The Capacitor

Learning Goals:

1. The main goal of this lab is to study capacitance.

2. You will learn how to measure capacitance.

3. You will determine parameters that cause an increase or decrease in capacitance.

Materials:

Parallel Plate Capacitor; Capacitance meter; Excel

References:

Giancoli, Physics 7th Edition: chapter 17, sections 1, 2, 3, 4, 5, 7

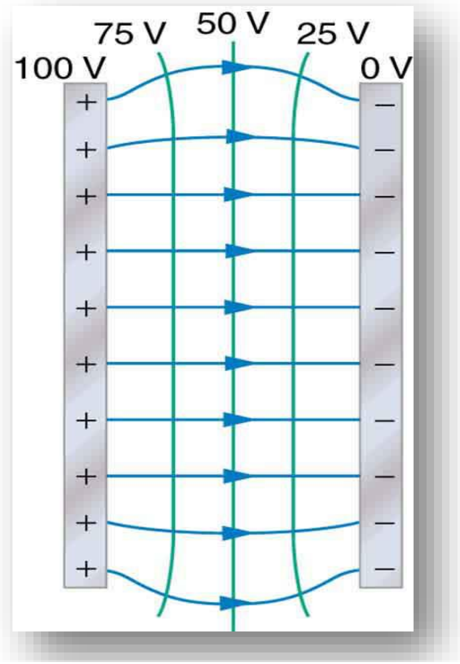

Figure 1: Parallel Plate Capacitor

Introduction:

A capacitor is a device that can store electric charge. The charge accumulated on the opposite plates of the capacitor, Q, is proportional to the potential difference, V, across the capacitor.

$$\boldsymbol{Q = CV} \tag{1}$$

The unit of capacitance is the Farad (F). From the definition above for capacitance we find that a Farad = Coulombs/Volt. A Farad is a large unit of charge storage and most capacitors found in electronic devices have capacitance values of μF, nF, or pF.
An idealized parallel plate capacitor consists of two parallel metal plates separated by a distance d. The capacitance for this geometry of the capacitor plates is given by

$$\boldsymbol{C = \frac{\kappa\epsilon_0 A}{d}} \tag{2}$$

Where κ is the dielectric constant, ε_0 is the permittivity of free space (8.85×10^{-12} C^2/Nm^2) and A is the cross sectional area of the plates.
In this experiment we will study several aspects of equation 2 using a large variable capacitor as in Figure 2.

Figure 2: PASCO Parallel Plate

Experiment:

This experiment consists of two activities. In the first one, you will determine how capacitance depends on the distance between the plates. To be able to measure the capacitance values you need to connect a multimeter to the two plates using the short cables provided. It should be noted that the connecting leads have some capacitance C_w (C_{wire} or wire capacitance) that must be determined and subtracted from all measurements. It is recommended to leave the leads in approximately the same location throughout the experiment to avoid changing C_w. Also note that large watches or metal near the capacitor may change the capacitance value. For this reason, make sure measurements are taken when hands are away from the experimental system.
In the second part you will determine the dielectric constant of rubber and Plexiglas.

You will use a Meterman CR50 Resistance and Capacitance meter. It has different measurement ranges. Today you will set it to picofarad (pF) and therefore zeroing out the meter is essential before any measurements are taken.
The meter contains a battery which provides a small constant voltage allowing charge to accumulate across the plates. Since the voltage is known, the amount of charge allows the meter to determine the capacitance reading.

Experimental Procedure and Data Taking for Activity I:

1. Verify that the plates are parallel. If not, use the two knobs on the back of one plate to adjust that plate horizontally and vertically.

2. Determine the capacitance of the cables that connect the capacitor to the meter. C_w is very small. Equation 2 shows that capacitance is inverse proportional to the distance between the plates. If the distance between plates is very large, C approaches zero. What does not approach zero, is the capacitance of the wires. Move the plates as far apart as possible to the end of the track. Connect the meter and measure C_w. This value is an estimate for the wire capacitance. It must be subtracted from all future measurements so that the recorded values only reflect the capacitance of the plates.

3. Start with a separation between plates of 0.5 cm and record the capacitance. Now increase the separation in steps of 0.5 cm to 4 cm and record the capacitance for each step. Each student has to do a complete set of measurements. Record all data in Excel.

Analysis of Activity I:

1. Determine the average and standard deviation of each measured capacitance value for each of the eight distances. Make sure you subtracted C_w before averaging the values. Now create a graph that shows each of the 3 runs on one plot. How repeatable were your group's measurements?

2. Calculate the predicted capacitance values using equation 2.

3. Create a graph of $C_{predicted}$, and the average of $C_{measured}$. Add error bars equal to the calculated standard deviation (the uncertainty of each individual measurement) to the $C_{predicted} - C_{measured}$ values on the graph. Inspect the graph and comment on accuracy. How many data points cross the x-axis? What does this mean? (Refer to measurement uncertainties and see 68% of data falling within 1 standard deviation determines conclusive agreement with prediction, 95% within 2 standard deviation determines consistency.)

Experimental Procedure and Data Taking for Activity II:

1. Place two sheets of plastic between the plates and reduce the plate separation until the plastic touches the plates and record the capacitance for the plastic $C_{plastic}$. Note that spacers are present on one side of the plates – therefore making it impossible to have the plastic (or rubber dielectric) material to completely touch the plates. Because of these spacers, do you predict that the measured capacitance will be greater or less than the predicted capacitance? Explain.

2. Now slide out the plastic without moving the plates and record the capacitance for only air between the plates, C_{air}. Repeat 4 times and find the average and standard deviation.

3. Subtract C_w from each of the measured values of C. You now have at the same distance measurements of $C_{plastic}$ and C_{air} for comparison.

Analysis for Activity II:

1. Calculate the dielectric constant (with associated uncertainty) and compare it to accepted values.

$$\frac{C_p}{C_{air}} = \frac{\kappa_p}{\kappa_{air}} = \frac{\kappa_p}{1} \qquad (3)$$

2. Repeat 1-5 for rubber sheets.

References:

Image credit: PASCO scientific