Physics 196 Lab 4:   Capacitance

Equipment:
Variable Capacitor and Rail (PASCO ES-9079), Capacitance Meter (Extech LCR Meter 380193), Alligator-Alligator Leads (2 red and 2 black), dielectric sheets (glass, plexiglass, Styrofoam), Heavy Duty Aluminum Foil, 0.1 mm thick transparency film, sharpie, ruler, scissors.

Layouts:


Fig. 1: Single PASCO Capacitor

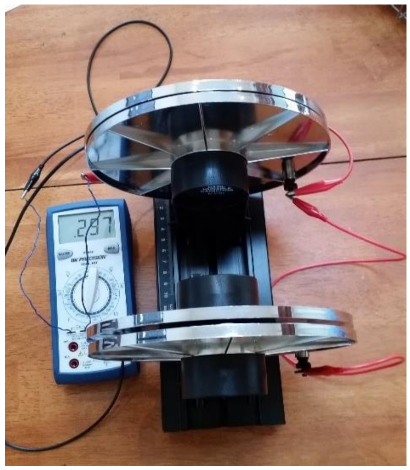

Fig. 2: Two Capacitors in Parallel

Fig. 3: Two Capacitors in Series

Fig. 4: Aluminum Foil Capacitor Electrodes

Summary:
Working in teams of three, students will investigate capacitance and its measurement. First, using the PASCO Variable capacitor plates, students will measure the capacitance (with a digital multimeter) at different capacitor plate separations. Then they will carefully plot the capacitance as a function of (1/separation) and compare their results to what they would expect from the standard parallel plate capacitance formula. Emphasis will be on graphing and slope determination. Next, students will measure the change in capacitance as various dielectric materials are inserted between the capacitor plates. Joining with a second team, students will next measure the capacitance of two capacitors in series and two capacitors in parallel, and compare their results to predictions. Finally, students will build their own capacitor out of household materials (aluminum foil and transparency plastic) and carefully measure its capacitance as the size of the aluminum foil electrodes are changed.

Prelab: Tape the first page of the write-up (with materials, equipment photographs and summary) in your lab notebook. Have the rest of the procedures available. Look up the standard formula for the capacitance of a parallel plate capacitor with area A and plate separation d, and write it in your lab notebook. Write down the value of ε_0. Look up and write down the expected dielectric constant κ for glass and plexiglass. Understand what it means to hook up two capacitors in series, and write down the formula for the combined capacitance of two capacitors in series. Understand what it means to hook up two capacitors in parallel, and write down the formula for the combined capacitance of two capacitors in parallel.

Lab: As usual, keep an accurate log of what you are doing at each step of the lab (your procedures and results) so that if you were to look back on your work a year from now, you could understand exactly what you had done. Also, include a summary with your conclusions and what you learned at the end of the write-up. The instructor's emphasis this week will be on graphs which show how capacitance varies with plate separation and area.

A: Set up the PASCO parallel plate variable capacitor so that the left plate indicator reads 0 mm on the scale which is attached to the rail. Move the right plate as close to the left plate as it gets (there are spacers). Use the V and H adjustment knobs on one plate to make sure the plates are parallel. Measure the separation (it should be 1 mm), and read out the right plate distance (in cm) indicated on the scale. Make a data table in your lab notebook. The first column will be for plate separation (in mm) with row values at 2mm, 3mm, 4mm, 5mm, 6mm, 7mm, 8mm, 9mm, 10mm, 12mm, 14mm, 16mm, 18mm, 20mm, 25mm, 30mm, 35mm, 40mm, 45mm, and 50mm. For the second column, calculate and record the readout distance (cm) expected on the scale for the right plate to get the desired separation. For the third column, calculate and record the value of (1/separation) in units of m^{-1}. (Don't forget the factor of 1000: for 2 mm plate spacing d you should have $1/d = 500\ m^{-1}$). For the fourth column, measure and record the capacitance at each spacing. The measured numbers should be in nF (10^{-9} F). Now make a careful graph (taking up just over half a page) in your lab notebook. The horizontal axis will be (1/d) going from 0 to 500 m^{-1} with each graph paper square cooresponding to $1/d = 20m^{-1}$. Mark the x axis line at 100, 200, 300, 400 and 500 m^{-1}, The vertical axis will be C in nF, ranging from 0 to 0.15 nF, with each graph paper square corresponding to 0.005 nF, and with the scale marked every 0.01 nF. Carefully graph the measured capacitance values, and draw in a best fit line (weighted towards the measurements at small separations). Draw in lines for "rise" and "run" and measure values of "rise" ΔC (converted to Farads) and "run" Δ(1/d) in m^{-1} and calculate the slope of the line (units of F*m). Rewrite your parallel plate capacitor formula solving for area A. Calculate A using the measured slope (C*d) and the value of ε_0. Compare this to the area you would get using the actual plate diameter of 0.175 m. Discuss why the answers might be different. Discuss any deviations from straight line behavior in your graph at large plate separations.

B: Insert a dielectric (glass, plexiglass or foam) between the capacitor plates and close them against the dielectric. Measure the Capacitance. Remove the dielectric and measure the capacitance again. Calculate the ratio of these two capacitances, which should be the material's dielectric constant (aside from a correction for a small remaining air gap). Do this for all three dielectrics. Compare to your expected values, and discuss your results. (Note that the values you looked up could be very different from the measurements since the values you looked up were generic for a range of material compositions).

C: Working with a second team that is ready with step B, set one capacitor to a spacing of 1mm and measure its capacitance C1 and set the second capacitor to a spacing of 2 mm and measure its capacitance C2. Measure the combined capacitance of the two capacitors in parallel using the correct configuration of shared alligator leads (see figure 2) and compare it to what you expect from your prelab formula. Measure the combined capacitance of the two capacitors in series (see figure 3) and compare it to what you expect from your prelab formula. Do you believe the formulas? Why?

D: You will now make your own capacitor by using two sheets of aluminum foil separated by a plastic transparency sheet (thickness 0.1 mm, dielectric constant of about 2). By folding the aluminum foil, you will make capacitors with four different plate areas. You will then plot the capactitance as a function of area.

First carefully obtain two pieces of aluminum foil that are about the size of a lab notebook page. Keep the foil as free of wrinkles as possible. You will need to cut the aluminum foil pieces (which will be your top and bottom electrodes) so they look like the electrodes in figure 4. These electrodes are 25 cm high by 20 cm wide, with tabs for connecing the capacitance meter. Use a sharpie to make vertical lines every 5 cm (where you will be folding the aluminum foil to make different capacitor areas). The connection tabs are 5 cm wide and 2.5 cm high. Notice that they are in different places on the two electrodes, so that connections can be made without the electrodes making electrical contact with each other.

Open a lab notebook to an unused portion and place the bottom electrode on the page. Place the transparency sheet above the bottom electrode, making sure to cover all of the aluminum except for the two tabs. Place the top electrode on top of the transparency sheet and line it up carefully with the bottom electrode. Your assembly should look like the picture in figure D1. Now close the notebook on the capacitor and connect the capacitance meter as in figure D2.

Fig. D1, aluminum foil electrodes separated by Transparency sheet, placed in open notebook.

Fig. D2, Measuring capacitance with pressure exerted on capacitor to smooth wrinkles.

Measure the capacitance while pressing down hard on the notebook. It will be helpful to place the two notebooks from your lab parners on top of the notebook with the capacitor. Apply increasing pressure until the capacitance stops changing (much) so you can be sure that the aluminum foil electrodes are flat. Record the capacitance value.

Now open up the lab notebook, and fold the two capacitor electrodes to ¾ of their former size (as in figure D3) and repeat the capacitance measurement, recording your new value. Do this again with ½ sized electrodes (figure D4) and ¼ sized electrodes (figure D5).

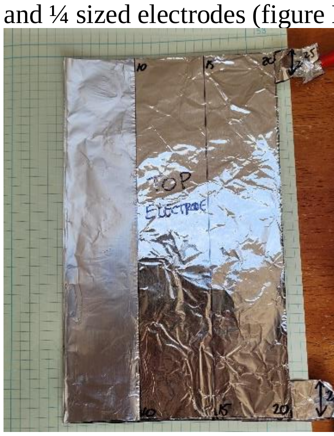

Fig. D3 (3/4 size capacitor)

Fig. D4 (1/2 size capacitor)

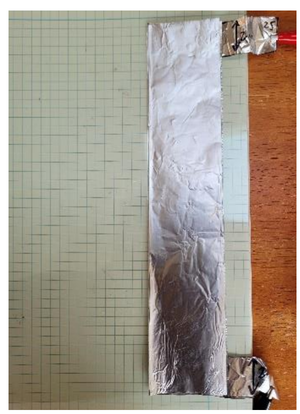

Fig. D5 (1/4 size capacitor)

Make a careful (1/2 page) plot of the measured capacitance (vertical axis) as a function of capacitor area (horizontal axis). Make a best fit line and calculate the slope (converted to units of F/m^2). Compare this value to what you would get using the capacitance formula from the prelab assuming a dielectric constant of 2 for the plastic. (You will need to look up a value for ε_0.) Discuss why your best fit line might not go through (0,0). Don't forget the conclusion paragraph at the end of your lab write-up.