Lab 4 - RC Circuits and the Time Constant

Safety and Equipment

- No special safety precautions are necessary for this lab.
- Computer with PASCO 850 Universal Interface and PASCO Capstone
- PASCO Voltage Sensor (Round DIN to two Banana plugs)
- 6V battery.
- 3 double alligator wires.
- 1.0 F capacitor, 10 Ω resistor (Brown, Black, Black), 50 Ω resistor, 100 Ω resistor

Introduction

When a DC voltage source is connected across an uncharged capacitor, the capacitor starts charging quickly. The only thing opposing the flow of current is any resistance in the circuit. But, as the capacitor fills, the potential of each plate gets closer to the potential of the corresponding terminal of the power supply. The drop in potential difference between a terminal of the power supply and a plate of the capacitor reduces the flow of current. This makes the rate of charging decrease as time passes. At first, the capacitor is easy to charge because there is very little charge on the plates and potential difference between a plate and a terminal is large. But as the charge accumulates on the plates, it becomes more difficult for the power supply to move additional charges onto the plates because the plates already have a charge of the same sign as the terminals on them. As a result, the capacitor charges exponentially, quickly at the beginning and more slowly as the capacitor becomes fully charged. The charge on the capacitor at any time is given by:

$$Q(t) = Q_{max}(1\text{-}e^{-t/\tau})$$

The voltage across the capacitor is proportional to the amount of charge on the capacitor:

$$V_{\text{cap}} = \frac{Q}{C}$$

The voltage across the capacitor at any time is given by:

$$V(t) = V_{\max}\,(1 - e^{-t/\tau})$$

Where $V_{\max}$ is the maximum voltage of the capacitor, and τ is the capacitive time constant ($\tau = RC$, where R is a resistance, and C is a capacitance). The time constant describes the rate of the charge of the capacitor. The greater the time constant the longer it takes to charge the capacitor and vice versa.

NOTE: Taking the extreme limits, notice that when $t = 0$, $V(0) = 0$ which means there is not any charge on the plates initially. Also notice that when t goes to infinity, V approaches $V_{\max}$. For any finite t, the voltage is less than $V_{\max}$, which means it takes an infinite amount of time to completely charge the capacitor.

Objective:

- *Experimentally determine the time constant of the R-C circuit.*
- *Investigate how a resistance affects the rate of charging of a capacitor.*

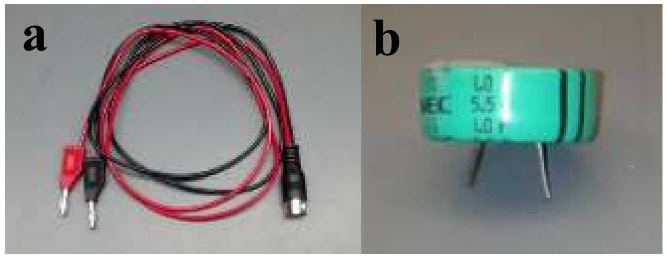

Figure 1. (a) The PASCO Voltage Sensor, which acts as a voltmeter for our purposes.
(b) The 1.0 F capacitor. The black stripes on the right side indicate the negative terminal.

Do not hook up the capacitor backwards!

Part #1. Data Recording

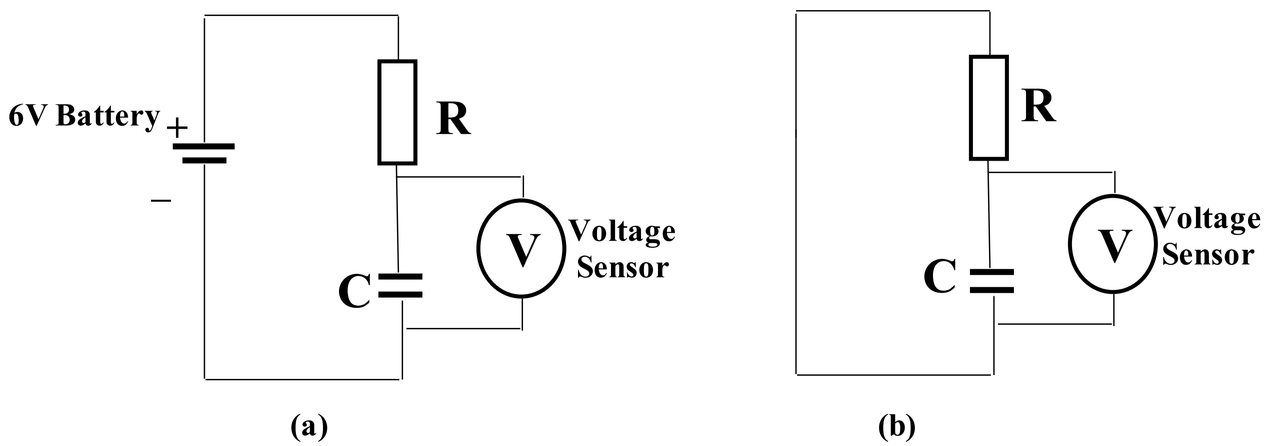

Figure 2. Schematic diagram of RC circuit for (a) charging and (b) discharging of the capacitor.

1. ***Very carefully*** insert Voltage Sensor into analog input A. The notch on the DIN plug must be facing up.
2. Use a double alligator wire to connect the 1.0 F capacitor in series with a 10 Ω resistor.
3. Construct the circuit shown in Figure 2(a) with Voltage Sensor connected across the capacitor.
   - **Important:** the negative (-) terminal of the capacitor gets connected to the negative (black) of both the power supply and the voltage sensor.
4. Open file "RC Circuit Experiment" from https://physlab.tamucc.edu/#Phy2
5. Discharge the capacitor by placing a metal object directly across it.
6. Start the Capstone recording. You should see the voltage start at a low value and build up toward 5 V.
7. Pull the banana cables from the terminals of the Power Supply when the voltage across the capacitor reaches 4.2 V. Don't let them touch; but wait to connect them together to discharge.
8. Immediately Stop recording.
9. ***Highlight and Copy*** values of both, ***time and voltage***, and transfer them to Excel spreadsheet.
10. Simultaneously connect the banana connectors (which used to be plugged into the power supply) and start recording. This is equivalent to Figure 2(b). You should see the voltage start between 1 and 4 V and decrease toward zero.
11. Stop recording when the voltage across the capacitor gets below 0.5 V.
12. ***Highlight and Copy*** values of both, ***time and voltage***, and transfer them to Excel spreadsheet.
13. Replace the resistor with a 50 Ω resistor, switch to the 50 Ω Capstone page. Repeat steps 5-12.
14. Replace the resistor with a 100 Ω resistor, switch to the 100 Ω Capstone page.

Part #2. Analyzing the Data

1. Plot the data collected during charge of the capacitor as ***three series*** of V vs. t on the same graph.
2. Label the plot as Graph 1 and include a legend to identify each of three series BUT omit the trendline.
3. Compare three graphed series and describe how the difference in the value of the resistance affected the rate of charge of the capacitor. Include this statement in the abstract.
4. Plot the data collected during discharge of the capacitor as ***three individual V vs. t graphs*** labeled as Graph 2a, 2b, and 2c.
5. Fit each plot into an exponential function and display the equation of the trend line on the graph.
6. Replace Y with V and X with t in the equation.
7. Determine the time constant, τ, from the trendline equation.

HINT: The voltage across the capacitor during the discharge varies by: $V(t) = V_{\max}\, e^{-t/\tau}$

8. Compare three calculated time constant and describe how the difference in the value of the resistance affected the rate of discharge of the capacitor. Include this statement in the abstract.

NOTE: The capacitor was 1.0 F.

RC Circuit	with 10 Ω resistor	with 50 Ω resistor	with 100 Ω resistor
Expected Time constant (s) (Calculated by formula)			
Experimental Time constant (s) (From the trendline)			
%Difference			

Table 1. Summary of the experimental results of the discharging capacitor where the expected value of the time constant was calculated by formula …., and the experimental value of the time constant was extracted from a trendline equation by ……

Requirements for the Data Report:

The report must contain a **Header** at the top (Title of Lab, Authors, and Date).

The **Abstract Section** must contain the following in the paragraph form:

- Brief Introduction with the objectives of the lab and background information about RC Circuits including
  - the description of an RC Circuit,
  - the definition of a time constant of an RC Circuit,
  - an example of a use of an RC Circuit as a timing device.
  - the theoretical equations for charging and discharging an RC circuit.
- Methodology broadly describing what was done, using what tools, and what was measured/recorded.
  - To avoid redundancy, use an example of one of three resistors; and then say that the same methods were used on the remaining resistors.
  - Make sure to describe how the collected data was analyzed through graphing and how the information on the time constant was extracted from Graphs 2a, 2b, and 2c.
- The Data Summary should point the importance of Graphs and Table 1 for achieving the purpose of the lab:
  - How Graph 1 was used to compare the length and rate of charge of the three RC circuits.
  - How Graphs 2a, 2b, and 2c were used to assess the effect of a resistance on the rate of discharge.
  - Is the length of charge similar for each resistor?
  - How does rate of charge compare to rate of discharge for each resistor?
  - What impact does the resistance have on charging and discharging?
  - Based on Table1, how does resistance affect the time constant?
  - For each resistor, how close the experimental values of the time constants to the expected values?
  - State the reasons for differences between the expected and experimental values of the time constant.
- The lab manual contains several imperatives in Part 2 that will guide you with the Data Summary.

Data Section must contain the following:
[*Each graph and table should be labeled and captioned based on purpose and circuit components*]

- DO NOT include raw data tables w/ voltage vs time.
- 1 Summary Table
- 1 Graph w/ all three sets of charging data (DO NOT fit trendlines)
- 3 Graphs w/ each set of discharge data (Fit trendlines to each discharge graph)