

PHY 152/252

RC Circuit – Laboratory 4

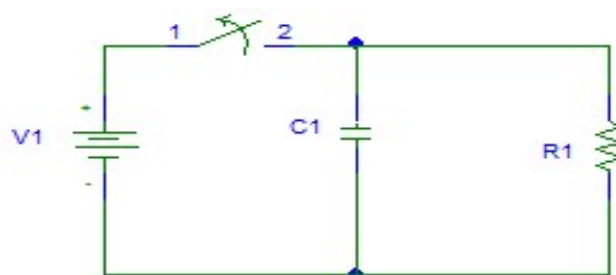
Objective:

The objective is to observe the behavior of a discharging and charging capacitor and to display the results graphically.

Theory:

A capacitor is a circuit device made up of two conductors separated by an insulator or by air. Capacitors serve as energy storage devices resulting from the electric field between the conductors. A capacitor has a capacitance value which is a measure of how much charge it can store at a specified potential difference (voltage) between its conductors. The formula for capacitance is $C = Q / V$, where Q is the magnitude of the charge stored on either conductor, and V is the potential difference between the two conductors due to this charge. When a capacitor is connected to a voltage source, the capacitor begins to charge. Unlike resistors, the voltage between the capacitor's conductors can be dependent on time. The **time constant** of a capacitor indicates the rate at which it charges and discharges. The smaller the time constant the faster the capacitor charges or discharges. The time constant is represented by τ and equals RC or $\tau = RC$, where τ is measured in seconds. A capacitor can be defined to be either fully charged or fully discharged after 5τ . The expression relating a charging capacitor and time is $V_c = V^*(1 - e^{-t/\tau})$, where V_c is the voltage across the capacitor at any time t , and V^* is the maximum voltage to which the capacitor is to be charged. Once the capacitor is fully charged it will have a voltage value equal to that of the source to which it is connected. In its charged state, a capacitor will not allow current to flow through it, acting like an open circuit, while a fully-discharged capacitor acts like a good conductor.

Considering the circuit below, when a fully charged capacitor is disconnected from the EMF, it will begin to discharge through the resistor, R_1 . The expression relating a discharging capacitor and time is $V_c = V^*e^{-t/\tau}$, where V_c is the voltage across the capacitor at any time t , after disconnecting from the EMF, and V^* is the maximum voltage to which the capacitor was originally charged.

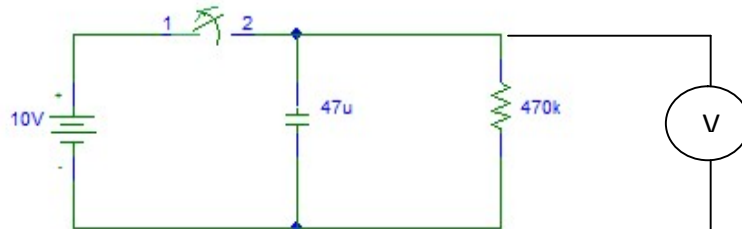


Procedure:

PART 1 – DISCHARGING

Construct the circuit shown at the top of the next page using a “breadboard” and individual components. Let $R = 470 \text{ k}\Omega$ and $C = 47 \text{ }\mu\text{F}$. To create a switch; just place a

wire between the EMF and the capacitor. Removing the wire will effectively open the switch. Connect your multimeter in parallel with the capacitor and resistor, as shown, and set it to the 20V DC setting. For this experiment we will use the Beckman meters, because they have a much higher internal resistance and thus have less effect on the results.



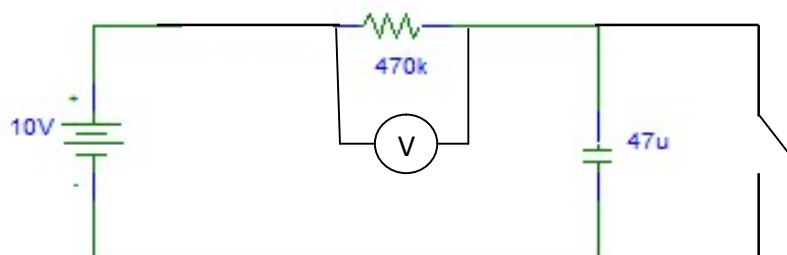
With the “switch” closed, turn the current-limit knob on the power supply fully clockwise, turn the voltage knob fully counterclockwise, turn on the power supply, and set the voltage to 10.0 volts as read on the Beckman multimeter. This will quickly charge the capacitor to the voltage of the power supply because they are in parallel. Next, simultaneously remove the wire connecting the capacitor to the power supply (open the “switch”) and start the stop watch. Record the times when the voltage across the capacitor is 37% (3.7V), 14% (1.4V), 5% (0.5V), 2% (0.2V), and 1% (0.1V) of the initial 10 V. These will be the 1τ , 2τ , 3τ , 4τ , and 5τ times for this circuit.

Make a two-column table to record these voltages and the times at which they occur. Note that 0 volts and 0 time are not allowed values for your table.

Repeat Part I with $R = 2.2 \text{ M}\Omega$. and $C = 47 \mu\text{F}$ (unchanged)

PART 2 – CHARGING

Turn the power supply switch off, leaving the voltage control knob at the position it was in Part 1 (10.0 volts). Construct the circuit shown below. Let $R = 470 \text{ k}\Omega$ and $C = 47 \mu\text{F}$. Place your multimeter in parallel with the resistor as shown in the diagram. Note that we are measuring the voltage across the resistor instead of the capacitor because we can get a more accurate measurement of our capacitor voltage by subtracting the resistor voltage from the supplied 10 V. This works because once the switch is opened and the capacitor begins charging, it starts resisting the flow of current through the circuit, and therefore reduces the voltage drop across the resistor.as time passes.



With the “switch” closed, turn the power supply on. The “switch will consist of a length of wire. We will use one of the colored connector wires for this purpose. Doing this ensures that you start with an uncharged capacitor; however, note that shorting out the capacitor does not “short out” the power supply. Instead, all of the 10 volts will appear across the resistor as indicated by the 10.0 volt meter reading. If the Beckman meter does not read 10.0 volts with the capacitor shorted, adjust the voltage control knob on the power supply to achieve this exact voltage. Next, open the switch by removing the shorting wire and simultaneously start your stop watch. The capacitor is now charging. Note that instead of the voltmeter reading increasing, it will be decreasing because the current through the circuit is decreasing as the capacitor charges. Record the times when the voltage across the resistor reaches 37%, 14%, 5%, 2%, and 1% of the power supply voltage. Specifically, the voltages at which you record the charging times are: 3.7 V, 1.4 V, 0.5 V, 0.2 V, and 0.1 V. These will be the 1τ , 2τ , 3τ , 4τ , and 5τ times for this circuit. If you fail to record any of the times when the voltage is at these 5 values, you should start over. Subtract these voltages from 10.0 V to get the voltage across the capacitor at each time and use the 10.0 – V as your table values for voltage.

Again, make a two-column table for both circuit configurations, recording the calculated voltage across the capacitor ($10.0 - V$) versus the time. You will **not** plot these data.

Repeat the Part 2 process with $R = 2.2 \text{ M}\Omega$ and $C = 47 \text{ }\mu\text{F}$ (unchanged)

Assuming you have access to Excel, before you leave the lab, complete the calculations for at least one circuit configuration to make sure that you haven’t made a blunder.

Calculations:

NOTE: These calculations apply only to Part 1 (there are no calculations for Part 2).

1. Make two(2) different plots using Excel, one for each of your Part 1 circuit configurations, graphing the time versus voltage across the capacitor. The measured time values will be on the x-axis and the associated voltage values on the y-axis. Then perform a **best fit exponential curve** for your 5 data points. You will find that your time values need to be in column 1 of your tables, and your voltages in column 2 (the reverse of how we think).

Depending on your version of Excel you will need to set the “intercept” and will need to request that the formula be displayed on your graphs. The intercept is the value of V when $t = 0$. It will be 10.0. Once you link your data table to the graphing function of Excel, and the data points appear, you will need to right-click any data point to bring up a menu from which you select “Add Trendline.” This brings up a Format Trendline menu on which you select the trendline option of “Exponential,” you enter the Intercept value as described above, and you put a checkmark in the box “Display Equation on Chart.” This equation will appear in the form: $y = Ae^{-Bx}$ from which you can calculate your experimental τ by comparing the value of B in this equation to the capacitor discharging equation shown in the Theory section.

2. Calculate the theoretical time constant for both discharging circuits by multiplying the resistance value by the capacitance.

3. Compare the two experimental time constants from Calculation 1 with the corresponding theoretical time constants from Calculation 2 for both discharging circuits, and calculate the two percent differences. You should have percent difference values in the 4-5% range. What are sources of error?