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Investigation into DC Transients

Module - Electrical and Electronic Principles

Assignment – RC Transients

Course: HNC Electrical and Electronic Engineering

Module: SGEE4000 – Electrical and Electronic Principles

Assignment Title: Investigation into DC Transients

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① VERY GOOD KNOWLEDGE DEMONSTRATED WITH
EVIDENCE OF CRITICAL ANALYSIS

MARK AS GOOD.

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Introduction

This assignment is to investigate the behaviour on R-L and R-C Circuits when connected to a DC Power Supply. We will be carrying out theoretical methods of working out how they will behave, and also we will then compare our answers to the simulation and noting down if there are any differences and if so; why?

The results that we obtain, will be analyzed and discussed followed by a conclusion which will include drawing of the circuits we created, many equations to suit as well as graphs. The time constant (τ) is the time required to charge the capacitor, through the resistor, from an initial charge voltage of zero to approximately 63.2% of the value of an applied DC voltage, or to discharge the capacitor through the same resistor to approximately 36.8% of its initial charge voltage.

Task 1

RC Transient behaviour for a charging of the capacitor.

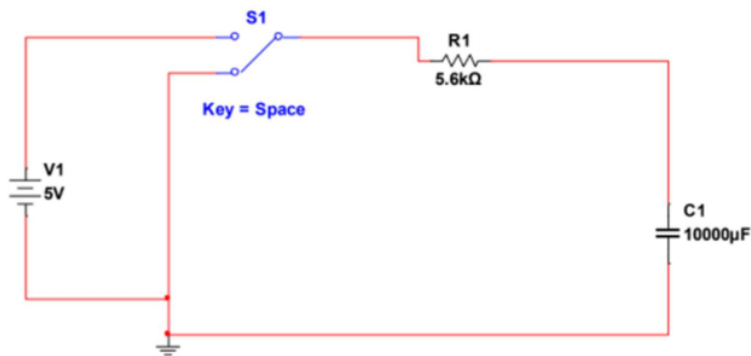


Figure 1

Figure 1 R-C circuit on Multi-Sim

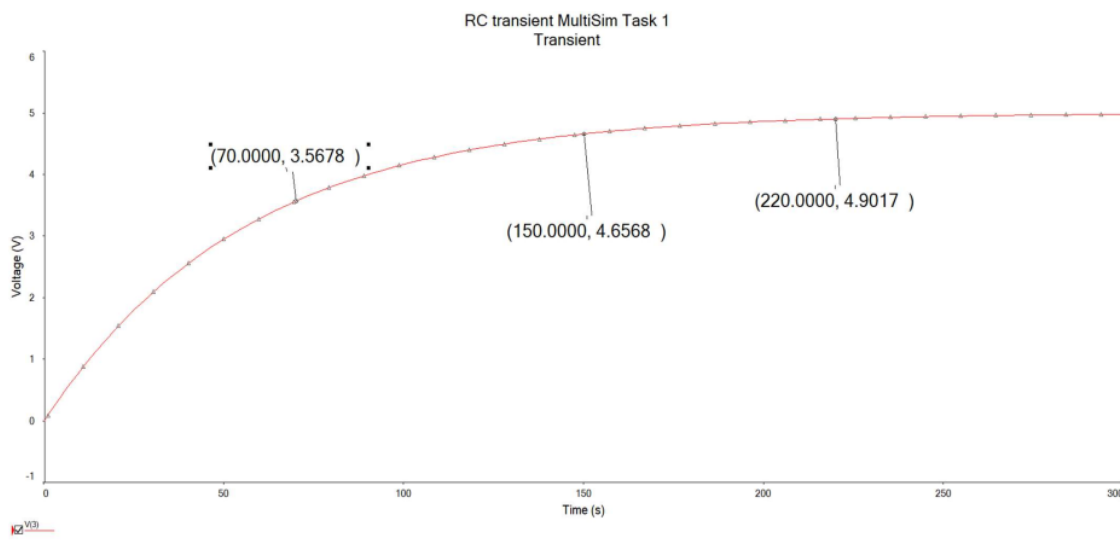


Figure 3 R-C Circuit Voltage Against Time

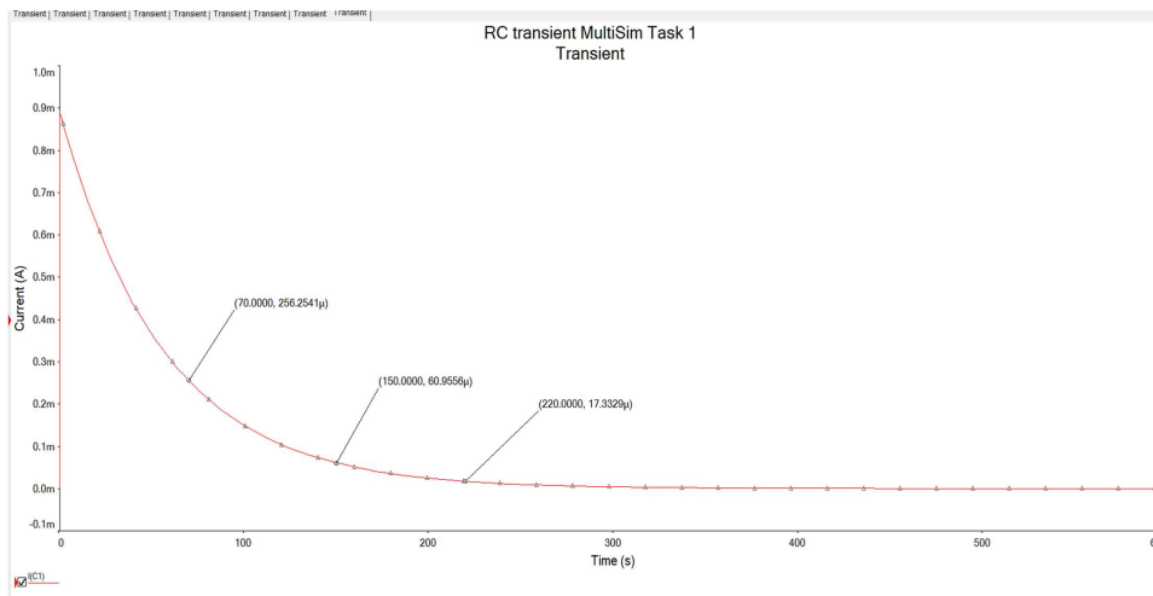


Figure 4 Current (A) against Time (s)

Steady State Conditions is 5 Tau

$$\text{Tau} = R \times C$$

$$= 5.6\text{K} \times 10,000\mu\text{f}$$

$$= \mathbf{56 \text{ seconds}}$$

$$5 \text{ Tau (steady state conditions)} = 5 \times 56 \text{ seconds}$$

$$= \mathbf{280 \text{ seconds}}$$

By looking at my equations; we can see that steady state conditions is achieved at 280 seconds.

The next step, we need to pick 3 random times between 0 (seconds) and 280 (seconds)

- 1) Time = 70 Seconds
Voltage = 5v DC

$$\begin{aligned} \text{Tau} &= R \times C \\ &= 5.6\text{k} \times 10,000\mu\text{f} \\ &= \mathbf{56 \text{ Seconds}} \end{aligned}$$

Voltage across the capacitor at 70 Seconds:

$$V_c = V_{\max}(1 - e^{-\frac{t}{\tau}})$$

$$= 5V (1 - e^{-\frac{70}{56}})$$

$$= \mathbf{3.57\ V}$$



Current across the capacitor at 70 Seconds:

$$I_{\max} = \frac{V}{R} = \frac{5}{5.6k} = 892.85 \times 10^{-6}\ \text{A}$$

$$i = I_{\max}(-e^{-\frac{t}{\tau}})$$

$$i = 892.85 \times 10^{-6} (-e^{-\frac{70}{56}})$$

$$i = \mathbf{255.81 \times 10^{-6}\ A}$$

Voltage across the capacitor at 150 seconds

$\tau = 56$ Seconds (We already know this from the previous workings)

$$V_c = V_{\max}(1 - e^{-\frac{t}{\tau}})$$

$$V_c = 5(1 - e^{-\frac{150}{56}})$$

$$V_c = \mathbf{4.66\ V}$$

Current across the capacitor at 150 seconds

$$i = I_{\max}(-e^{-\frac{t}{\tau}})$$

$$i = 892.85 \times 10^{-6} (-e^{-\frac{150}{56}})$$

$$i = \mathbf{61.30 \times 10^{-6}\ A}$$

Voltage across the capacitor at 220 Seconds

$$V_c = V_{\max}(1 - e^{-\frac{t}{\tau}})$$

$$V_c = 5(1 - e^{-\frac{220}{56}})$$

$$V_c = \mathbf{4.90\ V}$$

Current across the capacitor at 220 seconds

$$i = I_{\max}(-e^{-\frac{t}{\tau}})$$

$$i = 892.85 \times 10^{-6} (-e^{-\frac{220}{56}})$$

$$i = \mathbf{17.56 \times 10^{-6}\ A}$$

Comparison of the theoretical method and the simulation method

The only differences I can see from the results using both methods is that they differ slightly due to rounding up when using the calculation method. The simulation method is slightly more accurate because of that reason.

Voltage Comparison Table

Time (s)	Simulaton (Voltage)	Calculations (Voltage)
70	3.5678	3.57
150	4.6568	4.66
220	4.9017	4.90

Current Comparison Table

Time (s)	Simulation (Current)	Calculations (Current)
70	256.2541 μ A	255.81 μ A
150	60.9556 μ A	61.30 μ A
220	17.3329 μ A	17.56 μ A

Graphical Values

Unfortunately; we cannot compare the results to our exponential equations values due to the fact when carrying out this task we used a 6v DC supply and when we carried out simulated and calculated methods the voltage supply was 5v DC. None of the less; below we can see the answers we have recorded from the practical experiment of charging the Capacitor to 5 Tau which is when the capacitor is at its steady state condition (280 seconds).

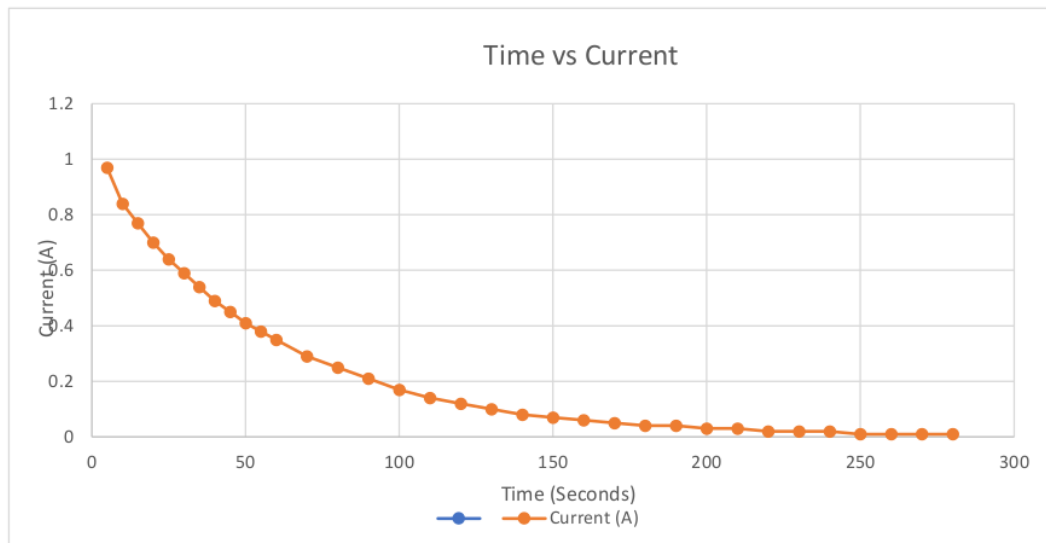
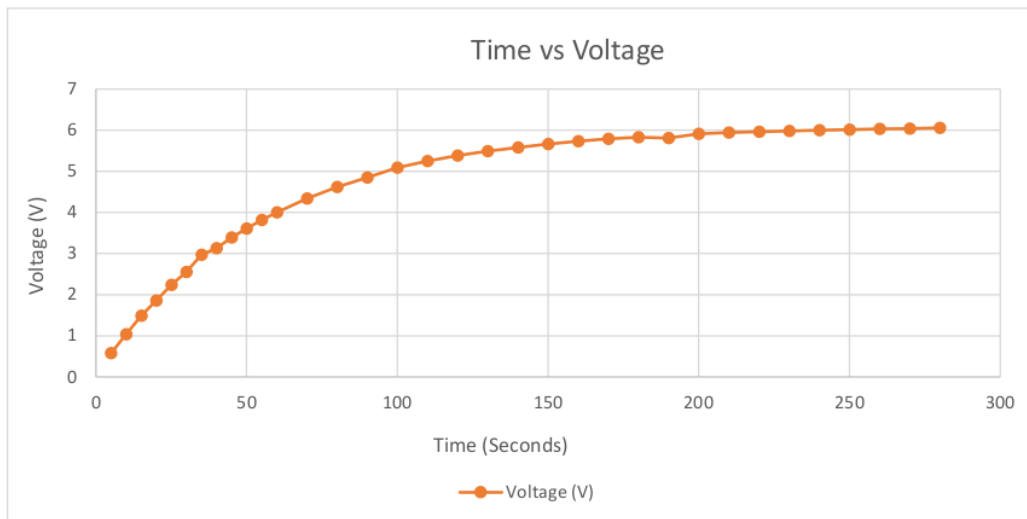


Figure 5 Time (s) against Current (A)



Task 2

This task is about the behaviour of a transient on a capacitor that is discharging.

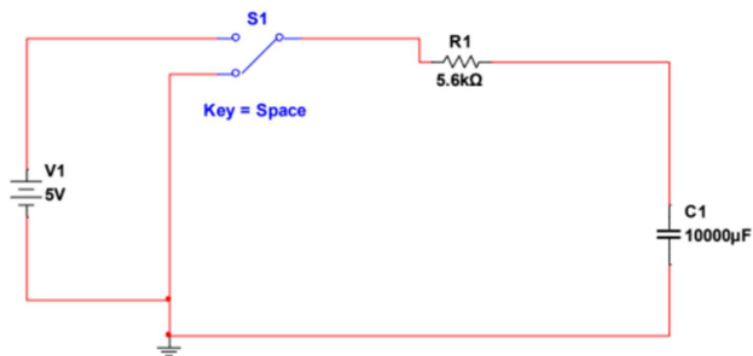


Figure 1

Figure 7 R-C circuit on Multi-Sim

Current against time using the Simulation Method

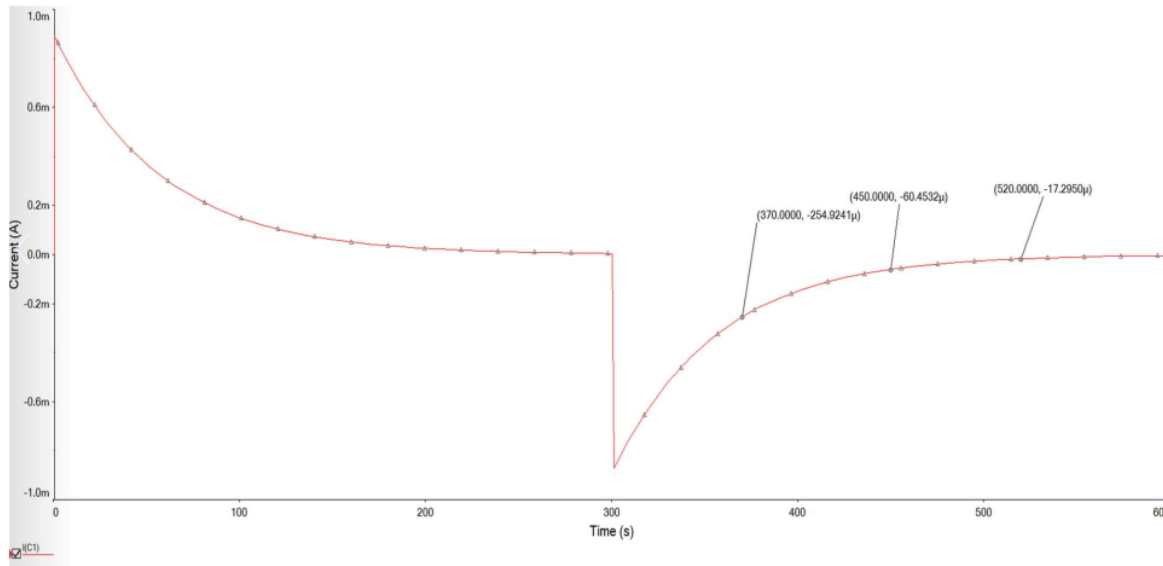


Figure 9 Discharging Capacitor

From the photo above, this is showing the Current (A) against Time (s) for a discharging capacitor. Our time at 0 start at 300s on the photo above, as the first half of the graph is to do with a charging capacitor. We can see that at 70 seconds, we have a current of $-254.9241\mu\text{A}$. At 150 seconds we have a current of $-60.4532\mu\text{A}$ and at 220 seconds the current is $-17.2950\mu\text{A}$. Using the mathematical way, we can prove that these answers are correct by following the exponential equations.

Current on a discharging Capacitor (Calculations)

$$i = -I_{\text{max}} \left(-e^{-\frac{t}{\tau}} \right)$$

$$\text{To work out } I_{\text{max}} = \frac{V}{R} = \frac{5}{5.6k} = 892.85 \times 10^{-6} \text{ A}$$

Once we know I_{max} we can then substitute into the correct equation to work out the answer to (i) by using the previous workings out for τ (56) and the 3 random time values that we had chosen.

70 Seconds

$$\begin{aligned} i &= -892.85 \times 10^{-6} \left(-e^{-\frac{70}{56}} \right) \\ &= -255.81 \times 10^{-6} \text{ A } (-255.81\mu\text{A}) \end{aligned}$$

150 Seconds

$$i = -892.85 \times 10^{-6} \left(-e^{-\frac{150}{56}} \right)$$

i = -61.30 × 10⁻⁶ A (-61.30 μA)

220 Seconds

$$i = -892.85 \times 10^{-6} \left(-e^{-\frac{220}{56}} \right)$$

i = -17.56 × 10⁻⁶ A (-17.56 μA)

Comparison of Current on the discharging Capacitor at set times

As we can see from both methods, the results are very similar. By doing the simulation method, using multi-Sim; it is more accurate due to the decimal placed as using the calculations we tend to round up to 2 decimal places. Other than that, the results are very accurate and align with each other. At 70 seconds, on the simulation we have -254.9241 μA and using exponential formula I calculated the current to be -255.81 × 10⁻⁶ A. At 150 seconds, the simulation has given us a current of -60.4532 μA and mathematically we have a current of -61.30 × 10⁻⁶ and again at 220 seconds we have a current of -17.2950 μA using the simulation on the graph, and when using the mathematical equation, we have a current of -17.56 × 10⁻⁶.



Current Comparison Table

Time (s)	Simulation (Current)	Calculations (Current)
70	-254.9241 μA	-255.81 μA
150	-60.4532 μA	-61.30 μA
220	-17.2950 μA	-17.56 μA

Voltage against Time on a discharging Capacitor

Simulation Method

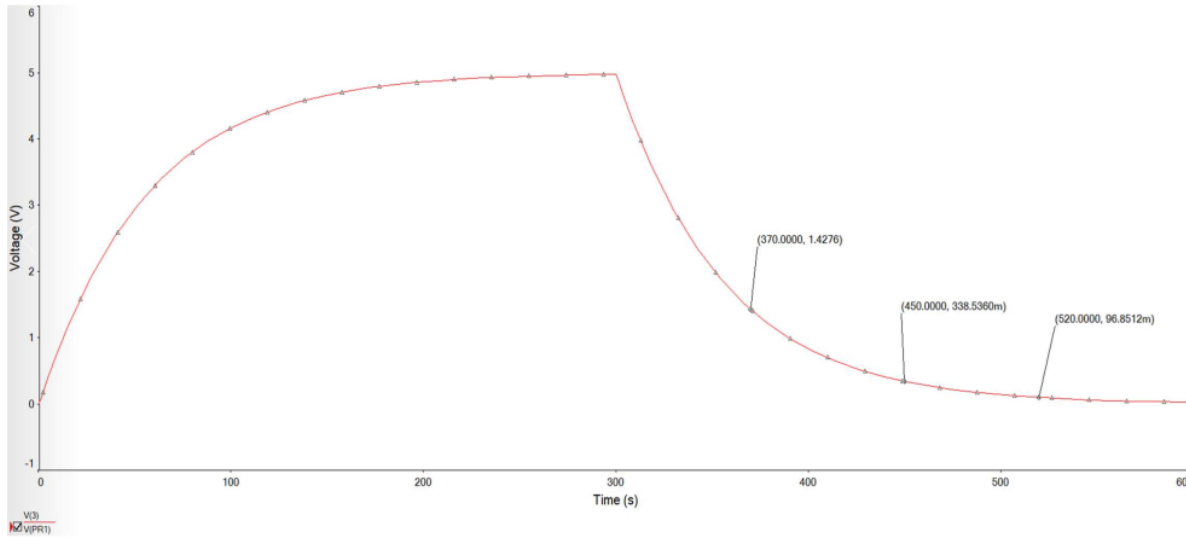


Figure 11 Voltage (V) against Time (s) on a discharging Capacitor

From the photo above, which is from the simulation method using multi-sim; we built the given circuit correctly and then analysed the transient graph with Voltage against Time on a discharging capacitor. Same as the previous graph, our start of the discharging capacitor will start at 300 seconds (0 seconds). Our first result that be obtained using the simulation method was at 70 seconds (370 seconds on the graph) which we have a voltage of 1.4276. Second to that, our next findings are at 150 seconds (450 seconds on the graph) which we found a voltage of 338.5360mV. Our last time which we picked was 220 seconds (520 seconds on the graph) and we found that the voltage then was 96.8512mV.



Voltage on a discharging Capacitor (Calculations)

Our V_{max} is given by us in the question as the Voltage Supply is 5v DC.

$V_{max} = 5v$ DC

Now that we know our V_{max} value, using the equation $V_c = V_{max}(e^{\frac{-t}{\tau}})$

To find the Voltage across the capacitor at a given time. We have previously calculated τ to be 56 Seconds.

Voltage at 70 Seconds

$$V_c = V_{\max}(e^{\frac{-t}{\tau}})$$
$$V_c = 5(e^{\frac{-70}{56}})$$
$$V_c = \mathbf{1.43 \text{ V}}$$

Voltage at 150 Seconds

$$V_c = V_{\max}(e^{\frac{-t}{\tau}})$$
$$V_c = 5(e^{\frac{-150}{56}})$$
$$V_c = \mathbf{0.34 \text{ V}}$$

Voltage at 220 Seconds

$$V_c = V_{\max}(e^{\frac{-t}{\tau}})$$
$$V_c = 5(e^{\frac{-220}{56}})$$
$$V_c = \mathbf{0.098 \text{ V}}$$

Comparison of Voltage on the discharging Capacitor at set times

Again, very similar to the comparisons on the previous calculations to do with current. Here, we can see that they result we have found using both methods (simulation and exponential formulas) our results are very accurate in terms of them both with only slight difference which are down to the rounding up to 2 decimal places when using the Calculation method.

With the simulation method at 70 seconds, we had 1.4276, whereas using the calculation method we had a voltage of 1.43. At 150 seconds using the simulation method we had voltage of 338.5360mV and using the calculation method we had 0.34v (340mV). On our third chosen time of 220 seconds, using the simulation method we have a voltage of 96.8512mV and using the calculation method we had 0.098 V (98mV).

Voltage Comparison Table

Time (s)	Simulation (Voltage)	Calculations (Voltage)
70	1.4276V	1.43V
150	338.5360mV	340mV
220	96.8612mV	98mV

Graphical Values

Unfortunately; we cannot compare the results to our exponential equations values due to the fact when carrying out this task we used a 6v DC supply and when we carried out simulated and calculated methods the voltage supply was 5v DC. None of the less; below we can see the answers we have recorded from the practical experiment of charging the Capacitor to 5 Tau which is when the capacitor is at its steady state condition (280 seconds).

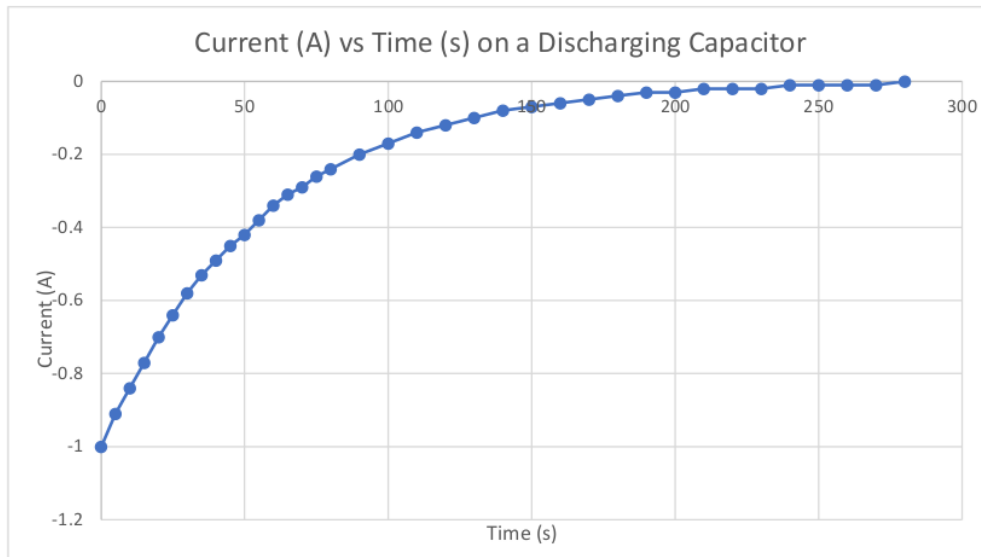


Figure 12 Current vs Time on a discharging capacitor

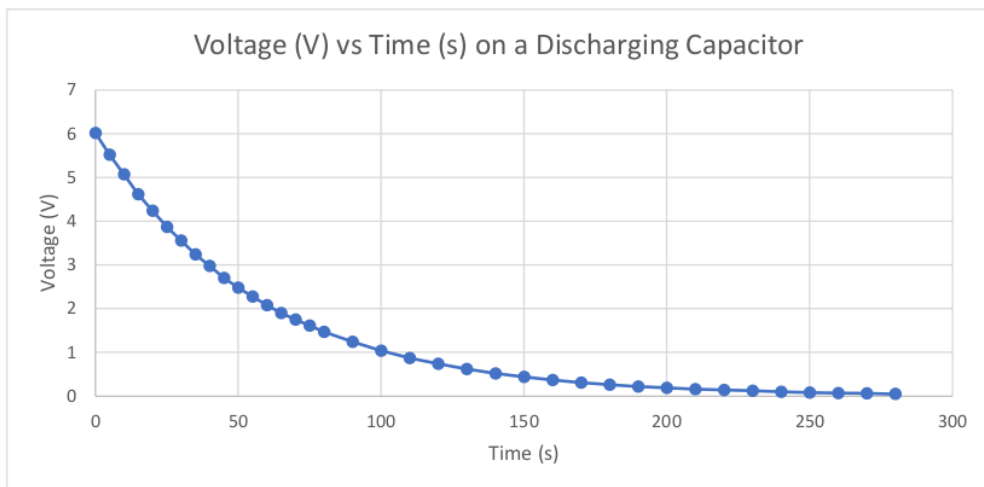


Figure 13 Voltage Vs Time on a Discharging Capacitor

Task 3

Transient behaviour for a more complex circuit.

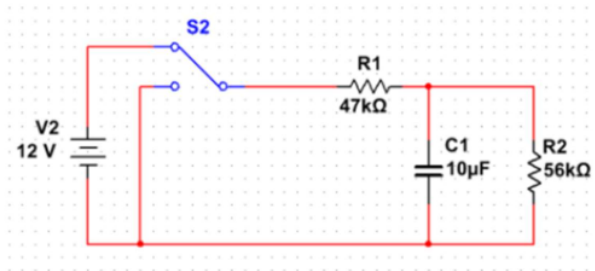


Figure 2

As we can see above, when dealing with the circuits in Task 1 and 2 there is only 1 resistor value which is enabling us to find out the time constant (τ). As this is classed as a complex circuit, to be able to find out the time constant we will need to simplify the circuit giving us a singular resistor.

Firstly, to do this we will need to use the product over sum rule to find out the total resistor value.

i)

$$\frac{R1 \times R2}{R1 + R2} = \frac{47K \times 56K}{47K + 56K} = 25553 \Omega$$

$$R_t = 25553 \Omega$$

Now we know our total resistor value, we need to calculate our supply voltage for the circuit.

To do this we need to follow the equation $\frac{R2}{R1 + R2} \times (V_{in}) = V_s$

$$\left(\frac{56K}{(47K + 56K)} \right) \times (12) = 6.5 V$$

Now we know our supply voltage is going to be 6.5 V and our resistor value is 25553 Ω we can draw up a simplified circuit on multi-sim keeping the capacitor the same

ii)

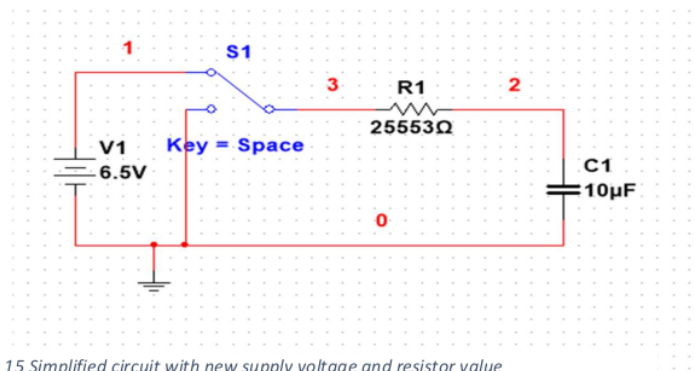


Figure 15 Simplified circuit with new supply voltage and resistor value

With the simplified circuit (above) being completed, we can now look at how to work out the time constant and how long it will take for the capacitor to reach steady state condition (5τ).

iii)

$$\tau = R \times C$$

$$\tau = 25.553K \times 10\mu F$$

$$\tau = \mathbf{0.255 \text{ Seconds}}$$

We know that 5τ is when the capacitor is at its steady state condition, now knowing that $\tau = 0.255$ we can calculate 5τ ;

$$5\tau = 5 \times 0.255$$

$$5\tau = \mathbf{1.3 \text{ seconds}}$$
 (This is the time that the capacitor will reach its steady state condition)

We next need to work out the current (I_{max})

$$I_{max} = \frac{V}{R} = \frac{6.5}{25.553K} = \mathbf{254\mu A}$$

To work out the estimate for both charge and discharge conditions of the capacitor we will multiply our I_{max} by 37.8% (0.378) (0.378 is the answer to e^{-1} which is the estimate of one time constant)

$$I_{max} = 254\mu A \text{ so; } 254\mu A \times 0.378 = \mathbf{96\mu A}$$

This gives us the current at one time constant. Now we know our current to one time constant (estimate) we can use this to plot on the graph using the working circuit built on multi-sim, which will then give us the simulated results for τ .

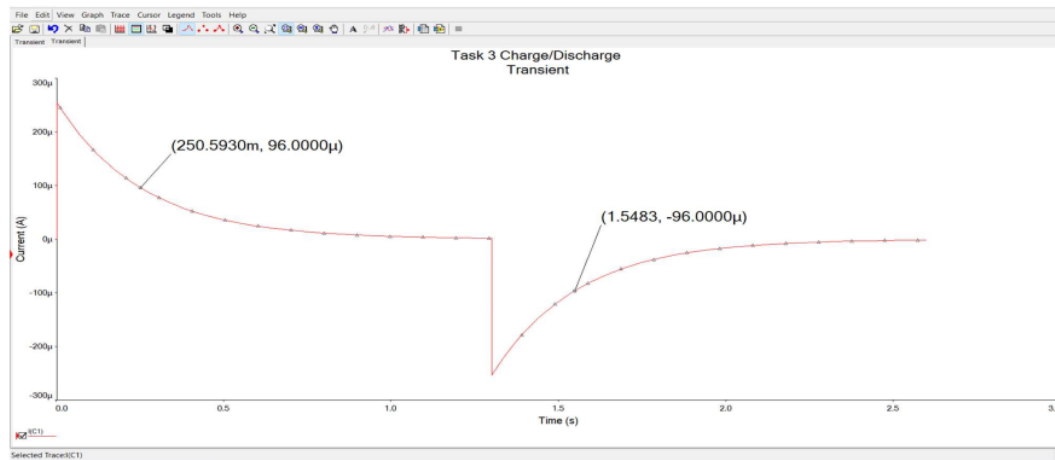


Figure 16 Charge and discharge of the capacitor at our calculated Current at one time constant

iv)



Calculated Result

$$\text{Tau} = R \times C$$

$$\text{Tau} = 25553 \times 10\mu\text{A}$$

$$\text{Tau} = \mathbf{0.255 \text{ Seconds}}$$

Simulated Result

From the graph above, we can see that the simulation result is 250.5930m seconds which is very similar the results we calculated theatrically (255m seconds – Capacitor charging)

The reason why it is showing as 1.5483 seconds on the discharging of the capacitor is because, its starting point is at 1.3 seconds (1.5483 – 1.3 = 0.2483 seconds)

v)

$$\text{The Initial Current} = I_{\text{max}} = \frac{V}{R} = \frac{6.5}{25553} = \mathbf{254\mu\text{A}}$$

$$\text{Final Current (at } 5\text{Tau)} = I_{\text{max}} \left(\frac{e^{-t}}{\text{Tau}} \right) = 254\mu\text{A} (e^{-5}) = 254\mu\text{A} \times 6.74 \times 10^{-3} = \mathbf{1.71\mu\text{A}}$$

Task 4

Transient behaviour for an Inductive Circuit

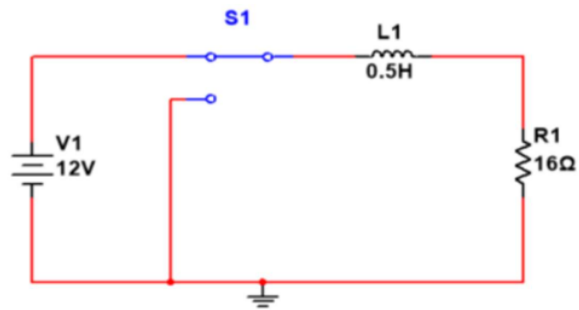


Figure 3

i)

To work out the value of Tau in an Inductive circuit = $\tau = \frac{L}{R}$

$$\tau = \frac{L}{R} = \frac{0.5}{16} = \mathbf{0.031 \text{ Seconds}}$$

$$2\tau = 0.031 \times 2 = \mathbf{0.062 \text{ Seconds}}$$

$$3\tau = 0.031 \times 3 = \mathbf{0.093 \text{ Seconds}}$$

$$4\tau = 0.031 \times 4 = \mathbf{0.124 \text{ Seconds}}$$

$$5\tau = 0.031 \times 5 = \mathbf{0.155 \text{ Seconds}}$$

ii)

Calculated Results

$$I_{max} = \frac{V}{R} = \frac{12}{16} = \mathbf{0.75A}$$

$$i = I_{max} \left(1 - e^{-\frac{t}{\tau}} \right)$$

$$\text{At } \tau : i = 0.75 \left(1 - e^{-\frac{0.031}{0.031}} \right) = \mathbf{474.090 \text{ mA} (3 \text{ d.p.})}$$

$$\text{At 2 Tau : } i = 0.75 \left(1 - e^{\frac{-0.062}{0.031}} \right) = 648.499 \text{ mA (3 d.p.)}$$

$$\text{At 3 Tau : } i = 0.75 \left(1 - e^{\frac{-0.093}{0.031}} \right) = 712.660 \text{ mA (3 d.p.)}$$

$$\text{At 4 Tau : } i = 0.75 \left(1 - e^{\frac{-0.124}{0.031}} \right) = 736.263 \text{ mA (3 d.p.)}$$

$$\text{At 5 Tau : } i = 0.75 \left(1 - e^{\frac{-0.155}{0.031}} \right) = 744.947 \text{ mA (3 d.p.)}$$

Manual Graph

Below is a graph showing my 5-time constants on Microsoft excel.

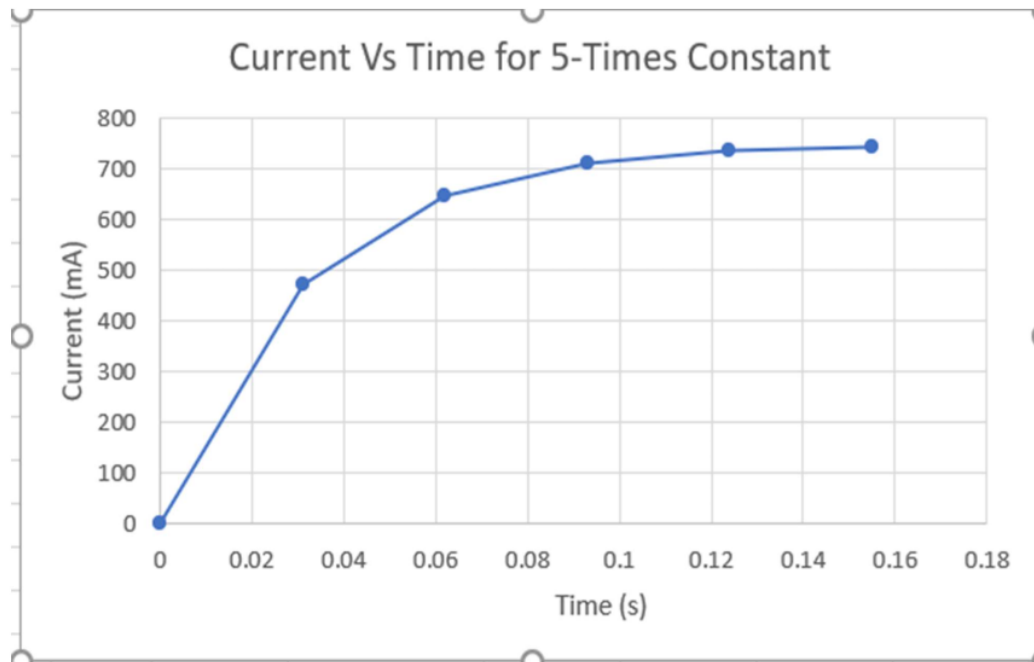


Figure 17 Current vs Time manually plotted graph

Simulation Results

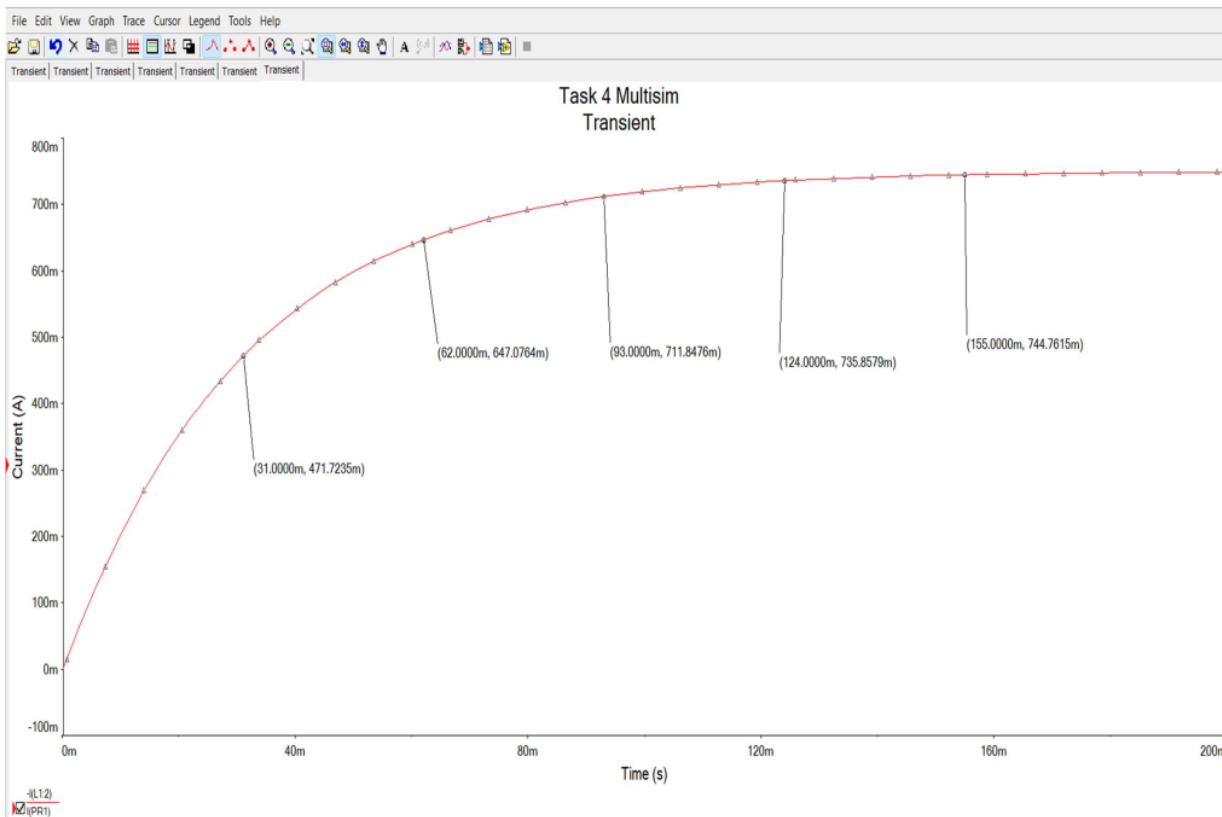


Figure 18 Charging current of an RL Circuit

Comparison Of Results

Time (seconds)	Calculated	Simulated
0.031	474.090 mA	471.7235 mA
0.062	648.499 mA	647.0764 mA
0.093	712.660 mA	711.8476 mA
0.124	736.263 mA	735.8579 mA
0.155	744.947 mA	744.7615 m A

From the table above, we can see that both answers from the calculated and simulated results, are basically identical; other than the rounding up on the calculated method (3 decimal places) whereas the simulated is slightly more accurate. An RL circuit operates slightly different compared to an RC Circuit, as when the RL circuit is charged up, the current rises and then begins to stabilise at at 5 Tau where its steady state condition is met. Also, for the simulated and the manual plotted graph, we can see that the trend on them both are very similar.

iii)

$$I_{max} = \frac{V}{R} = \frac{12}{16} = \mathbf{0.75A}$$

iv)

In Figure 16, we have the simulated results for our time constants. Below is the table completing the comparison of both methods.

Time Constant	Calculated (Figure 15)	Simulated (Figure 16)
1 Tau	0.031	0.031
2 Tau	0.062	0.062
3 Tau	0.093	0.093
4 Tau	0.124	0.124
5 Tau	0.155	0.155



As we can see, both results are the exact same, so no comparison can be made on these results.

v)

The equation for instantaneous current is;

$$i = I_{max} \left(\frac{e^{-t}}{\tau} \right)$$

To find the elapsed time, we will need to re-arrange this formula as suited below;

$$\begin{aligned} \frac{i}{I_{max}} &= \frac{e^{-t}}{\tau} \\ \ln \left(\frac{i}{I_{max}} \right) &= -\frac{t}{\tau} \\ \tau \times \ln \left(\frac{i}{I_{max}} \right) &= -t \\ t &= -\tau \times \ln \left(\frac{i}{I_{max}} \right) \end{aligned}$$

At 400 mA - Calculated

$$t = -0.031 \left(\ln \left(\frac{400 \times 10^{-3}}{0.75} \right) \right) = \mathbf{19.49 \text{ ms}}$$

At 200 mA - Calculated

$$t = -0.031 \left(\ln \left(\frac{200 \times 10^{-3}}{0.75} \right) \right) = \mathbf{40.97 \text{ ms}}$$

Simulated Results for 400 mA and 200 mA

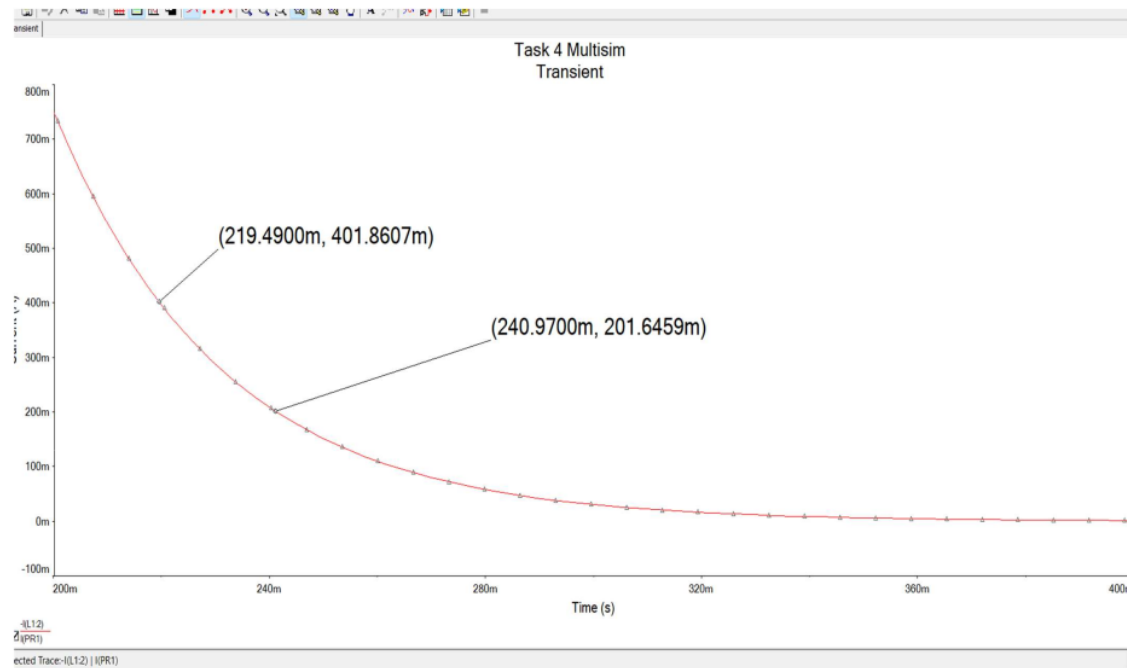


Figure 19 Simulated results of time given (mA)

Comparison of both methods

Current	Calculated	Simulated
400 mA	19.49 ms	19.4900 ms
200 mA	40.97 ms	40.9700 ms

In the graph above, due to pulse width being at 0.2 seconds the discharge will only happen when the switch has been activated, this will happen at 0.2 seconds. Taking this into consideration, 219.4900 ms is the same as 19.4900 ms (219.4900 ms – 0.2 seconds) and 240.9700 ms – 0.2 seconds will give us the result of 40.9700 ms. As we can see, the results are identical, proving that my calculations are correct.

Task 5

Conclusion and my personal recommendations

Starting off with the comparison with task 1, the results are exactly what I was expecting in regards if the calculated and simulated calculations. There was only a slight difference in the answers, but the only reason for this is due to the rounding up to certain decimal places when using the mathematical equation. In regards to the trend in the practical, we can still see that the trend is following the same pattern also. The only difference we have here, is the supply voltage for the practical task differs; which is why we had a different in the final results. The practical values could have differed in this task, could be because of the human error when noting down the results as it is hard to get the timings perfect every time.

When the capacitor is charged in task 1, the voltage increased and stabilised when its steady state conditions have been met (5Tau). With regards to the current, it decreases as the voltage increases, descending quickly at the maximum and then begins to stabilise at 5Tau near at 0mA.

In task 2, the capacitor is going to discharge as the positive leg of the capacitor is connected directly to ground. During all of the calculations and practical task, all values followed the same trend of the transient period. Again, same set up as task 1, the supply voltage differs to the simulated voltage, which is giving us slightly difference results, but they follow the same trend. When discharging the capacitor, the voltage follows the same trend as task 1 (as they are both RC Circuits). With the current, it is negative as this is showing the direction of flow for the current. When discharging a capacitor, the current will flow in the opposite direction compared to how it will flow in the when charging the capacitor. Current will flow towards the positive plate when the capacitor is charging and when the capacitor is discharging it will flow towards the negative plate (opposite direction).

In task 3, this is focusing more on a complex RC Circuit. The first step in tackling this problem, would be to make an equivalent circuit (similar to task 1 and task 2 circuit). To do this, a new resistor value is needed to be made, we can do this by using the product over sum rule. Once calculated we add the resistor in series to the circuit. Then using the new resistor value, we can calculate a new supply voltage, making this the equivalent circuit. As we can see in task 3, the time constant values are very

similar within more calculated and simulated methods (slight differences in rounding). I max is going to be multiplied by 0.378 (37.8%) to give us an estimated value. The discharge and charging result will be the same, but the negative is showing the direction the current is flowing in.

In task 4, an RL circuit is needed to be built, tested and calculated to complete the task. In an RL circuit, Tau is calculated by using L/R . Also, we need the instantaneous current, which will be calculated using the exponential current. We will use this method, to calculate all our results up to the steady state condition of the capacitor which is achieved at 5 tau. When a RL circuit is charged, the current will increase until it reaches its max, with the voltage across the inductor decreasing until it reaches zero. The current reaches its final current value at 5 Tau as well as the voltage will reach zero at the same given time. To find the elapsed time for the instantaneous current, we need to rearrange the formula.

There can be a couple improvements, that I can see which will make this assignment more accurate, is to set the supply voltage on the practical task to the same as the theatrical task, so we can have a better understanding on the results and which will allow us to compare both precisely. Secondly, we could make the scale on the multimeter a bit more specific if we set the readings to mA from Amps. Again, this would make our findings a little more precise.

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FINAL GRADE

GENERAL COMMENTS

Instructor

72/100

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Comment 1

reduce to a concise table of contents, you have too many sections

PAGE 4



Comment 2

write in the thrid person, past tense



Comment 3

many? how many?

PAGE 5

PAGE 6



Comment 4

do not include units in any equation

PAGE 7



Comment 5

graphical?

PAGE 8

PAGE 9



Comment 6

photo?

PAGE 10



Comment 7

avoid putting numerical results into a paragraph, use a table.

PAGE 11



Comment 8

avoid 'we'

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Comment 9

check cursor placement is accurate to more decimal places

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Comment 10

units?

PAGE 21

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GRADING FORM: NEW CSG-RUBRIC

AARON LUPTON**72****1. ENGAGEMENT WITH LITERATURE**

NA

0**2. KNOWLEDGE AND UNDERSTANDING**

Knowledge displayed is excellent and there is a depth to the report both in theme introduction and discussion of results. 18/25

18**3. COGNITIVE AND INTELLECTUAL**

Sound evaluation of results and good discussion, the conclusions and recommendations are also

21

justified and explained. 21/30

4. PRACTICAL APPLICATION



Advanced skills in using available technologies for circuit testing and good quality results displayed.
18/25

18

5. TRANSFERABLE SKILLS



Fluent report with all figures and results clearly presented and in a way which leads the reader to understand the process. 15/20

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