Lab 5: RC Circuits

Experiment for Introductory Physics E&M Labs at CSU Fullerton

What You Need to Know

Introduction

The manner by which the which the voltage on a capacitor increases or decreases is studied. The half-life for the decay is measured directly and also calculated using the capacitive time constant.

Theory

In DC circuits, capacitors store electrical energy by storing electrical charge, 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 ration of stored charge Q to the capacitor's voltage V is the *capacitance:*

$$C = \frac{Q}{V}$$
Equation 1

Based on this definition, the electrical resistance units are

$$[C]_{SI} = 1F \ (Farad), \qquad 1 Farad(F) = 1\frac{Coulomb(C)}{Voltage(V)}$$
Equation 2

We have sensors for measuring voltage and current, but none for measuring stored charge. The stored charge can be determined indirectly, however, by measuring the current flowing into the capacitor as it charges.

Electric current is the rate of charge flow: $I = \Delta q/\Delta t$, and this definition can be rearranged to calculate the charge due to a steady current. Unfortunately, the current in a charging capacitor isn't steady, so you'll use software to calculate the total charge delivered to the capacitor.

If you connect a resistor, capacitor, and power supply in series, current flows until the capacitor's voltage (V_C) equals to the voltage provided by the power supply (V_0).

$$V_C = V_0 \left(1 - e^{-\frac{t}{RC}} \right)$$
Equation 3

You can then discharge the capacitor by connecting the capacitor directly to the resistor. While discharging, the capacitor's voltage decreases exponentially:

$$V_C = V_0 \left(e^{-\frac{t}{RC}} \right)$$
Equation 4

Here, V_c is the capacitor's voltage at time t, and $V_\circ$ is its voltage at t=0 (when discharging begins). The quantity RC in the exponent of Equation 4 is called the *time constant, τ*:

$$\tau = RC$$

<div align="right">*Equation 5*</div>

In the experiment, you'll determine the time constant for the circuit by measuring the capacitor's "half-life" $t_{1/2}$, the time it takes for capacitor's voltage to decrease by 50 %. The half-life is related rather simply to the time constant:

$$t_{1/2} = RC \, ln \, 2$$

<div align="right">*Equation 6*</div>

Equipment

- DC power supply
- Voltage probe
- Connecting wires
- RC circuit board

- Alligator clips
- Jumper wire
- Stopwatch (On PC or otherwise)

What You Need to Do:

Pre-lab Questions

Question 1:

Show that the capacitive time constant RC has units of seconds.

Question 2:

If the capacitance in the circuit is doubled, how is the half-life affected?

Question 3:

If the resistance in the circuit is doubled, how is the half-life affected?

Question 4:

Linearize *Equation 4*: $V_c = V_\circ e^{-t/RC}$ so that what you plot results in a straight line, what quantity do you have to plot vs. time. What is the expression for the slope of this straight line?

Setup

Figure 1 – Circuit Diagram
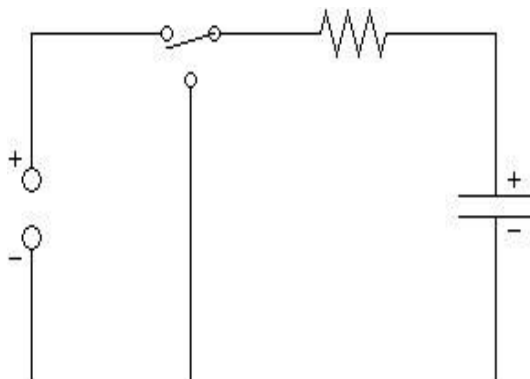
A) The circuit as shown in *Figure 1 – Circuit Diagram* is a representation of the RC circuit board provided.

B) Turn on the power supply and use recall button to select **Memory 1**.Voltage should be preset to 5 V and current to 0.5 A. Then press **OUTPUT** button.

C) Make a table like *Table 1* in your lab report.

Table 1 – Parts 1, 2, and 3 data.

	Half-life (Charging)	Half-life (Discharging)	Average Half-Life	Calculated Half-Life	Percent Error
Part 1					
Part 2	X		X	X	X
Part 3				X	X

Part 1: Half-life by Stopwatch

A) Open the accompanying logger pro file: Voltage And Timer.

B) Flip the switch on the circuit board to **Discharge.**

Note: If you ever want to quickly discharge the capacitor, use the small extra wire with clip ends. Just touch the ends on either side of the capacitor.

C) Open the stopwatch on the PC or otherwise.

D) Connect the voltage probe across the capacitor.

E) Press Collect in Logger Pro as you flip the switch to **Charge** and measure the time it takes to get to half of the maximum voltage of 5V. Record this value in *Table 1* of the lab report handout.

F) Let the capacitor continue to charge all the way to 5 V even though you have your data. It may take about two minutes. As long as it gets into 4.9 V region it's fine.

Now you are going to measure the half-life again but a different way.

G) Start your timer as you flip the switch to **Discharge** and measure the time it takes to get to half of the maximum value of 5 V. Record this value in *Table 1* of the lab report handout.

H) Sketch a graph of what you think the voltage of the capacitor vs time will look like for the full charge and discharge cycles.

I) Average your two half-life values and place this value in *Table 1*.

J) Use the color band chart to determine the resistance of your resistor. Also record the value of the capacitance of the capacitor.

R (Ω)	C (F)

K) Use these values to calculate the half-life and record it in *Table 1*.

Part 2: Half-life by Linearization

A) Flip the switch to **charge** and let the capacitor charge up.

B) Make a copy of Table 2 in your report.

Table 2 – Part 2

Time (s)	Voltage (V)	Time (s)	Voltage (V)
10		45	
15		50	
20		55	
25		60	
30		65	
35		70	
40		75	

C) Collect data for the discharge to fill in Table 2:

  a While the capacitor is discharging, you'll write down the capacitor voltage for the times listed in Table 2. This can be a little hectic, so work as a team. One person should monitor the stopwatch and LoggerPro while other should write down the data in Table 2 of the handout.

  b Once capacitor is fully charged and you're ready to collect, flip to **Discharge** and press Collect on LoggerPro at the same time.

D) Open Excel on the lab computer and use your answer to *Pre-lab Questions 4* to make a plot of your data in linear form.

Hint: You should have found to plot $\ln\left(\frac{V_C}{V_0}\right)$ *vs t.* **Hopefully you did the Q before finding this.**

Question 5:

Comparing your linearized version of *Equation 4* and the equation of a line $y = mx + b$ fill in the blank:

$$y = \ln\left(\frac{V_C}{V_0}\right), \qquad x = t, \qquad b = 0$$

$$m = \underline{\hspace{2cm}}$$

E) Calculate the slope and find the value of RC.

F) Find the half-life time using *Equation 6* and record it in *Table 1*.

Part 3: Half-life by a Continuous Graph

Charging

A) Open the accompanying Logger Pro File: RC Circuits.

B) Make sure the wireless voltage probe is attached across the capacitor and a switch is set to **Discharge**. For the fast discharge, use the extra jumper wire provided.

C) Push the Collect button. Wait 2 seconds and then flip the switch to **Charge**. The LoggerPro Interface will monitor voltage across the capacitor and plot it out on the graph as voltage increases. Let it charge to about 4.9 V and press **Stop**.

D) Use the mouse to highlight the region of the graph where it is charging (click and drag)

E) Push the "Curve Fit" button shown here. And scroll down in the General Equation section until you find "Inverse Exponent", then click Try Fit. Check to see if it's a good fit, then click OK.

If it's not a good fit, call over your Instructor.

F) Use the fit to calculate the half-life.

   a   In the little window that points to the curve, there is a value labeled "C". This is the fit coefficient C, not the capacitance.

   b   The fit coefficient C is equal to $1/RC$. Use this to calculate RC.

   c   Use the value you calculated for RC to calculate the half-life. Show your work in your report and place the value in *Table 1*.

Work for Calculating half-life

Discharging

A) Make sure the switch is set to **Charge** and the capacitor is sufficiently charged.

B) Push **Collect**, wait 2 seconds and then flip the switch to **Discharge**. Let it discharge till it gets close to 0 V and press **Stop**.

C) Repeat steps E) and F) from charging but this time pick "**Natural** Exponent" equation instead. You don't have to show work again.

D) Calculate the average half life from your two half life values and place this value in *Table 1*.

Part 4: Voltage Across the Resistor

A) Disconnect the voltage probe from the capacitor and attach it across the resistor. Push **Collect**, wait 2 seconds, and then flip the switch to **Charge.**

Question 6:

Why does the graph for the voltage of the resistor look the way it does on the computer screen? In your explanation you must use Kirchhoff's Loop Law.

Post Lab Questions

Question 7:

Notice that the three half-life values you measured in **Parts 1 – 3** are all somewhat similar. Notice also that they are not very similar to the half-life value you calculated with the given values of **R** and **C**. Explain this behavior. HINT: Both the voltmeter and the LabPro have an "internal resistance".

Question 8:

Why should you get the same half-life for charging and discharging cases? Base your answer on examining your graph.

Question 9:

Include the values found for the half-lives and the % differences. Does the theoretical value life within the range of precision of your measurements? Explain what causes the differences.

What You Need to Turn In:

Turn in all the data you took. Make sure you've shown all the work for any half-lives and such. All questions must be answered in the sections where they are asked.