PHYS 40C: Lab 4
Capacitors
(Includes Pre-Lab Assignment)

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.

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.

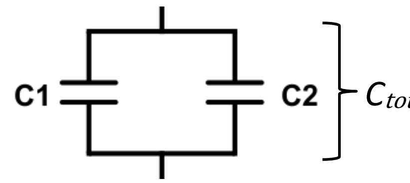
The standard picture of a capacitor is two parallel plate electrodes on which the charge is stored. Such a capacitor has a capacitance with units of Farads (F).

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

where *A* is the plate area, *d* the plate separation, κ is the *dielectric constant* of the material between the plates, and ε_0 = 8.85 pF/m is the permittivity of free space.

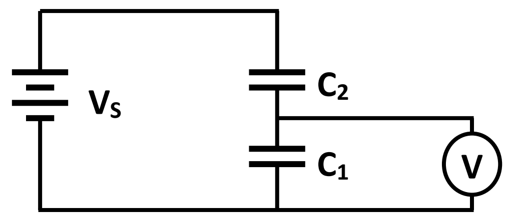
Measuring Capacitors in Parallel

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:



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

Measuring Capacitors in Series

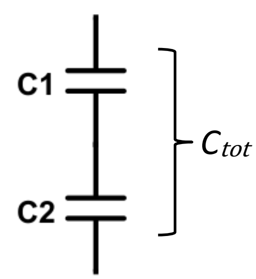


In Part 2, you will use a circuit like the one shown at right to measure the relative size of two capacitors. If C_2 is known, applying a source voltage V_s across the capacitors induces a charge Q on each. If the voltage across C_1 is V, then the voltage across C_2 is V_s-V, so, since we know $Q = CV$:

$$Q = C_1 V = C_2(V_S - V) \quad \text{or}$$

$$C_1 = C_2 \frac{(V_S - V)}{V} \tag{2}$$

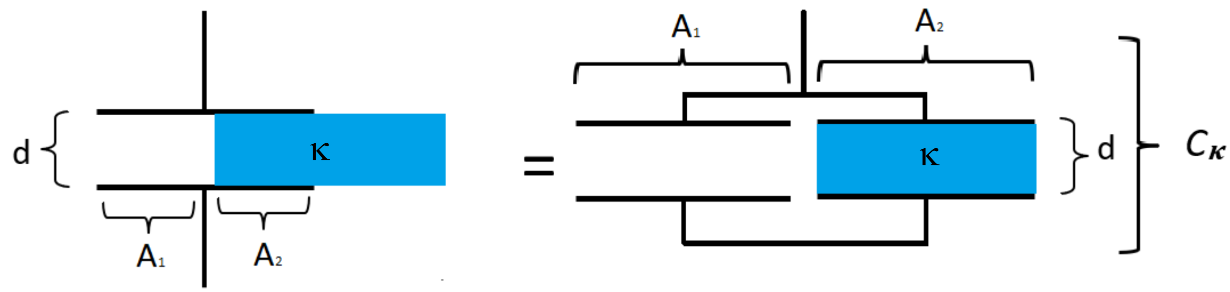
As a general rule, when two capacitors are in *series* configuration in an electric circuit (see right), the combined capacitance can be determined by an inverse sum:



$$\frac{1}{C_{tot}} = \frac{1}{C_1} + \frac{1}{C_2}$$

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 κ 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.

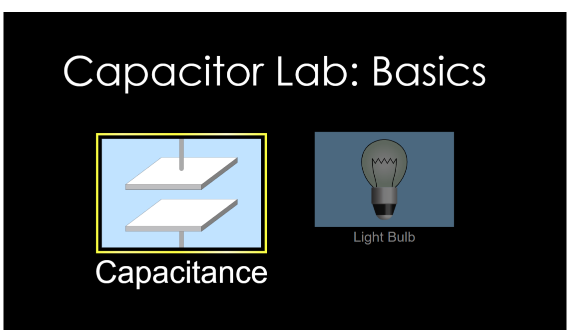


The equivalent capacitance across both elements, which we will call C_κ, is:

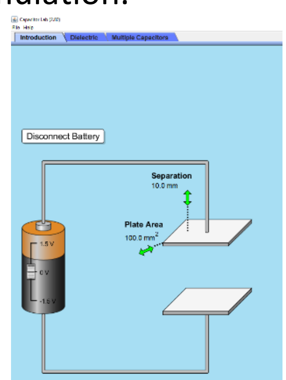
$$C_\kappa = \frac{\varepsilon_0 A_1}{d} + \frac{\kappa \varepsilon_0 A_2}{d} \tag{3}$$

Software

For the following activities you will be using two simulations from Colorado PhET simulations. Visit: https://uglabs.physics.ucr.edu/ for lab downloads and links. We will refer to these as "HTML simulation" and "Java simulation."



HTML Simulation

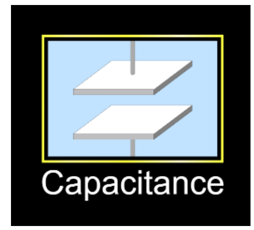


Java Simulation:

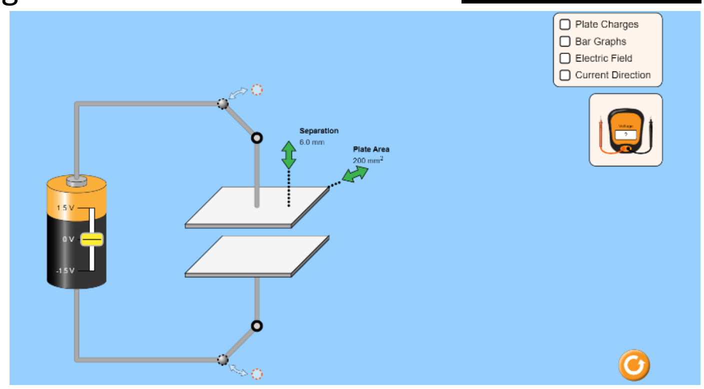
NOTE: This lab will require a Windows or Mac computer. You will find that tablets, phones, and Chromebooks will not work for this lab.

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 HTML simulation and click on the activity entitled "Capacitance." Move the capacitor plates to be 10 mm apart, change the Plate Area to 100 mm^2, 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 on the empty circle above the capacitor.

1.4: Record the voltage, capacitance, and charge for a plate separation distance of 10 mm. Repeat for decreasing plate separation distances in 1 mm decrements down to 2 mm. Record your data in your notebook then transfer it to an Excel table.

1.5: The equation below is a statement of "$Q = CV$" with Eq. 1 plugged in for C.

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

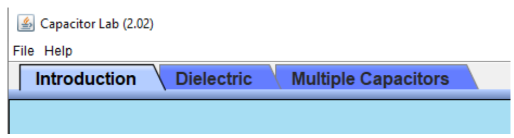
1.6: Using your data, develop a plot to verify that C is inversely proportional to d. Apply a linear fit to your graph and write down the best-fit equation. To what physical values does the slope of the fit refer?

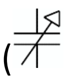
Thought Experiment: What would happen if the separation distance was increased or decreased when you charged the capacitor? Do the plates maintain the same amount of charge? Why or why not?

2. Capacitors in Series

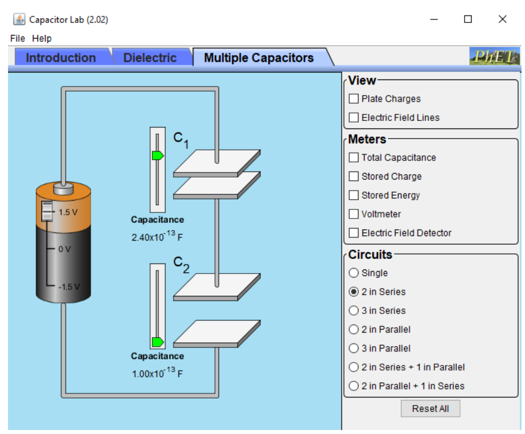
In this section, you will verify the capacitance of a fixed capacitor C_1 as a function of voltage across a varied capacitor, C_2 by taking advantage of the relation between two capacitors in series as shown in Eq. 2.

2.1: Open the Java simulation and select 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: Draw a circuit schematic to represent the apparatus below. This () is the symbol for a variable capacitor.

2.3: Set C_1's capacitor plates to 0.24 pf and C_2's to .10 pf. Set the voltage source to 1.5 V and record the voltage across C_2 in your notebook then transfer to an excel spreadsheet. Leave C_1 fixed throughout the experiment.

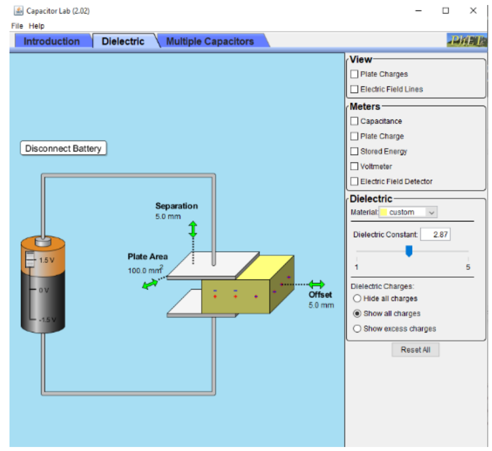


2.4: Using the slider next to C_2, vary its capacitance up to 0.3 pf over at least 5 steps. Record V_s, V_{C_2}, and C_2 at each step.

2.5: Add a column to your spreadsheet to calculate the voltage relationship described in Eq. 2 and then plot it over C_2 in Excel. Apply a linear fit to your graph and write down the best-fit equation. To what physical values does the slope of the fit refer?

3. Changing the Dielectric

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



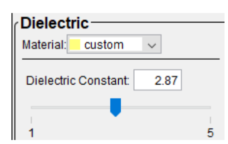
3.1: Navigate to the "Dielectric" tab of the Java simulation. Reset all settings by unchecking all boxes. Set plate Separation to 5.0 mm and Plate Area to 100.00 mm^2. **Important: These settings should not change during this experiment.**

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.

3.4: Now we will use your results from section 2 and set C_κ to the capacitance you verified in 2.5 with the slope of your graph. Calculate the κ needed to make the equivalent capacitance of the apparatus to equal C_κ.

3.5: Use the slider under "Dielectric" to input your results from the previous step. Check the "Total Capacitance" box under "Meters" to check your results.



- *Thought Experiment:* What would happen if you put two different materials in between the parallel plates of your capacitor? With one material, we modeled the system as two capacitors in series. 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?
- Why are capacitors important devices to allow us to control location and interaction of charges for use in electrical circuits?
- 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?
- How significantly would your measurements and calculations have been changed if you did not include the electrometer capacitance (C_e) term? Discuss.

Pre-Lab Assignment (1 point)

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.