Physics 212
Lab 3 – Capacitance

Introduction: In this lab we will study capacitance, which is the charge to voltage ratio between two separate conductors. You will first use a parallel plate capacitor with an induced charge on it, along with an electrometer, to discover the relationship between the voltage on the capacitor and the distance separating the two plates of the capacitor. Second, you will experimentally determine the capacitance of a commercial capacitor by partially discharging it through a known resistance.

Theory: Capacitance is a measure of how much electric charge a device can hold for a given voltage. The device consists of two conducting plates separated by a dielectric through which the electric field is able to propagate. The equation for capacitance is written

$$C = \frac{Q}{V}, \qquad \text{or} \qquad C = \frac{\Delta Q}{\Delta V}. \tag{1}$$

If two capacitors are connected together in parallel (same voltage across each capacitor), their effects add as follows:

$$C_{int} + C_{ext} = \frac{Q_{int} + Q_{ext}}{V}. \tag{2}$$

Therefore, if the total charge on the two capacitors remains constant, the total capacitance varies inversely with the voltage V. The simplest form of a capacitor is two parallel conducting plates, each of area A, separated by a distance d. From the geometry of the plates, we have

$$C = \frac{\varepsilon_o A}{d}. \tag{3}$$

When the charge on a capacitor is allowed to drain out through a resistive circuit (this is referred to as discharging the capacitor), the rate of the discharge with time can be used to calculate the electric current flowing through the circuit. This can be written

$$I = \frac{\Delta Q}{t}. \tag{4}$$

Also, as the charge flows out from the capacitor, the voltage will decrease. The current flowing in the circuit must follow Ohm's Law,

$$V_{avg} = IR. \tag{5}$$

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By combining equations (4) and (5), one can calculate the charge that flows through the circuit if the average voltage, resistance, and time for the current to flow are known.

$$\Delta Q = \frac{V_{avg} t}{R} \qquad\qquad (6)$$

Procedure:

Preparatory calculations for parallel plate capacitor with variable separation distance:

1. Calculate C_{ext1} the capacitance of the parallel plate capacitor at a separation distance of 10 cm using equation (3). The diameter of the plates is 20 cm.
2. Solve equation (2) for V.
3. Obtain an equation for V_1/V_2 assuming the total charge is constant, the internal capacitance is constant, and the external capacitor changes from C_{ext1} to C_{ext2}.
4. Substitute equation (3) into C_{ext2} and solve for d_2.
5. Calculate d_2 such that $V_1/V_2 = 2/1$, where C_{ext1} is your result from step 4 and C_{int} is 35 pF. This is the new separation distance that will reduce the voltage on the parallel plate capacitor by one-half.

Experimental determination of plate separations for 2:1 voltage ratio:

1. Connect the parallel plate capacitor to the electrometer as shown in Figure 1.
2. Separate the plates of the capacitor by 10 cm.
3. Set the electrometer to the 10 V setting.
4. Have one student zero the electrometer. The student should be sitting still and touching the ground wire with one hand, while the other hand is resting on and ready to move the plastic slider of the capacitor.
5. Have a second student charge a rubber rod with rabbit fur at a substantial distance (at least 6 feet) from the parallel plate capacitor.
6. Release the zero on the electrometer.
7. Move the rubber rod slowly towards the electrometer until the voltage reading on the electrometer reads 8 V. (The voltage reading occurs due to the rubber rod inducing a charge on the parallel plate capacitor and the internal capacitor of the electrometer.)
8. While both students remain as still as possible, slide the plates of the capacitor together until the voltage reading has decreased to one-half of its original value.
9. Record the new separation distance of the plates (d_2).
10. Repeat steps 2-9 until you have completed three trials and find the average value of d_2.
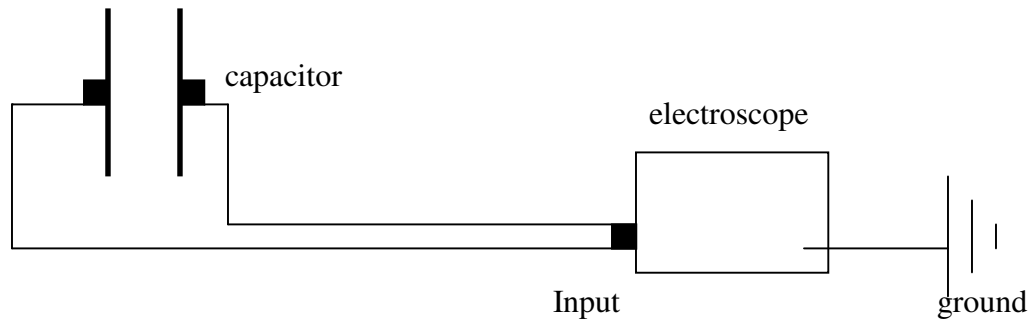
Figure 1: Parallel Plate Capacitor Setup

Experimental determination of capacitance by discharge:

1. Connect the ceramic, cylindrical capacitor as shown in Figure 2.
2. Charge the capacitor to 9 V using the battery provided by your instructor. This can be done by touching the battery terminals simultaneously to the corresponding terminals on the capacitor.
3. Set the resistor to a value between 1000 Ω and 5000 Ω.
4. Touch the free wire to the open resistor terminal. This will close the circuit and allow the capacitor the begin discharging.
5. Measure the time is takes for the voltage to drop from 9 V to 7 V using a stopwatch.
6. Repeat steps 2-5 until you have completed three trials and take the average of your time values.
7. Combining equations 1 and 6, compute your experimental value for the capacitance.
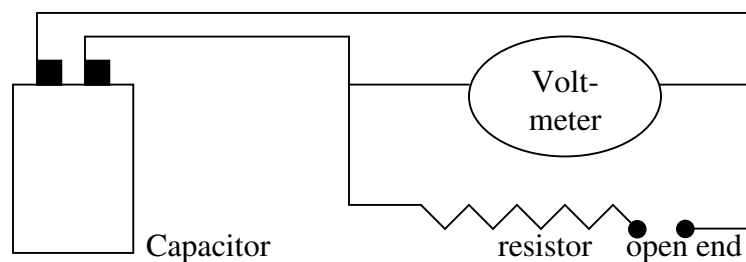8. Record the manufacturers value for the capacitance stamped on the capacitor.

Figure 2: Capacitor Discharge Setup

Report Sheet for Lab 3 – Capacitance

<u>Theoretical determination of plate separation for 2:1 voltage ratio with d_1 =10cm:</u>
Calculate C_{ext1}, the capacitance of the external parallel plate capacitor, using d=10cm.

Solve the capacitor combination equation (2) for V.

Obtain an equation for V_1/V_2 assuming the total charge is constant, the internal capacitance is constant, and the external capacitor changes from C_{ext1} to C_{ext2}.

Substitute equation (3) into C_{ext2} and solve for d_2.

Calculate d_2 such that $V_1/V_2 = 2/1$, where C_{ext1} is your result from step 4 and C_{int} is 35 pF. This is the new separation distance that will reduce the voltage on the parallel plate capacitor by one-half.

<u>Experimental determination of plate separation for 2:1 voltage ratio with d_1 =10cm:</u>

Trial   1: d_2 = _____

           2: d_2 = _____   Average d_2 = _____

           3: d_2 = _____

Experimental determination of capacitance by discharge:

Battery Voltage used to charge capacitor _____

Resistance used to to discharge capacitor _____

Time for 2V drop on capacitor

      Trial 1 _____

      Trial 2 _____   Average _____

      Trial 3 _____

Calculation of capacitance based on above information:

Value stamped on capacitor:

Questions:

1. For the parallel plate capacitor, compare the values of d_2 found by experiment and by calculation. Assuming the calculated value is correct, what was your experimental error?

2. Calculate the voltage you would expect if the plates were moved to a distance of 1 mm apart. 2mm? 3 mm?

3. For the ceramic capacitor, compare the values of the experimental and manufacturer specified capacitance. Assuming your experimental value is correct, what is the error of the manufacturer's value?

4. Why might the manufacturer stamp an inexact value on the capacitor?