Name	________________________________	Date	__________	Time to Complete	____h ____m
Partner	________________________________	Course/ Section	______/______	Grade	__________

Capacitance

Introduction

Doing some simple experiments, including making and measuring the capacitance of your own capacitor, will help you better understand the phenomenon of capacitance. In this lab, you will use a commercially available demonstration capacitor to investigate the basic principle of capacitance, expressed in the equation: $C = q/V$, where C is the capacitance of some system of conductors and insulators, q is the charge associated with the system, and V represents the potential difference between the parts of the system.

Equipment

The electrometer, the high voltage source, the insulated sphere and the proof plane are all equipment that you used in the first lab, *Electrostatics*. Recall how to read the analog scale on the electrometer properly. Also recall how to properly zero the electrometer.

The demonstration capacitor consists of two conductive discs, approximately 18 cm in diameter, mounted on a base. One disc is fixed to the base, the other disc is attached to a support which can be moved to change the spacing between the discs. Terminals are provided so that electrical connections can be made to the discs.

1. Investigating the capacitance equation

a. Proportionality of potential difference to charge

Introduction

The capacitance equation, $C = q/V$, applied to a parallel plate geometry, seems to imply that the capacitance of the system depends on the charge on the plates and the potential difference between them. But, in fact, this is not the case. The capacitance of a device depends only on its geometry and the insulating material between the plates. It is independent of the values of q and V. This must mean the ratio q/V remains constant even as the charge and potential difference change.

Rearranging the equation it reads $q = CV$. This says that for a given capacitance the potential difference between the two plates of the capacitor will be directly proportional to the charge on the capacitor. That is, doubling the charge should double the potential difference, tripling the charge should triple the potential difference, and so forth. This is the correct way to interpret the fundamental capacitor equation. Let's see if the demonstration capacitor obeys this relationship.

Procedure

- Adjust the demonstration capacitor so that the two plates are approximately 2.0 mm apart. This can be most easily done using the scale printed on the base of the capacitor.
- Connect the electrometer to the capacitor by connecting the black wire from the electrometer to the fixed plate of the capacitor and the red wire to the movable plate. Zero the electrometer by shorting the two plates with your hand while

simultaneously depressing the zero button. To start, select the electrometer’s 30 volt range.

- Connect the insulated sphere to the +1000V terminal of the electrostatics voltage source and connect the “com” terminal on the voltage source to the “gnd” terminal on the electrometer as you did in lab 1. Make sure the insulated sphere is as far away from the electrometer and the capacitor as possible in order to avoid erroneous readings due to the electric field of the sphere. (Keep the sphere well away from the computer monitor also.) Now turn on the voltage source.

- Re-zero the electrometer if necessary, charge the proof plane by touching it to the sphere, and transfer the charge to the movable plate of the capacitor. You only need to touch the proof plane to the edge of the plate, but be careful that you only touch the movable plate. Do not let the proof plane touch the fixed plate at any time. After transferring the charge note the voltage reading on the electrometer and record it in *Table 1* below. For the time being we will call the amount of charge transferred from the proof plane 1ctu, where “ctu” stands for “charge transfer unit”. This is a made up name for this amount of charge that we will use until you can determine how many Coulombs are transferred.

  In the same way, transfer a second “ctu” of charge and record the voltage reading. Do this six times. The voltage reading on the electrometer should increase with each transfer. Do not zero the electrometer after each transfer.

  [Note: Depending on atmospheric conditions and other factors in the lab it is possible that the capacitor will “leak”. That is, some of the charge will not stay on the capacitor but will be conducted off by moisture in the air or dirt or other contaminants on the supporting structure of the capacitor. If this happens, the potential difference across the plates of the capacitor will immediately begin to decrease after the capacitor has been charged. Should this occur, you will have to transfer the charges rapidly and make quick voltage readings in order to minimize the effects of this leakage on your experiment.]

Transfer #	**Charge on Capacitor (charge transfer units – ctu)**	**Electrometer Reading (V)**
1	1 ctu	
2	2	
3	3	
4	4	
5	5	
6	6	
7	7	

Table 1

- Use *Graphical Analysis* to make a graph of q *vs*. V, plotting q in ctu's on the vertical axis and potential difference on the horizontal axis. (Keep the graph on your screen for now. You will analyze it further in the next section.)

Conclusion

Analyze your data and see if it supports the proportionality between charge and potential difference predicted by the fundamental capacitor equation, $q = CV$. If the graph is reasonably straight then you can conclude that the prediction of the capacitance equation has been verified. If the graph is not straight think about whether that is due to capacitor leakage, or some other unforeseen factor affecting what is going on.

State your conclusion here, and discuss any unusual aspects of your data.

b. Estimating the charge of one "charge transfer unit"

Introduction

If your data can reasonably be fit with a straight line, it confirms the direct proportionality between charge and potential drop apparent in the fundamental capacitor equation $q = CV$. Clearly, the slope of this line gives the capacitance of the capacitor.

If the plates are not too far apart, the demonstration capacitor can be modeled as an *infinite parallel plate* capacitor. Then, its capacitance can also be calculated based on its geometry and material properties with the formula.

$$C = \frac{\kappa \varepsilon_0 A}{d} \tag{1}$$

Here, A is the area of the plates, d is the plate spacing and κ is the dielectric constant of the material that fill the gap, air in this case, which you can take as having $\kappa = 1.0$. In should be clear from the fundamental capacitor formula that capacitance has dimensions of charge over potential. Therefore, using SI units for all parameters in *Equation* 1 gives a capacitance with unit of Coulombs over Volts. This unit is given its own name, the Farad. That is 1 C/V = 1 Farad or 1 F.

You now have two means of determining your capacitor's capacitance. This makes it possible to determine how many Coulombs make up a ctu.

Analysis

- Have Graphical Analysis generate a best fit line to your data from the previous section. The slope of this line gives the capacitance of the capacitor. Record it here. Include the correct units. Print your graph and attach it to your finished report.

$C_{measured} =$ ______________________________

- Next, use *Equation 1* to calculate the capacitance. Show your work, and record your answer with the unit C/V.

$C_{calculated} =$ __________________________________

Conclusion

Both of these capacitance values represent the same quantity, just in different units. It is no different than saying a ruler is 12 inches or 1 foot. That means *equating* the two capacitances gives the conversion factor for converting between these two different units of capacitance. Follow this course to determine the number of Coulombs in one charge-transfer-unit. Show your work.

Now calculate how many *fundamental units* of charge transfer each time you touch the proof plane to the capacitor. Show your work.

If we assume it is electrons being transferred, does this number represent the number of electrons being transferred to the capacitor or removed from the capacitor? Explain.

c. Another test of the fundamental capacitor formula

Introduction

[Note: Although the next experiment is described in this paragraph, do not carry out the measurements until you have fully completed your predictions.] In this experiment you will first charge the capacitor. Once charged, the amount of charge on the capacitor is fixed; it does not change (assuming leakage is negligible). The charged capacitor will have a non-zero potential drop across its plates that can be measured with the electrometer. While monitoring the potential you will slowly separate the plates and observe what happens.

Prediction

Make a quick prediction. When the plates of the charged capacitor are separated do you think the potential will increase, decrease or remain about the same? Circle one.

Increase Decrease No Change

Combine the equation for the capacitance of infinite parallel plates with the fundamental capacitor equation to obtain an expression for the plates' potential difference V as a function of separation d. Show your work.

If this expression was used to plot potential difference vs. plate separation for fixed charge what would the graph look like? Be specific. (Make a sketch of your expectation.)

You should consider this a well-thought-out prediction for the experiment you are about to perform. Is it the same as your earlier quick prediction? Explain.

Procedure

- With the capacitor plates initially about 2mm apart, transfer a few ctu's of charge to the capacitor, and note the resulting potential difference. Make sure the potential is steady (not dropping or rising) before you continue.

- Increase the plate separation slightly, say 1 mm at a time, and slowly. Carefully observe the potential difference as you separate the plates.

Conclusion

When you first began to separate the plates did the potential increase, decrease or remain the same?

Was this consistent with your well-thought-out prediction?

Would you expect your well-thought-out prediction to hold true for all separations, or did your prediction rely on an approximation that would become invalid for large separations? Explain.

2. Making a capacitor and measuring its capacitance

Introduction

In this section you will construct a parallel plate capacitor. Then you will use a basic property of capacitor networks to measure its capacitance

Procedure

- Cut from a roll of aluminum foil a piece that is about 15cm long.
- Cut this piece into two equal parts as shown in *Figure 1* below. Discard the shaded pieces. The goal is to make two approximately square pieces with tabs on them which look like *Figure 2*. These pieces will be the capacitor plates.

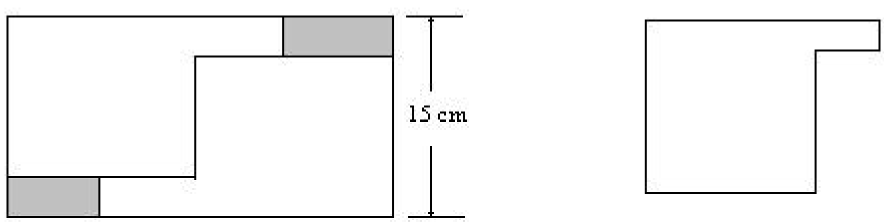

Figure 1 *Figure 2*

- Inspect the two pieces for any rough or sharp edges. Smooth any rough edges with your finger.

- Place a large sheet of mylar plastic on the worktable. Wipe the plastic with a damp (not wet!) paper towel to rid it of any dirt or stray charge which might affect the results of your experiment. Make sure there is no stray moisture left on the plastic.
- Place one of your foil pieces in the center of this sheet of plastic.
- Take a small sheet of mylar, clean it on both sides with a damp paper towel, and place it on top of the foil piece. Make sure the mylar completely covers the foil piece except for about two or three centimeters of the tab.
- Place the other foil piece on top of the mylar, with the tab on the opposite side from the first tab.
- Clean a third sheet of mylar and place it on top of the second piece of foil, making sure that only the two tabs protrude from under this sheet. When finished the stack should look like *Figure 3* below.

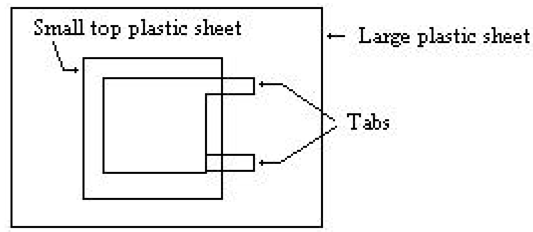

Figure 3

- Place a heavy book on top of the stack, leaving the tabs exposed so you can make connections to them. (Do not allow the tabs to touch the book. The book's surface can be somewhat conductive providing a path for charge leakage.)
- Connect the electrometer to your capacitor. Be careful not to tear the tabs.
- Connect two wire leads to a 6 Volt battery and charge your capacitor by briefly touching the leads from the battery to the tabs of the capacitor. Watch the electrometer to see whether the capacitor "leaks". If there is little or no voltage drop after about 30 seconds or so, then the capacitor is holding charge satisfactorily. Consult your instructor if this is not the case.
- If your capacitor passes this test, discharge the capacitor by simultaneously touching both tabs with your fingers. You are now ready to measure the capacitance of your capacitor.
- At your lab station, find the small 2 nF capacitor. Connect one terminal of this capacitor to the negative tab of your capacitor. Connect another wire to the other terminal of the 2 nF capacitor, but do not yet connect it to your capacitor. We'll call this the "test wire". At this point, the circuit should look like *Figure 4* below.

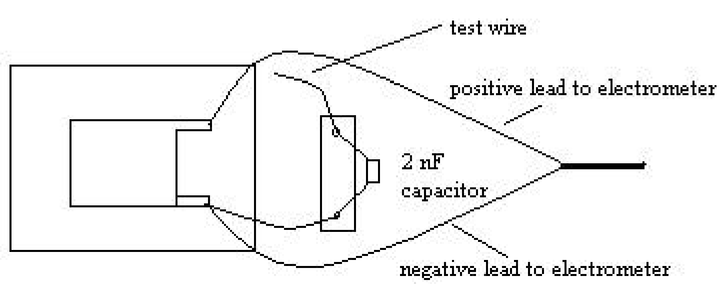

Figure 4: Capacitor test circuit

- Discharge both capacitors by briefly touching their terminals with your fingers.
- Charge your capacitor by briefly touching its terminals with the leads from the 6 V battery. The polarity is important. Make sure you touch the negative battery lead to the negative tab of your capacitor. Note and record the electrometer reading in *Table 3* below. We'll call this reading V_{before}. (It should be close to +6 V, right?)
- Now briefly touch the test wire to the positive tab of your capacitor. The electrometer reading should drop to a new, lower value. Note and record this reading for the first trial in *Table 3*. We'll call it V_{after}.
- Discharge both capacitors by briefly touching the terminals with your fingers. Repeat the procedure twice more, each time recording your results in *Table 3*.

Electrometer Range:___________		
Trial	V_{before}	V_{after}
1		
2		
3		
Average		

Table 3

Theory Interlude

The data you have just collected can be used to determine the capacitance of your capacitor by the method of *shared charge*. In a sense you are testing your capacitor against a known capacitance, which will reveal the unknown capacitance. Here we will outline the theory behind this method.

When two capacitors are connected in parallel, as shown in *Figure 5* below, they act as a single capacitor, which has a capacitance equal to the sum of the individual capacitances.

$$C_{total} = C_1 + C_2$$

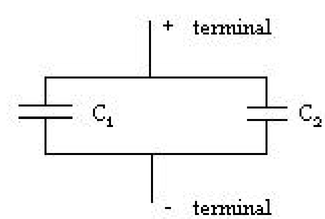

Figure 5: Capacitors in parallel

If a charged capacitor, C_1, having an unknown value, is connected in parallel with an uncharged capacitor, C_2, whose value is known, some of the charge from C_1 is transferred to C_2. As this transfer occurs, the potential difference across C_1 decreases and the potential difference across C_2 increases until they arrive at a common final value, which we can call V_{after}. This process takes place almost instantly. The total charge of the system remains the same, it has just been redistributed. In equation form we would write:

$$V_{before} = \frac{Q}{C_1} \tag{2}$$

$$V_{after} = \frac{Q}{C_1 + C_2} \tag{3}$$

Note that both Q and C_1 are unknown quantities in this system of equations. However, if we divide *Equation 2* by *Equation 3* we can eliminate Q and arrive at a single equation involving only one unknown, C_1. This equation can then be solved for C_1 in terms of the known quantities C_2, V_{before} and V_{after}.

Analysis

Derive an expression for the capacitance of your capacitor, C_1, in terms of the known quantities C_2, V_{before} and V_{after}. Show your work.

Conclusion

What is the capacitance of your capacitor in nano-Farads. Show your work.

Questions

- Take a look at the commercially available capacitor on the instructor's desk. It has a value of 0.47 µF. This capacitor is also made of plastic and foil, in much the same way as you made yours. Assuming that the plastic in this capacitor is the same thickness as the plastic you used to make yours (it's not, but assume that), what would the plate area of this capacitor have to be in order for it to have the capacitance it has? If these plates were square, what would be the length of one side? Show your work.

- In view of your answers to this last question, how do you think the manufacturers managed to make their capacitor as small as they did?