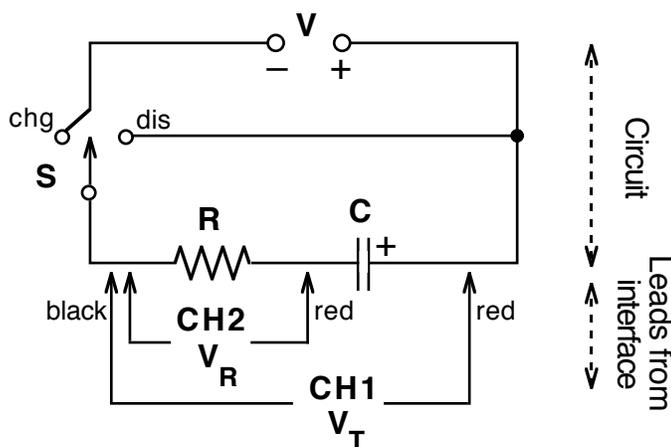# CAPACITOR CHARGE/DISCHARGE - EasyData

PURPOSE

The purpose of this lab is to examine the pattern of voltage vs. time and current vs. time for charging and discharging capacitors. In the process, you will examine the mathematical equation that describes the data.

CIRCUIT

MATERIALS

50-μF Capacitor, 47-KΩ Resistor, 1.5-volt cell, SPDT Switch, Wires, 2 Voltage Probes, Vernier Interface, TI graphing calculator with *EasyData*, extra capacitors and resistors (a LabPro or CBL2 is needed for two sensors) *

PROCEDURE

1. Set up the circuit as shown above using a 50-μF capacitor and 47-KΩ resistor. Pay attention to the polarity of the voltage source and the capacitor. The switch (S) can be a mechanical switch or simply a place where you can complete the circuit by connecting wires. This can easily be set up on a breadboard.

2. Connect the two Voltage Probes to Channel 1 (CH1) and Channel 2 (CH2) on the interface. Then connect the probes to the circuit, being careful to have the two black leads connected to the same point. Connect the interface to the calculator and launch *EasyData*. Press the button under ⟨Setup⟩ and follow these steps to prepare for data collection:

- Choose **Time Graph...**, then press the button under ⌈**Edit**⌉ to change the default values.
- Set the Sample Interval to 0.05 sec and press ⌈**Next**⌉, then the number of samples to 300 and press ⌈**Next**⌉. After the setup is shown to you and it is correct, press the button under ⌈**OK**⌉.

CHARGING:
3. Before charging the capacitor, move the switch to the position labeled "dis". Monitor the voltage on CH1 and CH2, and when they both reach a steady value close to 0.0, you may begin this portion of the data collection. [To hurry the discharge along, touch the two ends of a piece of wire to the terminals of the capacitor.]

4. Press the button under ⌈**Start**⌉ to begin data collection. At the same time, move the switch to the "chg" position. At the end of the 15-second data collection period, you should have one graph that remains constant at approximately 1.5 volts while the second graph line moves from a high value to a low one.

5. Press the button under ⌈**File**⌉ and choose **Save As**. You will be asked to name the data, and "**CHARGE**" seems appropriate. You will be returned to the main menu after the data is saved.

DISCHARGING:
6. Press the button under ⌈**Start**⌉ to begin data collection. At the same time, move the switch to the "dis" position. At the end of the 15-second data collection period, you should have two graphs, one for V_R and the other for V_T.

SELECTING
7. Press the button under [Plots] and choose V1, the total voltage. The graph should be a downward curve. The blinking cursor should be on the left side of the graph and its coordinates given near the top of the screen. Note that x is time in seconds while y is voltage in volts.

8. If the initial value is near zero while the first portion of the main discharge graph is much higher, you need to cut that first portion from the graph in order to perform analysis.
   - Press the button under ⌈**Anlyz**⌉ and choose **Select Region**. Use the arrow keys to move the blinking cursor until it is near the top of the curved section. Press the button under ⌈**OK**⌉ to set the left-hand boundary.
   - The blinking cursor is now on the right end of your graph. Use the left-arrow to move it until the y-value (voltage) is no longer negative, if it starts out negative. If it's positive, simply press the button under ⌈**OK**⌉, setting the right-hand boundary.

9. While we could do a good deal of analysis inside *EasyData*, we will move into the calculator proper for our analysis. Press the button under ⌈**Main**⌉ and then press the button under [Quit]. Note the screen that appears telling you where the data is saved.

CALCULATING

10. Examine your data by pressing the [STAT] button, then [ENTER]. You will note the three columns with Time, V1 and V2 data. [2ND] [QUIT] will get you out of this mode.

11. Voltage on the capacitor (V_C): Subtract the voltage on the resistor (V_R = CH2 = L3) from the total voltage (V_T = CH1 = L2).
    - On the home screen of the calculator, press this sequence:
      [2ND] [2] [-] [2ND] [3] [STO] [2ND] [4] [ENTER]
      This has the effect of subtracting each of the values in L3 (V_R) from each of the values in L2 (V_T) and storing them in L4 (V_C).

12. Current in the circuit, I: Divide the voltage across the resistor (V_R) by the size of the resistance, R.
    - On the home screen of the calculator, press this sequence:
      [2ND] [3] [/] [resistance] [STO] [2ND] [5] [ENTER]
      This has the effect of dividing each of the values in L3 (V_R) by the resistance value, giving you the current and storing it in L5 (I).

13. Note that the values you have been working with are the discharge values. The charging values are still in the interface. We will recover them in a bit.

ANALYSIS

1. Set up the calculator to show the Capacitor vs. Time graph:
   - Press [2ND] [STAT PLOT]. With plot #1 highlighted, press [ENTER]. Make sure On is toggled by pressing [ENTER] when it is highlighted. It will blink thereafter.
   - Arrow down to Ylist: and press [2ND] [4] to set the y-axis to L4, the capacitor voltage.
   - Press [GRAPH], then [ZOOM] [9].

2. Describe the graph in general. What is happening to the capacitor over time? Is the voltage constant? If it changes, does the rate that it changes vary over time? Use [2ND] [QUIT] to put this graph away.

3. Press [STAT] to enter the statistical calculations. Right-arrow to CALC., then down-arrow to ExpReg, the exponential regression. After pressing [ENTER], add [2ND] [1] [,] [2ND] [4] to get the calculator to look specifically at your capacitor voltage vs. time data. Press [ENTER] to begin the analysis.

4. The analysis done by the calculator yields an equation of the form $y = a\,b^x$. Record the value of **b**, as this is related to the general exponential equation as follows:
$$y = a\,b^x = a\,e^{-kx}$$
So the value of b is simply e^{-k}, where **e** is the base of the natural logarithms and **k** is the decay constant. Setting those two equal, gives the following
$$b = e^{-k}$$
$$\ln b = -k$$
$$k = -\ln b$$

5. Solve for **k**, the decay constant and enter it in your data table.

6. Calculate the product of the resistance **R** and the capacitance **C**. Then take the inverse product of this value, $(RC)^{-1}$. Record these values.

7. The mathematical equation that describes the voltage on a discharging capacitor is
$V(t) = V_0 e^{-\frac{t}{RC}}$. Note that the constant k that we calculated should be equal to the reciprocal of the **RC** product. Compare the inverse to the value of the exponent in your equation by calculating the percent difference. How does this difference compare to the tolerances for the resistor and for the capacitor?

8. Now set up the Current vs. Time graph:
   - Press [2ND] [STAT PLOT]. With plot #1 highlighted, press [ENTER]. Make sure On is toggled by pressing [ENTER] when it is highlighted. It will blink thereafter.
   - Scroll down to Ylist: and press [2ND] [5] to set the y-axis to L5, the current.
   - Press [GRAPH], then [ZOOM] [9].

9. Describe the graph in general. What is happening in the circuit over time? Is the change constant or does the rate change over time? Compare the shapes and meanings of the two graphs you obtained while the capacitor was discharging.

BACK TO CHARGING
10. Now re-capture the saved CHARGE data. Launch *EasyData* again. Press the button under (File), then choose Open. Highlight your CHARGE file then press the button under (OK).

11. Press the button under (Main) then [Quit]. Note the data is back in its original columns, but now it's charging data rather than discharging data.

12. Repeat steps 10-12 under CALCULATING above. Then complete steps 1-2 and 8-9 under ANALYSIS. Be sure to discuss differences and similarities not only between the two graphs for discharging, but also differences and similarities between the charging and the discharging processes.

DATA

Resistance, **R**				
Capacitance, **C**				
	Charge	Discharge	Charge	Discharge
Exponent, **k**				
Product, **RC**				
Inverse RC, **(RC)$^{-1}$**				
% Difference				

MORE ANALYSIS

1. If we examine the general equation for exponential decay, we could substitute the value $V_0/2$ for V(t), and solve for the time it takes for the voltage to drop to half its former value.

$$V(t) = V_0/2 = V_0 \ e^{-t/RC}$$
$$1/2 = e^{-t/RC}$$
$$\ln (1/2) = -t/RC$$
$$t_{1/2} = -RC \ \ln (1/2) = 0.693 \ RC$$

2. Now go to your data for the capacitor voltage during discharge. Pick a value for voltage near the highest one and record the voltage and time in the following table. Then scroll down until you get to a voltage that's half of that. Record these new values. Repeat, going down in halves.

Voltage	Time	$t_{1/2}$

3. Subtract the first time from the second, the second from the third, etc. to yield the half-voltage time. When finished, calculate the average half-voltage time.

4. What you have just done is to demonstrate that capacitors discharge in a mathematical pattern that is identical to the half-lives that radioactive materials demonstrate. Namely, that in equal times, half of the original decays away, then in an additional equal time, half of that decays. And right there on your lab bench!

5. Compare the average time your capacitor took to drop to half its voltage value with the theoretical 0.693 RC. How does the percentage difference compare to the tolerances of the resistor and capacitor?

* The data from the capacitor could be taken during one run then the data from the resistor could be taken in a second run if you are using only a single voltage probe. This requires four passes to get both charging and discharging.

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