Parallel Plate Capacitor

Capacitor Charge, Plate Separation, and Voltage

A capacitor is used to store electric charge. The more voltage (electrical pressure) you apply to the capacitor, the more charge is forced into the capacitor. Also, the more capacitance the capacitor possesses, the more a given voltage will force in more charge. This relation is described by the formula \( q = CV \), where \( q \) is the charge stored, \( C \) is the capacitance, and \( V \) is the voltage applied.

Looking at this formula, one might ask what would happen if charge were kept constant and the capacitance were varied. The answer is, of course, that the voltage will change! That is what you will do in this lab.

The Lab Capacitor
A parallel plate capacitor is a device used to study capacitors. It reduces to barest form the function of a capacitor. Real-world capacitors are usually wrapped up in spirals in small packages, so the parallel-plate capacitor makes it much easier to relate the function to the device.

This capacitor works by building up opposite charges on parallel plates when a voltage is applied from one plate to the other. The amount of charge that moves into the plates depends upon the capacitance and the applied voltage according to the formula \( Q = CV \), where \( Q \) is the charge in Coulombs, \( C \) is the capacitance in Farads, and \( V \) is the potential difference between the plates in volts.

Capacitors store energy
If a voltage is applied to a capacitor and then disconnected, the charge that is stored in the capacitor remains until the capacitor is discharged in some way. An electric field then exists between the plates, which allow the capacitor to store energy. This is one of the useful aspects of capacitors, the ability to store energy in an electric field so that can be utilized later on.

What determines the capacitance?
The surface area of the plates and the spacing between them determines the amount of charge that may be stored per volt applied. The larger the plates and the more closely they are spaced, the more charge can be stored for every volt of potential difference between the plates. The charge stored per volt applied is the capacitance, measured in Farads.

Can altering the capacitance of a charged capacitor change its voltage?
The lab capacitor is adjustable, so we can do an interesting experiment involving capacitance and voltage. If the capacitor has a constant charge, changing the capacitance should cause the voltage to vary. Moving the plates apart will reduce the capacitance, so the voltage should increase.
How can capacitance of our capacitor be mathematically determined?

For a parallel plate capacitor, the capacitance is given by the following formula:

\[ C = \varepsilon_0 \frac{A}{d} \]

Where \( C \) is the capacitance in Farads, \( \varepsilon_0 \) is the constant for the permittivity of free space \((8.85 \times 10^{-12})\), \( A \) is the area of the plates in square meters, and \( d \) is the spacing of the plates in meters.

A Farad is a very large quantity of capacitance, so we will use metric prefixes to produce more usable numbers. Capacitance is normally measured in microfarads (\( \mu F \)), which is \( 1.0 \times 10^{-6} F \), or picofarads (pF), which is \( 1.0 \times 10^{-12} F \). \( 1.0 F = 1,000,000 \mu F = 1,000,000,000,000 pF \)!

Be very careful with your calculations!

This calculation will give you an approximation of the capacitance of the lab capacitor. However, there are other factors that introduce errors into the real-world measurement of capacitance and voltage. You need to be careful to take these factors into account.

Lab Equipment:

To get good results, this lab activity requires some specialized equipment. You need a good regulated DC (direct current) power supply so that the voltage applied to the capacitor is the same in each trial. A battery would work but voltage applied changes over time.

You also need a very accurate way of measuring the voltage between the plates without putting a resistive load on the capacitor. The amount of charge stored is very small, so a conventional voltmeter will not work. The minute charge built up in the capacitor would simply discharge through the meter, rendering any measurement useless. You will use a special voltage-measuring device called an Electrometer that measures voltage without discharging the capacitor.

One problem with the electrometer is that it has some capacitance of its own. Since this capacitance is in parallel with that of the capacitor, the built-in capacitance of the leads must be added to that of the capacitor.

Purpose:

The purpose of this lab is to investigate the relationship between plate separation and voltage in a parallel plate capacitor kept at constant charge.

Equipment:

- Variable capacitor
- Electrometer
- Regulated Power Supply
- Jumper Leads
- Electrometer Leads
- Graph Paper

Cautions:

This equipment is delicate. Everything should go together with the lightest of touches. Do not force anything!

Your first task is to predict what will happen to the capacitor’s voltage when you charge it with a 15V source and then spread the plates apart (which reduces the capacitance). You will do this in the next section.
Theoretical Calculations:
You need to calculate the theoretical capacitance for each plate spacing. Here is the first one as an example. The hardest part of this is getting the units right. The easiest way to proceed is to put everything in meters for the calculations:

1. Measure the diameter of the capacitor plates in centimeters. Your measurement should be 17.8cm
2. Divide the diameter by 100 to put the measurement in meters. The result is 0.178m. Divide this by two to get the radius: 0.089m
3. The area of the plate is determined by the common formula $A=\pi r^2$. Plug in the numbers to get $A = \pi (0.089)^2 = 0.0249m^2$
4. Convert the plate spacing (1mm) to meters by dividing by 1000. $1/1000 = .001m$.
5. Use these numbers in the formula $C = \varepsilon_0 A/d$ to determine the calculated capacitance thus: $C = 8.85 \times 10^{-12}(.0249)/.001 = 2.20 \times 10^{-10}$. This is equal to $220 \times 10^{-12}F$ or 220pF
6. Add the built-in capacitance of the electrometer (50pF) to the theoretical capacitance to get 270pF.
7. Write this result (270pF) in the “Calculated Capacitance” column and the 1mm row.
8. Repeat this process for the other plate spacings. Note that the plate area and $\varepsilon_0$ is the same for all, so all you need to do is save that value in your calculator, then divide by inserting the correct values for the spacing in each case.
9. Now you will calculate the theoretical voltage for each spacing. We will assume a voltage of 15V for the 1.0mm spacing, so you can just put that value into the table directly. First, you determine the amount of charge in the capacitor at this spacing and voltage. Use the formula $Q=CV$ to determine the charge thus: $Q=270 \times 10^{-12}F(15V)=4050 \times 10^{-12}C$. This charge stays the same at all plate spacings, so you can fill the same value into the entire Calculated Charge column! Now use this charge value to determine the calculated voltage at all other spacings. For example, at the 5mm spacing, use the formula $V=Q/C$ thus: $V=4050 \times 10^{-12}C/100.0 \times 10^{-12}F=40.5V$. Enter this value in the Calculated Voltage column at the 5mm row.
10. Repeat the same voltage calculation for the remaining plate spacings. Use the calculated capacitance and the constant charge for each spacing and enter the voltage value in the Calculated Voltage column of the table.
11. Congratulations! You have finished the preliminary calculations! All you have to do now is make the actual measurements!

In the next sections, you will perform the actual experiment to verify (or perhaps not verify!) your theoretical calculations.

Procedure to set up the variable capacitor (if the lab is already set up, proceed to the next section!)

1. Place the variable capacitor in the middle of the lab table, with the 0cm mark to your left. Don’t put the capacitor too close to the edge of the table!
2. Place the power supply behind the variable capacitor. Plug the power supply in, but do not turn it on.
3. Connect the red and black jumper leads to the red and black terminals of the power supply. Simply clip the alligator clip to the hole and leave the other end of the leads free.
4. Place the electrometer to the left of the capacitor.
5. Attach the spade terminals of the electrometer leads to the binding posts on the backside of each capacitor plate. The red lead goes to the right plate; the black lead goes to the left plate.
6. Plug the BNC connector into the electrometer.
7. Put the plates at the minimum 1mm separation. The white bumpers prevent the plates from being set closer together. If the plates are not parallel to each other, use the adjustment knobs in the middle of the right support to align the plates. The left edge of the plastic tab that extends toward the scale should be aligned with the 1mm mark.

**Collecting Experimental Data**
1. Make sure that the equipment setup is complete and correct.
2. Turn all four controls on the power supply fully counterclockwise.
3. Turn the leftmost knob (Fine Current) to the 12 o’clock position
4. Turn the power supply on. *The displays should light.*
5. Use the Fine and Coarse Voltage knobs (the two rightmost knobs) to set the voltage to 15.0V.
6. Put the plates at their minimum setting
7. Set the Electrometer to the 30V scale.
8. Push the power button on the Electrometer. *The 30V LED should light.*
9. Push the zero button on the electrometer. *This zeros the meter and makes sure that the plates are at zero volts relative to each other.*
10. Momentarily touch the leads from the power supply to the plates, black to the left plate and red to the right plate.
11. The electrometer should read 15 volts at this point. If it doesn’t check your setup and try again. Sometimes you have to touch the leads to the plates a couple of times to get the proper 15V reading.
12. From this point on, you must be careful not to touch the plates. If you touch them you will alter the charge in the plates and spoil the data!
13. Watch the electrometer to make sure that the charge is being held. If you see a drop of more than a volt in 30 seconds stop and figure out what is wrong before proceeding.
14. Switch the electrometer to the 100V setting. *The meter should still read 15V, but on the 100V scale.*
15. Carefully slide the plates apart to the 2mm setting.
16. Take a reading from the electrometer and record it in the table under that Measured Voltage column.
17. Repeat the previous two steps for the other plate spacings and record the appropriate data.

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<tr>
<th>Plate separation (mm)</th>
<th>Calculated Capacitance (pF)</th>
<th>Calculated Charge (pC)</th>
<th>Calculated Voltage (V)</th>
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Data Analysis:
Make a graph of capacitance versus voltage. Place the theoretical capacitance on the horizontal axis and the voltage on the vertical axis. Plot both the theoretical and experimental data.

1. On graph paper, plot the Calculated Capacitance on the x (horizontal) axis versus the Voltage on the y (vertical) axis. Plot both the calculated value and the measured value for voltage, using either different colors or line styles to distinguish the two curves. Make sure that you choose appropriate scales and label the axes and scales clearly. It is best to orient the paper with its long axis in the horizontal direction (“landscape mode”).

2. Examine your graph and answer the following questions:
   A. Does your measured data support the measured values?
   B. Are the two curves the same shape? If so, what does this indicate?
   C. What would you do to improve the accuracy of the data collected?
   D. The formula for the energy stored in a capacitor is \( U_e = \frac{1}{2} CV^2 \). Does the energy stored in the capacitor remain constant when the plate spacing is varied? Does it go up or down? Discuss where the energy came from or went to.