

Experiment 4: Capacitors

Introduction

We are all familiar with batteries as a source of electrical energy. We know that when a battery is connected to a fixed load (a light bulb, for example), charge flows between its terminals. Under normal operation, the battery provides a constant current throughout its life. Furthermore, the voltage across its terminal will not vary appreciably - and when it does, it is an indication that the battery needs replacement.

Capacitors are devices in which electric charges can be stored. In fact, any object in which electrons can be stripped and separated acts as a capacitor. *Capacitance* is the ability of an object to store electric charge. Practical capacitors are made of two conducting surfaces separated by an insulating layer, called a dielectric. The capacitance of an ideal capacitor is defined by $C = Q/\Delta V$ where Q is the magnitude of the net charge on each surface, and ΔV is the potential difference between the two conducting surfaces. The SI unit of capacitance is the **farad** (F): 1 farad = 1 F = 1 coulomb/volt. The farad is ridiculously large. So large, in fact, that most capacitance measurements use microFarads (μF), nano (nF), and picoFarads (pF) as their unit of measure. The capacitance of a capacitor filled with a dielectric is given by $C = \kappa C_0$, where $C_0 = Q/\Delta V_0$ is the capacitance in the absence of the dielectric, and κ is the dielectric constant. The presence of a dielectric occupying the entire gap between the capacitor plates *increases* the capacitance by a factor κ . A list of dielectric constants of some materials (at room temperature, 1 atm) is given in following table:

Material	κ
Vacuum	1
Air	1.00054
Paper	1.5 - 3.0
Polystyrene	2.5
Hard Rubber	2.8
Cellulose Acetate	2.9 - 4.5
Plexiglas	3.4
Nylon	3.5
Vinyl	4.0

There are many different types of capacitors: tubular, mica, variable, and electrolytic to name a few. A simple capacitor is the *parallel plate* capacitor, represented in Figure 1. The plates have an area A and are separated by a distance d with a dielectric (κ) in between. The plates carry charges $+Q$ and $-Q$, respectively, on their surfaces. The capacitance of the parallel plate capacitor is given by

$$C = \kappa C_0 = \kappa \frac{Q}{\Delta V_0} = \kappa \frac{\epsilon_0 A}{d} \quad (1)$$

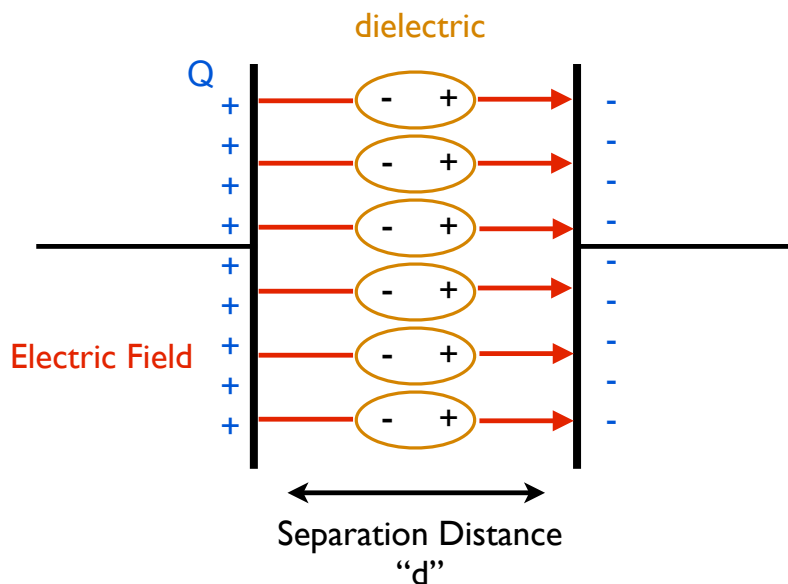


Figure 1: A parallel plate capacitor with dielectric (in orange). Note the electric field lines stop on the negative charges of the dielectric, reducing the \vec{E} density.

The symbol used to represent capacitors in circuit schematics reflects their physical construction, common capacitors (Fig. 2a) have no polarity, while electrolytic capacitors (which must be hooked up with the correct polarization) are represented by a curved plate for its negative terminal (Fig 2b). Capacitors can be arranged in series (see Fig. 3a) and/or parallel (Fig 3b). The effective net capacitances for n capacitors in series and parallel are as follows:

$$\text{Series : } \frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \dots + \frac{1}{C_n} \quad (2)$$

$$\text{Parallel : } C = C_1 + C_2 + C_3 + \dots + C_n \quad (3)$$

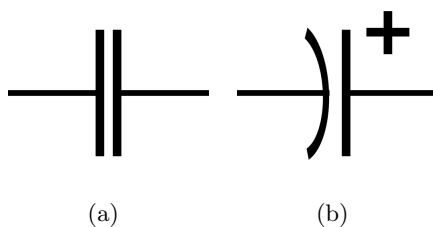


Figure 2: (a) Capacitor circuit symbol (b) Polarized capacitor

In this lab we will become familiar with capacitors - in series and parallel - in circuits using the breadboard. We will also use a parallel plate apparatus to investigate its capacitance with different plate spacings, and types of dielectrics.

Part 1: Capacitors in Series and Parallel

In this part of the lab you will be given 3 different capacitors, jumping wires, a breadboard, a multimeter and a capacimeter. You will investigate how capacitors behave in series and parallel and how voltages are distributed in capacitor circuits. With the given materials, complete the following tasks:

1. Using the Capacimeter, measure the capacitance of each of the three capacitors given.
2. Connect them in series using the breadboards which have connectivity between all sets of five holes (at a minimum). Measure the effective capacitance of this combination. Repeat this for a parallel configuration. Which configuration produces a higher capacitance? Compare the measured values with those calculated from Equations 2 and 3.

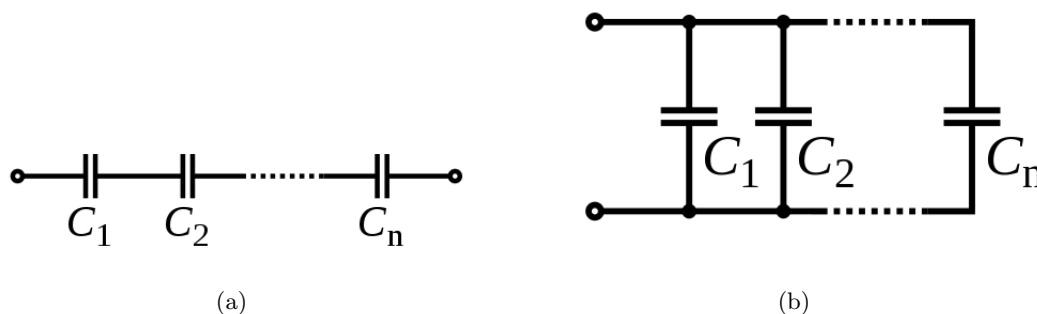


Figure 3: (a) Capacitor circuit symbol. (b) Parallel capacitor.

Part 2a: Parallel Plate Capacitor with Dielectrics

In this part of the lab you will be investigating a parallel plate capacitor with different dielectrics in-between them. You will be given a variable capacitor, consisting of two parallel aluminum plates which can be adjusted to various separations. The movable plates are mounted on a calibrated slide ruler, giving the separation distance in *cm*. You will also have a vernier caliper to make any measurements. Be sure to wear the provided grounding strap, properly connected to power supply ground, to minimize the effect of static charge on the plates. The conductive binding posts on the outer sides of the plates allow electrical connections, such as a capacimeter or electrometer, to be made. When attaching any cable leads to the binding posts, make sure their leads are separated as far as possible to avoid any error caused by stray capacitance from the wires. You will be given several dielectrics: Paper (10 sheets), Nylon (white mesh), Vinyl/PVC (opaque), Transparency Sheets/Cellulose acetate (3 sheets). With the given equipment materials, complete the following tasks (experiments):

1. Set the parallel plates 1 cm apart and measure the capacitance using the capacimeter. Repeat this for five other separation distances, up to 12 cm. In order to minimize random errors, it is very important that all of your measurements be performed several times. Don't forget to measure the diameter of the plates. To account for stray capacitance in the wire, zeroize the capacimeter by disconnecting one of the wires, but leave it near the binding post. Make sure your hands are not near the wires while zeroing.
2. Set the plate separation to 1 cm. Insert a sheet of paper in between the plates and observe the change in capacitance. Repeat this process for 10 sheets. Is there a difference in capacitance when more sheets of paper are used? Record your observations. The thickness of paper is 0.1 mm. Repeat this task with the 3 transparency sheets.

3. Devise (and perform) an experimental procedure to verify that a parallel plate capacitor filled with two different dielectrics (nylon and vinyl) placed in parallel, side by side (see Fig. 4), behaves as two separate capacitors in series. Record some values of the capacitance. Remember to measure the thickness of the nylon and vinyl sheets. *Hint: you may want to have the plates as close as possible.*

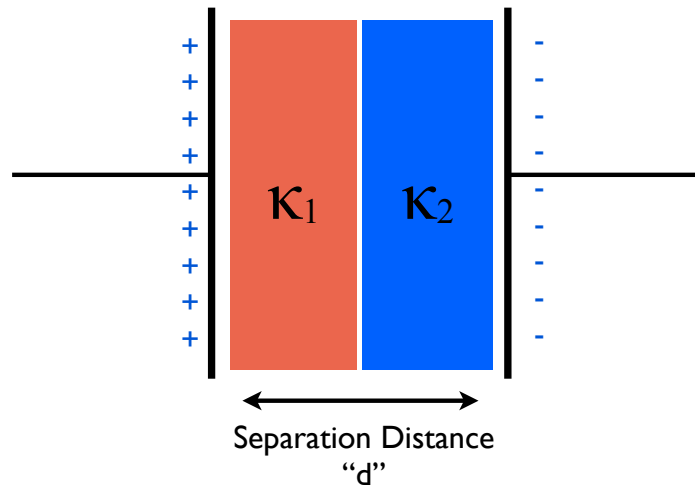


Figure 4: Parallel plate capacitor filled with two different dielectrics: κ_1, κ_2 .

Part 2b: Parallel Plate Capacitor with the Electrometer

An *electrometer* is a voltmeter that directly measures the voltage without draining appreciable charge from the object/system it is measuring. This allows for indirect measurements of charge and current. We will use the electrometer to measure the voltage across the parallel plate capacitors. To setup the electrometer:

1. Set the capacitor plate spacing to 0.5 cm. Connect the low-capacitance test cable (with BNC leads) to the electrometer input. Next, connect the ground lead of this test cable to the moveable plate of the capacitor plate and the other lead to the fixed plate + of the capacitor (see Fig. 5).
2. Connect the ground of the electrometer, and the movable plate of the capacitor to the (-) terminal of the power supply. Also connect the fixed plate to the (+) terminal of the power supply.
3. Turn on the electrometer and set it to the 30 VDC scale. Press the zero button to remove any excess charge from the electrometer. Turn on the power supply and set the voltage to 15.0 Volts. Use the reading on the electrometer to set the voltage, not the power supply meter.
4. Disconnect the (+) power supply wire lead from the terminal on the fixed plate of the capacitor. The capacitor is now charged and should remain charged for a while because of the electrometer. To charge the capacitor back to 15.0 V, momentarily touch the (+) lead from the power supply to the terminal of the fixed plate capacitor.

Your task: Charge the plates to 15.0 Volts and set the capacitor plate spacing to $d=0.5$ cm. Increase the separation distance between the capacitor plates slightly (use increments of 0.5 cm) and record the voltage off of the electrometer. Repeat this for 6 different capacitor plate spacings. What relationship do you observe? Try some plate separation distances less than 0.5 cm and observe what happens. Comment on your observations.

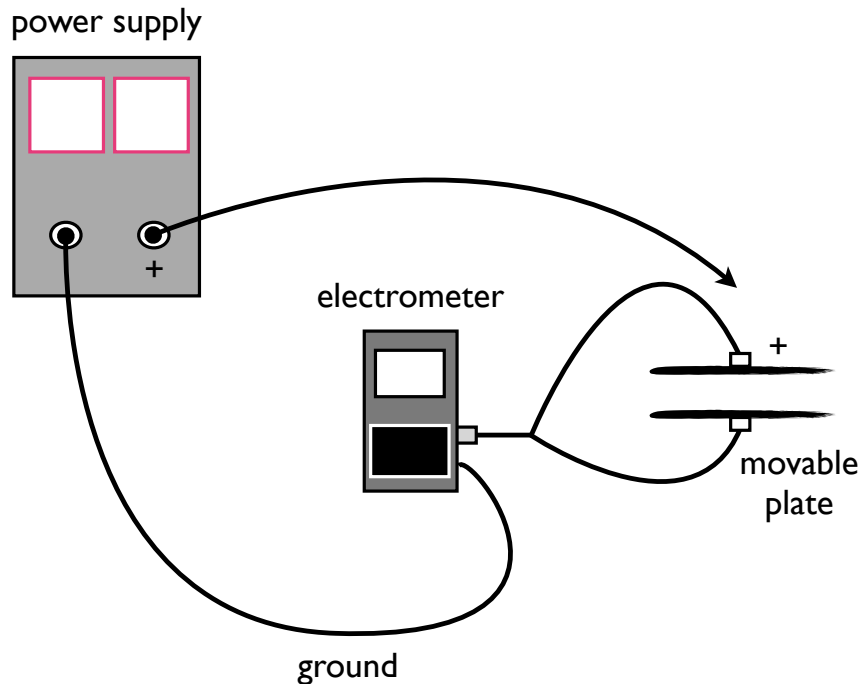


Figure 5: Electrometer set up.

A full lab report is not necessary for this lab. Instead complete the worksheet on the following page and turn it in with your signed data sheet.

PHYS 221, Lab 4 Questions

Name:

CWID:

Write your answers on a separate sheet and attach your signed datasheet when turning it in. You must show all of your work for full credit. Make it clear to me you understand what you're doing. Any graphs or tables should be made via computer software and attached to this handout.

Answer the following questions using the data you acquired from Part 2 (parallel plates) of this lab. Make sure to answer any questions from the circuit section (part 1) as well.

1. Calculate the capacitance using Equation 1 for the various separation distances of task 1 (for part 2a). How do these values compare with the data taken with the capacitor? Don't forget to take into account the dielectric constant for air.
2. Calculate the dielectric constant for the paper used. How do your values compare with the listed value from the table above?
3. Calculate the dielectric constant for the transparency sheets. Does the capacitance of the parallel plates depend on the thickness of the dielectric?
4. Show that the capacitance for the setup in Figure 4 is given by

$$C = \frac{2\epsilon_0 A}{d} \frac{\kappa_1 \kappa_2}{\kappa_1 + \kappa_2} \quad (4)$$

5. Compare your experimental results of task 4 with Equation 4.
6. The dielectrics you insert between the parallel plates may have excess charge. What happens when you charge the plates, if this turns out to be true?
7. For Part 2b, create a plot of V vs d. What does the slope represent?
8. How much charge is found on the plates in Part 2b?