E11a Series and Parallel Capacitors

Introduction:

If the charges move around a circuit in the same direction at all times, the current is said to be ***direct current*** (DC), which is the kind produced by batteries. In contrast, the current is said to be ***alternating current*** (AC) when the charges move first one way and then the opposite way, changing direction from moment to moment.

For this lab a new circuit component, the ***capacitor***, will be introduced with the purpose of examining the characteristics and behavior of capacitors using AC current. AC circuits are generally considered more complex than the DC circuits initially studied and have a larger variety of components.

Capacitor combinations will be constructed in a circuit with a function generator power supply and sensors for monitoring voltages and current, which will be used to determine charge and potential difference during a charge cycle. From this data, it will be possible to determine the capacitance of each capacitor in combination and the overall capacitance for each circuit.

Apparatus:

- Circuit Breadboard
- Pasco 850 Interface
- Pasco Current Sensor
- Pasco Voltage Sensors
- Hook-Up Wires & Connectors
- 3 Resistors, 50, 100 & 430 Ohm
- 3 Capacitors, 1000, 680 & 100 microFarad

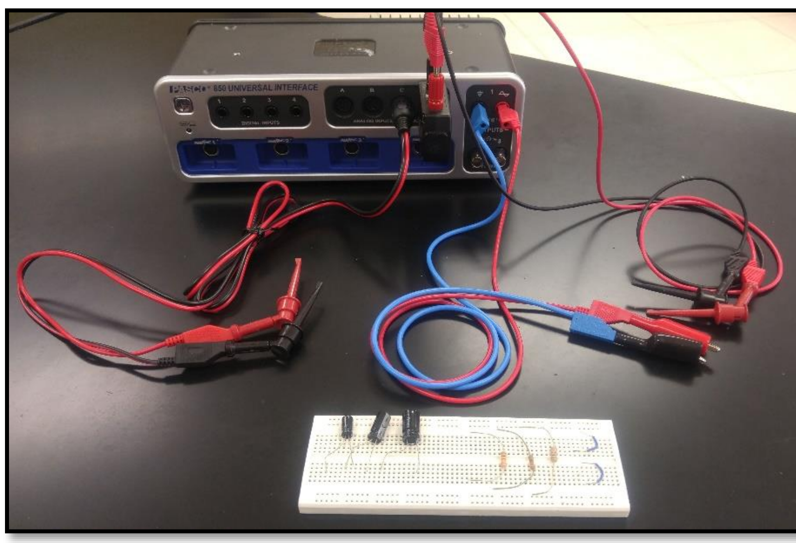


Figure 1

Discussion:

Before beginning this experiment, it is necessary to first read up on and understand the relevant material in your textbook.

Capacitors in series and parallel Cutnell & Johnson. **<u>Physics</u>**, *Chapter* **20** *section* **12**

Capacitors

A capacitor is a device used to store electric charge, where the amount of charge stored depends on the voltage applied to it and the capacitor's physical characteristics. A system consisting of two identical parallel plates separated by a distance is called a parallel plate capacitor.

When a potential difference *V* is applied across the capacitor plates, they will have equal and opposite charges, $+q$ and $-q$. Therefore, the charge q on a capacitor is directly proportional to the applied voltage and the constant of proportionality is called the capacitance, *C*.

$$q = CV \quad (1)$$

$$C = \frac{q}{V} \quad (2)$$

The units for capacitance in the International System is Farads (F), equivalent to Coulombs per Volt.

When a voltage applied to a capacitor over a period of time changes, the charge in the capacitor also changes storing electric potential energy.

$$\frac{\Delta q}{\Delta t} = C\frac{\Delta V}{\Delta t} \quad (3)$$

The change of the charge Δq divided by the change in time Δt is defined as the current *I* through the capacitor.

$$I = \frac{\Delta q}{\Delta t} \quad (4)$$

Substituting equation 4 in equation 3,

$$I = C\frac{\Delta V}{\Delta t} \quad (5)$$

Equation 5 tells us that there is current flow when the voltage changes across the capacitor; this occurs for alternate voltage sources. For a constant voltage source, there is no current flow through the capacitor and it acts as an open circuit.

When an alternate voltage is first applied across a capacitor, there is a large current due to the large potential difference across the plates. As the capacitor charges, the current dissipates until it becomes zero as seen in figure 2 (current vs time graph).

From equation 4, we can find the relation between the charge in the capacitor and the current flowing through it,

$$\Delta q = I\Delta t \qquad (6)$$

Analyzing figure 2, the area under a charging region of the curve ($A = I\Delta t$) represents the charge of the capacitor.

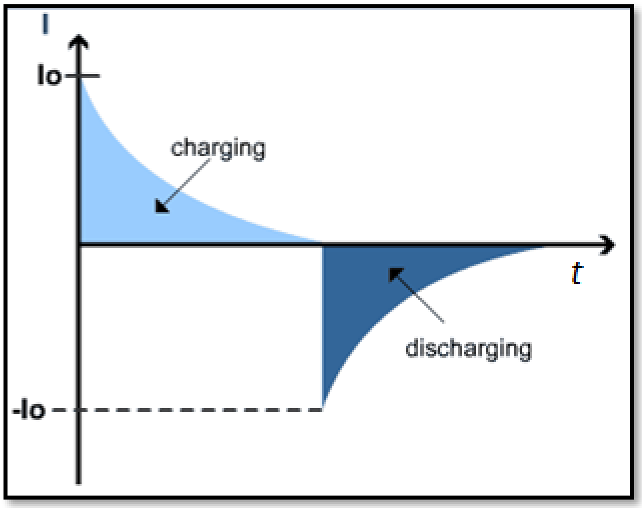


Figure 2. Current versus Time graph for a capacitor in a circuit

Like resistors, capacitors can be arranged in both series and parallel circuits. However, their behaviors are different from that of the resistor circuits. For both configurations of capacitors, an equivalent capacitance can be found to reduce the circuit.

For the capacitors arranged in parallel, the individual capacitances contribute to the overall capacitance,

$$C_p = C_1 + C_2 + C_3 + \dots C_n \qquad (7)$$

This behavior is opposite that of parallel resistors. The equivalent capacitor stores the same amount of energy and charge as the entire combination of parallel capacitors.

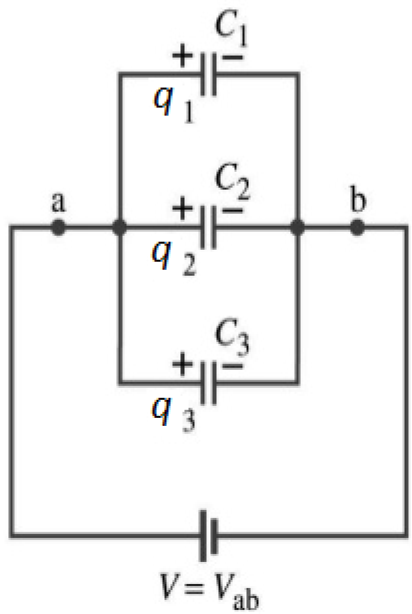


Figure 3. Capacitors $C_1, C_2,$ and C_3 form a parallel combination

The equivalent capacitance in series is different from that of the parallel combination. This is because capacitors in series combine together as reciprocals to determine the equivalent series capacitance.

$$\frac{1}{C_s} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \ldots \frac{1}{C_n} \qquad (8)$$

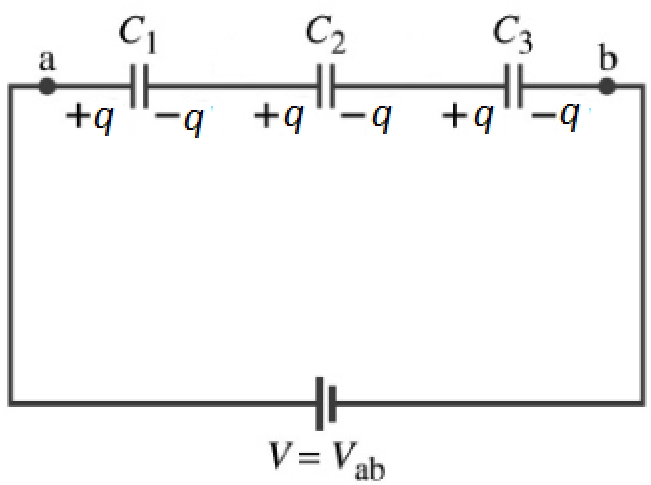
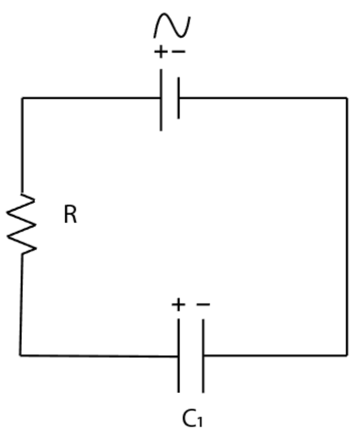


Figure 4. Capacitors $C_1, C_2,$ and C_3 form a series combination

Procedures:

Part I - Single Capacitor

1. Among the three capacitors available in your experiment, identify the one with the largest capacitance (C_1) to use on the first part of the experiment. Record the theoretical value in Data Table 1.
2. Assemble the circuit components on the breadboard. Connect the capacitor C_1 and the 100Ω resistor in series as shown in Figure 5.



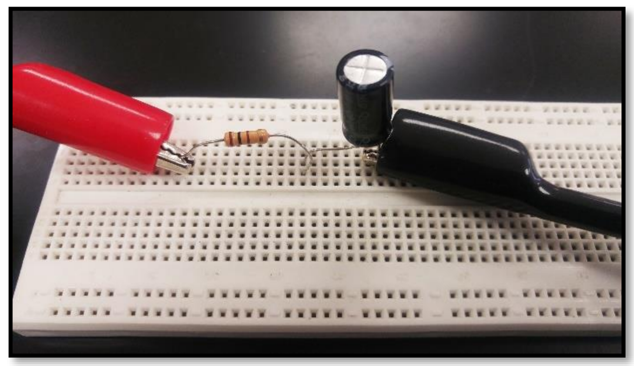


Figure 5. Circuit with single capacitor

3. Check the interface connections. Connect the AC source from Output 1 of the interface to the circuit, the positive output to the resistance and the negative output to the short leg of the capacitor. The voltage sensor should be attached to Input C on the interface; connect it across the capacitor. The current sensor should be attached to Input D on the interface; wire it in series from the positive side of the source to the resistor.
4. Activate the Capstone software start-up routine for the experiment E11a and turn on the interface.
5. Select the first tab display on the collection program, Part 1- Single Capacitor. To start collecting data click on the Monitor button located on the left-bottom corner of the screen. Watch the Voltage vs Time and Current vs Time graphs to appear. Only 5 seconds of data collection is necessary; click on the Monitor button again to stop the data collection.
6. Click on the (V, C) data label on the graph located at the left. This graph represents how the voltage on the capacitor changes as the voltage of the source changes during the time. You should have the maximum and the minimum voltage values displayed on the screen. If the values are not displayed, click on the statistic icon for active data . Document these voltages in Data Table 1.
7. Click on the (I, D) data label on the graph located at the right. This graph represents how the current through the capacitor changes with the time. Click on the icon for highlighting the

range of data ; move and resize the highlight box to enclose a region of data where the current is changing from the maximum value to zero. The area under the curve should be displayed. If not, click on the display area of active data icon . This area represents the charge in the capacitor; record it in Table 1.

8. Calculate the experimental capacitance using equation 2.
9. Compare the experimental capacitance with the theoretical value finding the percent error.

Part II - Capacitors in Series

1. Identify the theoretical values of the three capacitors (C_1, C_2 and C_3) available in your set up. Also, calculate the theoretical value for the equivalent capacitance of the capacitors connected in series using equation 8. Record the theoretical values in Data Table 2.
2. Assemble the circuit components on the breadboard. Connect the capacitors C_1, C_2, C_3 and the 430Ω resistor in series as shown is Figure 6.

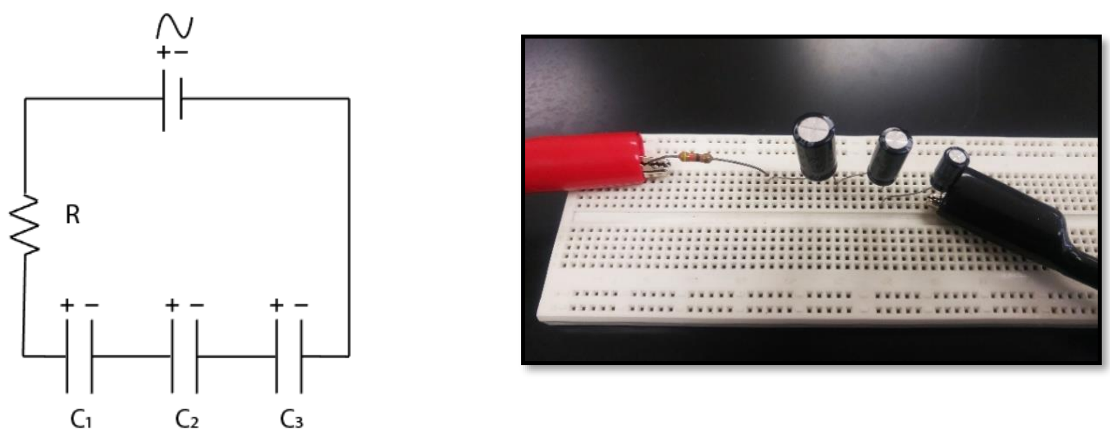


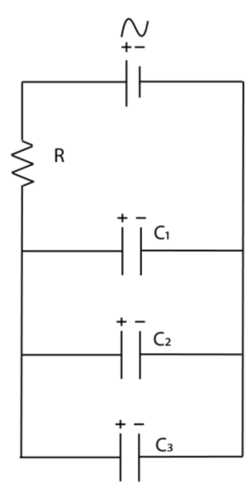
Figure 6. Circuit with capacitors in series

3. Check the interface connections. Connect the AC source from Output 1 of the interface to the circuit, the positive output to the resistance and the negative output to the short leg of the capacitor C_3.
4. Connect the voltage sensor (attached to Input C on the interface) across the set of capacitors. Make sure the positive cord from the sensor is connected to the positive (long) leg of C_1. Wire the current sensor (attached to Input D on the interface) in series from the positive side of the source to the resistor.
5. Select the second tab display on the collection program, Part 2- Capacitors in Series. To start collecting data click on the Monitor button located on the left-bottom corner of the screen. Watch the Voltage vs Time and Current vs Time graphs to appear. Only 5 seconds of data collection is necessary; click on the Monitor button again to stop the data collection.

6. Click on the (V, C) data label on the graph located at the left. This graph represents how the total voltage on the set of capacitors connected in series changes as the voltage of the source changes during the time. You should have the maximum and the minimum voltage values displayed on the screen. If the values are not displayed, click on the statistic icon for active data. Document these voltages in Data Table 2.
7. Click on the (I, D) data label on the graph located at the right. This graph represents how the total current through the set of capacitors connected in series changes with the time. Click on the icon for highlight range of data ; move and resize the highlight box to enclose a region of data where the current is changing from the maximum value to zero. The area under the curve should be displayed. If not, click on the display area of active data icon. This area represents the total charge in the equivalent capacitor; record it in Table 2.
8. Repeat steps 4 through 7, now connecting the corresponding sensors to measure voltage and current for each individual capacitor. Record the results in Table 2. Verify your results with a lab assistant.
9. Calculate the experimental capacitances C_1, C_2, C_3 and total equivalent using equation 2.
10. Compare the experimental capacitances with the theoretical values finding the percent errors.

Part III - Capacitors in Parallel

1. Identify the theoretical values of the three capacitors (C_1, C_2, C_3) available in your set up. Also, calculate the theoretical value for the equivalent capacitance if the capacitors would be connected in parallel using equation 7. Record the theoretical values in Data Table 3.
2. Assemble the circuit components on the breadboard. Connect the capacitors C_1, C_2 and C_3 in parallel. Then, connect the set of capacitors with the 50Ω resistor as shown is Figure 7.



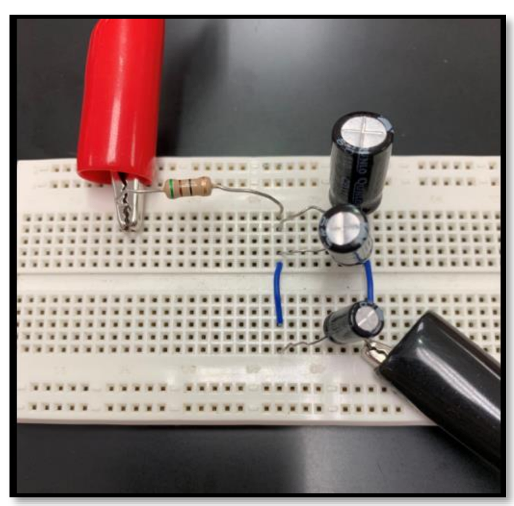
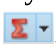
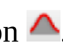


Figure 7. Circuit with capacitors in parallel

3. Check the interface connections. Connect the AC source from Output 1 of the interface to the circuit, the positive output to the resistance and the negative output to any of the negative (short) legs of the capacitors.
4. Connect the voltage sensor (attached to Input C on the interface) across the set of capacitors. Wire the current sensor (attached to Input D on the interface) in series from the positive side of the source to the resistor.
5. Select the third tab display on the collection program, Part 3- Capacitors in Parallel. To start collecting data click on the Monitor button located on the left-bottom corner of the screen. Watch the Voltage vs Time and Current vs Time graphs to appear. Only 5 seconds of data collection is necessary; click on the Monitor button again to stop the data collection.
6. Click on the (V, C) data label on the graph located at the left. This graph represents how the total voltage on the set of capacitors connected in parallel changes as the voltage of the source changes during the time. You should have the maximum and the minimum voltage values displayed on the screen. If The values are not displayed, click on the statistic icon for active data . Document these voltages in Data Table 3.
7. Click on the (I, D) data label on the graph located at the right. This graph represents how the total current through the set of capacitors connected in parallel changes with the time. Click on the icon for highlighting range of data  ; move and resize the highlight box to enclose a region of data where the current is changing from the maximum value to zero. The area under the curve should be displayed. If not, click on the display area of active data icon . This area represents the total charge in the equivalent capacitor; record it in Table 3.
8. Repeat steps 4 through 8, now connecting the corresponding sensors to measure voltage and current for each individual capacitor. Record the results in Table 3. Verify your results with a lab assistant.
9. Calculate the experimental capacitances C_1, C_2, C_3 and total equivalent using equation 2.
10. Compare the experimental capacitances with the theoretical values finding the percent errors.

E11a: Capacitors RC Circuits

Student Name______________________________________

*Lab Partner Name*______________________________________

*Lab Partner Name*______________________________________

Physics Course______________________________________

Physics Professor____________________________________

Experiment Start Date_______________________________

Lab Assistant Name	*Date*	*Time In*	*Time Out*

Experiment Stamped Completed

Data Sheet: E11a: Capacitors RC Circuits

NAME: ______________________________ DATE: __________________

Table 1- Individual Capacitor

Capacitor	Charge (from *I* vs *t* graph) (C)	Potential difference (from graph)			Capacitance (Experimental) (F)	Capacitance (Theoretical) (F)	% Error
		V_{Max} (V)	V_{Min} (V)	ΔV (V)			
C_1							

Table 2 - Capacitors in Series

Capacitor	Charge (from *I* vs *t* graph) (C)	Potential difference (from graph)			Capacitance (Experimental) (F)	Capacitance (Theoretical) (F)	% Error
		V_{Max} (V)	V_{Min} (V)	ΔV (V)			
C_1							
C_2							
C_3							
Total C							

Table 3 - Capacitors in Parallel

Capacitor	Charge (from *I* vs *t* graph) (C)	Potential difference (from graph)			Capacitance (Experimental) (F)	Capacitance (Theoretical) (F)	% Error
		V_{Max} (V)	V_{Min} (V)	ΔV (V)			
C_1							
C_2							
C_3							
Total C							

Questions:

1. What is the relationship between the individual charges (q) on the capacitors and the total charge of the equivalent capacitor for a series circuit? Do your results agree or disagree with this? (Show it with calculations)

2. What is the relationship between the individual potential differences (ΔV) across each capacitor and the potential difference across the equivalent capacitor for the series circuit? Do your results agree or disagree with this? (show it with calculations)

3. What is the relationship between the individual charges (q) on the capacitors and the total charge of the equivalent capacitor in a parallel circuit? Do your results agree or disagree with this? (Show it with calculations)

4. What is the relationship between the individual potential differences (ΔV) across each capacitor and the potential difference across the equivalent capacitor in the parallel circuit? Do your results agree or disagree with this? (show it with calculations)