

## Physics 15b Lab 1: Capacitance (Week of February 25, 2008)

Chapter 1 of Purcell introduces charge and its relationship to electric field fields, with the concept of the electrical potential added in Chapter 2. Chapter 3 states that for any system of  $N$  conductors, there is a unique linear relationship between the charges on a set of  $N$  conductors and the potentials at the surface of those same  $N$  conductors. This concept is the underlying principle of the circuit element known as the capacitor. The capacitor is one of three lumped circuit elements that are used to describe the behavior of electronic circuits. The other two elements are the resistor (Chapter 4) and the inductor (Chapter 7). Real circuit elements are combinations of the [three ideal elements](#).

A capacitor consists of two conductors, where one has a net charge of  $+Q$  and the other has an equal and opposite net charge of  $-Q$ . Given the linear relationship between charge,  $Q$ , and potential (voltage) difference,  $V$ , between the two conductors  $Q$  must be given by  $CV$ , where  $C$  is a constant characteristic of the capacitor.

As discussed in section 3.7 of Purcell, the work done to move free charge onto a capacitor is stored in the capacitor, where one can view the energy as stored in the electric field of the capacitor. In this lab we will consider the relationship between the work done to charge a capacitor and the energy that can subsequently be removed from the capacitor. The energy is removed by creating a conducting path between the two plates of the capacitor that allows the charge to flow between the two plates until both have no net charge.

### Prelab Questions:

Consider an infinite parallel plate capacitor with voltage difference  $V$  and a plate separation  $d$ . If an uncharged point particle is inserted between the plates, what is the force on the particle?

If you insert a charged point particle with charge  $Q$  between the plates, what is the magnitude of the force on the particle assuming that the particle does not significantly affect the  $E$  field between the plates?

If you insert a charged point particle with charge  $Q$  outside of the plates, what is the force on the particle?

For each of the three questions above, please state whether the answer changes if the parallel plates have finite size? If so, explain the reason for the change. You do not need to calculate the actual force.

If you have uncharged plates in an infinite parallel plate capacitor and insert a charged point particle between the plates, will it experience a force? Does the answer depend on the location of the particle?

Will any of the insertions discussed above result in a change in the potential difference between the plates if the capacitor is always connected to a voltage source with a constant voltage  $V$ ?

What is the capacitance of 2 cm diameter sphere in SI units? (Hint: Units conversion information is available in the supplemental information section)

What is the capacitance of parallel plates with separation  $d$  meters and area  $A$  meters squared in SI units?

### Bonus Questions:

If you have an infinite parallel plate capacitor with a voltage difference  $V$  and insert an uncharged conducting sphere with radius  $R$  between the plates, will the sphere experience a net force? Does the answer depend on the location of the sphere?

Draw a sketch of the electric field with the sphere inside the infinite capacitor.

Does the charge to voltage relationship for the parallel plates change when the sphere is inserted? If so, does the capacitance increase or decrease.

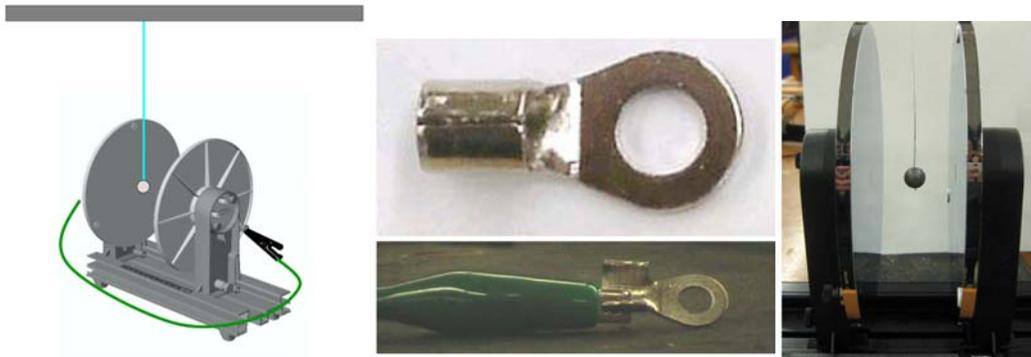
### Lab Goals

1. Increase understanding of the relationship between total charge, net charge, and spatially dependent surface charge on systems of conductors.
2. Illuminate the connection between stored charge, work, and energy in systems of conductors.
3. Highlight instances in which real world capacitors differ from ideal capacitors
4. Illustrate effects of measuring apparatus on experimentally determined values.
5. Provide an opportunity to learn about and use test equipment.

### 1. Charges, electric fields, and conductors

**Goal: Determine the behavior of a charged particle suspended between the plates of a parallel plate capacitor as a function of the plate separation and the separation of the sphere from a plate when there is no potential difference between the plates.**

- a. Materials: 1 small metal sphere on a string attached to a post; parallel plate capacitor; fur; PVC pipe; jumper cables with alligator clips



Connect the two capacitor plates by attaching alligator clips to the electrical connector on each of the plates, as shown in the figure at left above where the green shows the wire connection. Attach the alligator clips using the ring connectors that are shown in the center above, where the ring is located under the screw and the end of the connector is open allowing the alligator clip to be firmly attached. Separate the plates by 6 cm. What is the voltage difference between the plates? Charge the metal sphere by rubbing fur on the PVC pipe and then touching the sphere to the PVC pipe. Hang the sphere on the string so the sphere is at the center

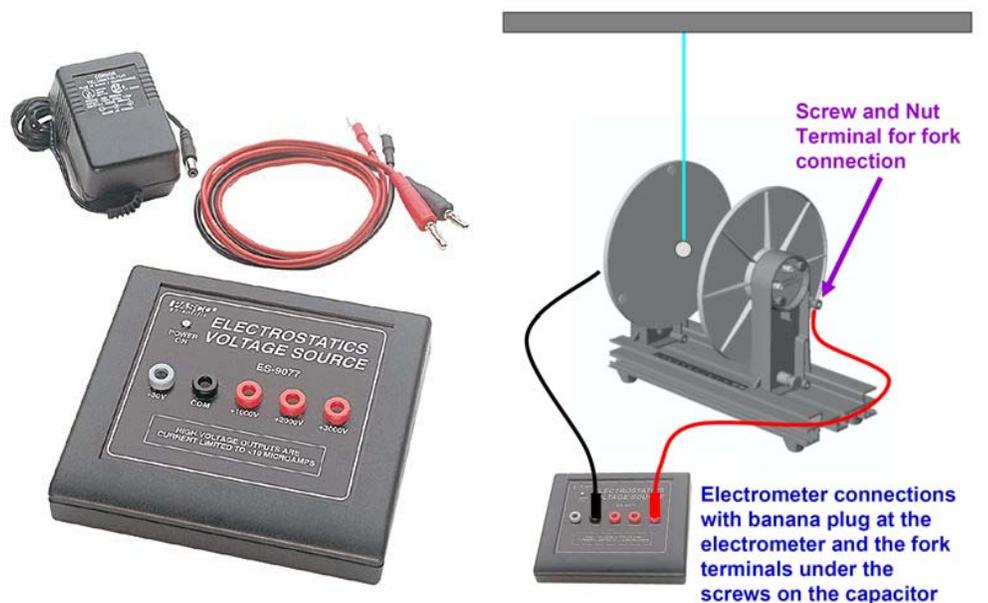
of the capacitor as shown in the figure at right above. What is the voltage difference between the plates? Slide the sphere toward one plate. What happens? Repeat the experiment, but move it toward the other plate. Explain your result. In some cases, the attraction is strong enough to make the sphere touch the plate. Does the result in a transfer of charge from the sphere to the plate?

Bonus: Why doesn't the force become repulsive if the plate and the sphere have a net charge with the same sign? What does that imply about the relative capacitance of the sphere and the parallel plates?

Find the charge on the sphere using the comparison with gravity given that the mass of the sphere is 0.12 g

**Goal: Determine the behavior of an uncharged conducting sphere suspended between the plates of a parallel plate capacitor as a function of the plate separation and the separation of the sphere from a plate when there is a large potential difference between the plates.**

- b. Materials: 1 small metal sphere on a string attached to a post; parallel plate capacitor; electrostatic voltage source



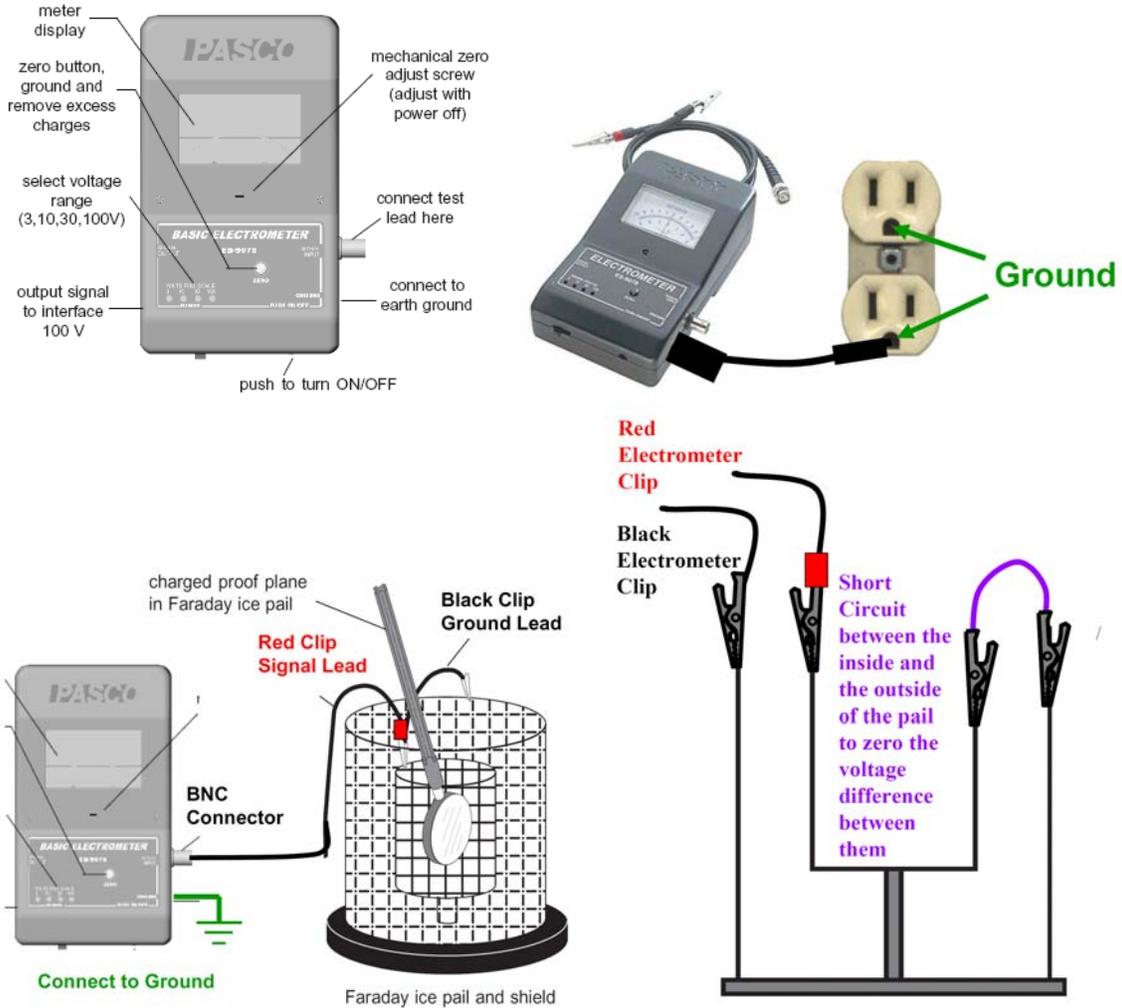
The electrostatic voltage source has 5 [banana jacks](#) on its front, as shown above left. The three red ones are labeled +3000V, +1000V, and +100V, and the gray one is labeled +30 V. This voltage labels represent the potential difference between labeled terminal and the ground, which is potential of the black jack labeled com, for common ground. The electrometer comes with two cables, one red and one black. Each has a banana plug connector on one end that can be inserted into the banana jacks on the electrometer. The other end of each cable is a two prong fork connector. A [banana plug](#) and [fork connector](#) are shown in the image above right. Banana plug connections are made by pressing the plug into the jack. The [forks](#) are attached by loosening the nut to create a space, inserting the fork, and tightening the nut to hold the fork in place.

Make sure the voltage source is off. Connect the two screw terminals to the cables with the banana plugs connected to the com and +3000 volt plugs on the electrostatic voltage source, as shown in the schematic on the right above. Do **NOT** turn on the voltage source. Discharge the sphere by touching it to the ground. Separate the plates by 1 cm. Hang the small metallic sphere on the string inside the capacitor plates so that it is centered on the plates. Does the sphere have a net charge? Wait for the sphere to stop moving, then turn on the voltage source. Why does the sphere move initially? Why does the sphere keep moving? In the absence of damping, would the sphere keep moving forever if the voltage source remains connected? If not, why would it stop? In the absence of damping, would the sphere keep moving forever if the voltage source is disconnected? If not, why would it stop?

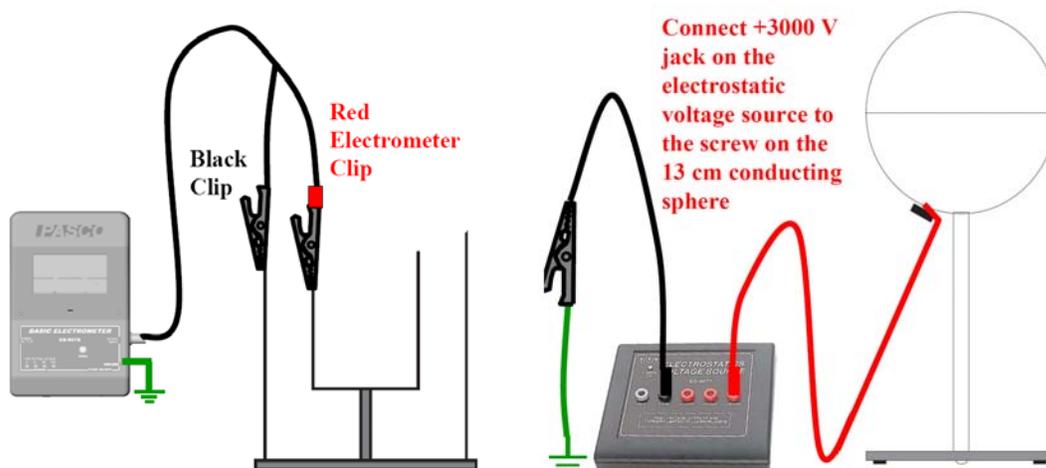
## 2. Capacitance

**Goal: Experimentally determine the capacitance of a sphere and study the redistribution of charges in conductors when physical contact between the conductors is created and removed.**

- a. Materials: 3 conducting spheres (15 cm diameter, 5 cm diameter, 5 mm diameter) ; Faraday pail; electrometer; electrostatic voltage source; proof plane; electrometer; parallel plate capacitor; 2 jumper cables with alligator clips



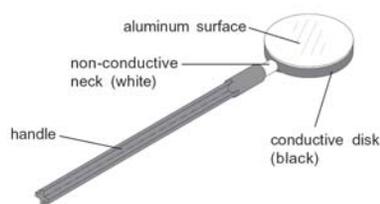
Your electrometer/charge pail combination is labeled with a conversion from voltage to charge. It is approximately  $0.13 \text{ nC/V}$ . The electrometer is shown in the first line above where the schematic shows the connections and the image at right shows a photograph including the [BNC](#) cable with the red and black clips and the banana plug connection of the electrometer ground to earth ground. The charge pail/electrometer combination is illustrated in the left center diagram. **DO NOT INSERT THE PROOF PLANE YET.** Attach the electrometer so that the black clip is attached to the outside of the pail and the red clip is attached to the inside of the pail as shown in the illustration.. If you put a charge inside the pail, but not touching it, then the charge will be equal to the voltage shown on the on the electrometer meter times a conversion factor. While keeping the electrometer connected, short the pail to the shield using a wire connected by alligator clips. This is shown as the purple line in the center right diagram. Use a second wire connected by alligator clips so short the combination to ground. This is shown by the green line in the same diagram. Press the zero button on the electrometer. Remove all of the shorts (the connections shown by the purple and green lines), but continue to leave the electrometer connected as shown in the diagram below left.



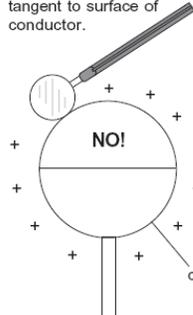
Charge the 13 cm sphere to 3000 V using the electrostatic voltage source shown in the image at right above. Insert the red lead into the +3000 V terminal, and the black lead into the black common ground terminal, labeled com. Connect the pronged end of the red lead to the sphere using the attached screw, as shown above. Connect the black pronged fork to ground. Use of other leads may allow significant leakage from the leads to ground and negatively affect output voltage accuracy. What is the expected charge density on the surface of the sphere? The charge on the sphere will be measured using a “proof plane. The proof plane is conducting disk on an insulating neck that is shown in the illustrating at the bottom left. The conductive disk material is carbon-filled black polycarbonate (about  $10^3$  Ohms) with an aluminum disk. The nonconductive neck is white polycarbonate (about  $10^{14}$  Ohms). Place the proof plane so its surface is parallel to and in contact with the surface of the sphere as shown in the bottom right figure above.

### The Proof Plane

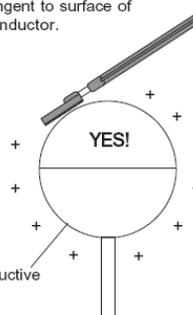
The proof plane is an aluminum-covered conductive disk attached to an insulated handle. It is used to sample the charge density on charged conductive surfaces.



Proof plane disk IS NOT tangent to surface of conductor.



Proof plane disk IS tangent to surface of conductor.



Why is the charge density on the proof plane the same as that on the sphere? Remove the proof plane. Did removing the proof plane change the surface charge distribution on the proof plane? Did removing the proof plane change the surface charge distribution on the sphere? Put the proof plane in the pail without touching

the sides. Find the total charge on the proof plane. Find the charge on the sphere. What is the capacitance of the sphere? Bonus: repeat with the 5 cm diameter sphere and the 5 mm sphere. How well does your measured capacitance match your actual capacitance? Try the same experiment with the truth plane perpendicular to the surface of the sphere.

**Goal: Study the redistribution of charges in conductors not in physical contact**

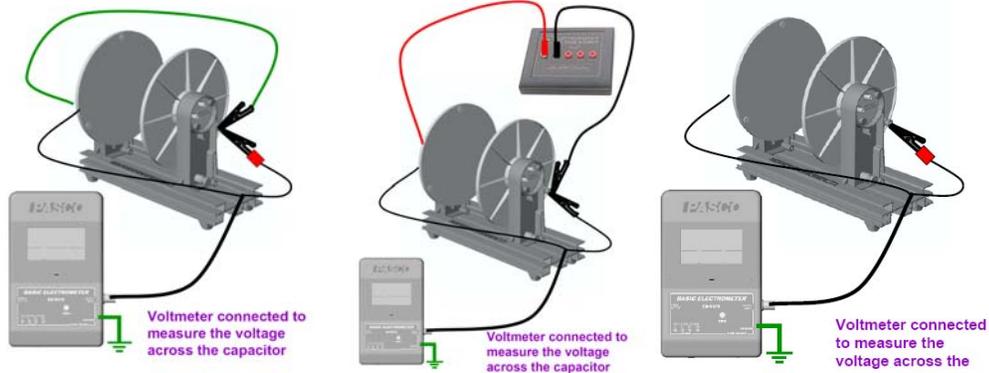
Materials: Faraday pail; electrometer; electrostatic voltage source; proof plane; electrometer; 15 cm sphere

Ground the proof plane and check that it has no net charge by inserting it in the Faraday pail. Charge the sphere to 3000V. Place the proof plane within 5 mm of the surface of the sphere. Test its charge in the Faraday pail. Repeat the experiment, but ground the proof plane by connecting it to ground using a jumper cable with alligator clips when it is within 5 mm of the surface of the sphere, then remove the ground. Test the charge on the proof plane. Explain your result.

### 3. Relationship between work and the energy stored in a capacitor

**Goal: Demonstrate that energy is stored when a capacitor is charged and study the efficiency of cycles that transfer mechanical energy to electrical energy and back.**

- a. Materials 1 PASCO parallel plate capacitor; 1 electrometer; 1 battery; current and voltage monitor



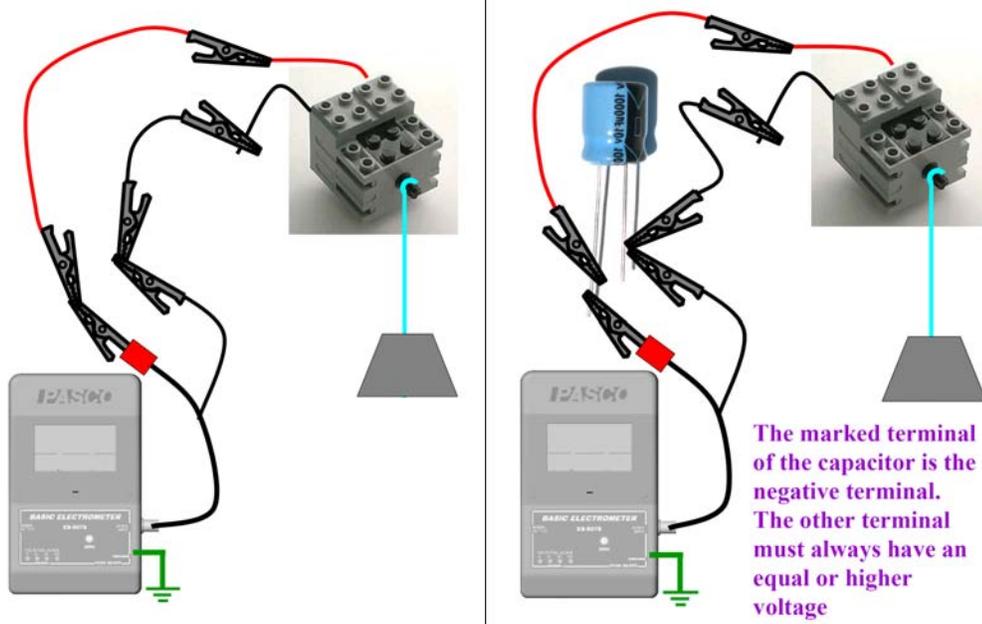
Separate the capacitor plates by 4 cm. Connect the two plates of the capacitor to each other using alligator clips and connect the electrometer to measure the voltage across the plates while keeping jumper connected between the plates as shown in the diagram at the left above. Choose the 30 V scale on the electrometer. Hit the zero button on the electrometer. Disconnect the alligator clips that attach the two plates of the capacitor together. This connection is illustrated by the green wire in the diagram on the left above. Make sure the electrostatic voltage source is off. Connect the electrostatic voltage source to the capacitor such that one plate of the capacitor is connected to the common terminal and the other plate is connected to the 30 V jack as shown in the central figure above. Make sure the red wire from the electrostatic voltage source is connected to the same terminal as the red alligator clip from the electrometer. After the connections are made, turn the electrostatic voltage source on. Allow the

capacitor to charge until the potential difference across the capacitor is the same as the 30 V electrostatic source voltage. What is the energy stored on the capacitor? Disconnect the battery, but leave the electrometer connected, as shown in the figure at the right above. Measure the voltage difference between the plates as the plates are moved to lower the separation to 1mm. Does the voltage change with distance? Does the charge density change with distance? Does is the energy stored in the capacitor change with distance? Does this violate energy conservation? Pull the plates back apart until they are again separated by 4 cm. How does the voltage difference compare to the initial voltage difference and the voltage difference for the 1 mm separation. Use the voltage difference for a 1mm plate separation and the voltage difference for a 1 cm plate separation to calculate the ratio of the capacitance for a 1 mm separation to the capacitance for a 1 cm separation. Is this ratio what you would expect theoretically? Separate the plate by 4 cm and reconnect the voltage source. Keep the voltage source connected and change the plate distance from 4 cm to 1 mm and back to 4 cm again. Does the voltage change with distance? Does the charge density change with distance? Does is the energy stored in the capacitor change with distance? Does this violate energy conservation? How could you measure the distance between capacitor plates using only an electrometer?

b. Materials: 1 motor/ generator; 1 Farad. capacitor; 1 weight; electrometer; jumper cables with alligator clips

DC electrical motors do work when a voltage difference is applied across their terminals. The same device can function as an electrical generator: if work is done to make the shaft of the motor rotate creates a potential difference across the leads of the motor. Many alternate energy systems, such as hybrid cars, transfer electrical energy to mechanical energy and then back to electrical energy. In this lab, you will consider the transfer of gravitational energy to electrical energy and then back to gravitational energy. The gravitational energy stored in a weight a distance  $h$  above the floor can be converted to electrical energy by allowing the weight to drop and using a string attached to the weight to turn a generator that charges a capacitor. The 1 Farad capacitor used in this experiment is polar, which means that terminal marked with the dark line must be maintained at a voltage that is lower than or equal to the voltage of the other terminal. In order to avoid accidents, please setup the apparatus as shown on the left below to check that the polarity of your apparatus is correct. Wind the string clockwise until the weight holder is at the top. Put the 0.5 kg weight on the holder and let it fall under gravity. The voltage on the electrometer should become positive as the weight falls, but should not remain positive for long. If the voltage on the electrometer was positive, wind the shaft clockwise until the weight holder is at the top. If the voltage was negative, wind the shaft counterclockwise until the weight holder is at the top. Hang the weight holder from the shaft and zero the capacitor and the electrometer. Allow the 0.5 kg weight to fall to the ground, and read electrometer voltage as the weight falls. When the weight gets to the ground, remove the 0.5 kg weight. The energy stored in the capacitor should be sufficient to lift the weight holder back up to the top. How efficient is the conversion of electrical energy stored in the capacitor to mechanical energy? Disconnect the

capacitor and allow the weight to fall again with a sand bucket placed to catch the falling weight. How does the rate at which the weight falls with the capacitor attached compare to the rate at which it falls without the capacitor.

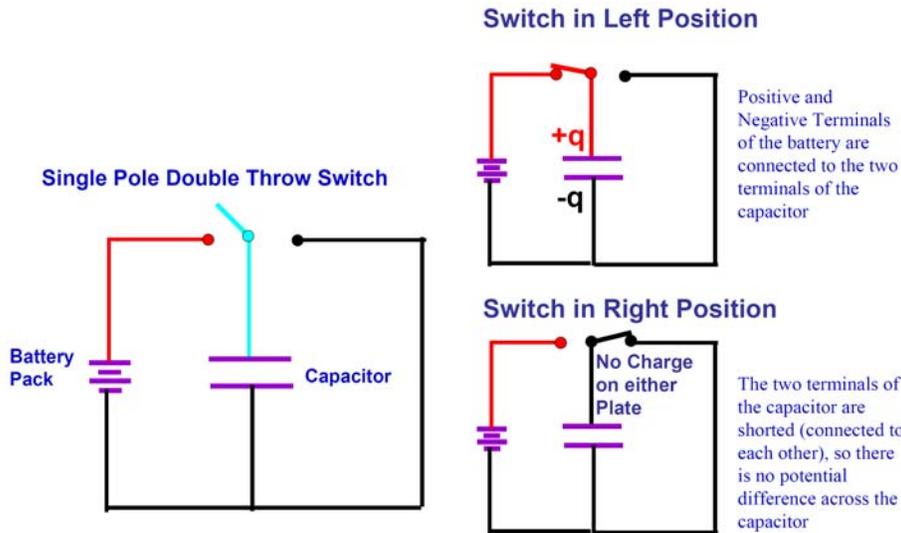


#### 4. Capacitors Leak

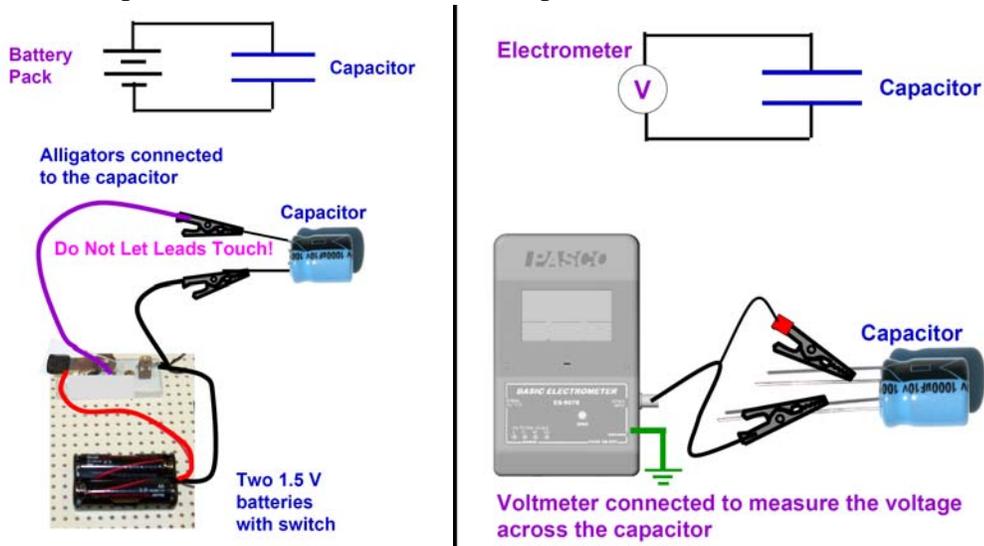
One of the biggest problems with DRAM computer memory is that the memory capacitors lose their stored voltage very rapidly. As a result, the charge has to be restored many times a second. This constant replacement of charge consumes a good deal of energy, and considerable effort is being expended trying to develop alternate memory systems that consume less energy

**Goal: Study differences between real and ideal capacitors.**

Materials: electrolytic 10 microfarad capacitor marked with black tape, 1 voltage monitor, 3V battery pack with switch; jumper cables with alligator clips



For this experiment you will use a single pole double throw switch and a 3V battery pack to charge and discharge a capacitor. A schematic of the circuit is shown on the left above. The wire connected to the positive terminal of the battery is shown in red. The wires connected to the negative terminal of the battery are shown in black. The center connection on the switch is connected to the top plate of the capacitor. The switch is shown in the open position, where the central terminal of the switch it is not connected to anything. The two images on the right above show the circuits that results when the switch is connected. When the switch is connected to the left, the battery is connected in parallel with the capacitor, so the voltage across the battery is the same as the voltage across the capacitor. When switch is connect on the right side, it connects the top of the capacitor to the bottom of the capacitor, shorting it out. This makes the potential difference across the capacitor zero.



Charge a 10 microfarad electrolytic capacitor to 3 V by connecting the capacitor to the electrostatic voltage source as shown above left, where the

circuit schematic is shown above the image. Make sure that the negative terminal on the capacitor is attached to the black wire coming from the battery pack. Remove the alligator clips that connect the capacitor to the voltage source. Measure the voltage across the capacitor using an electrometer where the red electrometer lead is connected to the positively charged side of the capacitor. Immediately disconnect the electrometer. Wait 3 minutes. Measure the voltage across the capacitor at the end of 3 minutes. Where did the charge that was on the capacitor go? Repeat the measurement with the electrometer connected during all three minutes. Is there a significant difference? Bonus: Try with a yellow mylar cap and a 10 microfarad low leakage electrolytic cap (no black tape), 10 microfarad low leakage cap poled in reverse

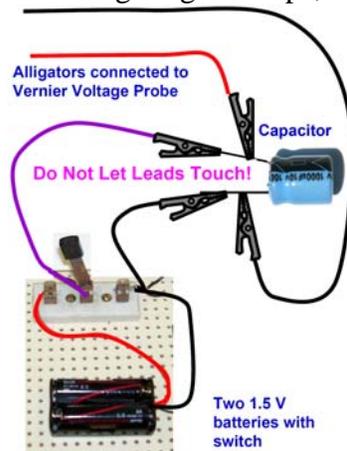
### 5. Making measurements changes the experiment.

In quantum mechanics there is a great emphasis on how measurements change the system being measured. In classical mechanics measurements can also change the system, though the origin of the change is different.

**Goal: Study effect of measuring apparatus on quantities being measured while the measurement is being made.**

- a. Materials low leakage 10 microfarad capacitor with no black tape, 3 Volt battery pack with single pole double throw switch, 1 vernier voltage monitor; jumper cables with alligator clips

For this experiment, you will use the vernier voltage monitor that measures the voltage and sends the voltage as a function of time to the computer where it is recorded in LoggerPro. The connections to the vernier voltage monitor are made using alligator clips, as shown below.



The negative terminal of the battery pack is connected to the right side of the switch, and the positive terminal of the battery pack is connected to the left side of the switch. Zero the capacitor using the switch, then move the switch to the other position to charge the capacitor to the 3V potential of the battery pack. Open LoggerPro. Set the time scale of the window so that the window shows 60 seconds of data acquisition. The voltage difference across the two alligator leads should appear in the window.

Once you see the voltage, move the switch so that it is in the central position so that the upper plate of the capacitor has no connection to the battery pack. Start data acquisition in LoggerPro and measure the voltage across the capacitor as a function of time for 1 minute using LoggerPro. It should appear as a plot on the screen. Replot the result on a semi-log scale with a logarithmic y axis and a linear x axis. Repeat the experiment, but remove the voltage probe after it has monitored the voltage for 15 seconds. Reconnect the probe again after another 15 seconds. What is the effect of connecting the vernier voltage probe to the capacitor? Bonus: Use the apparatus to find the resistance across one of your fingers. Draw the circuit schematic for the apparatus shown in the diagram above.

**Bonus: Goal: Study of the effect of changes in results due to interactions with the test equipment that are made to the test equipment between measurements.**

b. Materials: parallel plate capacitor, electrostatic voltage source, electrometer

Charge the parallel plate capacitor to 30 V using the electrostatic voltage source with the electrometer connected, as shown in the central image of the figure at the beginning of question 3. Monitor the voltage for 3 minutes. Remove the connection to the voltage source as shown in the far left image in the same figure. Disconnect the electrometer, connect the electrometer leads together, and zero the electrometer. Measure the potential difference across the parallel plate capacitor again. Explain your result and how it differs from the result in part a.

### Challenge Problems:

1. Determine the charge to voltage ratio of the setups used in part 1.
2. Verify Coulomb's Law
3. Blow the biggest fuse using 1 battery and up to 3 capacitors, any number of resistors. Compare with the result using just a battery.
4. Use the energy stored in up to 3 capacitors charged using the battery pack to light a light bulb so that it produces in volts on a photodetector for at least 10 minutes, compare with the result using just the battery.
5. Use energy stored in up to 3 capacitors charged using the battery pack to lift a given weight to the largest height. Compare with the result using just a battery. Do the same comparison, but the with goal of making the initial weight rise the most rapid.
6. Design a zero gravity pendulum clock using a capacitor and explain how you will control the period.

### 7. Theory Challenge:

- a. If a capacitor has no voltage across the plates at time  $t=0$  and the plates are not connected to any circuit, the capacitor will eventually acquire a voltage  $V$ . This "spontaneous" charging has caused significant injuries,

and as a result large capacitors are always stored with their plates connected by conducting strip. This effect also puts limitations on the possible size decrease in computer memory capacitance. What is the size and origin of this “spontaneous” voltage? What are methods of reducing the final voltage or the rate at which the capacitor charges?

- b. What is the capacitance of two metallic spheres that occupy separate volumes?

## Supplemental Information

Capacitors are ubiquitous in modern electronic circuits. You probably own more than a billion capacitors. The fast memory elements in computers (DRAM) are capacitors, where each memory element consists of an individual capacitor. One of the problems with DRAM is that the capacitors leak, so that the charge on the capacitor disappears in a time much shorter than a second.

[http://en.wikipedia.org/wiki/Dynamic\\_random\\_access\\_memory](http://en.wikipedia.org/wiki/Dynamic_random_access_memory)

Thus, in order to keep values stored in memory the stored values must be read and refreshed constantly. This uses a great deal of energy, so much research is going into memory that does not need to be refreshed as often. Capacitors are also used to smooth out unwanted variations in voltage. They play a crucial role in changing the time varying voltage that emerges from the wall plug, to the time independent voltages used by many electronic devices. <http://hyperphysics.phy-astr.gsu.edu/Hbase/electronic/rectbr.html> The rate at which charge can be added or subtracted from a capacitor is very well defined, so capacitors play key roles in timers and clocks. They are also used as filters to remove undesired low or high frequency noise from a signal, and to tune the frequency of radio receivers. Capacitors are also used in touch screen devices like the i-Phone to determine the location of your finger on the screen.

<http://electronics.howstuffworks.com/iphone.htm/printable> Capacitors play a vital role in distance measurement, where they can accurately measure distances as small as a few atom diameters.

[http://www.physikinstrumente.com/en/products/nanopositioning/nanopositioning\\_basics.php](http://www.physikinstrumente.com/en/products/nanopositioning/nanopositioning_basics.php) Finally, capacitors can be used to store energy or charge. They have long been used in devices where energy must be delivered very rapidly. For example, they are used to power camera flashes where relatively long charging time (~ 1 second ) is required to charge a capacitor that then releases the charge in a much shorter time.

<http://electronics.howstuffworks.com/camera-flash1.htm> They are also used in the famous Z pinch experiment at Sandia National Laboratory where researchers are trying to create fusion by briefly creating matter at high temperatures and pressures that approach conditions inside the sun. It releases 290 terawatts, which is 80 times the world's electrical power output for a few billionths of a second. <http://zpinch.sandia.gov/> There has also been great recent progress in developing “supercapacitors” to help solve one of the big issues with many renewable energy sources such as wind and solar: the energy is not produced constantly, and is often not being produced precisely during the time when the need for it is largest. <http://www.batteryuniversity.com/partone-8.htm>

<http://en.wikipedia.org/wiki/Supercapacitor> Thus, it is important to have some method of storing the energy when it is generated, so it can be used when it is needed.

Supercapacitors can also store the energy generated by regenerative braking that converts the energy required to stop a car or truck into electrical power, rather than wasting it in heat as conventional brakes do. [http://en.wikipedia.org/wiki/Regenerative\\_brake](http://en.wikipedia.org/wiki/Regenerative_brake)

[http://www.hybridsynergydrive.com/en/regenerative\\_braking.html](http://www.hybridsynergydrive.com/en/regenerative_braking.html) One of the purposes of this lab is to compare the energy storage and delivery properties of rechargeable batteries to those of capacitors. Capacitance is also a fundamental property of devices not normally called capacitors, such as photodiodes, solar cells, transistors, and electrical cables. Biological systems also feature double layer charge storage devices such as cell

membranes that have a 70 mV potential drop across a 20 nm spacing giving a capacitance of approximately  $8.8 \times 10^{-3} \text{ F/m}^2$ .

[http://www.lib.mcg.edu/edu/eshuphysio/program/section1/1ch1/s1ch1\\_27.htm](http://www.lib.mcg.edu/edu/eshuphysio/program/section1/1ch1/s1ch1_27.htm)

[http://www.guidolivolsi.it/Membrane\\_Potential.pdf](http://www.guidolivolsi.it/Membrane_Potential.pdf)

[http://www.mbi.osu.edu/eduprograms/2004ppts/mbi\\_summer\\_volume\\_HH2.ppt](http://www.mbi.osu.edu/eduprograms/2004ppts/mbi_summer_volume_HH2.ppt) A nice historical overview and introduction to capacitance is available at

<http://www.uoguelph.ca/~antoon/gadgets/caps/caps.html>

## Units Conversion Between SI and CGS

Dimension	Unit	Definition	SI
charge	electrostatic unit of charge, franklin, statcoulomb	$1 \text{ esu} = 1 \text{ statC} = 1 \text{ Fr} = \sqrt{(g \cdot \text{cm}^3/\text{s}^2)}$	$= 3.33564 \times 10^{-10} \text{ C}$
electric current	biot	$1 \text{ esu/s}$	$= 3.33564 \times 10^{-10} \text{ C/s}$
electric potential	statvolt	$1 \text{ statV} = 1 \text{ erg/esu}$	$= 299.792458 \text{ V}$
electric field		$1 \text{ statV/cm} = 1 \text{ dyn/esu}$	$= 2.99792458 \times 10^4 \text{ V/m}$
magnetic field strength H	oersted	$1 \text{ Oe}$	$= 1000/(4\pi) \text{ A/m} = 79.577 \text{ A/m}$
magnetic flux	maxwell	$1 \text{ Mw} = 1 \text{ G} \cdot \text{cm}^2$	$= 10^{-8} \text{ Wb}$
magnetic induction B	gauss	$1 \text{ G} = 1 \text{ Mw/cm}^2$	$= 10^{-4} \text{ T}$
resistance		$1 \text{ s/cm}$	$= 8.988 \times 10^{11} \Omega$
resistivity		$1 \text{ s}$	$= 8.988 \times 10^9 \Omega \cdot \text{m}$
capacitance		$1 \text{ cm}$	$= 1.113 \times 10^{-12} \text{ F}$
inductance		statH	$= 8.988 \times 10^{11} \text{ H}$
wavenumber	kayser	$1 / \text{cm}$	$= 100 / \text{m}$

From Wikipedia.

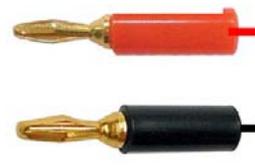
## Apparatus Information



Alligator Clips



Banana Jack



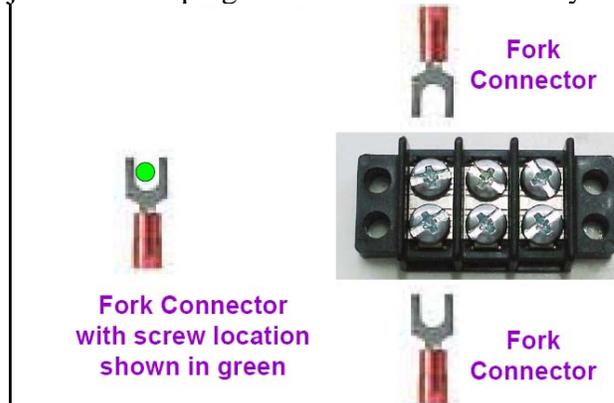
Banana plugs

### Alligator Clips

Alligator clips are shown in the image at left above. The rubber insulation is pulled back from the black wire to show the complete alligator clip. Jumper wires with "alligator" style spring clips at each end provide a safe and convenient method of quickly and temporarily electrically joining components together. The connection is made by pressing on the back of the clip to open the jaws, placing the jaws over the conductor to which the connection is to be made, and then releasing the back of the clip to allow the jaws to close. Note: to make a connection the alligator clips need to be connected directly to a metallic surface, attaching the alligator clip to the rubber insulation on a wire will not make a connection.

### Banana Plugs

Banana plugs are shown in the image on the right above. They are used to make rapid temporary connections. The connection is made by simply inserting the plug into the jack. Banana plugs are often used in audio systems.

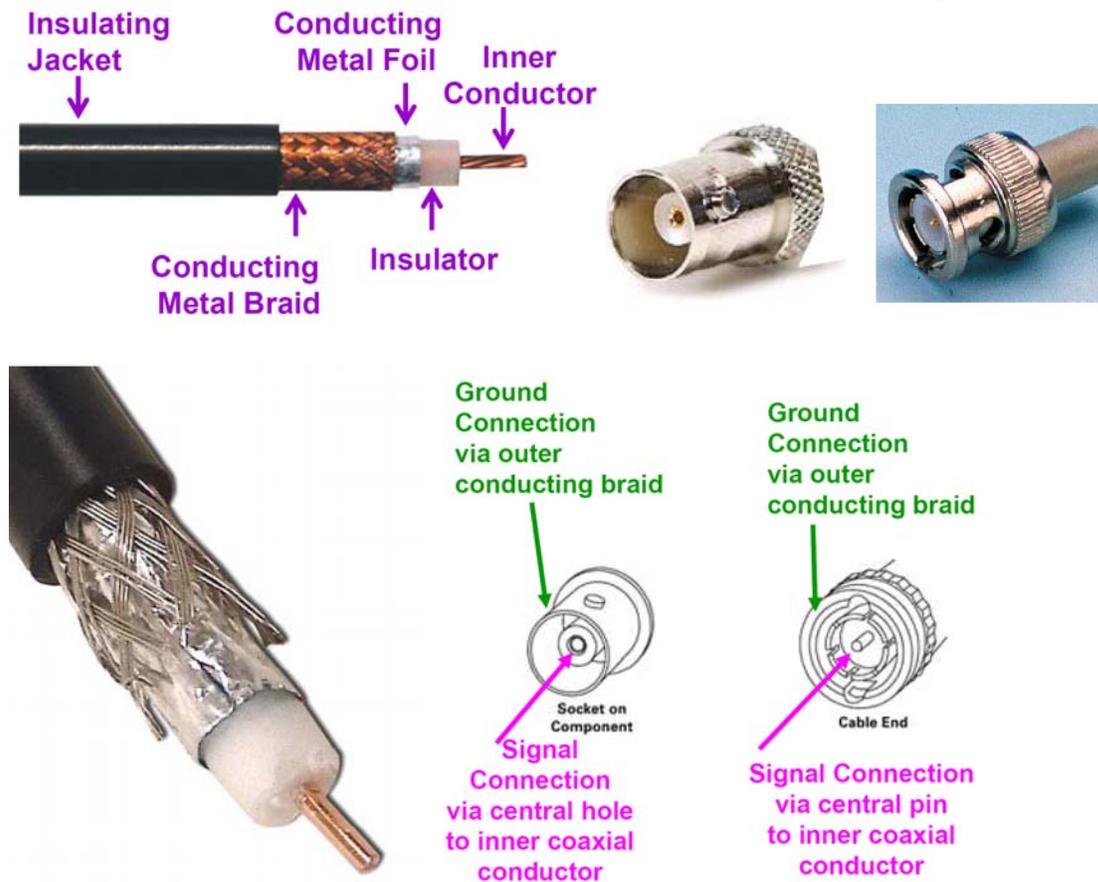


### Fork Connectors

Fork connectors are used to form strong temporary electrical connections, and are frequently used in terminal blocks that consist of pairs of screws joined by a conductor, as shown in the image above right. Fork connectors require more time to connect than banana plugs. The connection is made by loosening the screw, inserting the fork connector under it with the fork centered on the screw, and then tightening the screw to hold the fork in place. In 15b the fork connectors are used with the screw and nut connectors on the conducting spheres and the plates of the parallel plate capacitor.

## BNC Connectors

The connector was named after its bayonet mount locking mechanism and its two inventors, Paul Neill of Bell Labs (inventor of the N connector) and Amphenol engineer Carl Concelman (inventor of the C connector). Thus BNC stand for Bayonet Neill Concelman. BNC connectors are linked by BNC cables. BNC cables are coaxial cables. [http://en.wikipedia.org/wiki/Coaxial\\_cable](http://en.wikipedia.org/wiki/Coaxial_cable) They consist of a central conductor that is surrounded by an insulator, which is in turn surrounded by a second outer conducting layer that shares the same axis as the central conductor as shown below. The voltage at the input or output of a BNC connection is the potential difference between the inner conductor and the outer conductor, where the outer conductor is usually grounded.



<http://tara-labs-info.com/cable-technology-glossary.html>

In the image on the left above the foil has been bent back and the braided metal braid has been separated to show that it consists of many very small flexible wires that are collected into strands and then braided. A BNC jack is shown in the images in the center of the figure above, and the BNC connectors at the ends of cables are shown on the right. The connections between the cables and the connectors are illustrated in the schematic. The connector is attached to the jack by pressing them together, rotating the connector clockwise until the connector slips over the jack, then rotating clockwise by another quarter turn to lock the connector in place. To undo a BNC connection, gently press in and rotate  $\frac{1}{4}$  turn counterclockwise, then pull back to separate the connectors.

