Physics II
Lab 3 : Capacitors

Before Lab:
Complete the pre-lab. Detach the pre-lab paper from the manual.

During the lab:
Work through the items in this worksheet carefully reading the instructions. Complete the Procedure section first, recording the $T_{1/2}$ values and graphs for each experiment.

Caution:
First make sure the DC power supply is connected to an outlet but turned off. Turn the control dial all the way to the left.

At the end of lab:
Disconnect all equipment and keep as you found them.
Submit the completed lab worksheet.

Objectives:

- Observe the charging and discharging behavior of different capacitors
- Use the discharging curve and time constant, to experimentally calculate capacitor values
- Experimentally measure equivalent capacitance of capacitors connected in series and in parallel

Prelab Questions

1. Suppose a fully charged capacitor discharges through a R = 330 Ω resistor. If the half-life of the capacitor is 0.2s, what is the experimental value of the capacitance?
   a. 80 μF
   b. 875 μF
   c. 25 μF

2. The theoretical equivalent capacitance of C1 = 24 μF and C2 = 48 μF connected in series is
   a. 64 μF
   b. 36 μF
   c. 16 μF\

3. Series connection is made by connecting the capacitors one after the other.
   True False

4. Parallel connection is made by connecting the capacitors one after the other.
   True False

5. Theoretically we expect the equivalent capacitance of a series connection to be higher than the individual capacitor values.
   True False

Introduction:

In DC circuits, capacitors store electrical energy, which can be released to do work. When a voltage is applied to a capacitor, current flows until the capacitor can hold no additional charge. At every instant, the ratio of the stored charge q to the capacitor's voltage V is its capacitance.

$$C = \frac{q}{V} \tag{3.1}$$

This definition applies to all capacitors, no matter what their shape. The units of capacitance are farads (F): 1 farad = 1 coulomb/volt.

If you connect a resistor, capacitor, and power supply in series, current flows until the capacitor's voltage equals the power supply voltage (V0). You can then discharge the capacitor by connecting the capacitor directly to the resistor. While discharging, the capacitor's voltage decreases exponentially.

$$V = V_0 e^{-t/RC} \tag{3.2}$$

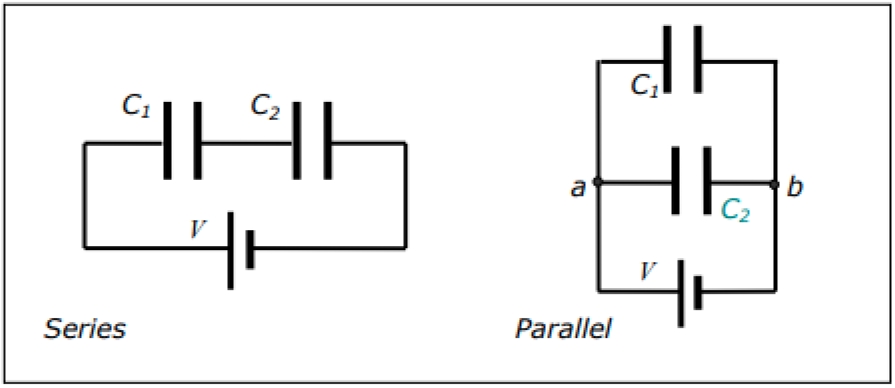
Here, V is the capacitor's voltage at time t, and V0 is its voltage at t = 0 (when discharging begins). The quantity RC in the exponent of equation (3.2) is called the time constant, τ.

$$\tau = RC \tag{3.3}$$

In Experiment II, you'll determine the time constant for two different circuits by measuring the capacitor's "half-life" T½, the time it takes for the capacitor's voltage to decrease by 50%. The half-life is related rather simply to the time constant.

$$T_{1/2} = \tau \ln 2 \tag{3.4}$$

Capacitors can be combined to form complex circuits. This lab introduces the basic characteristics of capacitors connected in series and parallel.



As you can see, a series connection means "one right after the other". Two capacitors in series behave like a single equivalent capacitor C_S, whose capacitance is given by

$$\frac{1}{C_S} = \frac{1}{C_1} + \frac{1}{C_2} \tag{3.5}$$

When connected in parallel, each capacitor offers an alternate path connecting the same two points (a and b). Current can get from a to b by flowing through C1 or through C2 Two capacitors in parallel behave like a single equivalent capacitor C_p, whose capacitance is given by

$$C_P = C_1 + C_2 \tag{3.6}$$

Procedure:

Equipment

2 capacitors with two different capacitance values
1 330 Ohm resistor
4 wires
4 patch cords
Pasco Voltage-Current sensor
Power Supply
Breadboard
Pasco Interface

Experiment

1. Turn on the power supply and turn to voltage control knob to 5V. Now turn off the power supply without changing the voltage control knob.

2. Read the labels on the capacitors. Find their capacitance values. Write down the label values of each capacitor (let's call them C1 & C2) below. These will be considered their theoretical capacitance.

   $C1_{theo}$ = ____ μF

   $C2_{theo}$ = ____ μF

3. Turn on the Pasco Interface Connect the Voltage-Current Sensor to the first port from the left on the Pasco Interface. Make sure the Pasco interface is connected to the computer. Open the Pasco Capstone software on the computer. Go to hardware setting, click on the port that is connected to the voltage sensor, and select 'Voltage-Current Sensor' from the drop down list.

4. Make a graph of Voltage vs Time. Set data sampling rate of the Voltage Sensor to 1kHz. This option is right below the graph.

Part 1: Experimental measurement of C1 capacitance

5. Use the breadboard to connect the circuit below with C1 capacitor and the 330 Ohm resistor. Check with instructor before turning on the power supply.

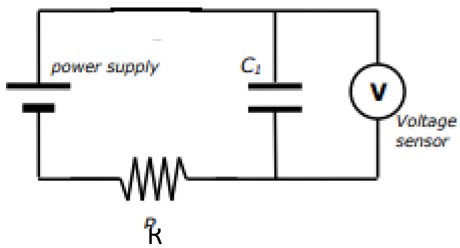


Fig. 1 : Circuit with resistor and capacitor.

6. Hit Record button on Pasco Capstone software. And then turn on the power supply. Observe the increase in voltage. Once the voltage reaches a plateau, switch off the power supply and short circuit the positive and negative leads connected to the power supply. This allows the capacitor to discharge through the resistor.
7. Zoom the section of the graph that shows the discharging curve. Save this graph to a Word document.
8. Observe the discharging behavior. Qualitatively describe your observation. How does it relate to equation 3.2?

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9. Measure the $T_{1/2}$ and use that information to calculate the experimental value of the capacitance (C) using equations 3.3 and 3.4

$T_{1/2}$ = ____________________________________s

Use equation 3.4 to find the time constant (τ)

τ = _______________________________________s

Use equation 3.3 to calculate the capacitance.

$C1_{exp}$ = _________________________________µF (Be sure to convert Farads to microFarads)

10. Calculate the percent difference between the experimental value and the theoretical value of capacitance C1.

$$\% \, diff = \frac{| \, C1_{theo} - C1_{exp} \, |}{\frac{1}{2}[C1_{theo} + C1_{exp}]}$$

Part II: Experimental measurement of C2 capacitance

11. Now we want to replace the capacitor C1 in fig. 1 with capacitor C2. Build the circuit and check with the instructor.

12. Hit Record button on Pasco Capstone software. And then turn on the power supply. Observe the increase in voltage. Once the voltage reaches a plateau, switch off the power supply and short circuit the positive and negative leads connected to the power supply. This allows the capacitor to discharge through the resistor.

13. Zoom the section of the graph that shows the discharging curve. Save this graph on the same Word document.

14. Measure the $T_{1/2}$ and use that information to calculate the experimental value of the capacitance (C) using equations 3.3 and 3.4

$T_{1/2}$ = ____________________________________s

Use equation 3.4 to find the time constant (τ)

τ = ______________________________________s

Use equation 3.3 to calculate the capacitance.

$C2_{exp}$ = _________________________________µF (Be sure to convert Farads to microFarads)

15. Calculate the percent difference between the experimental value and the theoretical value of capacitance C2.

$$\%\ diff = \frac{|\ C2_{theo} - C2_{exp}\ |}{\frac{1}{2}[C2_{theo} + C2_{exp}]}$$

Part III: Measuring equivalent capacitance for C1 and C2 connected in series

16. We now replace the C1 capacitor in fig.1 circuit with C1 and C2 connected in series. Build the circuit and check with the instructor.

17. Calculate the theoretical equivalent capacitance for this connection.

Cs_{theo} = ____ μF

18. Repeat step 12.

19. Measure the $T_{1/2}$ and use that information to calculate the experimental value of the equivalent capacitance (Cs_{exp}) using equations 3.3 and 3.4

$T_{1/2}$ = _________________________________s

Use equation 3.4 to find the time constant (τ)

τ = ___________________________________s

Use equation 3.3 to calculate the capacitance.

Cs_{exp} = ______________________________μF (Be sure to convert Farads to microFarads)

20. Calculate the percent difference between the experimental value and the theoretical value of capacitance C2.

$$\% \, diff = \frac{|\, Cs_{theo} - Cs_{exp} \,|}{\frac{1}{2}[Cs_{theo} + Cs_{exp}]}$$

Part IV: Measuring equivalent capacitance for C1 and C2 connected in parallel

21. We now replace the C1 capacitor in fig.1 circuit with C1 and C2 connected in parallel. Build the circuit and check with the instructor.

22. Calculate the theoretical equivalent capacitance for this connection.

Cp_{theo} = ____ μF

23. Repeat step 12.

24. Measure the $T_{1/2}$ and use that information to calculate the experimental value of the equivalent capacitance (Cp_{exp}) using equations 3.3 and 3.4

$T_{1/2}$ = ____________________________________s

Use equation 3.4 to find the time constant (τ)

τ = _______________________________________s

Use equation 3.3 to calculate the capacitance.

Cp_{exp} = _________________________________μF (Be sure to convert Farads to microFarads)

25. Calculate the percent difference between the experimental value and the theoretical value of capacitance C2.

$$\% \, diff = \frac{|\, Cp_{theo} - Cp_{exp} \,|}{\frac{1}{2}[Cp_{theo} + Cp_{exp}]}$$

Questions:

1. What differences do you observe in the discharging behavior of the three capacitors? Use the saved graphs in Part I and Part II, and observations of time constants in your description.

2. Is the above observation reasonable? Explain why or why not using the theoretical knowledge about capacitors.

3. Did the capacitors connected in series (in Part I) and parallel (in Part 2) behave as you theoretically expected? Explain.

4. Which of the 4 experiments have the smallest percent difference between the experimental and theoretical value? What do you think is the reason for that? Based on that reason can you think of a way to improve the capacitance measurements made by this method?

5. Would increasing the voltage of the power supply change your measurements of time constants? Why or why not?