RC Circuits

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)
- 2 Power Supply cables (Banana plugs with slip-on Alligator clip on one end)
- 2 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:

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

Where V_{max} is the maximum voltage of the capacitor, and τ is the capacitive time constant ($\tau = RC$, where R is resistance and C is 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*

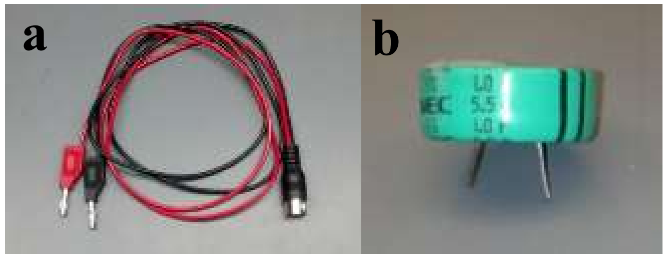

Figure 1. (a) The PASCO Voltage Sensor, which acts as a voltmeter for our purposes.

(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

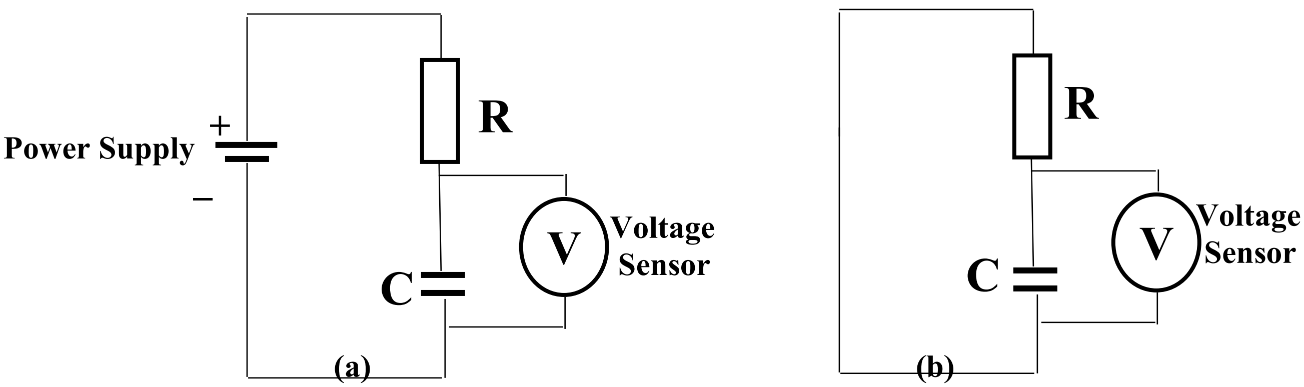

Figure 2. Schematic diagram of RC circuit for (a) charging and (b) discharging of the capacitor

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 http://physlab.tamucc.edu/.
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. Repeat steps 5-12.

Part #2. Analyzing the Data

1. Plot data collected **during charge** of the capacitor as ***three series*** of V vs. t ***on the same chart.***
2. Compare three graphed series and describe how the difference in the value of the resistance affects the rate of charge of the capacitor. Include this statement in the abstract.
3. Plot data collected **during discharge** of the capacitor as ***three individual V vs. t charts***.
4. Fit each plot into exponential function and display the equation of the trend line on the graph.
5. Replace Y with V and X with t in the equation.
6. Determine the time constant, τ, from the trendline equation.

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

7. 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.
8. Compare the three experimental time constants to the theoretical values. (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 Formal Report:

The report must contain a **Header** at the top (Title of Lab, Authors, and Date)
The **Abstract** is a summary of the Main Body, so write it last. Place **Abstract** at the top of report.
The **Main Body** of the report must address the following:

- The **Introduction** should have the objectives of the lab and background information about RC Circuits. Describe the purpose of an RC Circuit, and provide an example of an RC Circuit. Include the theoretical equations for charging and discharging an RC circuit.
- The **Methods** should describe broadly what was done, using what tools, and what was measured/recorded. A description of the methods using one resistor is sufficient; then you can say the same methods were used on the remaining resistors.
- The **Discussion** should incorporate the following:
  - Analysis of the length and rate of charge/discharge for each resistor during charging and discharging. Is the length of charge and discharge similar for each resistor? How does rate of charge compare to rate of discharge for each resistor? What impact does the resistor have on charging and discharging?
  - Analysis of the time constants based on measured and calculated data. How does resistance affect the time constant? Are the measured time constants similar to the theoretical time constants for each resistor? Explain differences between the measured and theoretical time constants.
  - The lab manual contains several imperatives in Part 2 that will guide you with the Discussion based on the table and graphs.
- **Conclusions** based on the quantitative results.

- **Data Section** must contain the following:
  [Each graph and table should be labeled and captioned based on purpose and circuit components]
  <u>DO NOT include raw data tables w/ voltage vs time</u>
  - 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)