Group: Amy Chang, Akaash Kolluri, Alex Zhang, Alice Zhong

RC Circuits

Night Lab 5

AP Physics C – E&M

Objective: I can describe the current through an RC circuit as a function of time by calculating the time constant of an RC circuit.

In this lab, you will be connecting a resistor (or resistors) and a capacitor in a circuit with a battery (or both batteries together). Your goal is to analyze the effect of equivalent resistance on the time constant (and therefore the amount of time required to charge and discharge the capacitor) and also the emf on the time it takes to charge and discharge the capacitor. You will want to compare the theoretical and experimental time constants for each circuit.

Pre-lab Questions

1. When charging AND then discharging a capacitor and wanting to collect data, is it beneficial to connect the resistor and capacitor in series or in parallel? Why? Will a switch be helpful for making it easy to go from charging to discharging and vice versa?
   In series, because in series only relies on normal addition for calculating instead of some random inverse harmonic sum thing. A switch will definitely make it much easier to change from charging to discharging as all we need to do is open/close the switch whenever we want to discharge/charge the capacitor since opening the switch cuts off the current.
2. Detail an example of charging/discharging an RC circuit in real life. Estimate the time constant of discharging in such an example given your knowledge of electronics.
   A windshield wiper is an example of charging/discharging because it acts on a timer. Each activation requires a certain amount of charge to be stored before it can be released. Time constant would probably be around 0.2 seconds as the total time it takes for the circuit to charge is around 1 second (1 swipe).
3. Is it possible to fully charge/discharge a capacitor? How do you know?
   Theoretically yes, but realistically no. In real life, the wires will offer some resistance, preventing all of the charge from gathering on/escaping the capacitor. Also, even theoretically it would take an infinite amount of time as the functions are considered exponential (an infinite amount of time is theoretically possible).

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Procedure

Detail your procedure and include one circuit diagram here. You should have at least 2 circuits for this lab. The difference in the two circuits should be the resistance so that the time constant changes, as indicated in the tables.

You will need to connect the voltmeter to Capstone. I also advise using the ammeter to measure current through the capacitor as well. In capstone display the voltage/time graph and a numerical display to make it easier to find the voltage.

1. Constructed a circuit with a 1.5 V battery and a 0.22 F capacitor in series with 133 Ω resistance in series. Connected another loop with a switch in the "junction" position, to be able to go from charging to discharging and vice versa. Shown in Figure 1.
2. Connected the voltmeter to Capstone and attached the clips to the capacitor.
3. Flipped the switch such that the capacitor was discharging. Waited until the capacitor nearly completely discharged.
4. Started recording the voltage vs. time graph on Capstone and flipped the switch such that the capacitor began charging. Waited until capacitor was nearly completely charged.
5. Measured 7 data points and recorded in Table 1.
6. Now, the capacitor was already "fully" charged. Reset the graph and began recording again. Flipped the switch so the capacitor was discharging. Waited until capacitor was "fully" discharged.
7. Measured 7 data points and recorded in Table 2.
8. Repeated steps 1-7 with 100 Ω resistance. Recorded data in Table 3 and Table 4.

Figure 1. Circuit diagram for setup with 133 Ω resistance

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Results and Discussion

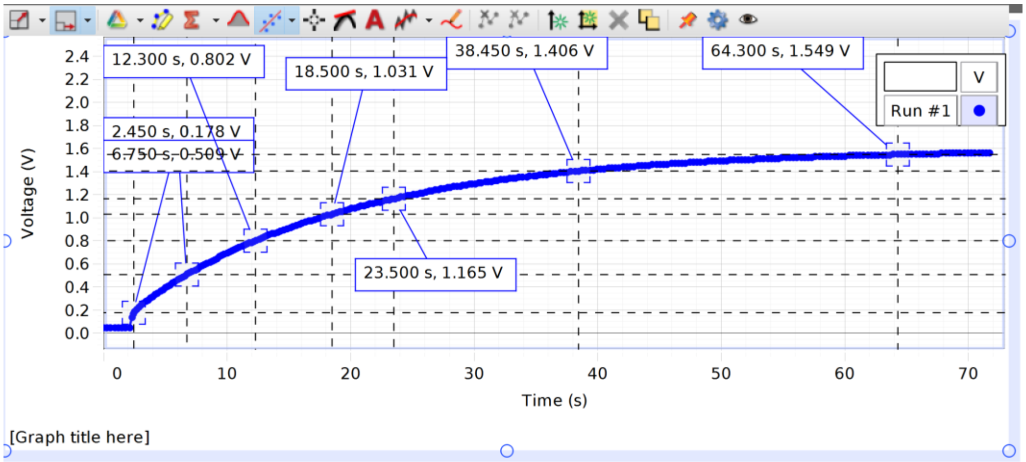

Figure 2. Voltage vs. time graph for charging the capacitor when resistance is 133 Ω

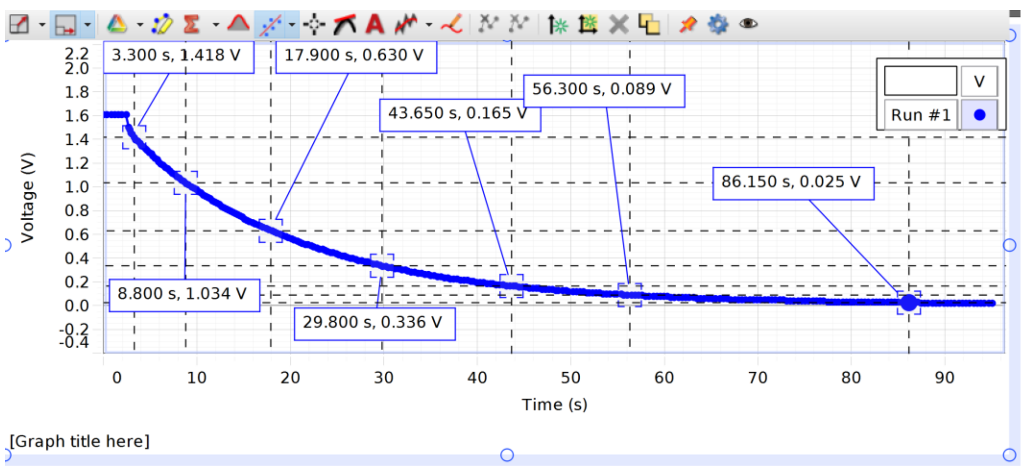

Figure 2. Voltage vs. time graph for discharging the capacitor when resistance is 133 Ω

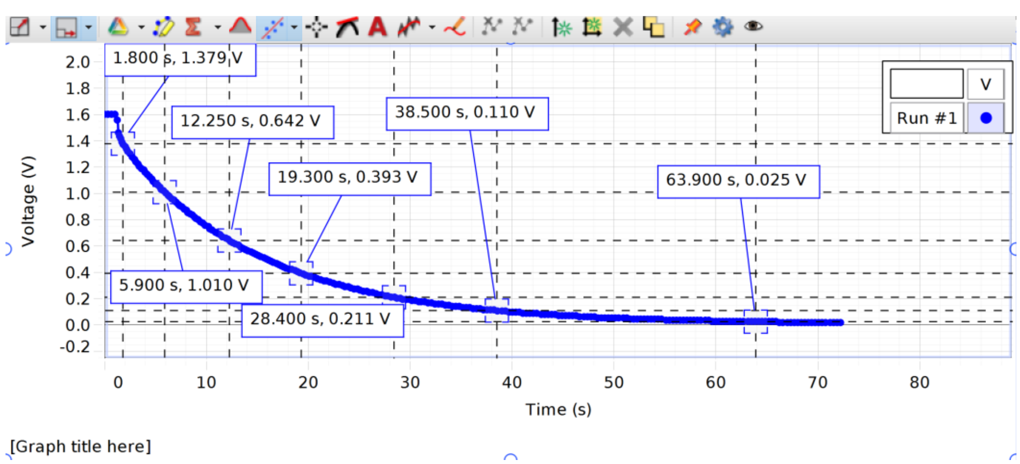

Figure 3. Voltage vs. time graph for discharging the capacitor when resistance is 100 Ω

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Table 1. Voltage measurements through the capacitor as a function of time while charging and discharging when the resistance is 133 Ω.

Charging w/ 1.5 V, 133 Ω resistance							
Time (s)	2.450	6.750	12.300	18.500	23.500	38.450	64.300
Approximate Voltage (V)	0.178	0.509	0.802	1.031	1.165	1.406	1.549
Theoretical τ (s): Product of Resistance and Capacitance $\tau = RC = 133 \cdot 0.22 = 29.26$			**Experimental τ (s):** $V(t) = \epsilon\left(1 - e^{-\frac{t}{\tau}}\right)$ $\frac{1}{3}\epsilon = \epsilon\left(1 - e^{-\frac{6.75}{\tau}}\right)$ $\tau = 16.65$			**Percent difference:** $\frac{29.26 - 16.65}{29.26} = 43.10\%$	
Discharging w/ 1.5 V, 133 Ω resistance							
Time (s)	3.300	8.800	17.900	29.800	43.650	56.300	86.150
Voltage (V)	1.418	1.034	0.630	0.336	0.165	0.089	0.025
Theoretical τ (s): $\tau = RC = 133 \cdot 0.22 = 29.26$			**Experimental τ (s):** $V(t) = \epsilon\left(e^{-\frac{t}{\tau}}\right)$ $\frac{2}{3}\epsilon = \epsilon\left(e^{-\frac{8.800}{\tau}}\right)$ $\tau = 21.70$			**Percent difference:** $\frac{29.26 - 21.70}{29.26} = 25.84\%$	

Table 2. Voltage measurements through the capacitor as a function of time while charging and discharging when the resistance is 100 Ω.

Charging w/ 1.5 V, 100 Ω resistance							
Time (s)	1.800	5.350	10.750	18.400	28.050	40.150	65.650
Approximate Voltage (V)	0.204	0.542	0.883	1.177	1.381	1.502	1.582
Theoretical τ (s): $\tau = RC = 100 \cdot 0.22 = 22.00$			**Experimental τ (s):** $V(t) = \epsilon\left(1 - e^{-\frac{t}{\tau}}\right)$ $\frac{1}{3}\epsilon = \epsilon\left(1 - e^{-\frac{-5.350}{\tau}}\right)$ $\tau = 13.19$			**Percent difference:** $\frac{22.00 - 13.19}{22.00} = 40.64\%$	
Discharging w/ 1.5 V, 100 Ω resistance							
Time (s)	1.800	5.900	12.250	19.300	28.400	38.500	63.900
Voltage (V)	1.379	1.010	0.642	0.393	0.211	0.110	0.025
Theoretical τ (s): $\tau = RC = 100 \cdot 0.22 = 22.00$			**Experimental τ (s):** $V(t) = \epsilon\left(e^{-\frac{t}{\tau}}\right)$ $\frac{2}{3}\epsilon = \epsilon\left(e^{-\frac{5.900}{\tau}}\right)$ $\tau = 14.55$			**Percent difference:** $\frac{22.00 - 14.55}{22.00} = 33.86\%$	

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Discuss your results, for each circuit. Analyze whether your time constant makes sense, and why it should be big or small. Did the graphs in Capstone look like how you expected? Discuss sources of errors and ways to minimize them.

For each circuit, the theoretical time constant, τ, is equal to RC, the product of the resistance and the capacitance in the circuit. For charging, the equation for the voltage, V, as a function of time, t, is

$$V(t) = \epsilon\left(1 - e^{-\frac{t}{\tau}}\right)$$

Where ϵ is the emf and is 1.5 V in our experiment. This equation makes sense because when $t = 0$, the voltage is 0 as the capacitor is completely discharged. With this equation, our graphs in Capstone look as expected being exponential functions that increase with time, as seen in Figure 2. We found the experimental time constant by plugging in a data point to the equation, expressing the voltage as a fraction of the emf, and then solving the equation. For the circuit with 133 Ω resistance, the theoretical time constant was $29.26\ s$, and the experimental was $16.65\ s$. For the circuit with 100 Ω resistance, the theoretical time constant was $22.00\ s$, and the experimental was $13.19\ s$. The time constants are significantly smaller than expected, which will be discussed when analyzing causes of errors. The value is big, meaning that it took a long time to charge. Similarly for discharging, the equation is

$$V(t) = \epsilon\left(e^{-\frac{t}{\tau}}\right)$$

Which makes sense because when $t = 0$, the voltage is ϵ, the capacitor is currently fully charged. Our graphs in Capstone look as expected being exponential functions that decrease with time, as seen in Figure 3 and 4. The experimental time constant was found in the same way as the charging section. For the circuit with 133 Ω resistance, the theoretical time constant was $29.26\ s$, and the experimental was $21.70\ s$. For the circuit with 100 Ω resistance, the theoretical time constant was $22.00\ s$, and the experimental was $14.55\ s$. The analysis for the time constant is the same as for charging.

The percent errors for the 133 and 100 Ω for charging the capacitor were 43.10% and 40.64%, respectively. For discharging, they were 25.84% and 33.86%. Causes of such high percent errors could have been partially due to the small amount of resistance in the wires which were not included in the theoretical calculation for time constant. However, in this source of error does not align with our results, as a higher resistance should lead to higher time constant. This could mean that the resistors and capacitor had much smaller values than indicated, making all our experimental values be smaller than expected. Another source of error was not precisely finding the ratio between our chosen data point and the emf (e.g., assuming 5.350 be a third of 1.5) causing a lot of rounding errors in the calculations. Strangely, from the Capstone graphs we see that the emf is actually around 1.6 V instead of 1.5, meaning that the time plugged into our equations were a bit smaller than they should have been, leading to a smaller time constant. Even with these potential sources of error, though, our time constant does not make that much sense because it is such a significant percent error, and the causes listed above should not create such a big difference. These errors could be minimized by using newer and higher quality equipment and being more precise with the calculations.