

I. Before you come to lab

- Read through this handout in its entirety

II. Learning Objectives

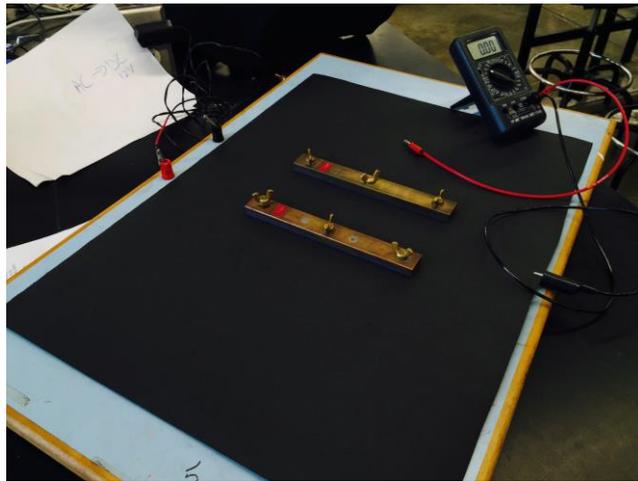
As a result of performing this lab, you will be able to:

1. measure an unknown capacitance by connecting it in parallel to a known capacitance and a voltage sensor;
2. explain why the human body can act as a capacitor;
3. measure equipotential contour lines and make predictions about equipotential contour lines given the shape of the electrodes

III. Materials

Potential plotting board

1. This is just a board with two rows of screw holes which are electrically connected to the terminals at the edge of the board.
2. Screwing an electrode tightly into one of the holes will create an electrical contact that will maintain the electrode at the terminal voltage.
3. Another way of attaching an electrode is by placing a piece of conducting tape on the sheet and connecting it to an external power supply using alligator clip leads.



Conductive paper

1. This is a sheet of carbon paper which is slightly conducting. Unlike metal, the sheet itself is not a good conductor that is at the same voltage everywhere. Rather, the presence of electrodes held at fixed potentials not the sheet will cause a distribution of voltages and fields all over the sheet, which can then be probed using a digital voltmeter.
2. The two sides of the sheet are not identical. To make sure you are working on the correct side, place the sheet on the equipotential board so that the edges of the paper curl upwards. The side you will be working on is the less glossy, more matte black side.
3. Try to handle the sheet as little as possible, and only around the edges. While you are making a voltage measurement, you can touch the paper lightly but do not rest your weight on it, as that could distort the electric potential on the paper.

Digital Multimeter

1. The multimeter is the tool you will be using to measure voltages. There are several settings on the dial; the one you will be using is the setting that says V with a pair of straight lines (not V with a wavy line, which is used to measure oscillating voltages).
2. Depending on the model for multimeter, you may also have to set the range of the instrument. For the purposes of this lab, you should use the 20-volt setting.
3. The multimeter probes must both be in contact with something in order to get a reading. The digital readout will indicate the voltage of the red probe minus the voltage of the black probe.
4. This is a general convention for electric components: red terminals and leads are considered "positive" and black ones "negative". For a meter, nothing bad will happen if you reverse the two -- you will just get a negative reading if you put the red probe at a lower voltage than the black probe.
5. If your probes are disconnected or you are switching probes, make sure to plug the red probe into the jack labeled "V Ω " and the black probe into the jack labeled "COM".

Equipotential Contours and Capacitance

DC power supply

1. This supply will maintain a constant voltage between terminals. The red terminal is held at a higher voltage than the black terminal, in accordance with the usual color convention. The potential difference between the terminals is 12 V.

Electrodes (either two rectangles or two circles)

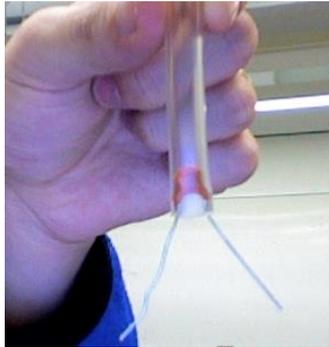
1. These are metal conducting blocks with screw holes.
2. To achieve the best electrical contact with the paper, place the side with raised edges facing down. Also, you may want to rub that side down with steel wool to make sure it is clean.

White and red pencils and crayons

1. These pencils will make non-conductive marks on the paper, unlike a regular lead pencil. Use them to draw equipotential contours.

Capacitor $C_1 = 100 \text{ pF}$

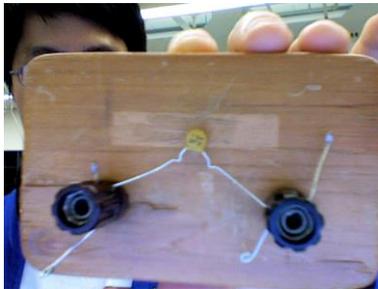
This capacitor is the one which is stuck in a little plastic sheath:



This is so that you can handle it without accidentally discharging it through your fingers.

Capacitor $C_2 = 0.11 \text{ } \mu\text{F}$

This is a relatively large capacitor connected across a pair of banana plug sockets on a wooden board:

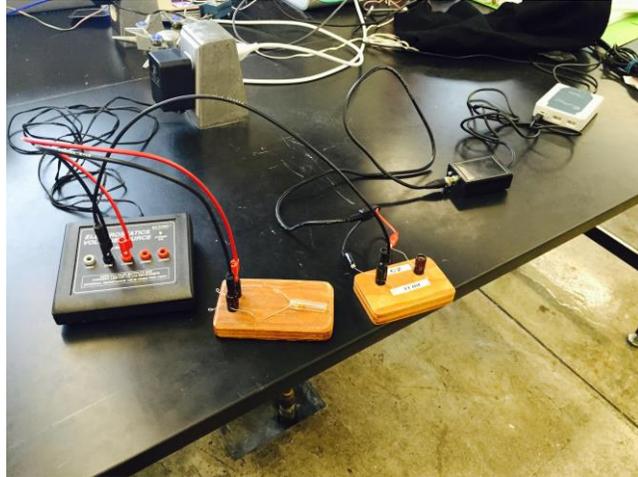


You will use this capacitor in conjunction with the charge sensor (see below). **Do not connect this capacitor directly across the high-voltage power supply!** It was not designed to handle high voltages.

High-voltage power supply (HVPS)

This is a DC power supply (the black box on the left of this picture). It maintains a very large voltage across its terminals; however, the current that it can supply is limited to under $10\ \mu\text{A}$ (for safety reasons).

The black cable plugged into the "COM" terminal of the HVPS is connected to the building ground (and thence to the actual Earth itself). The red cable can be plugged into any of the three terminals marked 1000 V, 2000 V, or 3000 V (or also to the +30 V, but that would be boring—kilovolts are *so* much more interesting) depending on which voltage you need.



If you plug the red banana cable into the 3000 V terminal, anything you bring into electrical contact with the red plug will be brought to 3 kV above ground. Likewise, to ground something (bring its potential down to zero), just touch it to the black plug in the COM terminal.

Charge sensor

This is another probe that connects to the LabPro interface and can be used to input data into Logger Pro.



It acts almost exactly like the differential voltage probe, except that its "internal resistance" is much higher, so that it won't discharge a capacitor while you are trying to measure its voltage. The downside is that the charge sensor has an internal time constant of 0.1 s, so you can't use it to measure anything that changes more rapidly than that.

Zeroing the charge sensor is slightly different from zeroing the differential voltage probe. First, touch the leads of the charge sensor together. Then, while they are connected, press the button located on the charge sensor itself (not a software button in Logger Pro) and hold for about a second to zero. Now you can disconnect the leads and measure something.

The charge sensor has three settings, controlled by a switch on the box. You should use the setting marked $\pm 10\ \text{V}$. Even on this setting the sensor is limited to about $\pm 9\ \text{V}$. If you attempt to put more than 9 V across it, it will saturate. If this happens, be sure to zero the charge sensor before attempting to make another measurement.

The reason that this object is called a "charge sensor" rather than just a voltmeter is that it is intended to be connected across a large capacitor of known capacitance (in this case, $C_2 = 0.11\ \mu\text{F}$). By measuring the voltage across the capacitor, you can calculate how much charge is on it.

The charge sensor should always be used in conjunction with C_2 (and vice versa). Just as C_2 is not intended

Equipotential Contours and Capacitance

to support high voltages, neither is the charge sensor. Try not to put more than 10 volts across it.

V. Procedure

Who are you? (group picture, full names, and emails please)

A:

Part 1: Equipotential contours (1 hour)

In this part of the lab, you will use a multimeter probe to **map out equipotential contours around a pair of electrodes on a sheet of conducting paper.**

1. Set up your potential plotting board and carbon conductive paper as described in the Materials section. Remember to place the correct side of the sheet facing up.
2. Place two electrodes on your paper and bolt them into the board tightly. Use either two small circles or two long bars, so that you get one of the configurations you made predictions for in the warm up exercise. If you are using the long bars, each bar should be attached with two bolts, one at either end of the bar.
3. Connect the red and black terminals of the board to the DC power supply. Connect the power supply to the electrical outlet.
4. Using an alligator clip lead, connect the black terminal of the multimeter to the edge of the conducting paper, halfway between the terminals of the board, as in the picture below:



5. Using the red probe of the multimeter, measure the voltage of the positive and negative terminals of the board relative to the point halfway in between them where you clipped the alligator lead. Adjust the position of the alligator clip until you get approximately equal magnitude with opposite sign values for the voltage on the terminals.
6. Move the red probe around the sheet of paper to explore the electric potential on the sheet. Make sure the probe is in contact with the sheet, but you do not need to press it very hard (the weight of the probe itself is usually sufficient), and be sure not to drag the probe across the surface. Above all, do not poke a hole through the paper or tear it. Be especially careful around the places in the board where there is a screw hole beneath the paper surface. By exploring the sheet with the multimeter probe, you can "map out" the potential in the two-dimensional space you are working in.
7. Move the red probe around the sheet until you find a point which gives you a reading of a voltage

Equipotential Contours and Capacitance

your team agreed on. Mark that point with the pencil. Move the probe a short distance away from this point until you find another point with the same voltage. Mark this point with the pencil. Continue in this fashion until your contour either closes in on itself or reaches the edge of the paper. At places where the contour is highly curved, it will be necessary to take more measurements closer together than in the areas where the contour is fairly straight. The idea is to get enough points that you can be fairly sure of the shape of the equipotential contour.

8. Map several equipotential contour lines around your electrodes. Make sure you switch tasks among the members of your team so everyone gets a chance to use the equipment.

When you are done, find another group that has a different set of electrodes and share your results with them. Take a picture of both equipotential contour maps and include them below.

Equipotential lines for two circles

Picture:

Equipotential lines for two rectangles

Picture:

Part 2: Are you a capacitor? (20-30 minutes)

In this part of the lab you will charge and discharge a capacitor and then repeat the procedure with yourself in order to determine if you are a capacitor.

Warning: If you have a pacemaker or other implanted electronic medical device, do not do any of these parts on yourself. Let your lab partners do all the shocking work (pun intended). It should not cause any damage, but there is no reason to take unnecessary risks.

Start by plugging the red plug of the HVPS into the +3000 V jack.

One thing we know about capacitors is that we can put a voltage across one and it will stay there until we discharge it. To demonstrate this, take capacitor C1 (the one in the plastic tube - **not** the one attached to the wooden posts), and clip one end of it to ground using an alligator lead. Taking care to only hold it using the plastic tube, touch the free end of the capacitor to +3 kV for a moment. Now bring the free end (which is now at +3 kV) near a grounded wire and touch it to ground. **What happens?**

A:

Just as you charged and discharged C1, you can do the same with your own body! First, ground yourself by touching the ground terminal of the HVPS. Then touch the +3 kV end and hold it for a second. **This will not hurt.** Now go back and touch the ground again. **Describe what happens**

A:

Are you a capacitor? If so, where's the other terminal?

A:

Part 3: What is your capacitance? (1 hour)

In this part of the lab you will learn how to measure the capacitance of a charged capacitor by connecting it in parallel with another capacitor of known capacitance and measuring the voltage across. You will then use the same procedure to measure your own capacitance.

Equipotential Contours and Capacitance

Switch the positive terminal of the HVPS to the +1000 V jack.

Using the charge sensor with the Logger Pro file "Lab1.cmb1"

1. Open the "Lab1.cmb1" Logger Pro file. Click on the "Data Collection" button and set the collection length to 60 seconds, then click OK.
2. The charge sensor's leads should be connected across capacitor C2. Connect the black terminal of C2 to the HVPS ground. Using a banana plug touch the terminals of C2 together and then press the button on the charge sensor to zero the reading. You should see a reading of close to 0 volts in the lower right of the Logger Pro window. Unplug the banana cable so that C2 is no longer shorted out (but leave its black terminal grounded).
3. Start collecting data in Logger Pro. The file displays the voltage across C2 as a function of time.

Charge C1 to high voltage by attaching one end to ground and touching the other to the +1 kV lead. This time, instead of discharging it to ground, discharge to the red terminal of C2 (connected to the charge sensor). Observe what happens to the voltage reading of the charge sensor.

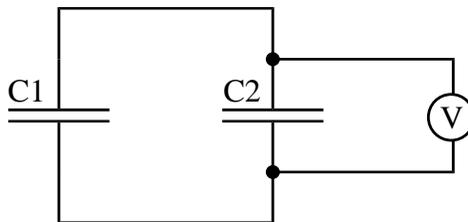
How much did it change from its previous (near-zero) value when you touched the two capacitors together?

A:

How much charge did you put on C2?

A:

C1 is much smaller than C2. When you connect the two capacitors together, you can think of them as being combined **in parallel**, as shown in the following diagram (the V represents the voltmeter, which in this case is the charge sensor):



Two capacitors connected in parallel act like a *single* capacitor with a capacitance

$$C_{\text{equiv}} = C1 + C2.$$

Since C2 is much bigger than C1, the **equivalent capacitance is approximately equal to C2 alone**. So the *total charge* on the two capacitors can be found from:

$$Q = (C2)\Delta V.$$

In addition, since C2 was initially uncharged, all of the charge must have come from C1. **Using these relationships, how much charge was on C1 before you touched the two capacitors?**

A:

Equipotential Contours and Capacitance

Calculate the observed value of C1 based on this charge and the fact that it took 1 kV of voltage to put this much charge on C1. **Does your calculation agree with the stated value of C1? Explain.**

A:

Now repeat the measurement except with your own capacitance in place of C1. **Remember to zero the charge sensor before you start taking data.** (At only 1 kV you will not feel a shock.) Only one member of your lab group needs to do this part, although (**BONUS**) if you have time and are interested in your own capacitance, feel free to try it on all three of you. **Warning: if you have a pacemaker or other implanted electronic device, do not do this part.**

What is the final voltage on C2?

A:

What is the capacitance of your body? (Include a snapshot of your work)

A:

Now you know your capacitance. How much capacitance is that, anyway? Imagine a solid conducting sphere with the same capacitance (relative to a faraway ground) as your body. **What would its radius be? How does this compare with your own length scale?**

A:

Consider a parallel plate capacitor whose plates each have an area of about 1 cm². When the plates are separated by 1 mm, the capacitance is about 1 pF. **At this separation, roughly how big would the plates have to be for this capacitor to have a capacitance comparable to your own?**

A:

VI. Conclusion

What is the most important thing you learned in lab today?

A: