Objectives

In this lab, you will first explore the relationship between capacitance and the plate separation of a single parallel-plate capacitor. You will then place another capacitor in series and measure the effects of plate separation on the capacitance as a system. Finally, you will introduce a dielectric between a capacitor plate and calculate the dielectric constant of that material.

Software

For the following activities you will be using a simulation from Colorado PhET simulations. Visit: https://uglabs.physics.ucr.edu/ for lab downloads and links.

NOTE: This lab will require a Windows or Mac computer. You will find that tablets, phones, and Chromebooks will not work for this lab.
Capacitors

Introduction

A capacitor is an electrical device that stores electric potential energy. There are different configurations and geometries, but the most basic capacitor consists of two parallel metal plates. One of the plates can be charged positively and the other can be charged negatively by connecting to the appropriate terminals of a voltage source such as a battery. In both plates, the charges are squeezed together against the repulsive forces between the neighboring charges. This means that something did work to counteract the Coulombic repulsive force and bring the charges together. This work is stored as electric potential energy in the capacitor. It can be recovered as kinetic energy via moving charges (current) when the capacitor is discharged.

The standard picture of a capacitor is two parallel plate electrodes on which the charge is stored. Such a capacitor has a capacitance with units of Farads (F).

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

(1)

where \( A \) is the plate area, \( d \) the plate separation, \( \kappa \) is the dielectric constant of the material between the plates, and \( \varepsilon_0 = 8.85 \text{ pF/m} \) is the permittivity of free space.

Measuring Capacitors in Parallel

As a general rule, when two capacitors are in parallel configuration in an electric circuit (see right), the combined capacitance is determined by a linear sum:

\[ C_{tot} = C_1 + C_2 \]
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Measuring Capacitors in Series

As a general rule, when two capacitors are in series configuration in an electric circuit (see right), the combined capacitance can be determined by an inverse sum:

\[
\frac{1}{C_{tot}} = \frac{1}{C_1} + \frac{1}{C_2}
\]

Measuring the Dielectric Constant

As discussed above, for a capacitor without any material present between two parallel plates, the capacitance is given by Eq. 1 with \( \kappa = 1 \). When the capacitor gap is partially filled with a dielectric with constant \( \kappa \) as shown below, the material, with Area \( A_2 \), and the remaining gap, with area \( A_1 \), can be regarded as two capacitors connected in parallel.

The equivalent capacitance across both elements, which we will call \( C_\kappa \), is:

\[
C_\kappa = \frac{\varepsilon_0 A_1}{d} + \frac{\kappa \varepsilon_0 A_2}{d}
\]  

(2)
1. Single Capacitor

In this section, you will graphically determine the capacitance of a single capacitor apparatus at a series of different separation distances to develop an understanding for how the amount of charge stored in a capacitor varies according to Eq. 1.

1.1: Open the simulation and make sure you are on the “Introduction” tab. Move the capacitor plates to be 10 mm apart, change the Plate Area to 100 mm², and clear all settings by unchecking all boxes as seen below.

1.2: Draw a circuit schematic to represent the apparatus shown on the right. Be sure to indicate across which elements voltage is measured.

1.3: You are now ready for voltage measurements. Set the battery voltage to 1.5V. Now disconnect the battery by clicking the “Disconnect Battery” button above the battery.

1.4: Now check all the meters to the right (Capacitance, Plate Charge, Stored Energy, and Voltmeter). Record the voltage (with the multimeter), capacitance, and charge for a plate separation distance of 10 mm. Decrease the plate separation by 2 mm. Repeat the process for collecting voltage, capacitance, charge data for decreasing plate separation distances in 2 mm decrements down to 5 mm (you should have four data points total: 10 mm, 8 mm, 6 mm, and 5 mm separation distance).
Capacitors

1.5: Create a table in your spreadsheet program like the one below and populate the table with your four data points from 1.4:

<table>
<thead>
<tr>
<th>d (m)</th>
<th>C (Farads)</th>
<th>Q (C)</th>
<th>V (Volts)</th>
<th>1/d</th>
<th>1/V</th>
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1.6: Rearrange the relation below into \( y = mx + b \) for with \( y = \left( \frac{1}{V} \right) \) and \( x = \left( \frac{1}{d} \right) \). The equation below is a statement of “\( Q = CV \)” with Eq. 1 plugged in for \( C \).

\[
Q = \left( \frac{\varepsilon_0 A}{d} \right) V
\]

1.7: Using your spreadsheet program, make a graph of your data with "\( \frac{1}{V} \)" on the y-axis and "\( \frac{1}{d} \)" on the x-axis. This should create a linear plot. Fit this line.

1.8: What is the slope of line that you created in 1.7. Does this result match with the above?

1.9: Did \( Q \) vary with separation distance in this situation (if so how)? Did \( C \) vary with separation distance in this situation (if so how)?

Thought Experiment: What would happen if the separation distance was increased or decreased when the capacitor was still connected to the battery? Do the plates maintain the same amount of charge? Why or why not?

2. Multiple Capacitors

In this section, you will work with multiple capacitors to see how the charge distributes across them in various situations.

2.1: Switch to the tab for “Multiple Capacitors.” Under the “Circuits” menu on the right side
of the program, select the option for “2 in Series.”

2.2: Set $C_1$’s capacitor plates to 0.24 pF and $C_2$’s to 0.12 pF. Set the voltage source to 1.5 V.

2.3: Now check the following meters to the right (Total Capacitance, Stored Charge and Voltmeter). Measure the voltage on either side of capacitor 1 by using the Voltmeter. Then, measure the voltage on either side of capacitor 2 by using the Voltmeter.

2.4: Record the Total Capacitance, the Stored Charge, and the voltage drop for $C_1$ and $C_2$ in your notebook.

2.5: Now select the option for “2 in Parallel.”

2.6: Set $C_1$’s capacitor plates to 0.24 pF and $C_2$’s to 0.12 pF. Set the voltage source to 1.5 V.

2.7: Now check the following meters to the right (Total Capacitance, Stored Charge and Voltmeter). Measure the voltage on either side of capacitor 1 by using the Voltmeter. Then, measure the voltage on either side of capacitor 2 by using the Voltmeter.

2.8: Record the Total Capacitance, the Stored Charge, and the voltage drop for $C_1$ and $C_2$ in your notebook.

2.9: In which scenario (“in series” or “in parallel”) did $C_2$ have the greatest voltage drop? Explain using your results.

2.10: Which scenario had the greatest total capacitance (“in series” or “in parallel”)? Explain using your results.
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2.11: Which scenario had the greatest charge stored (“in series” or “in parallel”)? Explain using your results.

3. Changing the Dielectric

In this section, you will demonstrate the effect of the dielectric medium between the parallel plates on the capacitance value.

3.1: Navigate to the “Dielectric” tab of the Java simulation. Reset all settings by unchecking all boxes. Set plate Separation to 5.0 mm and Plate Area to 100.00 mm². Important: These settings should not change during this experiment.

3.2: Draw another circuit schematic to represent the apparatus. Represent the capacitor apparatus as two capacitors in parallel as described in the introduction and be sure to indicate across which elements voltage is measured. Note that since we have placed the dielectric 5 mm into the capacitor, we have set \(A_1 = A_2\). Check your drawing with your TA before proceeding.

3.3: How should you change the configuration of the dielectric to determine \(C_0\)? After making that change, use the tool bar to show the charge on the plate. Use this to calculate \(C_0\) and record it in your notebook. Return the dielectric block to 5 mm offset.

- Thought Experiment: What would happen if you put two different materials in between the parallel plates of your capacitor? Draw and describe what the model might look/function like with another material (with a different dielectric constant).
Write a brief summary of the experiment you performed today. In your summary, think about the following questions:

- What is capacitance?
- Today we studied parallel plate capacitors, meaning the capacitance was dependent on the distance between the plates and the area of the plates. Think about a different geometrical configuration (maybe think about what geometries you studied in last week’s “Equipotential Mapping” lab). What geometric properties will affect the capacitance of this different configuration?
- If you needed to use multiple capacitors to increase the overall capacitance should you attach them in series or in parallel?
1. Rank in order, from largest to smallest, the equivalent capacitance \( (C_{eq})_a \) to \( (C_{eq})_d \) of circuits a to d (as shown below). Explain your reasoning.

![Diagram of circuits a to d]