LAB 4: CAPACITANCE

Equipment List:
Electrometer (ES-9078A)
Proof plane - wand with aluminum coated disk on the end
Faraday ice pail (ES-9042A)
Electrostatic Voltage Source (ES-9077)
Variable Capacitor (ES-9042A)
Handheld (Extech) DMM
Signal input cable for electrometer - has two alligator clips
Red and black banana to fork terminal leads
1 Red and 2 Black banana leads
Alligator clips

Purpose: To explore the relationship between charge, potential difference, and capacitance and see how altering the geometry of the conductors in the capacitor can change the capacitance.

Introduction: This lab will use the variable capacitor. Charge will be measured from its plates using the proof plane, Faraday ice pail, and electrometer. The electrometer measures the potential difference across the inner and outer cages of the Faraday pail. It does this by connecting each cage to one plate of an internal capacitor, labeled C_E in figure 1 and the potential difference across that capacitor can be measured by the internal voltmeter.

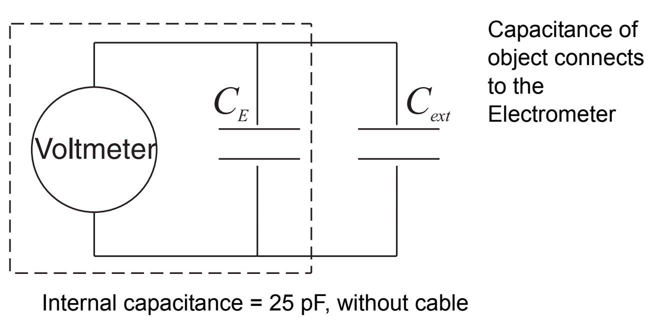

Figure 1: Electrometer circuit diagram. Figure from Pasco Electrostatics manual 9080A.

Procedure: Setup - To relate the potential difference read on the electrometer to the actual charge on the proof plane in the Faraday pail, you will need to find the capacitance of the Faraday pail, signal leads, and the electrometer's internal capacitance as one unit. This will allow you to use the formula:

$$Q_{\text{pp}} = C_F\,(\Delta V_E)$$

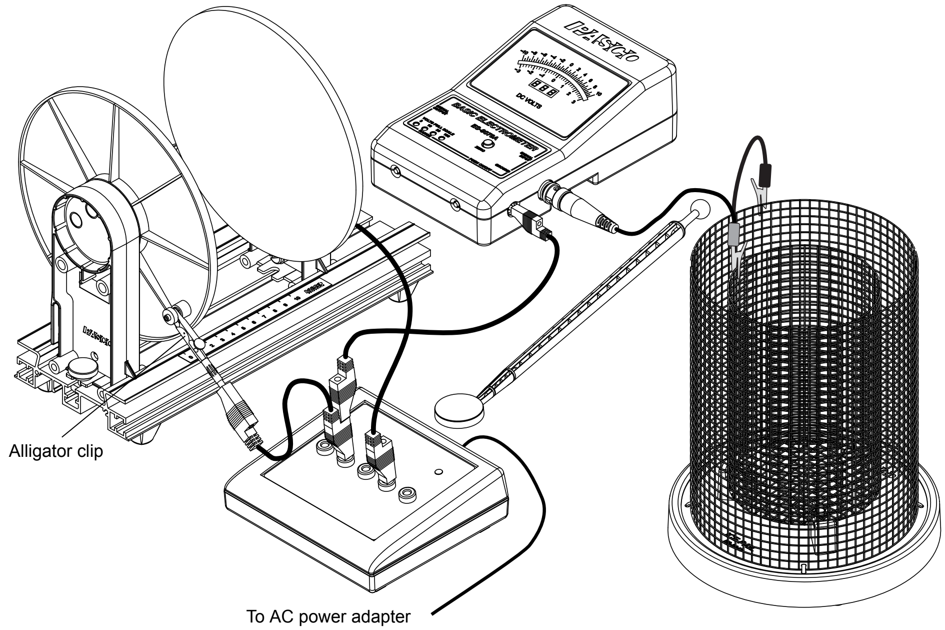

Figure 2: Variable Capacitor, Faraday ice pail, and electrometer setup. Figure from Pasco Electrostatics manual 9080A.

1. Set up the electrostatics voltage source, Faraday ice pail, and electrometer as shown in figure 2, being careful to make sure the electrostatic voltage source is plugged into the mains socket on your bench, but not yet switched on, and the electrometer is grounded through the COM port on the electrostatic voltage source.

2. Use the handheld DMM to measure the capacitance across the Faraday ice pail **with the electrometer connected** by clipping the black lead from the DMM to the outer cage and the red lead from the DMM to the inner cage and record the value as C_F.

Part 1 -

1. Set up the all equipment as shown in figure 2. Arrange these devices so that the variable capacitor is as far away from the electrometer as possible. The variable capacitor has an initial plate separation of 6 cm and is connected to the +2000 VDC port on the voltage source and switch on the source. The Faraday Ice Pail should be connected to the electrometer, and the electrometer is grounded through the COM port on the electrostatics voltage source. Ground the cages and zero the electrometer.

2. Momentarily ground a proof plane and then use it to examine the charge density of the capacitor, using the ice pail to measure the charge. Investigate the charge density at various points on the plates — both on the inner and the outer surfaces. How does the charge density vary over the plate? Record a few values of the potential difference from the electrometer together with a diagram showing where on the plates the samples were taken.

3. Choose a point near the center of the positive capacitor plate and sample charge density

at that point. Record the value of the voltage that appears on the electrometer ΔV_E. You will use this to find the charge on the variable capacitor plates.

4. Use $Q_{\text{pp}} = C_F\,(\Delta V_E)$ to calculate the charge on the proof plane and record the result.

5. Calculate the expected capacitance for the variable capacitor in this arrangement using the formula for the capacitance of a parallel plate capacitor. The diameter of the capacitor plates is 18 cm.
$$C = \frac{\epsilon_0 A}{d}$$

6. Calculate the charge that should be on the capacitor according to theory by using the equation $Q_{\text{th}} = C\,(\Delta V)$, where $\Delta V = 2000$ V is the potential difference across the capacitor plates.

7. Now compare the theoretical value for the charge with what is measured by the electrometer. Measure the diameter of the proof plane. (Notice that the area of the proof plane is much smaller than the area of the plates of the capacitor!) Calculate the ratio of the area of one capacitor plate A_{cap} to the area of the proof plane A_{pp} and multiply that by the charge of the proof plane Q_{pp} to get the total charge measured on the capacitor:
$$Q_{\text{meas}} = Q_{\text{pp}} \frac{A_{cap}}{A_{pp}}$$

8. How does your measured value Q_{meas} compare to the value expected from theory Q_{th}? If they are different, what effects might have contributed to the discrepancy?

Part 2 -

1. Keep the same setup from the previous part. Again, choose a point near the center of one capacitor plate and measure charge density at this same point using 5 different capacitor plate separations, d, in total (one of them should be the initial 6 cm separation). Is the capacitance greater when the plates are closer together or farther apart? How does the charge vary with capacitance?

2. Plot the inverse of the plate separations ($1/d$) on the horizontal axis of the graph against ΔV_E on the vertical axis. You may use the computer to do this if the printer is working, or you may plot it by hand in your lab book.

3. If your graph is a straight line, find the slope of the line. Why do you think the graph has the shape it does? (Remember from the previous part that $\Delta V_E \propto Q$ where Q is the charge on the capacitor.) Does this support the idea that the capacitance of a parallel plate capacitor is inversely proportional to the separation of the plates?

Part 3 -

1. Keep the basic setup of the equipment as in part 2. The variable capacitor has an initial plate separation of 6 cm and is connected initially to the +3000 VDC port on the electrostatics voltage source. Make sure the Faraday Ice Pail is still grounded as before.

2. Keep the plate separation constant and change the potential across the plates by changing the setting of the voltage source. You have to move the connecting cable from the +3000 V to the +2000 V port. Examine the charge density near the center of one capacitor plate. Repeat with +1000 VDC. How does the charge vary with the voltage? Why?

Conclusion: How does the charge on the plates vary as capacitance is changed, but potential difference held constant? How does charge change when the potential difference is varied, but the capacitance is constant? Are there any sources of error in this experiment (that you did not already point out in part 1)? How might you alter the experiment or apparatus to avoid those errors? How could you extend this experiment / what other questions might you investigate?