RC Circuits

Lab

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Abstract

The following report tasked students with applying current knowledge to understand what had previously been taught to them and required for the given equations to be derived in order for the relationships between variables to be visualized. The students theorized that the time constant for a charging and discharging capacitor must be the same because the circuit remains the same. This was tested by measuring the voltage across a capacitor utilizing a multimeter and finding the relationship between voltage and time. After data collection and calculations, the group's thoughts on the time constants were proven to be correct. The students were able to prove that the time constant would remain unchanged as long as the resistor and capacitor remained unchanged. Ultimately, this experiment solidified the students' understanding of the variables being studied and basic knowledge on RC circuits.

Objectives

The objective of the lab was to have students examining and understanding the process of charging and discharging of the voltage on a capacitor. The students had to utilize their recently acquired knowledge on RC circuits to use their data to discover the time constant. Throughout the lab, each student had to implement the information that had been learned dealing with capacitance (C), voltage (V), time (t), and the time constant (τ). By measuring and collecting data on the voltage as a capacitor charged and discharged, the relationships between the variables, previously listed, had to be derived and explained. Ultimately, students were expected to receive a thorough understanding of how RC circuits function through experimentation and data collection.

Introduction / Background

After receiving their task and dividing into groups, the lab group had to examine their understanding of RC circuits before devising a hypothesis. Before the lab, the students had been introduced to the formula for charge

$$(q = C \times V). \tag{1}$$

After the introduction to capacitance, the relationships between time and charge were explained using a formula for a charging capacitor

$$(q(t) = q_{max}[1 - e^{-t/RC}]) \tag{2}$$

and one for a discharging capacitor

$$(q(t) = q_{max}[e^{-t/RC}]). \tag{3}$$

Knowing that charge and voltage are proportionally related (1), the group was able to utilize the charging and discharging formulas to solve for voltage at a given time with the maximum voltage

$$(V(t) = V_{max}[1 - e^{-t/RC}]) \quad (4)$$

$$(V(t) = V_{max}[e^{-t/RC}]) \quad (5)$$

These formulas displayed the exponential growth and decay rates when the capacitor had been fully charged or discharged

$$(V = .63 \times V_{max}) \quad (6)$$

$$(V = .37 \times V_{max}). \quad (7)$$

With the growth and decay rates, the students had a method for finding the voltage of the capacitor at the time constant after collecting their data. In order to display the relationship between the voltage at the time constant and time, the lab group rewrote the exponential growth and decay rate formulas (6 & 7) as

$$(ln[1 - V(t) \div V_{max}] = - t/\tau) \quad (8)$$

$$(ln[V(t) \div V_{max}] = - t/\tau). \quad (9)$$

Having an understanding of the formulas and their derivations, the group hypothesized that if the voltage is measured as a capacitor charged and discharged, then the time and voltage could be used to find the shared time constant. The voltage at the time constant (8 & 9) and time could also be used to find the time constant and support the values that would be found using only voltage and time. To calculate the time constant, the group planned on graphing their data and utilizing a trend line to receive an equation that could be solved for the time constant.

According to the students, the trend line equations for charging and discharging, including voltage v. time and $-t/\tau$ v. time, should all solve for the same value of the time constant.

Materials

The lab groups were provided with the materials needed to construct a simple RC circuit and measure the voltage on the capacitor. For tools, the students used multimeters, an arduino, and the record video feature on their phones. In order to construct their RC circuits, the following materials were used: wires, clipper wires, a capacitor, a resistor, and a battery. All of the supplies that were used throughout the experimentation process are presented and labeled below.

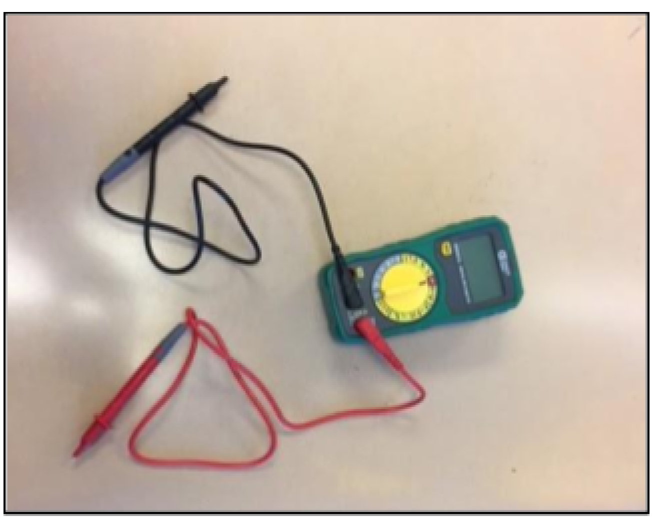


Figure 1 - Multimeter

Figure 2 - Arduino & Breadboard

Figure 3 - Clipper Wire

Figure 4 - Wire

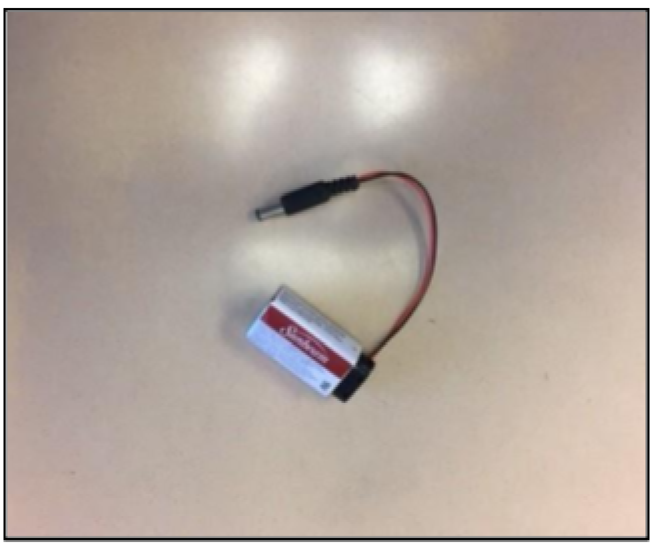


Figure 5 - Battery

Figure 6 - Resistor
(not actual resistor used in experiment)

Figure 7 - Capacitor

Procedure

With the materials and tools depicted above, the group was able to construct a simple RC circuit to measure the voltage as the capacitor charged and discharged. First, a series circuit consisting of a resistor and capacitor was constructed on the breadboard and connected to the arduino. Wires were used to connect the breadboard to the ground and arduino. Clipper wires attached the multimeter probes to the capacitor in order to provide the best measurements. To initiate the experiment one student would connect a 9V battery to the arduino while the other student filmed, using a smartphone camera, the voltage values displayed by the multimeter. Once the values stopped incrementing, the recording would be stopped, and it was started again as the battery was disconnected from the arduino. The experiment would end once the multimeter values returned to zero and the recording was stopped. Using the two videos, the students recorded the voltage every four seconds for both the charging and discharging video.

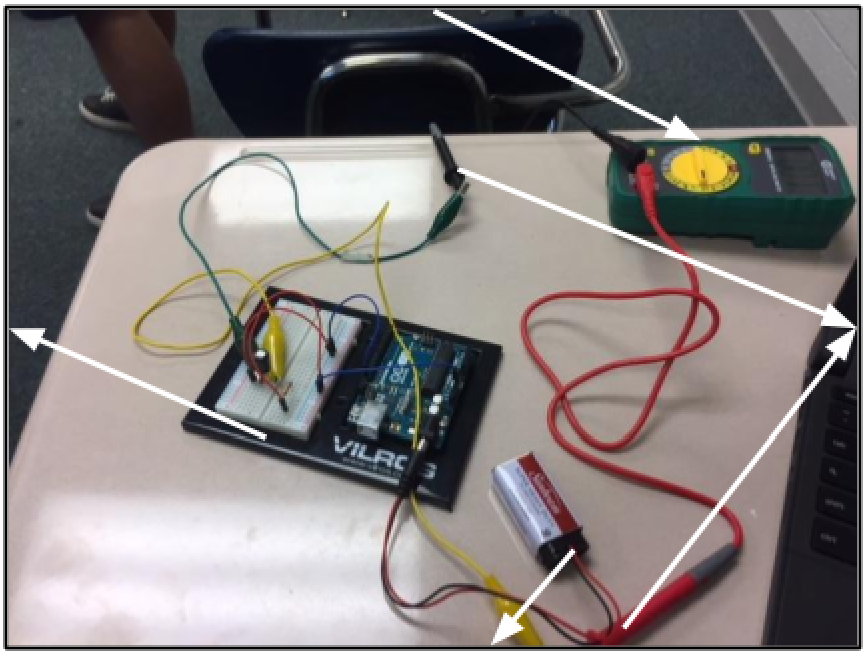


Figure 8 - Lab Setup

Lab Steps

1. Construct a simple RC circuit on a breadboard consisting of a resistor and capacitor in series
2. Wire the circuit to an arduino
3. Connect the positive and negative multimeter probes to the corresponding ends of the capacitor using clipper wires
4. Apply power to the circuit by connecting the 9V battery to the arduino and record the values that appear on the multimeter with a smartphone camera
5. Disconnect the battery once the capacitor stops charging and record the multimeter values

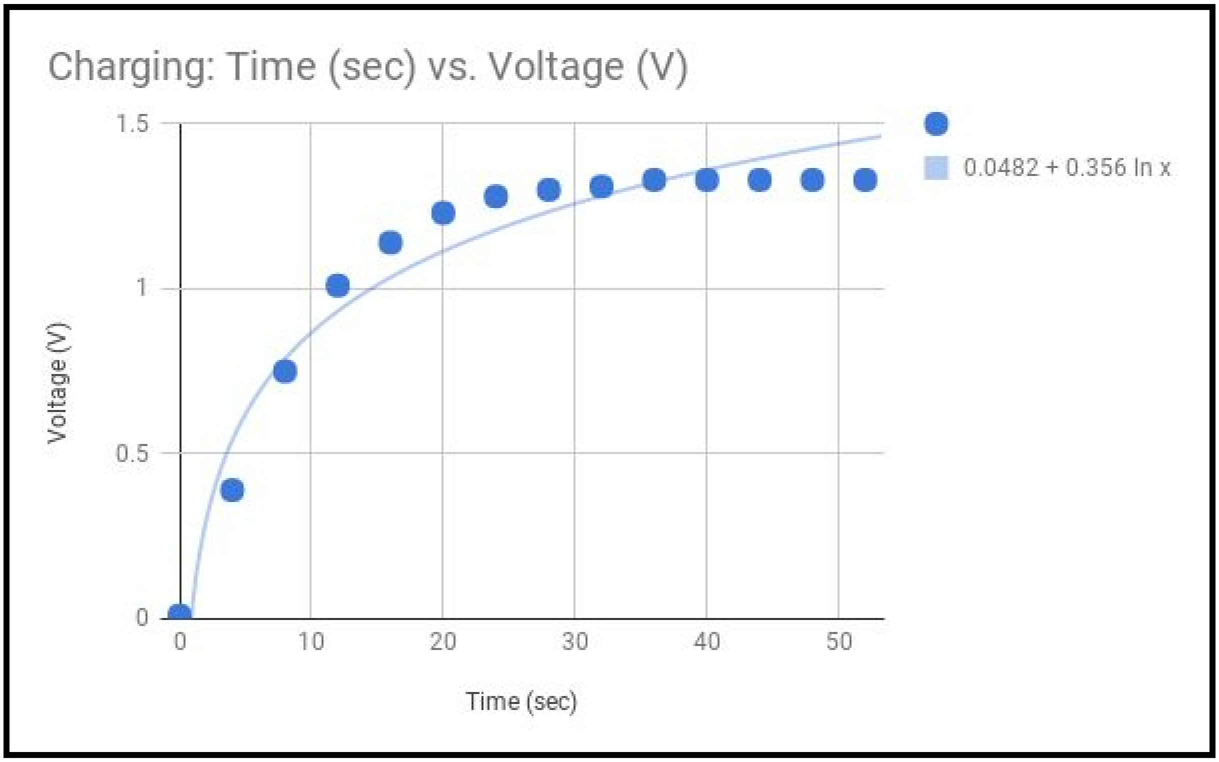
Data & Results

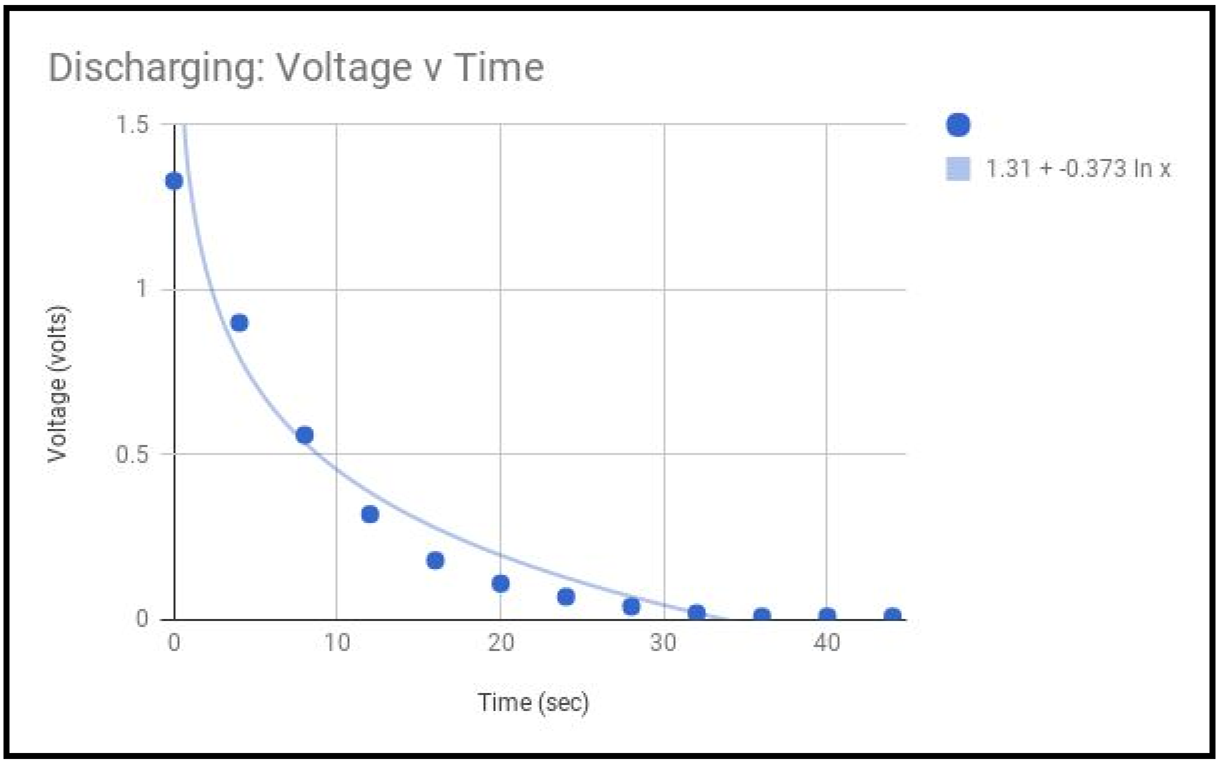
Having completed the experiment, the group recorded the voltage values every four seconds when the capacitor was charging and discharging. The data for charging and discharging were recorded in separate tables to show the voltage increasing and decreasing over time, as shown below.

Charging	
Voltage (V)	Time (sec)
0.01	0
0.39	4
0.75	8
1.01	12
1.14	16
1.23	20
1.28	24
1.3	28
1.31	32
1.33	36
1.33	40
1.33	44
1.33	48
1.33	52

Discharging	
Voltage (V)	Time (sec)
1.33	0
0.9	4
0.56	8
0.32	12
0.18	16
0.11	20
0.07	24
0.04	28
0.02	32
0.01	36
0.01	40
0.01	44

The data was applied to logarithmic plots in order to generate a trend line and its equation (depicted below). The equation was used to find the time constant by solving for the unknown variable when the product of the maximum voltage and exponential growth / decay rate (at full charge or discharge) were applied. The equation for Charging: Voltage v. Time resulted in a time constant of 9.1 sec, and the equation for Discharging: Voltage v. Time resulted in 8.9 sec.

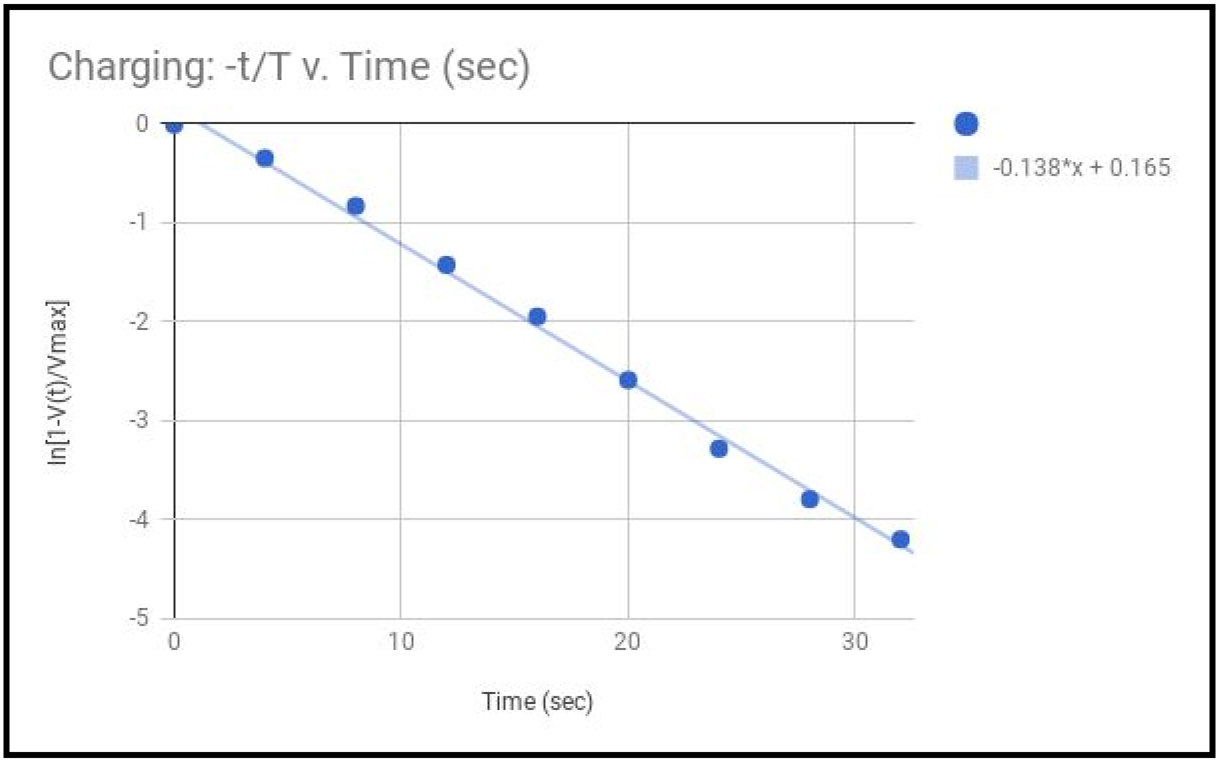

Charging: Time (sec) vs. Voltage (V)
Voltage (V)
Time (sec)
0.0482 + 0.356 ln x
1.5
1
0.5
0
0
10
20
30
40
50

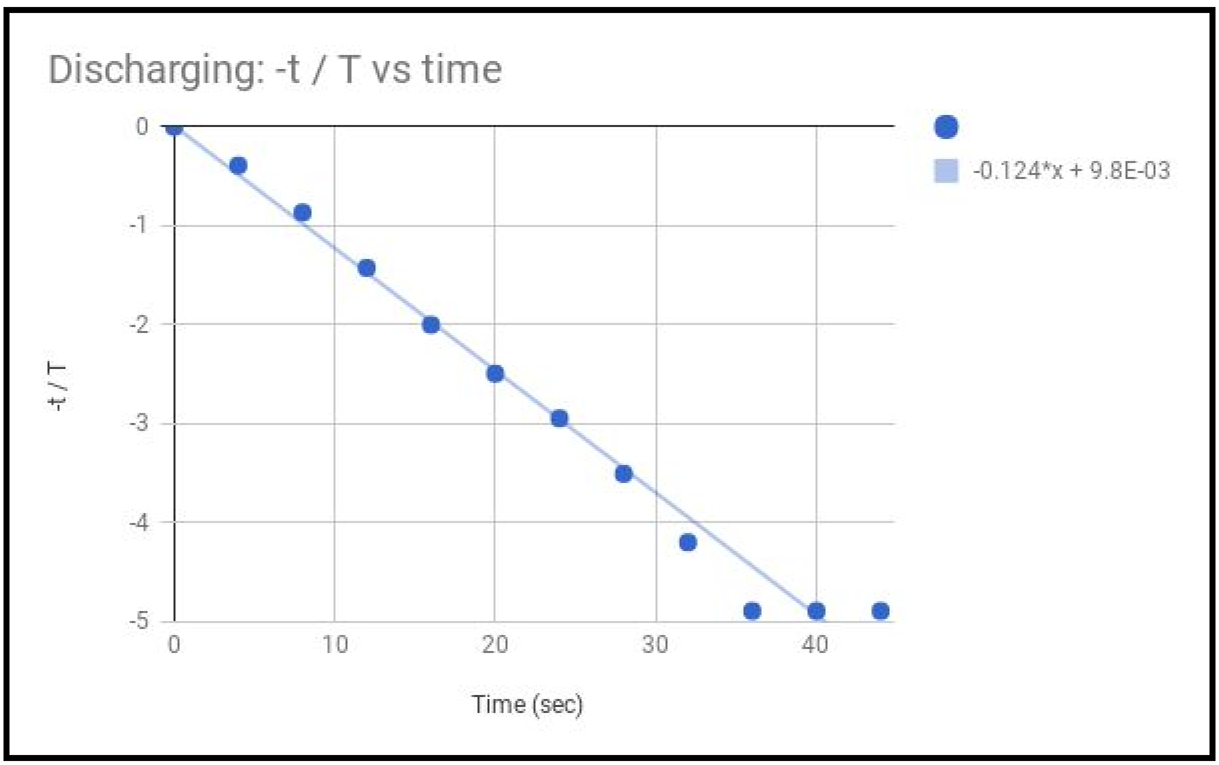

Discharging: Voltage v Time
Voltage (volts)
Time (sec)
1.31 + -0.373 ln x
1.5
1
0.5
0
0
10
20
30
40

Due to the difference between the charging and discharging time constants, the group aimed to generate an improved average by utilizing the voltage values at the time constant which was found by utilizing the exponential growth and decay rate equations (8 & 9). The resulting values were recorded in data tables and plotted similarly to the previous sets of data. The data created linear plots and equations which resulted in the time constants: 8.4 sec for charging and 8.1 sec for discharging.

Table 3 - Charging	
ln[1-V(t)/Vmax]	Time
-0.007547205635	0
-0.347054346	4
-0.8299061177	8
-1.424613225	12
-1.945910149	16
-2.587764035	20
-3.280911216	24
-3.79173684	28
-4.197201948	32
Undefined	36
Undefined	40
Undefined	44
Undefined	48
Undefined	52

Table 4 - Discharging	
ln[V(t)/Vmax]	Time
0	0
-0.3905394579	4
-0.8649974375	8
-1.424613225	12
-1.99997737	16
-2.492453855	20
-2.944438979	24
-3.504054767	28
-4.197201948	32
-4.890349128	36
-4.890349128	40
-4.890349128	44


Charging: -t/T v. Time (sec)
-0.138*x + 0.165
ln[1-V(t)/Vmax]
Time (sec)
0
-1
-2
-3
-4
-5
0
10
20
30


Discharging: -t / T vs time
-0.124*x + 9.8E-03
-t / T
Time (sec)
0
-1
-2
-3
-4
-5
0
10
20
30
40

Calculations

$V_{max} = 1.33\text{V}$

$x = \tau$

τ *found with logarithmic equation (charging)*

$1.33V \times .63 = .0482 + .356\, ln\, x \rightarrow x = 9.1\, sec$

τ *found with linear equation (charging)*

$1.33V \times .63 = -.138 \times x + .165 \rightarrow x = 8.4\, sec$

Average time constant τ

$(8.4\, sec + 9.1\, sec + 8.9\, sec + 8.1\, sec) \div 4 = 8.6\, sec$

The four sets of data allowed the group to narrow the resulting time constant to 8.6 sec by finding the average of the four time constant values found. The causes for the varying time constant values is reviewed in the upcoming section.

Conclusion

The group's hypothesis was proven to be accurate due to the similar time constant values that were found with each trend line equation. The students know that the time constant must be equivalent throughout all four data sets because the resistor and capacitor never change. Thus, the discrepancies in the results are effects of faulty materials and limited data. When the circuit was being tested before collecting data, the group discovered that the battery was reaching a maximum of 1.33V instead of the expected 5V. Reconfiguring the circuit and changing the battery did not resolve the issue, therefore the students continued with the experiment. Knowing that the results could vary, the group planned on finding the time constant by utilizing the resistance and capacitance ($100\mu F$)

$$(R \times C = \tau). \tag{10}$$

It was thought that the lab setup images would allow the students to read the resistance on the resistor. Ultimately, the resistance could not be found due to resistor appearing very small in the images. The group was left with using their average time constant as their best result. Although these obstacles were in place, the students were still able to use the given equations and previous knowledge on RC circuits to determine whether the time constant could be found and if it remained the same when the capacitor charged or discharged. The exact value for the time constant could not be determined, but the overall objective of applying their understanding and deriving what had been learned was accomplished by the students.