Capacitors and a Galvanometer

1 Object

To investigate, understand and verify how capacitances are added together both in series and parallel, to consider the charge leakage of a capacitor, and to employ a galvanometer to measure capacitance.

2 Apparatus

Voltage supply, ballistic galvanometer, double pole-double throw switch, voltmeter, wires, capacitor circuit board.

3 Theory

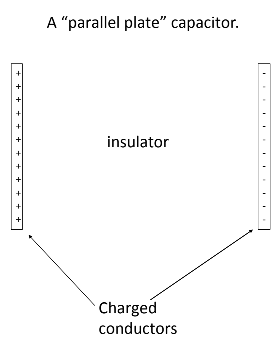

Figure 1: A parallel plate capacitor consists of two flat metal plates facing each other, separated by an insulator or "dielectric".

A capacitor, or condenser, consists of two conductors separated by some insulating medium such that equal but opposite charge may build up on the conductors. As charge builds up on each conductor, a potential difference across the capacitor also builds.The capacitance of a capacitor is defined by the relationship between the quantity of charge on each conductor and the potential difference between them:

$$C = \frac{Q}{V} \tag{1}$$

where C is the capacitance, Q is the quantity of charge on the positive side of the capacitor, and V is the resulting potential difference across the capacitor. Q is often referred to simply as the charge on the capacitor (even though the total charge on a capacitor is zero). The greater the capacitance of a capacitor, the more charge Q it can hold at a given potential difference. Equation 1 may be rewritten in the form

$$Q = CV \tag{2}$$

to see that the amount of charge on a capacitor is directly proportional to both the capacitance and the voltage or potential difference. When capacitors are connected either in series or parallel, the combination has some equivalent capacitance, C_{eq}. When capacitors are added together in *series*, the charge on each capacitor must be the same and the potential differences add together which leads to the result

$$\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \dots . \tag{3}$$

When the capacitors are connected in *parallel*, the potential differences are the same for each capacitor, and the charges add together leading to

$$C_{eq} = C_1 + C_2 + C_3 + \dots \tag{4}$$

How can we determine the capacitance of a capacitor or combination of capacitors using a galvanometer? When a charged capacitor is discharged through a galvanometer, the maximum needle deflection is proportional to the charge which passes through the instrument. You will verify this in the lab. Restating this in equation form we have:

$$\text{Charge} = k * \text{Deflection} \tag{5}$$

where k is a constant of proportionality to be determined for a particular galvanometer. Once the galvanometer is calibrated, which involves determining k, any capacitor or combination of capacitors, may be charged by some voltage source and then discharged through the galvanometer. If the deflection is measured, one may use equation 5 to determine the charge which was on the capacitor and a voltmeter may be used to determine the potential difference across the capacitor before it was discharged. Knowing both Q and V, equation 1 may be used to determine the capacitance of the unknown.

4 Procedure

4.1 Calibration of the Galvanometer

1. Be sure the galvanometer is on a flat, stable surface. Zero the galvanometer using the zero turn-pot on the top of the galvanometer. Once you have satisfactorily zeroed the device, ***leave this control alone***.

2. Assemble the circuit shown in figure 2 involving the voltage source, double pole-double throw switch, galvanometer and the known standard capacitor. On your circuit board, be sure to connect red to red and black to black.

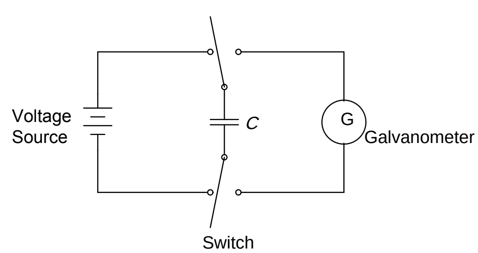

Figure 2: circuit with one capacitor

3. Set the source voltage to about 6 volts.

4. Throw the switch such that the capacitor is charged by the source. When the voltmeter reads a steady value (this will happen almost immediately), record this value in the data.

5. Check that the galvanometer needle has stabilized at the zero mark. Throw the switch over to the second position such that the charged capacitor is now discharged through the galvanometer. Observe the needle deflection and note the maximum deflection. You should try to record these to the nearest quarter division if possible; certainly to at least the nearest half division. You may want to practice once to see just how far the needle will deflect.

6. Repeat steps 2 and 3 until you have recorded two values for this voltage with deflection to that side. Switch the polarity of the galvanometer by exchanging the ends of the wires connected between it and the switch: put the black wire into the red connection at the switch, and the red wire into the black connection as in the photo above. When the capacitor discharges now, the charge will move in the opposite direction through the galvanometer, like water reversing its flow. In response, the galvanometer needle will deflect in the reverse direction. Repeat till you record two values deflecting that way.

7. Repeat this process for 7 other source voltage values spanning the full range of deflections if possible.

4.2 Determining unknown capacitances.

1. Set the Voltage source to about 8-9 Volts.

2. Disconnect the known capacitor and connect to C_1. Again, measure the deflection of the needle twice going in each direction and record these values in the data tables. If the needle deflects off the scale, lower the voltage. If the deflection is too small, increase the voltage

3. Repeat steps 1-2 for unknowns C_2 and C_3 in place of C_1.

4. Connect C_1, C_2, and C_3 in series as shown in figure 3 on page 4. Repeat steps 1 and 2 with this configuration in place of C_1.

5. Now connect C_1, C_2, and C_3 in parallel. You can "stack" the banana connections at the end of the wires to accomplish this. Repeat steps 1-2 with this configuration in place of C_1.

6. 6. Finally, connect C_1 and C_2 in series,and then connect C_3 in parallel with both C_1 and C_2 as in the "Combination" diagram in figure 3. Again, repeat steps 1-2 with this configuration in place of C_1.

4.3 Charge leakage of a capacitor.

1. You should have one more capacitor available, which is an electrolytic capacitor. Be sure to connect red to red and black to black when working with this capacitor because it is polar, meaning it can only be connected a particular way. Double check to make sure that the stripe on the capacitor faces the black connection and that the capacitor legs are not twisted. If the capacitor is connected backwards it may rupture.

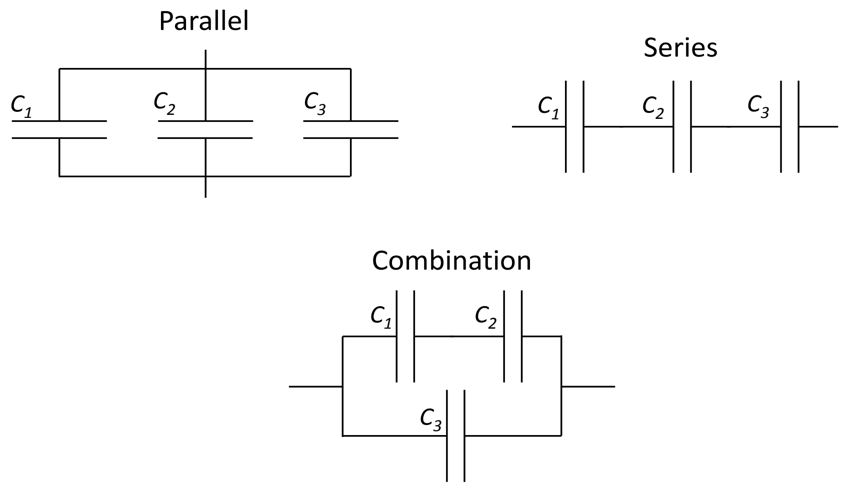

Figure 3: Various three capacitor configurations

2. Once you are sure the electrolytic capacitor is connected properly, charge and immediately discharge the capacitor. The deflection should be nearly full scale. If it is not, increase the voltage until you get a deflection of at least 80% of full scale.

3. After the voltage is set and the needle has settled back at 0, charge, then discharge the capacitor and record the deflection.

4. Repeat step two with the same capacitor but this time after charging the capacitor move the double pole switch to the center position so that the capacitor is hooked to nothing. Let it sit for 1 minute and then discharge the capacitor and measure the deflection. Repeat for 2, 3 and 4 minute waits.

5. Repeat this process for one of the unknown capacitors, but adjust the voltage value carefully so that the initial deflection matches that of the electrolytic capacitors.

5 Calculations

5.1 Calibration of the Galvanometer

1. For part 1 of the procedure you should have eight different sets of four measured galvanometer deflections which correspond to eight different voltages using the standard, "known" capacitor. For each of these trials, calculate the average deflection. Also calculate the charge on the capacitor before it was discharged using equation 2. List these values in your results section.

2. Construct a graph of capacitor charge vs deflection. Perform a linear regression of the data on the graph. The equation of this line is your calibration relationship for converting galvanometer deflection to capacitor charge.

5.2 Determining unknown capacitances

1. First you will determine the capacitances of the unknown capacitors. For each of the three unknown capacitances, calculate the average deflection. Then determine the charge Q which

was on the capacitor before it was discharged. Finally, determine the capacitance of the unknowns using equation 1.

2. Now that you know the capacitance of the unknowns, in a likewise manner, calculate the capacitance of the three different combinations of capacitors. These results are your experimental results. Using the previously determined values for the capacitances of the unknowns and equations 3 & 4, determine a theoretical expected value for the capacitance of these combinations. Determine the percent error between the experimental and theoretical results.

5.3 Charge leakage of a capacitor

Construct a graph of deflection vs elapsed time for the two capacitors. Put both sets of data on the same graph, if possible, clearly labeling which data is associated with which capacitor.

6 Questions

1. If you used a known capacitor with a different capacitance and repeated the experiment, would you expect to find the same regression coefficients in calculation step 5.1 #2? Explain.

2. What characteristics of a capacitor do you think would affect how well it is able to hold charge? List some and explain why you feel they would affect charge leakage. Is a capacitor that readily leaks charge worthless? Explain.

3. If you had only used the forward polarity during calibration, would that introduce an error? If so, how large would the error be and what type of error is it?

Capacitors and the Galvanometer Data Sheet

Part 1 - Calibration of the galvanometer.

Trial	Voltage	Def. right	Def. right	Def. left	Def. left
Units					
1					
2					
3					
4					
5					
6					
7					
8					

Part B - Determining Capacitance.

Unknown	Voltage	Def. right	Def. right	Def. left	Def. left
Units					
C_1					
C_2					
C_3					
Comb. 1					
Comb. 2					
Comb. 3					

Part C - Charge leakage of a capacitor.

	0 min	1 min	2 min	3 min	4 min
Units					
Electrolytic Cap.					
Additional Cap.					