

RC Circuits

Introduction

The manner by 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*:

$$C = \frac{Q}{V}. \quad (1)$$

Based on this definition, the electrical resistance units are

$$[C]_{SI} = 1F \text{ (Farad)}; \quad 1\text{Farad}(F) = 1 \frac{\text{Coulomb}(C)}{\text{Voltage}(V)} \quad (2)$$

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: $I = \frac{\Delta q}{\Delta t}$, 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_o).

$$V_c = V_o(1 - e^{-t/RC}) \quad (3)$$

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

$$V_c = V_o(e^{-t/RC}) \quad (4)$$

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

$$\tau = RC \quad (5)$$

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:

$$t_{1/2} = RC \ln 2 \quad (6)$$

Experiment

Equipment

- DC power supply
- PASCO SPARK LXi interface
- PASCO wireless current probe
- PASCO wireless voltage probe
- Connecting wires
- RC circuit board
- Alligator clips
- Jumping wire
- Stopwatch (Using your Cell Phone is highly recommended)

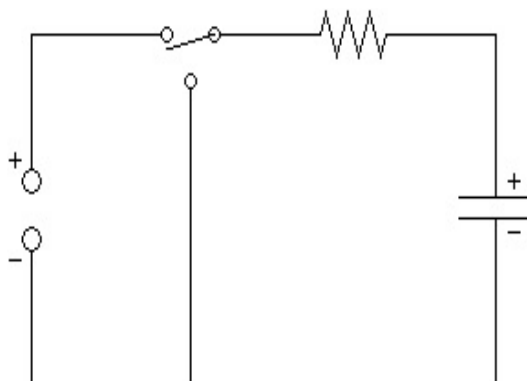


Figure 1: RC Circuit Diagram

Setup

1. The circuit as shown in Figure 1 is a representation of the RC circuit board provided.
2. 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.
3. On PASCO SPARK LXi interface, open SPARKVue app, open PASCO experiments, select PHYSICS 212L, select RC Circuit.
4. Connect the wireless voltage probe by pressing **Bluetooth** icon on the top right area of the screen. **Each sensor has it's unique Bluetooth ID. Make sure they match with your interface.** You can use Proximity Connect to detect the sensors around you.
5. Make sure Voltage meter is displayed on the interface and the tab on the top reads "Part 1 and 2".

Procedure

Part 1: Half-life by Stopwatch

1. Flip the switch on the circuit board to **Discharge**. **Hint:** 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.
2. Open the stopwatch on your cell phone.
3. Connect the voltage probe across the capacitor.
4. Press start on your PASCO interface 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.
5. 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.
6. 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.
7. Average your two half-life values and place this value in your table.
8. Use the color band chart to determine the resistance of your resistor. Also record the value of the capacitance of the capacitor. Use these values to calculate the half-life and record it in the table.

Part 2: Half-life by Linearization

1. Flip the switch to **charge** and let the capacitor charge up.
2. Once capacitor is fully charged, flip to **Discharge** and press Start on your PASCO interface at the same time. While the capacitor is discharging, write down the capacitor voltage for the times listed in the chart. This can be a little hectic, so work as a team. One person should monitor the stopwatch and the PASCO interface while other should write down the data in Table 2 of the handout.
3. Open Excel on your tablet or computer and make a plot of your data $\ln(\frac{V_c}{V_o})$ vs. t
4. Transform equation 4 into a linear form, (i.e. $y = mx + b$). On your paper note what "y, x, m, and b" will represent.
5. Plot y vs. x with their respective variables.
6. Calculate the slope and find the value of RC. Using Equation 6, you can find the half-life time.

Part 3: Half-life by a Continuous Graph

Charging

1. Go to the second tab on the PASCO interface. The tab should read **Part 3**.
2. 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.
3. Push a **Start** button. Wait 2 seconds and then flip the switch to **Charge**. The PASCO 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**.
4. See the Analysis section to calculate the half-life.

Discharging

1. Make sure the switch is set to **Charge** and the capacitor is sufficiently charged.
2. Push **Start**, wait 2 seconds and then flip the switch to **Discharge**. Let it discharge till it gets close to 0 V and press **Stop**.
3. See the Analysis section to calculate the half-life.

Part 4: Voltage Across the Resistor

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

Analysis

1. **SPARKVue** software defaults to analysis mode, when you press **Stop**. You can expand the graph icon to view all the options available in graph toolbar. **Your TA should go over how to use SPARKVue in detail**
2. Click the dotted rectangle on the graph toolbar, then select data on graph. Push the Curve Fit button which is next to icon **T** and choose **Natural Exponential Fit**.
3. In the little window that points to the curve, there is a value labeled "C". **This is not the capacitance**. It is equal to $1/RC$. Use this to calculate RC and then calculate the half-life. Show your work. Place this value in the chart.
4. Now set the voltage in the power supply to 10 V and press **Enter** on the keypad. Repeat part 3 with the new voltage.