net negative charge, predict the sign of the charge acquired by the metal plate? _____

These predictions will be tested in Activity #6, part 4-c. (page 14).

Comment

The process by which the metal plate of the electrophorus becomes charged is called "charging by induction". Note that this process, while critically dependent upon the presence of the charge on the lower plastic plate, does not take charge from that plate! Note that the metal plate gains charge of opposite sign from that on the plastic plate on which it rests!! (Actually, a bit of charge probably is transferred from the plastic to the metal, but clearly this process is small compared to the dominate process of "induction".)

At this point, ask your instructor to **check** your work. You may continue the experiment while waiting for your instructor.



Activity 4 Qualitative observation of electrical forces

1. Locate the equipment listed below:
 - a. A small rotating stand on which a rod may be placed; Rotating stand
 - b. A collection of hollow plastic rods. With their low moment of inertia, for a given torque, these acquire a sizable angular acceleration!!
 - c. Note that on your table, there should be **two** solid gray (PVC) rods, and **two** solid clear (acrylic) rods.
2. **Attractive and repulsive electrical forces:**
 - a. Demonstrate the electrical force between two charged rods.
 - i. Charge a rod of your choice and center it on the rotating stand.
 - ii. Charge a second rod, and **without making contact between their surfaces**, use the second rod to pull, or push, the rod on the stand, so that it spins!
 Without making contact, can you cause the mounted rod to spin? _____
 - b. Demonstrate (if you can) both attractive and repulsive electrical forces between charged rods. Try various rods as necessary.
 Did you observe a sizable **electrical force of attraction** between rods? _____
 Describe the two rods involved: _____
 Did you observe a sizable **electrical force of repulsion** between rods? _____
 Describe the two rods involved: _____
3. **Electrical forces between like charges, and between unlike charges:**
 - a. **The triboelectric properties of the solid rods** are summarized in the table below.

appearance of solid rods	composition	sign of charge acquired by the plastic when rubbed with tissue	How effective is rubbing with tissue in producing a net charge?
gray	PVC plastic	negative	very effective!
clear	acrylic plastic	positive	very effective!

- b. **The electrical force between unlike charges (i.e., charge of opposite sign):** Refer to the table above as necessary. Then use the appropriate solid rods and the rotating stand to observe the nature of the force between concentrations of **unlike** charges.
 Describe the nature of the force observed: _____
 Describe the rods used: _____
- c. **The electrical force between like charges (i.e., charge of the same sign):**
 Using the appropriate solid rods and the rotating stand, observe the nature of the force between two concentrations of **positive** charge.

Describe the nature of the force observed: _____

Describe the rods used: _____

Using the appropriate solid rods and the rotating stand, determine the nature of the force between two concentrations of **negative** charge.

Describe the nature of the force observed: _____

Describe the rods used: _____

Comment

Although you have not proved it, **two (and only two) types of electric charge are needed to explain all observed electrical phenomena.** The assignment of the names “positive” and “negative”, commonly attributed to Benjamin Franklin, was arbitrary. However, the assignment in one case determines the assignments of names (positive or negative) for all other cases. For example, if we agree that glass rubbed with silk accumulates positive charge, then experiments can be done to assign a name (positive or negative) to the charge on any other object.

4. The Electrical force between a charged object and an uncharged (neutral) conductor.

- a. Place an aluminum rod on the rotating stand. Then momentarily “ground” the rod (say by touching it with your hand). For reasons that will be clear later, be sure that no charged object is near the metal rod while it is “grounded”.

Is the metal rod now on the rotating stand, and uncharged? _____

Prediction

Predict the nature of the electrical force between a charged object and an uncharged conductor, such as the rod. Is it attractive, repulsive, or zero?)

- b. Now observe the nature of **the force, if any, between a negatively charged (gray PVC) rod and the uncharged metal rod.** (Occasionally “ground” the metal rod to insure that it remains uncharged! Again, be sure that no charged object is near the metal rod while it is “grounded”.)

Plastic rod used: _____

Describe the nature of the force observed: _____

- c. Now observe the nature of **the force, if any, between a positively charged (clear acrylic) rod and the uncharged metal rod.** (Again, occasionally “ground” the metal rod to insure that it remains uncharged!)

Plastic rod used: _____

Describe the nature of the force observed: _____

Comment

Although an uncharged object has a **net** charge of zero, it does contain both positive and negative charges, as do all macroscopic objects. And in the case of a metal, some of the negative charge (electrons) move quite freely about within the metal. This occurs whenever there is an electric field present within the metal; such a field is produced by the approach of charged object.

- d. Explain (if you can) why a neutral conductor is **always attracted** by a charged object, regardless of the sign of the charge on the object.

5. **The electrical forces acting on the vane of an uncharged electroscope!**

The vane of an uncharged electroscope will deflect as a charged rod is lowered toward its disk, even before any charge has transferred from the rod to the electroscope. Try to observe this process.

- i. Discharge the electroscope (say by touching its disk with your hand).
- ii. Lower a charged rod toward the disk of an uncharged electroscope. Bring the rod close enough to cause the vane to deflect, but not so close that a discharge (spark!) occurs. (A discharge likely would carry charge from the rod to the electroscope!)
- iii. Then raise and remove the rod; the vane should return to its vertical orientation, confirming that no spark occurred and that the electroscope has no net charge.

Were you able to observe the phenomenon described above? (Try a few times if necessary!) _____

If not, describe what you did observe. _____

Questions

Q1. Explain as best you can what causes the vane of the uncharged electroscope to deflect as the charged rod is lowered toward the disk.

Assume that the vane of the uncharged electroscope has been deflected by the approach of a rod carrying a net **negative** charge.

Q2. At this moment, what is the likely nature of the charge on the vane and its vertical support structure? _____

Q3. At this moment, what is the likely nature of the charge on the disk at the top of the electroscope? _____

Activity 5 Qualitative observation of electric current using a neon lamp

Prepare to discharge a charged electrophorus plate to ground, using a circuit path that passes through a neon lamp!

1. Locate the small neon lamp mounted within a black plastic light shield.
2. Make the connections shown in the figure, namely,
 - a. connect one end of the neon lamp to a convenient "ground" connection.
 - b. connect a wire insulated with Teflon to the other end of the lamp.
3. Position the neon lamp so that the lamp is well shaded from the room light.
4. Charge the metal plate of the electrophorus.
5. Then while watching the neon lamp, **discharge the electrophorus plate** by touching the plug on the loose end of the Teflon wire to the plate.

neon lamp "circuit"

Repeat the process of charging and discharging the plate (steps 4 & 5) until you have confidence in your observations.

Describe your observations, in particular with respect to the neon lamp.

Comment

The neon lamp glows only in the region of one of its two similar electrodes! And if the electrophorus plate carries charge of the opposite sign, the other electrode will glow during discharge!

Thus one can tell the direction of the current by observing which electrode is glowing. The electrode which glows collects negative charge (electrons) from the partially ionized neon gas within the lamp. This directionality of the simple neon bulb rests on asymmetry of atomic structure, namely, the fact that the heavy nucleus is positive, while the much lighter electrons are negative. The electrode that glows brightest collects the lighter particles, which in our world are the (negative) electrons!

Quantitative Measurements of Electrostatic Effects (Activities #6 to #10)

Activity 6 A calibrated coulombmeter for measuring electric charge

This coulombmeter can measure the net electric charge on an object placed within its inner metal cup to an accuracy of about 1%.

coulombmeter

As an object with a net charge, Q , is lowered into the inner metal cup, charge of (nearly) equal magnitude and opposite sign will be drawn to the cup from the circuit. As this happens, charges of magnitude, Q , accumulate also on each of the plates of the capacitor, C .

label capacitor with a C!

Hence, the net charge, Q , on the object lowered into the cup is given by

$$Q = C \Delta V$$

where ΔV is the change in the P.D. across the capacitance, C . Note that ΔV is measured by a common voltmeter.

(Some terminology: A metal cup used in this way to measure charge is sometimes called a "Faraday cup".)

1. **Example result:** Assume that when a charged object is lowered into the inner cup, the change in the reading of the voltmeter, ΔV , is 15.1 mV. If the capacitor has a value of $C = 1.00 \mu\text{F}$, then the net charge on the object is:

$$Q = C \Delta V = (1.00 \mu\text{F}) (15.1 \text{ mV}) = +15.1 \text{ nC}$$

2. **Some features of the coulombmeter:**

- a. **The sign of voltmeter reading indicates the sign of Q ,** the charge placed into the cup!!!. Thus you are using an ordinary digital voltmeter to measure the magnitude and sign of static electric charges!!!!!!

(Explanation: If a positive charge is lowered into the cup, negative charges are drawn to the cup, leaving the top plate of the capacitor positive. This positive charge (on the upper plate) attracts a (nearly) equal amount of negative charge to the lower plate from ground.

- b. **The coulombmeter measures the net charge placed within the cup, whether that charge is transferred to the cup or remains on the object!** Thus, the net charge on insulators and conductors can be measured equally well, and without the need to disturb the charge on the object.
- c. **You can select one of several capacitors, namely, 0.1, 1.0, or 10 μF .** These correspond in essence to three ranges for measuring charge.
 - i. The middle value, 1.0 μF , is a convenient beginning choice. When using this capacitor, the reading of the meter in mV can be interpreted directly as the charge in nC! For example, a reading of 2.0 mV implies a charge of 2.0 nC. This follows from:

$$Q = C \Delta V = 1 \mu\text{F} \times 2.0 \text{ mV} = 2.0 \text{ nC}$$

As you will see, the nC is a unit of convenient size for static charges on objects with dimensions of the order of centimeters.

- ii. The smallest C gives the highest sensitivity, and is best for measuring small Q;
- iii. The largest C gives the greatest useful range, and is best for measuring large Q;

3. **TYPICAL OPERATING PROCEDURE OF THE COULOMBMETER:** Refer to the procedure in the shaded box below as needed in the sections that follow.

1. Turn both the coulombmeter and its separate power supply ON.
2. Select the 1 μF capacitor (unless you prefer another).
3. Discharge the capacitor within the coulombmeter (by pressing the push-button);
4. Note the initial reading of the voltmeter (should be at or near 0.0 mV);
5. Place the charged object within the inner cup (or transfer charge to the inner cup);
6. Note the final reading of the voltmeter, and ΔV , the change in P.D. (in mV).
7. Determine the magnitude and sign of the charge on the object from the relation, $Q = C \Delta V$.
8. Most detailed information concerning the coulombmeter is given at the end of this activity.

4. **Some interesting measurements made with the coulombmeter:**

- a. **The charge on a solid gray PVC rod rubbed with tissue:** Rub the rod vigorously, trying to maximize the charge on the rod. Then using the 1.0 μF capacitor range and the operating procedure outlined above, use the coulombmeter to measure the charge on the rod, while the rod is touching the bottom of the inner cup. (Actually, you are measuring the charge on that portion of the rod that fits within the cup!). Record your result below.

charge on gray PVC rod (including sign!): _____

Is the sign of the charge observed here consistent with the information given in the table on page 8? _____

- b. **The charge on a solid clear acrylic rod rubbed with tissue:** Rub the rod vigorously, trying to maximize the charge on the rod. Measure the charge on the rod (while the rod is touching the bottom of the inner cup), and record your result below.

charge on clear acrylic rod (including sign!): _____

Is the sign of the charge observed here consistent with the information given in the table on page 8? _____

Questions

In exercise 4-f of the pre-lab, you were asked to estimate **the maximum charge that can reside on the surface of a rod** (of given diameter and length) without a spark forming in the air around the rod. The correct answer to this pre-lab exercise is approximately **159 nC**.

By design, the value of the diameter used in this pre-lab exercise approximately equals that of the solid rods which you used above, and the value for the length of the rod nearly equals the depth of the inner cup of the coulombmeter.

Q1. What **percentage of the maximum charge possible** were you able to generate on the gray PVC rod? _____

Q2. What **percentage of the maximum charge possible** were you able to generate of the clear acrylic rod? _____

c. **The charge produced by the electrophorus:**

- i. Locate a conducting Ping-Pong ball mounted on a white (Teflon) insulating rod. (These Ping-Pong balls are coated with a black conducting paint.)
- ii. Charge the metal plate of the electrophorus in the usual way (using the gray PVC plate of the electrophorus).
- iii. Since the metal plate is too large to fit into the coulombmeter, transfer some its charge to the conducting ball, say by touching the ball with the metal plate.
- iii. Now, using the coulombmeter, measure the charge on the ball.
charge on ball (including the sign!): _____

Questions

Q3. Explain the sign of this charge, in light of the operation of the electrophorus and the triboelectric properties of gray PVC plastic.

Q4. What is the name of the process by which the metal plate of the electrophorus gains a net charge? _____

In exercise 1-d of the pre-lab, you were asked to estimate **the maximum charge that can reside on the surface of a sphere** (of given diameter) without a spark forming in the air around the sphere. The correct answer to this exercise is approximately **114 nC**.

By design, the value of the diameter used in this pre-lab exercise approximately equals that of the Ping-Pong ball which you used above.

Question

Q5. What **percentage of the maximum charge possible** were you able to transfer from the electrophorus to the ball? _____

At this point, ask your instructor to check your work. You may continue the experiment while waiting for your instructor.
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You need not read the following more detailed information concerning the coulombmeter. It is here mainly if some problem or question arises, for coulombmeter aficionados, and for your instructor's benefit.

OTHER SIGNIFICANT CHARACTERISTICS OF THE COULOMBMETER

1. **An inaccurate reading results** if the P.D. exceeds 200 mV at any time. (When V exceeds 200 mV, the meter automatically changes from its lowest range to a higher range. In the higher ranges, the meter has a much lower resistance (to protect the meter!). This causes a rapid discharge of the capacitor until the P.D. becomes small enough for the meter to return to its lowest range.)
2. Some drift of the meter reading, while undesirable, is normal. The drift is largest when using the smallest C, sometimes being as large as 0.1 mV/s. If the meter reading is drifting, it is important to try to observe the **change** in P.D. caused by the insertion of charge when making a measurement.
3. The uncertainty in the value of the charge is determined principally by that of the meter, namely, $\pm (0.7\% + 2 \text{ counts in the LSD})$.
4. In normal use, an extension of the outer grounded tube should be (taped) in place (to double the tube length to 14"); this extra length provides better isolation of the inner cup from external electric charges.
5. Is the meter used in the coulombmeter (Soar model ME-540) an ordinary digital multimeter? Yes, with one caveat. The standard input resistance of digital voltmeters is 10^7 ohms (10 mega-ohms). However, some inexpensive autoranging multimeters have a much higher input resistance on their most sensitive D.C. voltage range. Our coulombmeter design relies on this fact. For the voltmeter we use, the meter resistances are: 10^9 ohms or greater on the lowest DC voltage range; 10^7 ohms on all others. Without this very high input resistance, the charge induced on the capacitor within the coulombmeter would "decay" through the meter too rapidly for convenient measurement (time constant = $\tau = RC = (10^7 \Omega)(1 \mu\text{F}) = 10 \text{ s}$)

Activity 7 Calibration of a Braun-type Electroscope (for use as a voltmeter)

The following equipment is available on a special "High Voltage" table in the lab.

figure

1. Inspect the apparatus shown in the figure above. Note that:
 - a. The **high-voltage probe** allows you to measure very high potentials safely and without damage to ordinary meters.
 - b. **This probe attenuates (reduces) the potential difference (P.D.) by a factor of 1000**; hence, you must multiply the voltmeter reading by 1000 to determine the true potential at the tip of the probe.
 - c. The probe is designed for measuring potential with respect to ground; one wire from the probe must connect to ground (to protect you and the meter!).
2. **A WARNING: An ordinary voltmeter would be instantly destroyed if connected to the high voltage output of the power supply.** The **high voltage probe** must be used when making high voltage measurements with the meters!
3. Use the high voltage power supply to increase the electric potential of the disk of the electroscope to high values (up to several kilovolts). Note and record the value of potential that causes a 45° deflection (approximately) of the vane. _____

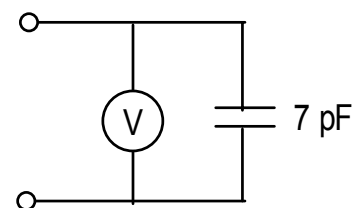
Comments

Really, what is an electroscope?

The electroscope can be modeled as an ideal voltmeter in parallel with a capacitance of about 7 pF. Thus, if you apply a potential of 1000 volts to the scope, approximately 7 nC will be transferred to the scope.

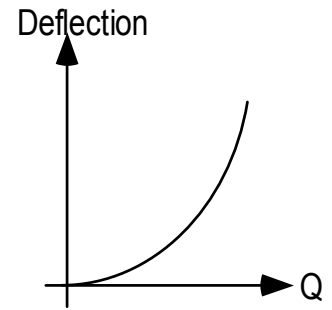
$$Q = CV = 7 \text{ pF} \times 1000 \text{ V} = 7 \times 10^{-9} \text{ C}$$

Voltmeters that produce a reading by a mechanical deflection that is caused by electric forces typically are called **electrostatic voltmeters**. Typically they are suitable only for measuring high potentials.



Model of Electrostatic Voltmeter

1. The deflection of the electroscope vane is intrinsically non-linear, with the deflection being roughly proportional to the square of the charge. Hence, you need quite a bit of charge on the electroscope before much happens!
2. Occasionally, the vane of the electroscope is not well balanced, with the vane pinned slightly against the vertical structure of the electroscope when the electroscope is uncharged. In this case, even more charge is needed before getting a particular deflection.



Activity 8 The charge on an isolated sphere at a known potential

The electric potential, V , at the surface of an isolated conducting sphere (of radius R carrying a charge of Q) is given by:

$$V = Q / (4 \pi \epsilon_0 R) = (1 / 4 \pi \epsilon_0 R) \cdot Q$$

Comparing this expression to that which defines capacitance, namely,

$$Q = C V \quad ; \text{or} \quad V = (1/C) \cdot Q$$

we see that the capacitance of such a sphere is given by:

$$C = 4 \pi \epsilon_0 R$$

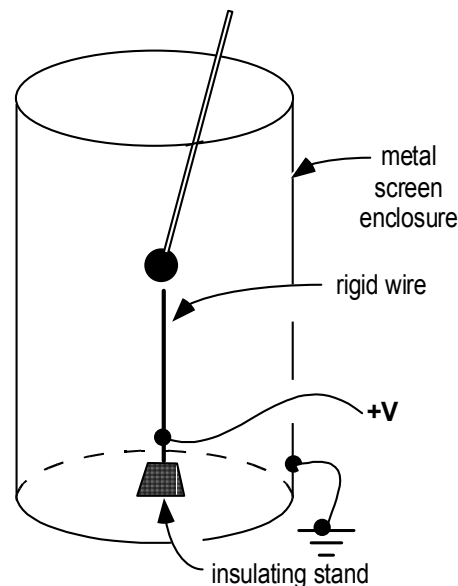
For a sphere the size of a ping pong ball, namely, $R = 1.85 \text{ cm}$, this equation yields:

$$C = 2.06 \text{ pF} = 2.06 \text{ nC} / \text{kV}$$

The situation of an isolated sphere at known potential can be approximated by touching a ball to the tip of a wire at known potential centered within a sizable grounded enclosure.

Prediction

Consider an initially uncharged conducting ping pong ball that is touched to the tip of a wire that is at an electrical potential of $+4 \text{ kV}$. Predict the quantity of charge that will be left on the ball.



1. Prepare to perform the experiment described in the Prediction section above, namely, "charge" a ball in this way, and then use the coulombmeter to measure the resulting charge on the ball. **But first read these comments and warnings!**
 - a. The potential of the center wire can be set to the desired high voltage by adjusting the available high voltage power supply. There should be a digital meter connected to special (low voltage!) monitoring terminals on the back of the power supply. The P.D. at the monitoring terminals is a factor of 10^3 lower than the P.D. between the power supply output wires.
 - b. After being charged, carry the ball to a coulombmeter on another table. Do not bring the coulombmeter to the H.V. table!
 - c. The grounded enclosure provides a controlled electrical environment, shielding the ball (while it touches the tip of the stiff wire) from extraneous charge on nearby objects, such as that on you and (especially!) your clothing.
 - d. Your results will be affected by any charge present on the rod on which the ball is mounted. Before serious measurements, you may want to test for such charge; if it is greater than 0.5 nC , try discharging the ball again. If the charge is still larger than 0.5 nC , try a different ball. If all else fails, see the discussion in the shaded box near the beginning of Activity 9.

2. **Now perform the measurements!** Set the potential of the rigid wire to the desired (high) value, "charge" the ball by touching it to the tip of the wire, and then use a coulombmeter to measure the resulting charge on the ball. Do this several times to see whether your results are reproducible.

Potential of wire: _____

Measured charge on ball: _____

3. Describe any significant way in which your observations differ from your prediction, and give possible reasons for this difference.

At this point, ask your instructor to **check** your work. You may continue the experiment while waiting for your instructor.



Activity 9 Faraday's "ice pail" demonstrations

As discussed in the pre-lab, Ben Franklin found that the charge remaining on a conducting object that makes contact with a metal can (Faraday later used an "ice pail") depends strongly upon the location of the point of contact. These effects are particularly interesting when the can is highly charged.

1. First locate a (conducting) Ping-Pong ball, mounted on an insulating (Teflon) rod.
2. **Discharge the ball.** To do this, hold its (insulating) support rod, and lower the ball into the inner coulombmeter cup, making contact between the ball and the bottom of the cup.
3. **Measure the residual charge on the ball**, using the coulombmeter ($1.0 \mu\text{F}$); record the result in the table below. (The charge should be small, say less than 0.5 nC . If it is not, try again to discharge it. If it still is not small, try a different ball. If all else fails, see the comments below.)

Read this only if the ball cannot be fully discharged ($>0.5 \text{ nC}$) !!

- i. This effect likely is due to charge located on the Teflon rod, near the ball.
- ii. Charge on Teflon can be removed by gently wiping the surface with tissue dampened with alcohol. Do not rub hard, or you will generate more charge by friction!!
- iii. Do not wipe the ball itself; alcohol damages the conducting paint on the ball.
- iv. After allowing the Teflon to dry, discharge the ball (as described above) and use the coulombmeter to measure the residual charge, if any.

3. **Place a metal can atop the electroscope.** Note that:

- a. located here, the can is insulated from the environment and thus can hold charge well;
- b. and, conveniently, the electroscope vane will indicate the presence of charge on the can!

figure
can atop electroscope

4. **Place a sizable charge on the can**, using the electrophorus as appropriate. The electroscope vane should be well deflected from the vertical!

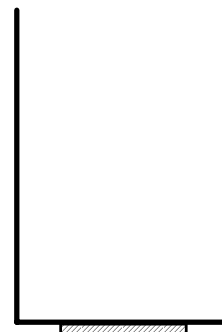
Predictions

Before proceeding, **predict the residual charge on the ball** after it momentarily touches the inside bottom of the highly charged can. (E.g., a significant positive (or negative) charge, or approx. zero, etc.) _____

Predict the residual charge on ball after it touches the outer, bottom edge of the can.

5. **Now touch the ball to some point on the charged can, and measure the resulting charge on a ball.** Record the result in the table below.
 - a. Do this for at least two different points on the can, one deep within the can and another on its outer surface.
 - b. Repeat your measurements until you have confidence in your result.

location touched (if appropriate, indicate location in the figure with a letter.)	measured residual charge	(for part 6 below) initial charge



Questions

Q1. Do your observations agree with your predictions? _____

can

Describe any significant ways that your observations differ from your predictions, and give possible reasons for those differences.

Q2. How "strong" is the effect of position? For example, consider those two locations for which you find the most and the least charge on the ball. For these locations, respectively, what is the ratio of the charge left on the ball (e.g., 2 to 1, or 5 to 1?). _____

Predictions

Do these results depend significantly upon the initial charge on the ball? For example, if the ball is touched deep within the can, is its residual charge much affected by whether the ball is initially charged or not? _____

6. Now test your prediction.

- a. Give the ball a significant charge, either by touching the can appropriately, or by using the electrophorus. Then measure its charge. Record this initial charge in the column on the right in the table above (use a blank line in the table).
- b. Now touch the ball to a point deep within the can, preferably approximately as you did previously.
- c. Measure the residual charge on the ball, and record the result in the table above.

Questions

Q3. Do your observations agree with your prediction above? _____

Describe any significant ways in which your observations differ from your predictions, and give possible reasons for those differences.

Activity 10 The conservation of charge in various processes

Using the coulombmeter, you can measure the electric charge on various objects both before and after various processes.

First locate two (conducting) Ping-Pong balls, mounted on insulating (Teflon) rods. We will refer to these as ball A and ball B.

1. Contact between two conductors, with one initially charged and the other uncharged (with contact occurring in a region where $E = 0$, i.e., in a location far from other charges):

- Discharge ball A**, preferably by having it make contact with the inside bottom of the coulombmeter cup. Then use the coulombmeter ($1.0 \mu\text{F}$) to measure its charge; record the result in the table below. (The charge should be small, say less than 0.5 nC . If it is not, try again to discharge it. If it still is not small, try a different ball. If all else fails, see the comments in the previous activity.)
- Give ball B a substantial charge**, preferably greater than 25 nC (we recommend that you use the electrophorus for this). Again, use the coulombmeter to measure the charge, and record the result in the table below. Also enter the sum of the charge on the two balls.

Prediction

Before proceeding, **predict the final charge on each ball** after they touch one another. Also enter your predictions in the table below. (Don't dilly-dally; you don't want charge to "leak" off the balls!) Explain the logic of your predictions here.

- Now cause the balls to make momentary contact**; do this far from any charged rods and the electrophorus, etc. Then measure the final charge on each ball, recording the results on the right in the table below. Again, calculate the sum.

Process	initial charge			final charge		
	Ball A	Ball B	Sum	Ball A	Ball B	Sum
#1, contact ($E = 0$)						

Predictions ----->			

- Do you have confidence in your results above? ____ If not, what is your concern? _____ You are welcome to repeat your measurements until you have confidence in them, recording your new results in an unused line in the table above.

Questions

Q1. Do your observations agree with your predictions? ____

Describe any significant ways that your observations differ from your predictions, and possible reasons for those differences.

2. Contact between two conductors, with one initially charged positively and the other negatively (with contact occurring in a region where $E = 0$, i.e., in a location far from other charges):

- a. **Give each ball a substantial charge of opposite signs**, preferably each greater than 25 nC. Record the initial charge (including the sign!) of each in the table below. Also enter the sum of the charge on the balls.

Prediction Before proceeding, **predict the final charge on each ball** after they touch one another. Enter your predictions in the table below. (Don't dilly-dally; you don't want charge to "leak" off the balls!)

- b. **Now have the balls make momentarily contact**; do this away from any charged rods and the electrophorus, etc. Then measure the final charge on each ball, recording the results on the right in the table below. Again, calculate the sum.

Process	initial charge			final charge		
	Ball A	Ball B	Sum	Ball A	Ball B	Sum
#2, contact ($E = 0$)						

Predictions ----->			

- c. Do you have confidence in your results above? ____ If not, what is your concern? _____ You are welcome to repeat your measurements until you have confidence in them, recording your new results in an unused line in the table above.

Questions

Q2. Do your observations agree with your predictions? ____

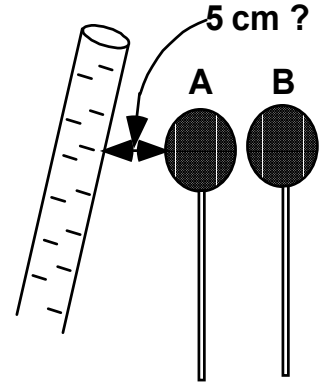
Describe any significant ways that your observations differ from your predictions, and possible reasons for those differences.

3. Contact between uncharged conductors in an electric field

Prediction

Consider two uncharged balls, A and B, that are located as shown below in the vicinity of a negatively charged rod. Assume that the balls make momentary contact with one another. **Predict whatever you can about the charge, if any, that each ball will have afterwards.**

- a. Charge the gray PVC rod by rubbing it vigorously with tissue (until you hear crackling!), and then mount it vertically (by itself) in its wooden stand.
- b. **Discharge both balls**, preferably by having each touch the inside bottom of the coulombmeter cup. Then use the coulombmeter ($1.0 \mu\text{F}$) to measure the charge remaining on each; record the results in the table below. Also enter the sum of the charge on the balls.
- c. **Now cause the balls to make momentary contact, as described below and illustrated above.** Note that:
 - i. neither ball should touch the rod!
 - ii. neither ball should get too close to the rod (to avoid having charge “spark” across to the ball!); we suggest a minimum distance of 5 cm or so.
 - iii. to maximize the interesting effect (!), ball B should touch ball A on the far side from the rod (as suggested in the figure above)!



After making contact as described above, measure the final charge on each ball, recording the results in the table below. Again, calculate the sums.

Process	initial charge			final charge		
	Ball A	Ball B	Sum	Ball A	Ball B	Sum
#3, Touching, $E \neq 0$						

- d. Do you have confidence in your results above? ____ If not, what is your concern? _____ You are welcome to repeat your measurements until you have confidence in them, recording your new results in an unused line in the table above.

Questions

Q3. Do your observations agree with your predictions? ____ Describe any significant ways that your observations differ from your predictions, and possible reasons for those differences.

Comment

The process by which the balls became charged without touching the charged rod is yet another example of “**charging by induction**”. Although both balls are initially uncharged, and no charge is added or removed from them collectively, they each gain a net charge when they touch. This happens because of the presence of an electric field, E .

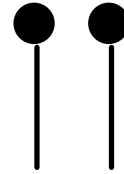
4. Rubbing, frictional contact between two uncharged insulators

Prediction

When you rub the gray PVC rod with tissue and the rod gains a sizable negative charge, from what object(s) does this charge come? _____

If you do not wear the wrist strap, but rather wear a stylish Teflon suit and shoes, describe your net charge after rubbing the rod? _____

First locate the pair of small metal disks (mounted on insulated rods) which have dissimilar plastic pads attached.



disks with plastic pads, mounted on rods

- Discharge both disks**, preferably by having each touch the inside bottom of the coulombmeter cup. Then use the coulombmeter ($1.0 \mu\text{F}$) to measure the charge remaining on each; record the results in the table below. Also enter the sum of the residual charge on the disks.
- Now holding each by its (insulated) rod, rub the disks together, plastic pad to plastic pad.** Do this with some vigor. Then measure the final charge on each disk, recording the results in the table below. Again, calculate the sums.

Process	initial charge			final charge		
	Ball A	Ball B	Sum	Ball A	Ball B	Sum
#4, rubbing disks						

- Do you have confidence in your results above? ____ If not, what is your concern? _____ You are welcome to repeat your measurements until you have confidence in them, recording your new results in an unused line in the table above.

Questions

Q4. Are your observations of the behavior of the disks consistent with the logic of your predictions above? ____

Justify your answer as best you can.

At this point, ask your instructor to **check** your work. You may continue the experiment while waiting for your instructor.



