Lab: Capacitors in Series and Parallel

Objective

The objective of this experiment is to measure the equivalent capacitance of several capacitors connected in series and parallel. First the individual capacitances and their equivalent will be measured. Then we will charge the capacitors by connecting the combination to a battery and then measuring the voltage across each capacitor. This will allow us to calculate the charge on the capacitors and then calculate the equivalent capacitance using the equation $C = Q/\Delta V$.

Equipment

- (3) capacitors of different values
- 6-volt battery
- Multimeter (voltage and capacitance measurement capability)
- connecting wires (leads)
- alligator clips

Background

A capacitor consists of two conducting objects (plates) separated by a non-conducting medium (dielectric). Figure 1 shows a capacitor connected to a battery. The capacitance of this capacitor is the ratio of the magnitude of the charge on one of the conducting plates to the potential difference across them.

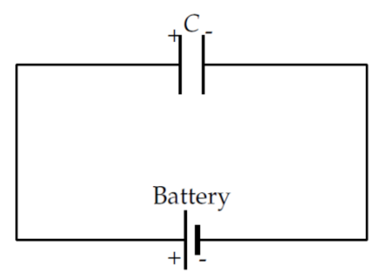

Figure 1 Capacitor connected to a battery

$$C = \frac{Q}{\Delta V}$$

Capacitors may be combined in series or parallel. Figure 2a shows three capacitors connected in series and connected to a battery. Figure 2b shows three capacitors connected in parallel and connected to a battery. Note the polarity in each case. Theoretically, the equivalent capacitance for the series connection is given by

$$C_{\text{eq}} = \left(\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}\right)^{-1}$$

and that for the parallel connection is given by

$$C_{\text{eq}} = C_1 + C_2 + C_3$$

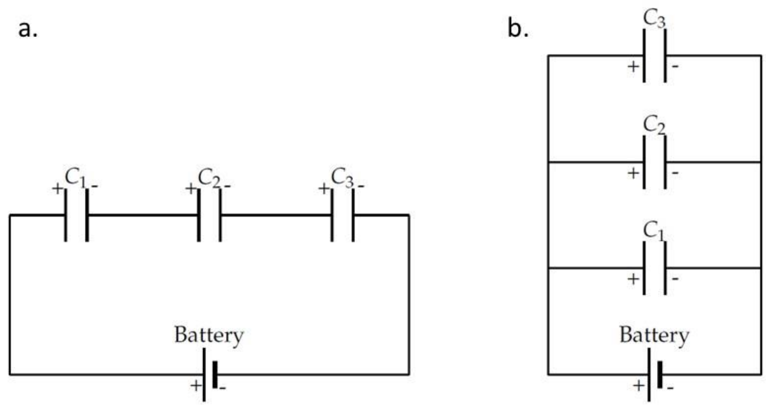

Figure 2 Capacitors in (a) series and (b) parallel

Procedure

1. Make sure that each capacitor is discharged ($V = 0$) by connecting a wire lead across the capacitor for about 30 seconds.
2. Use the capacitance meter to measure the capacitance of each capacitor. Record the values in your data table.
3. Make sure each capacitor is still discharged by repeating step (1) here.
4. Wire the capacitors in series as shown in Figure 2a <u>(but do not connect them to the battery)</u>. Pay close attention to the polarity of the capacitors and the way they are connected. The capacitors used in this experiment are electrolytic capacitors and the polarity of the plates is important. Make sure the ends of the lead wires do not come in contact with each other.
5. Using a capacitance meter, measure the capacitance of the series combination (connect the meter to the free ends). This is $(C_{\text{eq}})_{\text{act}}$.
6. Connect the battery to the series combination of capacitors.
7. Measure the voltage across each capacitor and the battery voltage and record these values in your data table. You are finished with the series combination. NOTE: The longer you keep the meter engaged with the capacitors, the more they will discharge (and the voltage will reduce). If your meter is equipped with a hold button, have a 2nd person press it shortly after you place the 2nd electrode from the meter to the capacitor.
8. Disconnect the capacitors, discharge each capacitor as you did before and wire the circuit in parallel as shown in Figure 2b <u>(but do not connect them to the battery)</u>.
9. Using a capacitance meter, measure the capacitance of the parallel combination. This is $(C_{\text{eq}})_{\text{act}}$.
10. Connect the battery to the parallel combination of capacitors.
11. Measure the voltage across each capacitor and the voltage across the battery and record in your data table. See note in step 7. The recorded voltages should all be about the same.
12. Show your data to the instructor to make sure your data are OK. If so, you are finished with the experimental procedure.

Analysis

Series Connection

1. For each capacitor, calculate the charge on each capacitor using the relation $Q_i = C_i \Delta V_i$ where $i = 1, 2, 3$. Each capacitor should have about the same charge. If this is not the case, you will need to disassemble your setup, discharge each capacitor and conduct the lab again.
2. The values of the charges should be the same within the limits of experimental error. Find the average value of the charge $\bar{Q}$. This is the charge on the equivalent capacitor.
3. Calculate the experimental equivalent capacitance $C_{\text{eq}} = \bar{Q}/\Delta V_{\text{bat}}$ and record it in the data table.

4. Calculate the equivalent capacitance predicted by theory, $(C_{\text{eq}})_{\text{theo}}$ and record it in the data table.
5. Calculate the percent difference between the equivalent capacitance predicted by theory $(C_{\text{eq}})_{\text{theo}}$ and the measured equivalent capacitance $(C_{\text{eq}})_{\text{act}}$.
6. Calculate the percent difference between the equivalent capacitance predicted by theory $(C_{\text{eq}})_{\text{theo}}$ and the experimental equivalent capacitance, C_{eq}.
7. For each connection, calculate the amount of energy stored in each of the three capacitors. Add up these energies to get the total energy stored.
8. Calculate the amount of energy stored in the equivalent capacitance and show that this energy is equal to the sum of the energies stored in the individual capacitors.
9. Calculate the percent difference between the equivalent capacitance total energy U_{eq} and the total electrical potential energy of the individual capacitors ΣU.

Parallel Connection

1. For each capacitor, calculate the charge on each capacitor.
2. Calculate the total charge, $\Sigma Q = Q_1 + Q_2 + Q_3$.
3. Calculate the experimental equivalent capacitance $C_{\text{eq}} = \Sigma Q / \Delta V_{\text{bat}}$ and record it in the data table.
4. Calculate the equivalent capacitance predicted by theory, $(C_{\text{eq}})_{\text{theo}}$ and record it in the data table.
5. Calculate the percent difference between the equivalent capacitance predicted by theory $(C_{\text{eq}})_{\text{theo}}$ and the measured equivalent capacitance $(C_{\text{eq}})_{\text{act}}$.
6. Calculate the percent difference between the equivalent capacitance predicted by theory $(C_{\text{eq}})_{\text{theo}}$ and the experimental equivalent capacitance, C_{eq}.
7. For each connection, calculate the amount of energy stored in each of the three capacitors. Add up these energies to get the total energy stored.
8. Calculate the amount of energy stored in the equivalent capacitance and show that this energy is equal to the sum of the energies stored in the individual capacitors.
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Series Connection

Capacitor	Capacitance C [μ F]	Voltage V [V]		Charge Q [μ C]		Elec. Pot. Energy U [μ J]
0.1 μ F						
10 μ F						
100 μ F						
$(C_{eq})_{act}=$		$\Delta V_{bat}=$		$\bar{Q}=$	$\Sigma U=$	
$C_{eq}=$		% Difference (act. vs theo.)			$U_{eq}=$	
$(C_{eq})_{theo}=$		% Difference (eq. vs theo.)			% Diff (U) =	

Parallel Connection

Capacitor	Capacitance C [μ F]	Voltage V [V]		Charge Q [μ C]		Elec. Pot. Energy U [μ J]
0.1 μ F						
10 μ F						
100 μ F						
$(C_{eq})_{act}=$		$\Delta V_{bat}=$		$\Sigma Q=$	$\Sigma U=$	
$C_{eq}=$		% Difference (act. vs theo.)			$U_{eq}=$	
$(C_{eq})_{theo}=$		% Difference (eq. vs theo.)			% Diff (U) =	

Questions

1. Which way should capacitors be connected to give you the largest amount of energy stored? Explain you answer!
2. How well do your data confirm the theoretical equations for the parallel combination of capacitors? Answer the question as quantitatively as possible.
3. How well do your data confirm the theoretical equations for the series combination of capacitors? Answer the question as quantitatively as possible.
4. What do you think are the two most important sources of error?
5. Using three capacitors that are exactly 5 μF, 9 μF, and 11 μF, how would you arrange all (3) capacitors to make an equivalent capacitance of exactly 4 μF?